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Framework for Rating the Sustainability of the
Residential Construction Practice

by

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Dedication

This thesis is dedicated to my beautiful wife, Cristina, for her love, encouragement, and support. In addition, this thesis is dedicated to my two sons, Matthew and Nathan, whom I hope are inspired to fulfill their dreams.

Abstract

Sustainable development issues and environmental concerns continue to gain headlines as demand within Canada's residential construction industry escalates. Current construction practices adhere to traditional methods of construction, with inherent weaknesses such as high labour costs, negative environmental impact during and after construction, and minimal technological advancement. Many programs exist to rate building environmental performance, including Leadership in Energy and Environmental Design (LEED) and Built Green, which are primarily performance-based, not practice-based evaluations. Considerable research has supported these performance ratings; however, there has been very little research in construction practice ratings. Hence, the purpose of the research presented in this thesis is to bridge this gap by proposing a construction practice rating program in order to challenge builders' claims of being sustainable. Although rating programs should include measurements of both performance and practice—given that great performance does not equal great practice, particularly if the standard of performance achievement is low, current programs are based on performance alone. The goal of this thesis is to enhance the sustainability of the residential construction practice through the incorporation of sustainability evaluation rating tools. To achieve this goal, a framework has been developed which encompasses sustainability rating tools that include an integrated construction practice rating program, an application of Building Information Modeling (BIM) for carbon dioxide (CO_2) emissions quantification, and implementation of a mathematical linear optimization model as a tool that minimizes cost while incorporating user-defined preferences and numerous environmental criteria under a green building rating system. CO_2 emissions of various house construction stages are quantified and utilized in a 3D BIM. Application of the proposed framework is demonstrated in a case study with findings that show the weak results of sustainability ratings for a particular home builder. Hence, the findings in this research demonstrate a residential builder's ability to measure his sustainability efforts and enhance construction practices based on a rating analysis. The introduction of BIM for quantifying emissions in the construction process is found to be of significant value.

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Nomenclature

3i	Initiated, Intermediate, Integrated
2D	Two (2) Dimensional
3D	Three (3) Dimensional
AEC	Architecture, Engineering and Construction
ASHRAE	American Society for Heating, Refrigeration, and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
BCCA	British Columbia Construction Association
BEES	Building for Environmental Economic Sustainability
BGRP	Built Green Rating Program
BIM	Building Information Modeling
BM	Building Materials (Built Green)
BP	Business Practices (Built Green)
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Methodology
BTU	British Thermal Unit
CAD	Computer Aided Drafting
CMHC	Canadian Mortgage and Housing Corporation
CSA	Canadian Standards Association
CSCE	Canadian Society for Civil Engineering
CO_2	Carbon Dioxide
CSI	Construction Specifications Institute
DJSI	Dow Jones Sustainability Index
DQT	Data Quantity Types
EIF	Exterior and Interior Finishes (Built Green)
EPA	Environmental Protection Agency
EPS	Expanded Polystyrene
FSC	Forest Stewardship Council
GA	Generic Algorithms
GBC	Green Building Challenge
GBTOOL	Green Building Tool
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GVRD	Greater Vancouver Regional District
HVAC	Heating, Ventilating and Air Conditioning
IAI	Industry Alliance for Interoperability
IAQ	Indoor Air Quality (Built Green)
ICF	Insulated Concrete Form
ICPRP	Integrated Construction Practice Rating Program
IEQ	Indoor Environmental Quality
IFC	Industry Foundation Classes
IGB	Integrated Green Building
ISO	International Organization for Standardization

LCA	Lifecycle Analysis
LEED	Leadership in Energy and Environmental Design
LBS	Location Breakdown Structure
LCC	Life Cycle Cost
MBA	Master Builders Association
MEP	Mechanical, Electrical and Plumbing
NGO	Non-Governmental Organization
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NAHB	National Association of Home Builders
NRC	Natural Resources Canada
O & M	Operations and Maintenance
OECD	Organization for Economic Co-operation and Development
OS	Operational Systems (Built Green)
OSB	Oriented Strand Board
PAH	Polycyclic Aromatic Hydrocarbons
PATH	Partnership for Advancing Technology in Housing
SCSH	Sustainable Construction Safety and Health
SCORE	Sustainability Competency and Opportunity Rating and Evaluation
SEE	Social, Environmental, Economic
SIP	Structural Insulated Panel
SWOT	Strengths, Weaknesses, Opportunities & Threats
TNS	The Natural Step
USGBC	U.S. Green Building Council
V	Ventilation (Built Green)
WBS	Work Breakdown Structure
WC	Water Conservation (Built Green)
WCB	Worker's Compensation Board
WM	Waste Management (Built Green)
XPS	Extruded Polystyrene

n_i = number of j options in category i

m_{ij} = number of k choices in the option j in the category i

α_{ijk} = 1 if the k^{th} choice in the j^{th} option in the i^{th} category is selected
0 if the k^{th} choice in the j^{th} option in the i^{th} category is not selected

C_{ijk} = cost of the k^{th} choice in the j^{th} option in the i^{th} category

P_{ijk} = points allotted to the k^{th} choice in the j^{th} option in the i^{th} category

P_{des} = points desired between minimum and maximum for each i^{th} category

L_s = selected certification level

Chapter 1: Introduction

1.1 Background

The North American method of house construction involves onsite wood framing either on cast-in-place concrete basement walls or a foundation. Shortcomings of the current construction method include lengthy construction times, high rates of material waste, and significant carbon dioxide (CO_2) emissions into the environment. Negative environmental impacts due to CO_2 emissions from the transportation and onsite use of construction equipment have also been verified (Nepal *et al.*, 2006).

Research and analysis of the housing industry is both valuable and instructive, especially considering the contribution of the housing industry to Canada's Gross Domestic Product (GDP) which amounts to $98 billion (Statistics Canada, 2010). Furthermore, the relationship between housing construction and CO_2 emissions has been made evident: the residential sector is the third-largest energy user in Canada, accounting for 17% of secondary energy and 16% of greenhouse gas (GHG) emissions (Natural Resources Canada, 2006). A recent project funded through the Canadian Mortgage and Housing Corporation (CMHC) on Net Zero Housing has provided the impetus for this research through its goals of reducing the environmental impact of the house construction process and encouraging sustainable construction. More broadly, all citizens and organizations must contribute to mitigating climate change while providing value to society (Yu *et al.*, 2008).

Previous findings have shown that CO_2 emissions produced during the conventional framing of a single-family dwelling amount to more than 45 tonnes of CO_2 (Gonzalez and Navarro, 2005). During 2007, over 50,000 residential units were built in Alberta, Canada, contributing a total footprint of more than two million tonnes of CO_2. These numbers demonstrate the environmental impact of building construction under current construction practices and its relationship to CO_2 emissions. The research indicates the possibility of a 30% reduction in CO_2 emissions through the selection of building materials with low environmental impacts (Gonzales and Navarro, 2005).

Studies have highlighted the relationship between construction materials and CO_2 emissions in terms of the entire lifecycle of a constructed facility, from manufacturing and construction to operation and demolition (Seo and Hwang, 2001). Other studies have focused on assessing CO_2 emissions rates based on the embodied energy of different materials (Upton *et al*., 2008) (although the embodied energy aspect does not fall within the scope of this thesis). The total GHG emissions in Canada are estimated to have reached 758 mega-tonnes in 2004, and 67% of these emissions were the result of secondary energy use (Natural Resources Canada, 2006). For example, from site excavation to the installation of interior drywall, more than nine tonnes of CO_2 are emitted (Yu *et al*., 2008) in the transportation and material installation processes associated with the construction of just one single-family dwelling.

The advancement of Building Information Modeling (BIM) software allows end users to create an efficient analysis both of building processes and of the effect of the type and size of materials used, as well as to coordinate complex mechanical, electrical and plumbing (MEP) systems (Korman *et al.*, 2008). Through the utilization of intelligent data repositories, 3D models are frontloaded with complex information about construction materials, crew types and sizes, and equipment transportation and installation (Vilkner *et al.*, 2007). Most of the implementation to date in regards to BIM, has occurred at the design stage; little has been done to provide construction trades with an equivalent level of information. Accurate models have been developed by consulting companies in North America, but there has been relatively little practical implementation (Sacks and Barak, 2005). There is thus a concerted need to connect the design and construction sectors of this industry in order to fully realize the benefits of the rendered models. Process documents for construction activities and their relationship with cost estimates, construction schedules, quantity takes-offs, and, in this case, CO_2 emissions are easily incorporated, manipulated, updated and depicted through the use of BIM (Goedert and Meadati, 2008). BIM is defined by the National Institute of Building Sciences as a "digital representation of physical and functional characteristics of a facility."

They go on to explain,

> It serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward. A basic premise of Building Information Modeling is collaboration by different stakeholders at different stages of the lifecycle of a facility to insert, extract, update or modify information in the Model

to support and reflect the roles of that stakeholder. The Model is a shared digital representation founded on open standards for interoperability (National Institute of Building Sciences - WBDG, 2009).

The work presented in this thesis focuses on quantifying the CO_2 footprint of wood framing in the new-detached house construction process in Canada. Although Nässén *et al.* (2007) have highlighted the need to address the issue of CO_2 emissions resulting from housing production, only limited research exists to quantify CO_2 emissions incurred directly by the construction process. Literature in this area includes works by Suzuki *et al*. (1995), who discuss CO_2 emissions from housing construction in Japan, and Yan *et al*. (2010), who describe a case study focusing on CO_2 emissions in the building process. The objectives of this research study are to gain a better understanding of current house construction practices and to propose recommendations to improve the construction process with respect to CO_2 emissions reduction. Moreover, the imperative to deliver vital, timely information to house builders and other interested parties, such as government agencies, forms the keystone of this research. The utilization of BIM to quantify CO_2 emissions can provide the critical information needed for decision-makers to enhance current practices. Accurate information can be provided by means of information technologies that connect real-life, complex, time-consuming processes with information management databases. Through the use of an intelligent database, flaws related to CO_2 emissions in the construction process can be identified and mitigated before construction begins.

This paper also illustrates the power and effectiveness of parametric CAD modeling in quantifying the effect of CO_2 within the house construction industry. CO_2 quantifications are automatically obtained through modeling and analyses of rich 3D models and comprehensive lists of construction methods. The proposed methodology is also applicable to other types of construction processes in which materials, labour, and equipment are utilized.

1.2 Motivation and Scope

The contribution of the construction industry to the Canadian economy accounted for approximately $98 billion—6.4% of Canada's annual Gross Domestic Product (GDP)—in 2009 (Statistics Canada, 2010). In 2005, Canada's residential construction industry reached its highest production level in almost two decades. A total of 238,830 new residential units were built, 62% of which were single-family and semi-detached homes (Statistics Canada, 2010). Given the importance of Canada's residential construction industry and the ongoing demand for housing, coupled with emerging environmental concerns, it is imperative that any approach to meeting housing demand be sustainable.

The term sustainability in this thesis follows the definition proposed by the World Commission of Environment and Development: "Sustainability is about meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). Green building programs are emerging across public and private sectors throughout Canada and the world. The term "green building" is defined in this thesis as the practice of building structures and applying construction processes that are environmentally responsible and resource-efficient. Similarly, Kibert (2008) has described green buildings as healthy facilities designed and built in a resource-efficient manner using ecologically-based principles. In this regard, the Canadian Society for Civil Engineering (CSCE) has produced a document entitled, “Guidelines for Sustainable Development.” The CSCE (2007) endorses green construction with design decisions intended to minimize the environmental burden. In addition to the intrinsic social benefits implied, a compelling incentive for building owners and developers to invest in green building is the financial benefit of operating more efficient and affordable facilities (British Columbia Construction Association (BCCA), 2008). The greatest barriers to green building have primarily been economic, but evidence indicates that green building can in fact be cost effective. For example, facilities with higher energy efficiency can offset the higher cost of initial construction with lower operating costs. Home builders believe that they are building highly rated performance products, as evidenced through certification programs; however, they may not score well in a construction practice evaluation. Hence, ratings programs should include measurement of performance and practice in order to truly measure sustainability efforts. Advancements in tools, processes, and materials have led to incremental construction improvements; however, the fundamentals of the construction practice remain stagnant, and relatively little improvement has been observed in the building production process (Zhang *et al*., 2005). The justification for green building is becoming more clearly defined globally, and sustainable facilities are becoming a growing reality for many forward-thinking organizations (Buchanan, 2007). While there have been improvements to current practices, meaningful and substantial change can only occur as a result of contractual requirements. The US government, for instance, now requires that all federal construction projects exceeding a certain size meet certain sustainability standards (Buchanan, 2007). Many government agencies also require project certifications that support sustainable development.

In addition, the building construction process can reduce CO_2 emissions through the adoption of better practices such as panelized construction. The above factors demonstrate the need for green (environmentally-friendly) programs as well as the opportunity to advance current construction practices as a means of promoting sustainable development. Yudelson (2006) has identified two critical factors expected to dictate the success of green building: (1) the ease of deployment; and (2) the degree to which an environmental crisis exists. These factors, in turn, correspond to the two drivers of green building: the ease in implementing green building and the perceived need for change. The research outlined herein serves to address these two critical factors. It should be noted that, in this thesis, the terms, “green building,” “sustainable building,” “sustainable construction,” and “green construction” are analogous. Likewise, the terms “building practice” and “construction practice” are analogous.

The perspective described in this research seeks the implementation of a sustainability rating tool that combines performance certification and organizational practice evaluation that could be effectively applied to new residential construction. In addition, other tools are developed to facilitate the measurement of sustainability efforts, which include the development of an application of Building Information Modeling (BIM) for quantification of parameters related to the rating of the construction practice and the development of a mathematical linear optimization model for a building rating program to minimize the cost of achieving certification levels. Figure 1.1 outlines the scope of the research within the context of a construction project timeline, as well as its effects on costs and sustainability. As illustrated in the figure, these tools, when utilized at the upstream of a project timeline, greatly impact costs and influence design changes. The opportunity for change diminishes along the project timeline, indicating that changes that affect cost and sustainability need to be implemented early on in the design stage. Otherwise, the costs are dramatically higher later on in the project. In other words, these tools provide stakeholders with the information to make changes to their construction practices that can meaningfully affect sustainability at the upstream end of a project.

Stakeholders recognize the value of green building, as the benefits to society and the environment are evident. However, some stakeholders, such as builders, may perceive green building as an expensive initiative associated with increased operational costs that puts strain on their bottom line. Nevertheless, builders do want to be recognized for sustainability efforts in some form, such as those offered through green building certification. The value of developing this model is that stakeholders can benefit from their efforts in meeting certification aims, while addressing economic barriers at minimum costs.

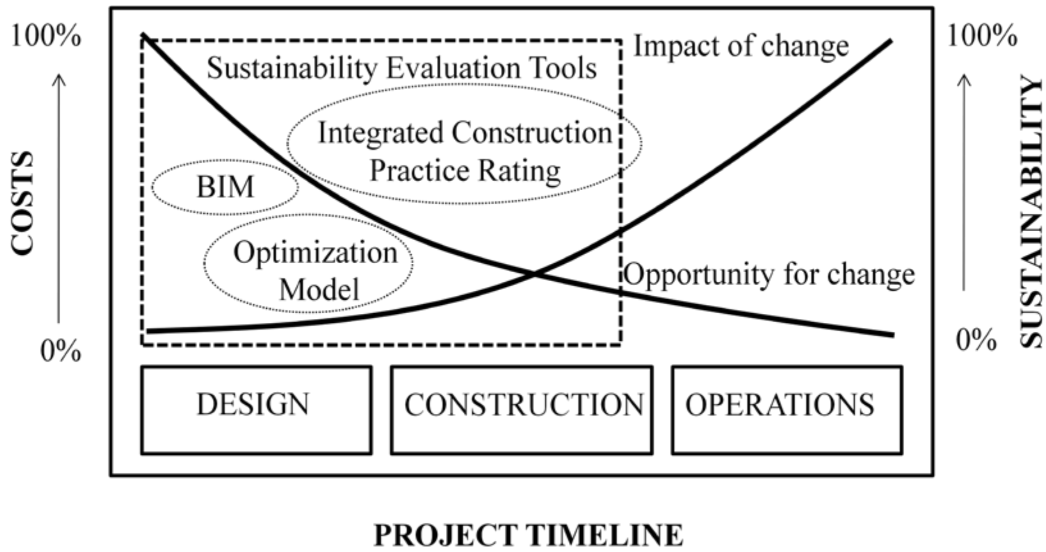


Figure 1.1: Scope of Research within Construction Project Timeline

1.3 Research Goal and Objectives

The goal of this thesis is to enhance the sustainability of the residential construction practice through the proposal of construction practice evaluation rating tools. The results of this research will allow stakeholders to measure their sustainability efforts and change their residential construction practices based on a rating analysis. This research will address the gap in research concerning rating of the residential construction practice.

To attain the research goal, the following specific objectives are pursued:

1. The development of an Integrated Construction Practice Rating Program (ICPRP), which combines the existing Built Green Rating Program (BGRP) with the proposed practice rating program.
2. The application of Building Information Modeling (BIM) for the quantification of the CO_2 parameter related to the rating of the residential construction practice; and

3. The formulation of a mathematical linear optimization model as a tool for cost-minimization associated with the implementation of existing Built Green Rating Program (BGRP).

These three objectives contribute to the development of a framework for a rating system for the sustainability of the house construction practice. These three components were chosen as they move beyond the traditional paradigm in construction of quality, time, and cost dimensions. Specifically, the integrated construction practice rating program examines the construction practice in terms of social, environmental, and economic perspectives. Through the application of BIM, rating of the sustainability of current construction practice is achieved through quantification of certain parameters, such as CO_2 emissions. This parameter was chosen to address residential construction's contribution to climate change and its effect on sustainability. Other parameters in BIM may include ergonomic, respiratory, and safety concerns (however, they are not within the scope of this thesis). Finally, the mathematical model facilitates the sustainability rating through the integration of cost and environmental preferences. The objective of the mathematical model is to develop a linear optimization model that minimizes cost while incorporating user-defined preferences and numerous environmental criteria under the Built Green rating program for houses. The rationale for using the linear optimization model for the green building rating program is to obtain required minimum points under numerous environmental criteria at a minimal cost. In other words, the model should optimize the selection of points under various competing criteria while meeting the objective of minimum cost.

1.4 Thesis Organization

This thesis consists of five chapters. Chapter 1 introduces the background of green building, certification issues, and other construction issues. The goal and objectives of this research are then presented, along with the scope of the research. Chapter 2 provides a review of the literature on sustainable construction, CO_2 emissions, green building rating programs, software assessment tools, sustainability practice models, and mathematical models. Chapter 3 outlines the research methodology used to achieve the research goal through each of the objective areas. In Chapter 4, the framework is developed and implemented, followed by a case study and analysis in Chapter 5. Chapter 6 consists of a summary and a discussion of the contributions of this research.

Chapter 2: Literature Review and Background

2.1 Introduction

This chapter commences with a literature review of research in the area of sustainability, green building performance and practice rating programs, material waste, health and safety, building information modeling, and mathematical linear optimization models. The chapter concludes with an in-depth background description on particular rating programs used in the research methodology and framework development.

As Gowri (2004) summarized, green building rating programs in general focus on the following five categories of building design and lifecycle performance: site, water, energy, materials, and indoor environment. For each category, a number of prerequisites and credits with specific design and performance criteria exist. Due to its relative complexity, most measures of sustainability have been incorporated into labelling or certification programs and evaluation tools for buildings.

The sustainable movement has been embraced in the building industry. The growth of the green building trend has spawned a myriad of third-party rating programs and the ubiquitous term "certified." All green building rating programs share the essential principles of environmental protection, energy efficiency, and water conservation. However, the application, documentation, and certification procedures for each program, as well as potential costs, vary widely. In addition to the hard numbers, there are more intangible benefits to consider, such as marketability and brand recognition.

Sustainable construction can refer either to the building process or to the built object (Mora, 2007). Sustainable construction techniques provide an ethical and practical response to issues of environmental impact and resource consumption. Green buildings almost always make economic sense when assessed on a Lifecycle Cost (LCC) basis, although they may be more expensive when considered on a capital or "first-cost" basis. Importantly, sustainable design acknowledges the potential effects of the building, including its operations, on the health of its occupants (Kibert, 2008).

The principles of sustainable construction—which are applied across the entire lifecycle of the project from design, construction, and operation to de-construction—include the following: reduce resource consumption; re-use resources; use recyclable resources; protect nature; eliminate toxics; apply LCC; and focus on quality (Kibert, 2008). Lifecycle Assessment (LCA) involves the collection and evaluation of the inputs and outputs of any potential environmental impact made by the product throughout its lifecycle (Mora, 2007). Despite the merits of these programs, there are opponents of green programs who would wish to discount these benefits. Their reasons vary, but some claim that the programs fail to effectively take into account LCC. The research herein will explore this attribute in its analysis as well as by fully mapping the cradle-to-grave costs. It should be noted that a comparison of the data arrays for various building features exposes further complications in this regard (Kibert, 2008).

Kibert (2008) has defined LCA as a method to determine the environmental and resource impacts of a material, a product, or even an entire building across its lifespan. LCA is an important comprehensive approach which examines all the dimensions of the impact of material selection decisions, rather than simply looking at an item's performance with respect to a given facility. Specifically, LCA is a cost/benefit analysis performed for each year of a building's expected lifespan. The ability to model a building's financial performance over its entire lifecycle is necessary to justify measures that may require greater initial investment, but yield significantly lower operational costs over time (Kibert, 2008).

Gerilla *et al*. (2007) have pointed to LCA as a procedure which evaluates the sustainability of a product through a consideration of all the environmental implications of its development, from primary inputs to disposal of final outputs and by-products (e.g., wastes). In this respect, LCA can be used to assess the eco-balance of a product.

2.2 Sustainable Construction and CO_2 Emissions

A literature review was conducted on the basis of the definition of sustainable construction which is defined in this research as the practice of construction that applies processes that are environmentally responsible and resource-efficient throughout a building's lifecycle. The purpose of sustainable construction is to create and sustain healthily-built and environmentally-friendly facilities based on the principles of resource efficiency and ecological design (Kibert, 2008). As Kibert (2008) purports in this regard, "sustainable construction is a subset of sustainable development and addresses the role of the built environment in contributing to the overarching vision of sustainability." The lifecycle of a building can be divided into four stages: manufacturing, construction, operation, and demolition. The effects of CO_2 emissions or other environmental indicators vary between these stages (Seo and Hwang, 2001). In the lifecycle of a residential facility, for instance, the operation stage creates the most emissions—approximately 96% of the facility's total emission output (Seo and Hwang, 2001). Accordingly, it is essential that stakeholders look beyond mere capital costs in assessing the environmental impact of a facility. Researchers at the Organization for Economic Cooperation and Development (OECD) (2003) have noted that although policies that limit material waste at the demolition stage (e.g., landfill bans) are often implemented, relatively few jurisdictions have applied policies at the upstream stages. Although the scope of this research strictly encompasses residential construction, it is important to relate its impact on sustainability with regard to other sectors of construction, such as the commercial sector. In residential buildings, for instance, 51% of energy use is accounted for in space heating compared to only 31% in commercial buildings (see Figure 2.1 and Figure 2.2). These findings suggest that different efforts and products need to be targeted based on the given construction sector.

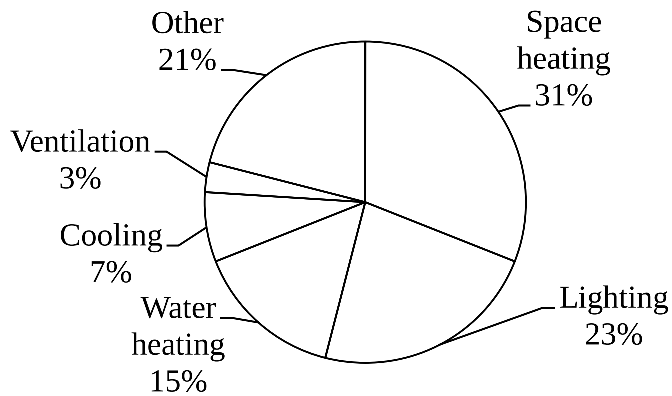


Figure 2.1: Energy Consumption by End Use: Commercial Buildings

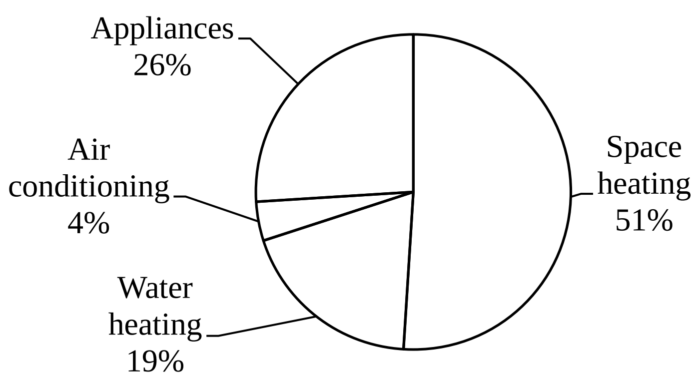


Figure 2.2: Energy Consumption by End Use: Residential Buildings

Although the above data focus only on energy consumption for operations after construction, the depth of sustainable development measurement must be related in terms of embodied energy. Embodied energy refers to the total energy consumed in the acquisition and processing of raw materials, including manufacturing, transportation, and final installation (Kibert 2008).

2.2.1 Literature Review related to CO_2 Emissions in Residential Construction

Limited research to quantify the CO_2 emissions incurred directly through the construction process has been conducted. Nassen *et al*. (2007) have highlighted the need to address the issue of CO_2 emissions resulting from house production.

The relationship between operating a house after its been built and CO_2 emissions has been made evident: the residential sector is the third-largest energy user in Canada, accounting for 17% of secondary energy and 16% of Greenhouse Gas (GHG) emissions or 77 mega-tonnes (Natural Resources Canada (NRC), 2006). A recent project funded through the Canadian Mortgage and Housing Corporation (CMHC) on Net Zero Housing has provided the impetus for this application through its goals of reducing the environmental impact of residential construction and encouraging sustainable construction. More broadly, all citizens and companies must contribute to mitigating climate change while providing value to society (Yu *et al*., 2008). Previous findings have shown that embodied energy during the conventional construction of a house amounted to more than 45 tonnes of CO_2 (Gonzalez and Navarro, 2005).

Embodied energy is this thesis is defined as the commercial energy (fossil fuels, nuclear, etc) that was used in the work to make any product, bring it to market, and dispose of it. Embodied energy is an accounting methodology which aims to find the sum total of the energy necessary for an entire product lifecycle. This lifecycle includes raw material extraction, transport, manufacture, assembly, installation, disassembly, deconstruction and/or decomposition.

In Alberta alone during 2007, the construction of nearly 50,000 residential units would mean the release of more than two million tonnes of CO_2. These numbers demonstrate the economic and environmental impacts of building construction and their relationship to CO_2 emissions within the context of current construction practices. Gonzalez and Navarro (2005) also have shown the possibility of a 30% reduction in CO_2 emissions from the selection of low-environmental impact materials. Other studies have highlighted the relationship between construction materials and CO_2 emissions in terms of lifecycle, ranging from manufacturing to construction to operation and finally to demolition (Seo and Hwang, 2001). As well, there is a body of literature that provides CO_2 emissions rates based on embodied energy from different materials (Upton *et al*., 2008).

Based on a survey conducted at the University of Alberta, the direct CO_2 emissions (i.e., material transportation, workforce travel, and construction equipment) in stick-built house construction in the Edmonton area, from stake-out to move-in completion, amounted to 10.6 tonnes per dwelling (Yu *et al*., 2008).

2.2.2 Literature Review related to Equipment and Maintenance Impact on CO_2 Emissions

Proper maintenance often results in fuel savings, although the magnitude of savings varies by equipment type and condition. Maintenance may include systematic equipment inspection, detection of potential failure, and prompt correction. Two examples of maintenance activities that can reduce GHG emissions include forklift maintenance and improperly inflated tires with poor wheel alignment. A recent study of forklift maintenance estimated that 50% of forklifts were not properly maintained, each of which could be wasting more than 400 gallons of propane annually (Michigan Occupational Safety and Health Administration, 2009). Propane emits about 12.7 lbs of CO_2 per gallon, resulting in more than 2.3 tonnes of CO_2 emitted by each improperly maintained forklift each year. With the cost impact, at the average 2007 propane price of $1.87 per gallon, 400 gallons wasted costs about $750 per year. Improperly inflated tires and poor wheel alignment can adversely affect fuel efficiency of a small truck by 3-4%. Under-inflated tires increase the tires' rolling resistance, and increased rolling resistance requires more fuel to move the vehicle. The GHG emissions impacts of a 3-4% improvement in fuel efficiency can reduce CO_2 emissions per vehicle by 650–860 lbs (0.3 to 0.4 metric tonnes of CO_2) annually for a typical light-duty diesel truck (US EPA, 2008).

2.3 Green Building Rating Programs

2.3.1 Introduction

The building sector is the largest source of greenhouse gas emissions around the globe. Being green, or sustainable, is one pressing issue coming from both internal and external drivers for construction and engineering companies (Wu and Low, 2010). Green building has experienced rapid growth in the past several years. To assess how green, or sustainable the building is, several green rating systems have been developed including Leadership in Energy and Environmental Design (LEED) and Green Globes. The importance of practice, such as managing people, organizational structure, building commissioning, performance documentation, and so on, cannot be neglected, as can be seen from the evolution of the green rating systems (Wu and Low, 2010).

Green building rating programs in general focus on the following five categories of building design and lifecycle performance: site, water, energy, materials, and indoor environment (Gowri, 2004). For each category, a number of prerequisites and credits with specific design and performance criteria exist. This section provides a description of the rationale, limitations, and emerging direction of green building rating programs. The literature on green building programs does not distinctly distinguish among the terms "rating system," "certification program," and "assessment tool." Accordingly, this section describes rating programs and certification programs together; assessment tools are regarded as the software tools used within and/or independent of the programs described.

The sustainable movement has been embraced in the building industry. The growth of the green building trend has spawned a myriad of third-party rating programs and the ubiquitous term "certified." All green building rating programs share the essential principles of environmental protection, energy efficiency, and water conservation. Due to this complexity, most measures of sustainability have been incorporated into labelling or certification programs, and evaluation tools for buildings (Canadian Architect, 2008).

2.3.2 Green Building Rating Programs

The following section provides a brief overview of various green building rating programs.

Leadership in Energy and Environmental Design (LEED) is a voluntary, market-based rating program defining what elements make a building "green" and quantifying precisely how "green" a building is in comparison to other facilities (BCCA, 2008). LEED principles are based on a set of energy and environmental principles, and they serve to strike a balance between existing effective practices and emerging concepts. Unlike other rating programs currently in existence, the development of the LEED program was instigated by the USGBC on behalf of all segments of the building industry and has been open to public scrutiny.

In this program, different levels of green building certification are awarded based on the total credits earned. LEED certification is a paperwork-intensive process designed to be comprehensive in scope, yet simple in operation (Canadian Architect, 2008). While there is still no single standard for sustainable building, LEED has emerged as a globally recognized benchmark for green building (Buchanan, 2007).

The Leadership in Energy and Environmental Design (LEED) green building rating system has been gaining increased attention (Schaufelberger and Cloud, 2009). Considerable literature has been published that describes the roles of the owner and designer, but little research has been published on the role of the constructor.

The aim of LEED is to incorporate best practices within numerous environmental categories: sustainable sites; water efficiency; energy and atmosphere; materials and resources; and indoor environmental quality. The Innovation and Design Process is an additional category that points can be earned for exceptional building design and performance over and above LEED requirements or for innovative performance in green building categories not specifically addressed by LEED.

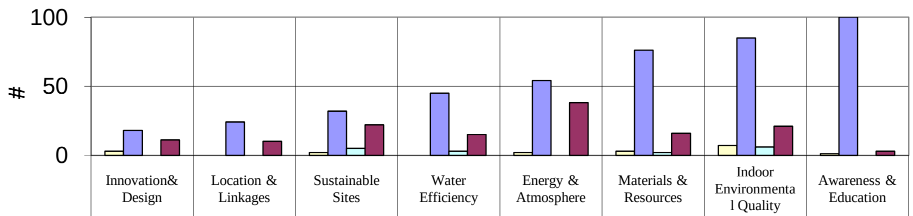
In this system, different levels of green building certification are awarded based on the total credits earned. The system is designed to be comprehensive in scope, yet simple in operation (Canadian Architect, 2008). While there is still no single standard for sustainable building, LEED has emerged as a globally recognized benchmark for green building (Buchanan, 2007).

The system rates facilities in terms of their performance in the various categories as certified, silver, gold, or platinum. The USGBC (2008) has specified the required points for each certification level for LEED-H (Homes) as shown in Figure 2.3. Points can be earned in each category, and these points are performance based rather than prescriptive, thus encouraging innovation and an integrated approach to design. After a building has been completed, a project will be evaluated based on the total number of points earned on a menu of green building measures.

Certification Levels	Points
Platinum	90-136
Gold	75-89
Silver	60-74
Certified	45-59

Figure 2.3: LEED-H (Homes) Certification Levels

Figure 2.4 shows the USGBC's detailed breakdown of the six criteria categories of the LEED-H rating system.



	Innovation& Design	Location & Linkages	Sustainable Sites	Water Efficiency	Energy & Atmosphere	Materials & Resources	Indoor Environmental Quality	Awareness & Education
# Prerequisites	3	0	2	0	2	3	7	1
# Credits	18	24	32	45	54	76	85	100
Min Points	0	0	5	3	0	2	6	0
Max Points	11	10	22	15	38	16	21	3

Figure 2.4: LEED-H (Homes) Rating System

Building Research Establishment Environmental Assessment Methodology (BREEAM) is one of the earliest building rating programs for environmental performance assessment (Gowri, 2004), and it is still the most widely used international method to assess building quality and performance in terms of energy, environmental impact, and health indicators. BREEAM was launched in 1990 by the Building Research Establishment (BRE), the principal building research organization in the UK. The broad scope of BREEAM establishes best practice criteria for building materials and services as well as for operation and management. BREEAM's widespread acceptance, sound research, comprehensive approach, and applicability to a range of building types make it a suitable core program upon which to build specialized applications.

BREEAM/Green Leaf was introduced as Canada's version of BREEAM by ECD Energy and Environment Canada Ltd. in 1996 (Gowri, 2004). BREEAM/Green Leaf was developed in response to the need in the Canadian marketplace for a less expensive methodology and one that could be partially conducted in-house. Its methodology was developed by combining BREEAM's set of environmental issues with the Green Leaf Eco-Rating procedure.

The **Green Building Challenge (GBC)** 2002 is an international collaborative initiative committed to developing a global standard for environmental assessment (Gowri, 2004). GBC developed an environmental assessment tool, Green Building Tool (GBTool), which exposes and addresses controversial aspects of building performance that the participating countries can selectively draw ideas either to incorporate into or by which to modify their own assessment tools.

Green Globes (Canada) has begun to emerge as a competitor, providing alternate paths and much needed competition, although LEED remains the driving force behind green building in the US (Kibert, 2008). The origin of the Green Globes program was in fact BREEAM. In 1996, the Canadian Standards Association (CSA) published BREEAM Canada for application to existing buildings (Green Globes, 2008). In 2000, this evolved into an online assessment and rating tool.

Green Globes uses a 1,000-point program, although the applicant may confirm that certain points are not applicable to the project. Green Globes does not have prerequisites; instead, it allows actions to count toward certification points. In contrast to LEED, Green Globes provides a web-based self-assessment tool that can be completed by any team member with a general knowledge of the building's parameters.

Built Green is a residential construction industry-driven voluntary program that promotes green building practices to reduce the impact that a building has on the environment. This is the leading program among the various green rating programs for homebuilder associations in the provinces of British Columbia and Alberta. The intent of the program is to provide benefits to the homebuyer, the community, and the environment (Built Green Canada, 2008).

Built Green houses offer the following stronger benefits in areas such as energy efficiency, indoor air quality, resource use (including waste management), and overall environmental impact. Built Green uses a checklist program and is generally a self-certification program. It includes an energy efficiency requirement, and a menu of options in categories, addressing a range of "green" items from which the builder can select to meet one of four certification levels (lowest to highest): Bronze, Silver, Gold, and Platinum.

Upon completion of construction and a satisfactory blower door test/inspection, the builder will receive an EnerGuide for New Houses rating label and report together with an official Built Green seal for the new home. The EnerGuide label and Built Green seal are affixed to the furnace in the new home to provide assurance of its Built Green status to the new as well as future owners. Figure 2.5 shows an example of an EnerGuide label that is provided for a house that is evaluated for an EnerGuide score.

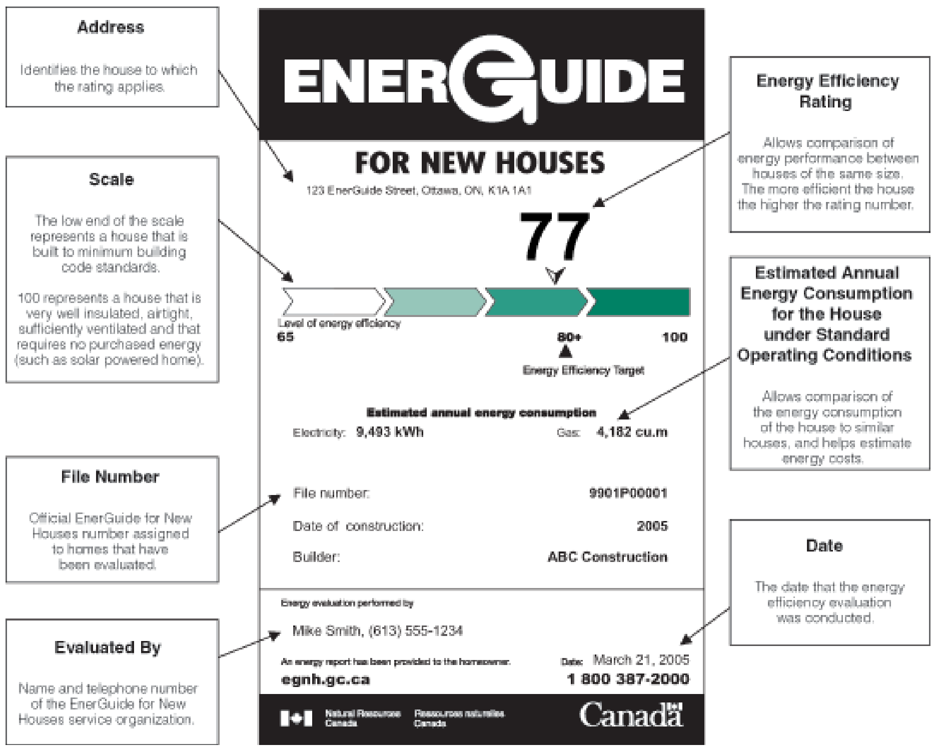


Figure 2.5: EnerGuide Rating

To confirm selected checklist items are being included in the homes, 5% of enrolled homes will be audited at random during different phases of construction. The audit can consist of a consultant visiting the home to confirm the Checklist items or the builder may be requested to submit documentation and/or certificates as outlined on the Checklist.

Only those homes registered in the program that successfully achieve the program criteria may receive the Built Green designation. Look for the Built Green seal to identify a Built Green home.

Table 2.1 shows the EnerGuide rating for various types of houses. New residential construction under the Built Green program requires a minimum EnerGuide rating of 72.

Table 2.1: EnerGuide For Housing Rating Chart

Type of House	Rating
Older house not upgraded	0-50
Upgraded old house	51-65
Energy-efficient upgraded old house or typical new house	66-74
Energy-efficient new house	75-79
Highly energy-effiecient new house (For a brand new house, a rating of 80 or higher is excellent.)	80-90
An "advanced house" that uses little or no purchased energy	91-100

2.3.3 Summary and Comparison of Building Rating Programs

BREEAM, GBTool, and LEED, which differ in terminology, structure, performance assessment methodology, relative importance of the environmental categories, and documentation requirements for certification (Gowri, 2004), are among the most prominent rating programs, but a number of other construction sector rating programs are also in use. Table 2.2 provides a sample listing of building rating program applicability to type of projects (Farooqi, 2007). Each of these is described in this chapter.

Table 2.2: Green Building Rating Program Applicability Comparison

Green Building Rating Systems	Year Introduced	Type of Project			
		Residential	Commerical	Institutional	Industrial
LEED	1998	Y	Y	Y	Y
BREEM	1990	Y	Y	Y	Y
BREEM/Green Leaf	1998	Y	Y	Y	Y
GBC/GB Tool	1996	Y	Y	Y	Y
Green Globes	2004	Y	Y	Y	Y
Built Green	2005	Y	N	N	N

Table 2.3 contrasts the various rating programs with respect to various technical environmental categories.

Table 2.3: Green Building Rating Program Technical Criteria Comparison

Green Building Rating System	Technical Criteria						
	Optimize Site Potential	Optimize Energy Use	Protect and Conserve Water	Material and Resources	Enhance IEQ	O & M Practices	Other
LEED	20%	25%	7%	19%	22%	---	7%
BREEM	15%	25%	5%	10%	15%	15%	15%
BREEM/Green Leaf	22%	33%	8%	10%	22%	---	5%
GBC/GB Tool	12.50%	20.80%	---	---	16.70%	16.60%	33.40%
Green Globes	11.50%	36%	10%	10%	20%	---	12.50%
Built Green	---	20%	12%	34%	20%	---	16%

IEQ in the above table refers to enhancing indoor environmental quality and O & M Practices refers to operations and maintenance. Optimize site potential refers to the scoring available, such as site orientation, to earn points or credits from the various rating systems.

The following section examines green building certification programs for the residential construction industry, namely the Built Green and LEED-H programs. Based on the literature review, these two programs are the suited to be considered in this research due to their application in the residential construction industry and adoption by house builder associations.

Built Green vs. LEED-H Analysis

The selection of an appropriate green building program is critical, as the selected program must meet the particular purpose of the stakeholder. Table 2.4 illustrates the comparison between two residential building rating programs in the house building industry in Alberta, Built Green and LEED-H (Homes). This review provides a better understanding of a framework for green building performance evaluation rating programs. Built Green was selected as the rating program model for this work as it provided a comprehensive evaluation in sustainability in the residential construction sector from the builder perspective. As well, Built Green is the adopted program of the Alberta Home Builders' Association.

A comparison was conducted through an evaluation of a Landmark Group Catalina II model house. The findings of the comparison between these two building rating programs show that given the same input one program results in a rating of Silver while the other program provides a Gold certification. This could imply that a Gold rating in one program is not equivalent to a Gold rating in another program. For instance, the Gold rating from the Built Green program and the Silver rating from the LEED-H program could suggest that the LEED-H program is more rigorous or stringent; however, that is not necessarily the case. Each rating program has its benchmarks and target users. The LEED-H program focuses on the "designer" while the Built Green program is targeted at the "builder."

The research literature review from this section provides better knowledge and understanding of an integrated framework for rating the sustainability of the residential construction practice. As stated earlier, performance ratings must be conjoined with practice ratings in any comprehensive evaluation program. The selection of an appropriate green building program is essential, as the selected program must meet the particular criteria of the owner. Table 2.4 illustrates the comparison between two residential building rating programs in the house building industry in Alberta, Built Green and LEED-H (Homes).

Built Green is used for the performance measurement component of the integrated rating program for this research, while the construction practice rating program is developed later on in the research. Built Green provides a performance rating program in the residential construction sector from the builder's perspective.

The findings show that given the same input one program results in a rating of Silver while the other program provides a Gold certification. This could imply that a Gold level in one program is not equivalent to a Gold in another program. For instance, the Gold level from the Built Green program and the Silver rating from the LEED-H program could suggest that the LEED-H program is more rigorous or stringent; however, that is not necessarily the case. Each rating program has its benchmarks and target users. The LEED-H program focuses on the "designer" while the Built Green program is targeted at the "builder."

Table 2.4: LEED-H and Built Green Comparison

		LEED-H				
			points	min	max	% (max)
	1	Innovation & Design Process	4	0	11	8%
	2	Land & Linkages	4	0	10	7%
	3	Sustainable Sites	8	5	22	16%
	4	Water Efficiency	6	3	15	11%
	5	Energy & Atmosphere	19	0	38	28%
	6	Materials & Resources	13	2	16	12%
	7	Indoor Environmental Quality	10	6	21	15%
	8	Awareness & Education	2	0	3	2%
Totals			66	16	136	100%
Certification			**Silver**			
			LEED-H			
Levels		Platinum	90-136			
		Gold	75-89			
		Silver	60-74			
		Certified	45-59			
		BUILT GREEN				
			points	min	max	% (max)
	1	Operational Systems	15	10	84	20%
	2	Building Materials	19	15	72	17%
	3	Exterior & Interior Finishes	16	10	70	17%
	4	Indoor Air Quality	23	15	58	14%
	5	Ventilation	9	6	24	6%
	6	Waste Management	7	7	35	8%
	7	Water Conservation	9	7	50	12%
	8	Business Practices	14	6	30	7%
Totals			112	76	423	100%
Certification			**Gold**			
			Built Green			
Levels		Platinum	120-423			
		Gold	100-119			
		Silver	90-99			
		Bronze	76-89			

2.4 Software Assessment Tools for Environmental and Energy Efficiency Measurement

The aim of this section is to describe the software assessment tool to be used for measurement of energy and environmental impact. There are numerous assessment tools available that measure the energy and environmental effects of a whole building or of the componential systems and the literature review has provided an outline of a number of viable alternatives. The HOT2000 software is utilized for modeling the performance of a house and is the energy performance measurement tool used by Built Green. The results from the modeling provide an EnerGuide score. This EnerGuide score corresponds to a Built Green certification level. Input criteria include information such as house type, number of storeys, floor plan shape, front orientation, and so forth.

2.4.1 Introduction

This section provides information on various building software tools that evaluate energy efficiency, renewable energy, and sustainability in buildings. The energy tools listed here include databases, spreadsheets, component and systems analysis tools, and whole-building energy performance simulation programs.

The two distinct categories of tools required for design and documentation in formulating a green building rating are: (1) performance evaluation tools; and (2) integrated assessment tools (Gowri, 2004). An assessment tool should address three distinct categories—technical, economic, and environmental and regulatory (Park and Martin, 2007). However, at present no tool exists that effectively addresses these categories collectively. The LEED calculator from the USGBC or the GBTool from the GBC, however, do offer a comprehensive spreadsheet tool that can be used as a design checklist as well as for keeping track of the rating points (Gowri, 2004).

2.4.2 Tools

The evaluation tools available at present are qualitative and/or quantitative and can assist in decisions ranging from building materials and component selection to whole-building system design. Many of the evaluation tool descriptions below have been based on information obtained from online sources.

GBTool (Canada) is a spreadsheet tool that is available as free-ware, and it supports the GBC 2002 rating program. The Green Building Challenge 2002 represents both a continuation of the GBC 1998-2000 process and a multi-year period of review, modification, and testing of the GBC Assessment Framework and GBTool—the operational software for the assessment framework.

ATHENA (Canada), developed by the Athena Sustainable Materials Institute, is a practical, easy-to-use decision support tool that provides high-quality environmental data and assists with the complex evaluations required to make informed environmental choices. The ultimate goal of the ATHENA model is to encourage the selection of material mixes and other design options that minimize a building's potential environmental impact while fostering sustainable development (Trusty and Meil, 2002).

Building for Environmental and Economic Sustainability (BEES) is a program developed by the US National Institute of Standards and Technology (NIST) Green Building Program beginning in 1994. The goal of BEES is to develop and implement a systematic methodology for selecting environmentally and economically balanced building products (Lippiatt, 1999). BEES is implemented through a decision support software established on consensus-based standards and is designed to be practical, flexible, and transparent. It includes environmental and economic performance data for a number of building products. Like other rating programs, BEES analyzes all stages in the life of a product, including raw material acquisition, manufacturing, transportation, installation, use, and recycling and waste management.

HOT2000 (Canada) is an online evaluation tool available through the Natural Resources Canada (NRC) website. The aim of the tool is to provide an energy guide rating for houses based on design and product input parameters (NRC, 2008). HOT2000 building energy simulation tool is the most current reference calculation program for the ecoENERGY Housing Retrofit Program, the EnerGuide New Housing Program, and the basis for government policy work in energy efficiency in Canadian housing. The results are calculated from pull-down menus offering hundreds of input options for details on the building design, site, and climatic zone.

Applications for HOT2000 include the following:

- Forecast energy consumption for your residential construction projects more accurately than ever before
- Project energy costs and performance of natural gas, electric, propane, oil and wood heating equipment

- Check to make sure your low-rise residential designs comply with energy regulations before you start to build
- Calculate thermal resistance of envelope components, including thermal bridging of construction materials
- Improve the energy efficiency of your building designs for better cost-control and materials use
- Predict and control natural, temperature and wind-induced air infiltration to reduce your clients' energy bills
- Exploit the potential of passive solar heating to increase the energy performance of your buildings
- Plan for adequate interior ventilation for good indoor air quality and superior comfort.
- Estimate energy requirements for space heating and cooling, water heating, lighting and appliances at the design stage
- Boost your standing as a designer and your profile as a builder of well-designed, energy-efficient homes

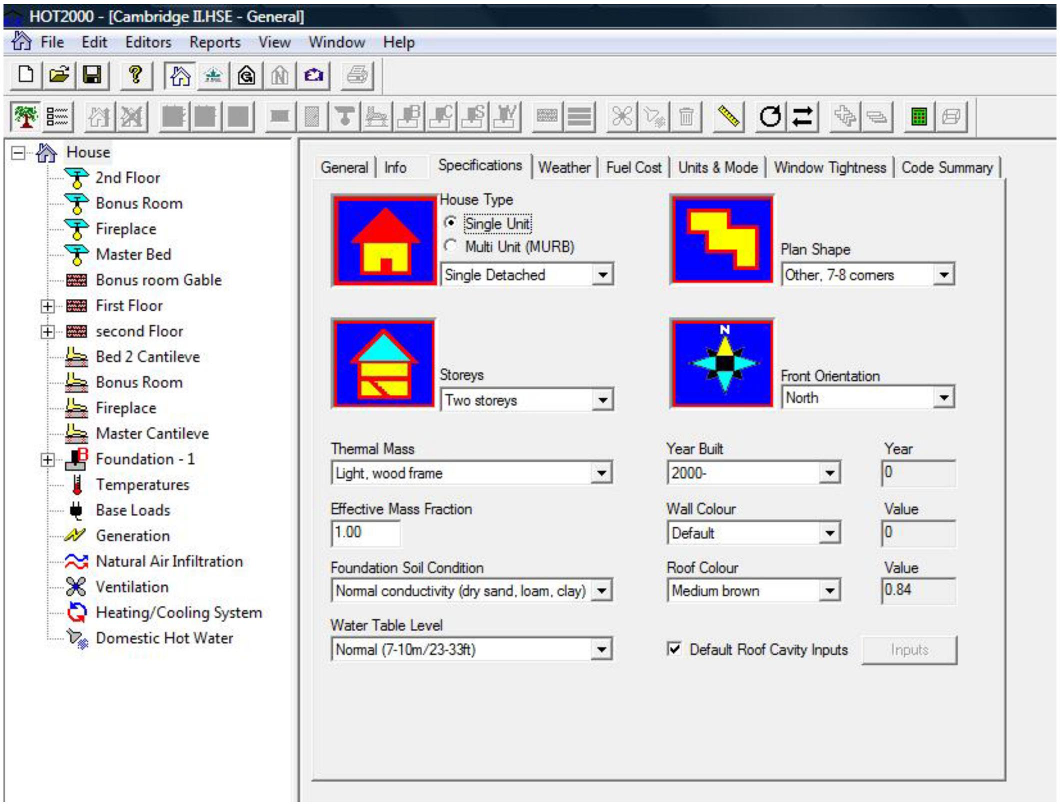


Figure 2.6: HOT2000 Input – General Data

The user inputs a variety of building parameters (see Figure 2.6). These include:

- House type (single unit or multi-unit)
- Location
- Storeys (one, two)
- Plan Shape
- Front Orientation (e.g. North)
- House Thermal Mass Level (A- light, wood frame)
- House temperatures:
- Window characteristics (location and type)
- Ceiling, wall types
- Foundation type

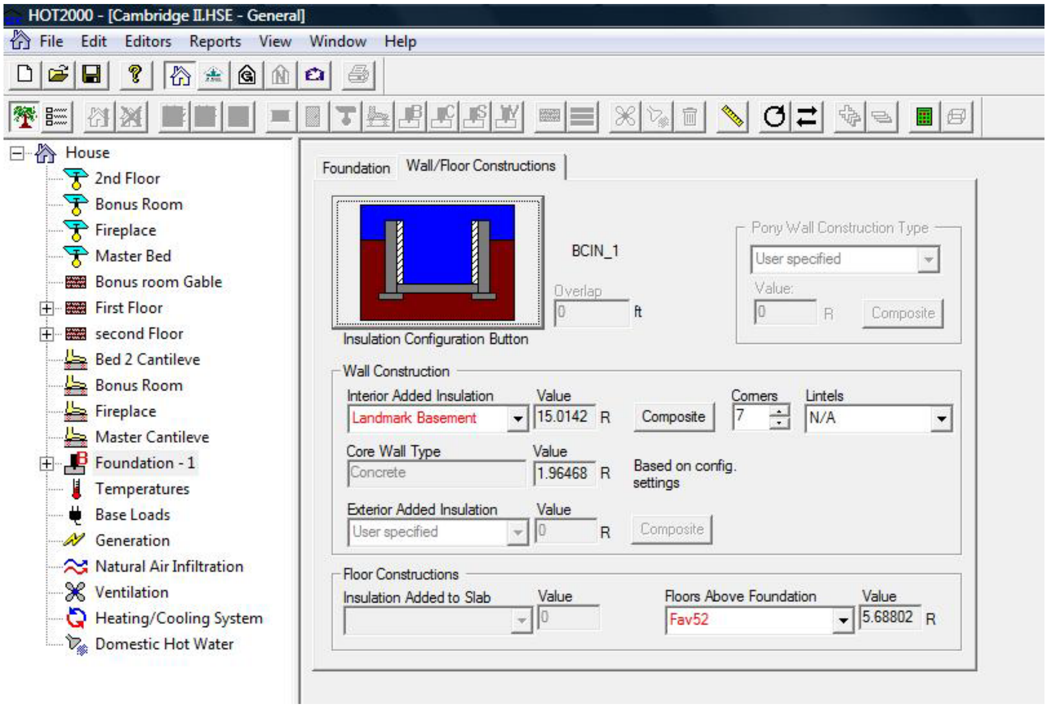


Figure 2.7: HOT2000 Input – Foundation

Figure 2.7 shows the input parameters for the foundation. The user would input parameters by toggling through the different component menus in the software. Once all the required parameters are inputted, the program will output numerous results such as estimated annual fuel consumption, foundation energy profile, space heating system performance, monthly estimated energy consumption, and the Energuide rating which is used as part of the Built Green rating system in Alberta.

2.4.3 Summary

Environmental assessment programs for buildings, along with the tools that support them, are evolving rapidly, although they are not yet fully mature. Problems with these methods have to do with the considerable effort associated with first developing and then assessing various alternatives at the design stage.

These programs and evaluation tools represent a valuable means to improving design practices and raising awareness about sustainable construction, provided clients are willing to absorb the additional costs of developing alternative schemes and performing comparative assessments. At present, the level of sustainability attained by Canadian buildings is not being consistently assessed, and the comparison between various design strategies is still largely subjective.

2.5 Background on Performance and Practice Rating

This section provides a background on the development of a framework for the integration of current performance criteria with a set of practice criteria for the residential construction industry. In keeping with what Roy *et al*. (2003) have contended, the framework is based on the "practice criteria" which affect product quality and process efficiency (speed and dimensional precision) and "product performance criteria" (e.g., energy, air tightness efficiency).

The framework is used to identify and balance multiple criteria when evaluating options for materials and associated costs. As Buchanan (2007) has advanced, integrating green building programs into the capital planning process allows organizations to evaluate greening opportunities that can provide both short and long-term social, environmental, and economic benefits. Furthermore, Yost (2002) has cited the notion that "the soul of green building is programs integration in design and construction" as support for integrated design.

Enhancements to green building programs should provide flexibility, comprehensiveness, and locality. This involves the development of a new rating program that provides an opportunity to rate projects based on the importance given to various performance criteria and integration processes. The basic premise of the rating program to be developed is that a higher number of credits and/or points received by a project indicate a higher potential for sustainable construction. None of the models examined considers social, environmental, and economic aspects in a holistic manner, despite the fact that, as Liebing (2008) has asserted a key to the success of any project is the appropriate blending of design, construction, and management. This gap in the literature will be addresses in this research.

2.6 Industrialization of the Construction process

The resource-intensive nature of today's construction industry suggests that there is much promise in changing the current design and construction practice. Despite dramatic increases in demand for housing in the residential construction industry, this field still lags behind sectors, such as car manufacturing, in terms of widespread technological innovation. As Senghore *et al*. (2004) have argued, the construction industry can certainly benefit from the use of more modern equipment and the incorporation of less labour-intensive technologies. New techniques, materials, tools, and organizational initiatives are often localized, and they face numerous obstacles to becoming broadly implemented (O'Brien *et al*., 2000). Tam *et al*. (2007) have also suggested that one of the best methods of effectively reducing the generation of waste is to promote the use of prefabrication.

In construction, industrialization—either through modularization, panelization, or a combination of both—is a general approach to the construction process whereby a building structure and its systems are prefabricated in a factory setting through some form of manufacturing and are then transported to the construction site and assembled into the final structure. Construction industrialization provides numerous advantages in terms of cost and time savings, production and quality control enhancements, and innovation opportunities. Figure 2.1 and Figure 2.10 shows photpgraphs of typical panelized construction onsite assembly, including installation of the pre-cast concrete foundation walls and main floor wall panels.

Construction industrialization provides numerous advantages in terms of cost and time savings, production and quality control enhancements, and innovation opportunities. These innovation opportunities include enhancing the level of industrialization of the modular and panelized processes. In this regard, a critical criterion for flexible application is the suitable design of standard connections of all modules (Gotthard and Bercsey, 2006). Moreover, the following section will examine new innovations and techniques in construction methods.

Modular Construction consists of one or more structure units fabricated in a manufacturing plant away from the jobsite. In the building industry, prefabricated modules are normally completed with trim work, electrical, mechanical and plumbing installed. Previous studies have proved that Modular Construction provided many advantages to the built environment, including the reduction of need for workforce, the reduction of onsite Greenhouse Gas (GHG) emissions, and the improvement of construction schedule and product quality (Lu and Korman, 2010).

Modular construction is a sub-classification of factory-built construction, along with panelized, pre-cut, and manufactured construction. In this dissertation, any discussion of modular construction in terms of benefits and illustrations can be extrapolated to refer more broadly to factory-built construction. Modular construction provides the opportunity to build structures in a factory with the end appearance of site-built structures and with only the earthwork, foundation work, and utility installation having to be completed onsite. The economy of scale and repetition, which characterize the construction of multi-unit buildings, serve to accentuate the benefits of an industrialized and automated solution. Most of these benefits relate to the fact that a controlled indoor working environment and stable, experienced labour are conducive to the assembly of products with consistent quality. These also produce opportunities for innovation whereby companies familiar with their product can more easily integrate unfamiliar materials and techniques with other trades working side-by-side. Finally, another benefit of the shorter building cycle of modular construction can reduce or eliminate job-site theft. Modular construction structures typically consist of boxlike sections which can be stacked vertically and horizontally with a crane. A possible disadvantage of modular construction could be the dimensional constraints of each modular component. Typically, each box is approximately 14’ wide and up to 50’ long; however, these dimensions can vary considerably (National Association of Home Builders (NAHB) 2008). The dimensions of these units can also be constrained by transportation regulations. A dimension of 14’ in width is common in North

America, with lengths typically ranging from 20’ to 50’. Most highway corridors allow for over-sized wide loads; however, permits are required.

An example of the efficiency of modular construction is illustrated in Kullman Buildings Corp.’s erecting of five dormitory buildings at Muhlenberg College, Allentown, Pennsylvania. Five modular residential buildings, each three storeys high and approximately 8,130 sq. ft. in area, were assembled in 10 working days. The residence totalled 41,000 sq. ft. in liveable space comprised of 90 steel and concrete modules (Kullman Buildings Corp. 2008). The effectiveness of modular construction in residential construction has been evidenced in other cases as well. One residential construction company, for instance, was able to erect a 42-unit apartment building in just 12 days, using a six-person crew to install modules at a rate of nine modular sections per day. Of course, this time does not include fabrication of the modular sections, but fabrication work can be carried out while the site is being prepared, providing ample time to examine the details, dimensions, and materials within a factory setting. This simultaneous work can entail savings in time, money, and potential project coordination aggravation. Often, modular components are also more securely constructed than traditional, site-built components, primarily due to the practice of gluing the components together in addition to conventional fastening to make the modules road-worthy. This results in energy efficiency through decreased air infiltration, in addition to less squeaking and structural movement.

In fact, there are a number of benefits associated with prefabrication, specifically when compared to onsite construction. Most notably, these benefits include material waste minimization and shorter construction schedules. Prefabricated methods reduce initial raw material use, onsite waste, and the labour necessary for construction compared to traditional onsite construction (Robinson, 1998).

At present, almost all types of buildings can be constructed in factories, which offer numerous advantages as noted on the Modular Building Systems (2008) website:

- Time savings—no lost time due to weather or vandalism. Portions of the building construction and site preparation occur simultaneously (see Figure 2.8);
- Cost savings—material prices are driven down by bulk purchases; and
- Productivity—workers perform more efficiently with less re-work and better quality control.

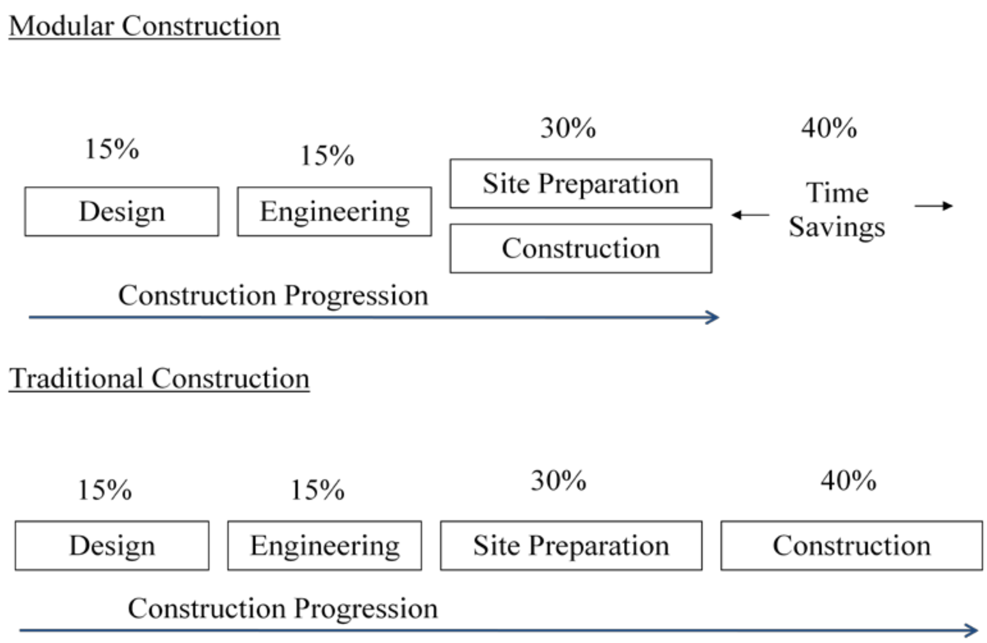


Figure 2.8: Modular Construction Time Savings

Figure 2.9 shows photographs illustrating the onsite assembly of pre-cast foundation walls.

2.6.1 Pre-Cast Foundations


Pre-Cast wall panels delivered to site


Wall section placement


Crane lifting wall panel


Garage wall panel

Figure 2.9: Photographs of Pre-Cast Foundation Construction Onsite Assembly

2.6.2 Pre-Fabrication Wall Assemblies

The section below provides an analysis of studies that quantify the actual savings linked to prefabrication through field investigations conducted in Edmonton, Canada, in addition to other findings from the literature. For example, a study conducted in cooperation with Landmark Homes, Edmonton, observed reductions in material waste as a result of using factory-type panel-wall systems (Yang, 2007). A detailed summary of the field work for this study is included in

Appendix B and C. Another field study in Edmonton, conducted by Habitat for Humanity, demonstrated savings both in terms of time and in lumber used. Overall, the study indicated that panelized construction provided the following benefits: less time, fewer man-hours, less waste, fewer experienced-labour requirements, and increased production. Specifically, prefabrication offered a 40% reduction in labour, a 55% decrease in site wastage of dimensional lumber and Oriented Strand Board (OSB), and a 5.5% reduction in OSB material required to complete the project (FPInnovations Forintek, 2007). Figure 2.10 shows some of the pre-fabricated walls and roof sections.

Roof section

Shipping wall panels

Roof section at fabrication shop

Assembly of wall panels

Figure 2.10: Photographs of Pre-Fabrication Wall and Roof Construction Onsite Assembly

2.7 Construction Materials and Products

A growing global movement seeks to promote the "greening" of the construction sector (Irland, 2007). Green building materials use resources in an environmentally responsible way and respect the limitations of non-renewable resources. An example of this type of green building material is with carpets used in the carpet industry. Green materials can garner high ratings in terms of indoor environment quality as well as with respect to performance measures such as energy efficiency (Spiegel and Meadows, 2006). "Material selection usually involves a complicated multi-variable process augmented by a number of qualitative considerations" according to Fernandez (2006). In the design scenario, two sets of entities must be defined, where the first describes the performance criteria and the second the physical entity (i.e., building product). As a result, a link between these two entities is formed based on opportunities and constraints when selecting appropriate materials (Fernandez, 2006). A prominent aspect of this is a bolstered impetus to boost the availability of green building materials such as wood products. The Forest Stewardship Council (FSC) oversees the development of forest management standards and the certification of wood products (FSC, 2008). Furthermore, building-related contributions to environmental problems are considerable and therefore must be addressed. Accordingly, selecting environmentally preferred building products is one strategy to improving a building's environmental performance (Lippiatt, 1999).

Goverse *et al*. (2001) have pointed out that innovation of materials is often constrained by various factors ranging from social to economic ones. Nonetheless, newer products and materials have been successfully introduced into the marketplace. The selection of construction materials with a low-environmental impact has resulted in a reduction in CO_2 emissions by 27% (Gonzalez and Navarro, 2005). This was quantified in a demonstration study on conventional materials and low-environmental impact materials. These materials include wall structures made of perforated brick, timber roofs, and insulation made from natural cork (Gonzalez and Navarro, 2005).

As a further example, the use of wood building material in place of concrete, coupled with greater integration of wood by-products into energy systems, would be an effective means of reducing fossil fuel use and net CO_2 emissions into the atmosphere (Gustavsson and Sathre, 2006). In fact, there are numerous innovative construction products available in the current market, with further innovations under development. Examples of these novel products in use in construction include Insulated Concrete Forms (ICFs) and Structural Insulated Panels (SIPs). ICFs are a rigid plastic foam form which holds concrete in place during curing and remains in place afterwards to serve as a thermal insulation for concrete walls. The foam sections are lightweight, resulting in energy-efficient, durable construction. ICFs are comprised of an insulating foam—usually either Expanded Polystyrene (EPS) or Extruded Polystyrene (XPS). Polystyrene is generally known as a thermoplastic substance. The three basic form types are hollow foam blocks, foam planks secured with plastic ties, and 4’ x 8’ panels with integral foam or plastic ties. ICFs can be used to form various structural configurations, such as a standard wall or post-and-beam construction. They also provide backing for both interior and exterior finishing.

A publication by the National Association of Home Builders (NAHB) (2008) reported that the insulation values of ICF walls vary depending on the material and its thickness. EPS and XPS provide low thermal conductivity with typical insulation values ranging from R-17 to R-26 for ICFs, compared to a range of just R-13 to R-19 for conventional wood-framed walls. The strength of ICF structures relative to lumber depends upon its configuration, the thickness of the form, and its reinforcement. With that said, all ICF walls are designed as reinforced concrete walls, giving them high wind and seismic resistance.

There are numerous ICF wall types available, and the various options are differentiated based on the type of form involved and the shape of the concrete sections. Products are further differentiated in terms of how the forms attach to one another, how the finishing components (drywall, siding, etc.) are attached to the wall, and what specific insulating values, foam types, and other features are at play (NAHB 2008).

In addition to ICFs, a modular breathing wall panel has been developed which replaces conventional insulation with dynamic insulation, but leaves the rest of the wall virtually unchanged (Imbabi, 2006). Imbabi (2006) has pointed out that this new approach to breathing wall construction forms the basis for a distributed air supply system in which the wall functions as a supply source, a heat exchanger, and a filter of airborne pollutants. Imbabi (2006) further described dynamic insulation as a method for supplying fresh filtered ventilation air to indoor spaces, bringing us nearer to the establishment of a natural ventilation concept.

SIPs are another product type which provide opportunities to minimize material waste, improve energy efficiency, and enhance sustainability. SIPs are high-performance thermal-efficient panels for use as walls, roofs, and floors in new residential and commercial buildings. Panels vary in size of up to 8’ x 24’ with a thickness of 11¼”. The core of the panel is made of EPS sandwiched between two OSB structural skins. The bond uses waterproof urethane glue, resulting in a product that is strong, predictable, and energy-efficient (SIP Building Systems Inc., 2008). Figure 2.11 shows examples of the SIP, ICP and structural foam panels.

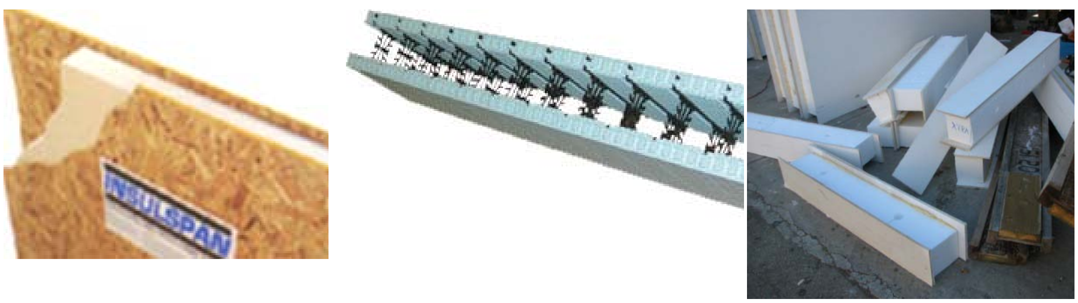


Figure 2.11: Structural Insulated Panels (SIP), Insulated Concrete Forms (ICF) and Structural Foam Panels

2.8 Material Waste

In Alberta, around 22% of the materials required for new constructions and renovations are wasted and land filled (approx. 650 thousand tonnes in 2006) (C & D Waste Reduction Advisory (2006). Alberta Environment has set a goal of 500 kg/capita to be reached on 2010, which represents 50% of the current material waste generated in the province. In terms of new construction for the homebuilding industry, it has been found that in average, 4.38 lb. of material waste are produced per square-foot (California Integrated Waste Management Board (CIWMB), 2007). Some of the mechanisms that can be used for reducing construction material waste are the implementation of build green programs, building componentization methodologies, and landfill levies C & D Waste Reduction Advisory (2006). Most of the waste recycling programs incentive construction companies and contractors to look after material leftovers (Kelleher Environmental, 2006), but minimum has been done to maximize material usage. Manufacturing building components and the inclusion of automated building designs are solutions to minimize material waste and better utilize primary materials for construction. As an example, wood stick-framed dwellings can be framed with less than 1% of materials waste for nominal lumber (Manrique *et al*., 2008). Previous research in material waste in residential constructions (Mah, 2007) has show that wood waste accounts for 60% (by volume) of all waste and is the best resource with respect to which to address enhancements to sustainability.

Typically, in residential constructions there are three waste pick-ups, with the first pick-up coming after the conclusion of the framing phase. Figure 2.12 breaks down the distribution of waste per category after the first pick-up (Mah, 2007). A detailed summary is provided in Appendix B.

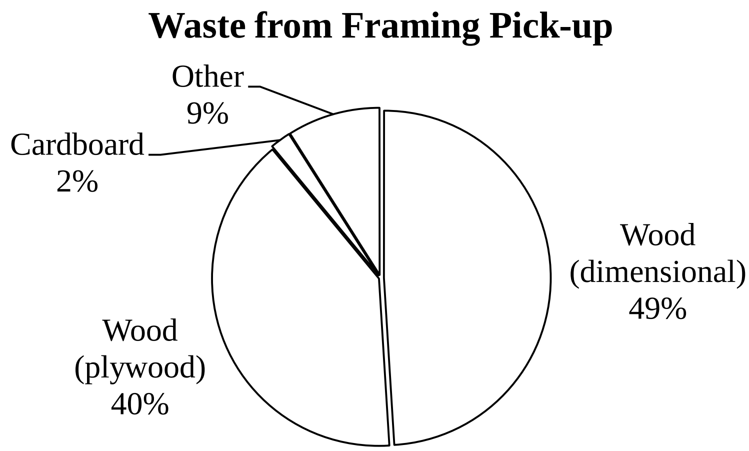


Figure 2.12: Material Waste from Framing Pick-Up (by volume)

The Greater Vancouver Regional District (GVRD) (2008), in this regard, has highlighted the magnitude of material wastage in the construction industry as shown in Table 2.5. The volume of waste per unit rate for each construction sector is not as erratic as the weight per unit rate values. One explanation based on these findings suggests that the production process and product usage both vary based on the type of sector and the magnitude of the economy of scale.

Table 2.5: Construction Waste Generation Rates

	Residential/ Commercial High-rise		Residential Low-rise		Commercial Low-rise	Institutional Low-rise
Material	**cu.yd/ 1000 sq.ft.**	***tonnes/ 1000 sq.ft***	**cu.yd/ 1000 sq.ft.**	***tonnes/ 1000 sq.ft***	**cu.yd/ 1000 sq.ft.**	**cu.yd/ 1000 sq.ft.**
Wood	3.3	*0.40*	6.0	*0.73*	5.6	7.0
Gypsum	3.6	*0.92*	1.1	*0.27*	0.2	0.9
Metal	0.2	*0.09*	-	-	-	0.4
Concr./Asph.	1.7	*1.79*	0.04	*0.05*	-	0.7
Cardboard	-	-	2.4	*0.05*	7.1	-
Other	5.6	*1.54*	0.5	*0.14*	1	0.2
Total	14.4	*4.74*	10.04	*1.24*	13.9	9.2

Also drawn from the GVRD (2008), Figure 2.13 indicates that wood by volume (60%) is the material with the largest contribution to waste and the best resource to address enhancements to sustainability.

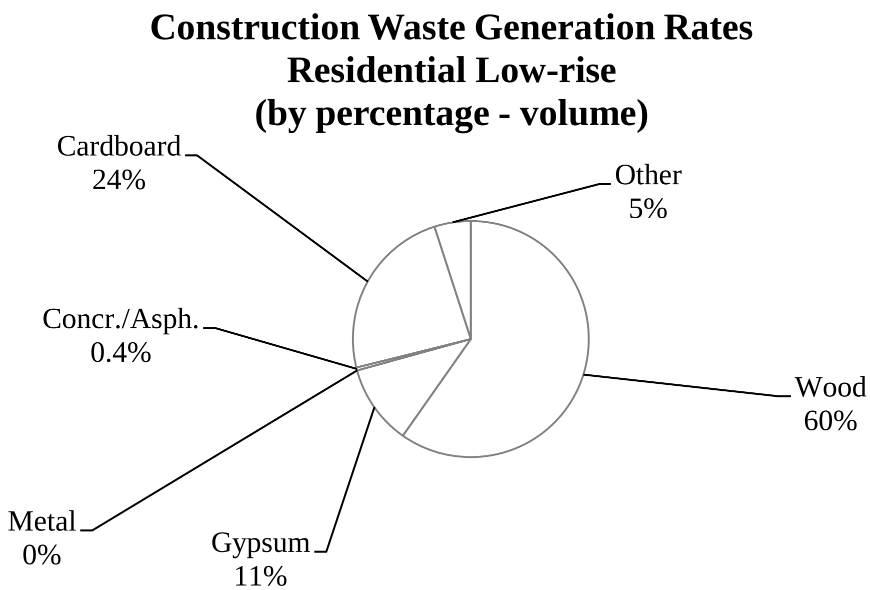


Figure 2.13: Construction Waste by Percentage (Volume)

In addition, research data indicates that 9% of materials by weight delivered to a construction site end up as waste (Bossink and Brouwers, 1996). Reducing the initial quantity of materials delivered to a site, will in turn reduce the total amount being wasted. Again, this fact turns the attention to the need to address waste reduction prior to construction disposal; fact that can be achieved under a controlled environment such as construction at manufacturing shops. Innovation of materials is often constrained by factors ranging from social to economic (Goverse *et al*., 2009). Nonetheless, newer products and materials have been successfully introduced into the marketplace. The selection of construction materials with a low-environmental impact has resulted in a reduction in CO_2 emissions by 27% (Gonzalez and Navarro, 2006).

Products like roofing asphalt shingles are thrown away at a rate of 1.25 million tonnes per year in Canada; many different applications can be made on these materials to avoid land filling (Alberta Construction Magazine, 2007). Leftovers of these products can be easily stored and sent to recycle if construction takes place under a controlled environment (manufacturing shop). The implementation and further control of waste management procedures at manufacturing shops are easier to achieve due to the storage of bulked material waste.

A study conducted by the Construction Group at the University of Alberta (Mah, 2007) found that, on average, almost 1400 Kg of waste are generated in the construction of a single residential facility, 89% of which is wood waste. It is of interest that the variation in material waste was almost 600 kg for the same house model between different framing contractors (see Appendix B for raw data).

Based on data collected from five onsite houses' waste during framing stage, the percentage of dimension wood, OSB and joist waste are shown in Figure 2.14 below.

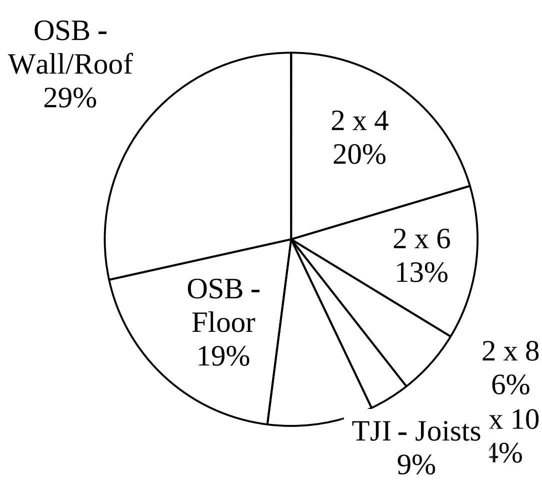


Figure 2.14: Percentage of Waste Components by Weight (Onsite)

The pre-fabrication method's components contribute different weight from workshop and assembing site as shown in the summarized Table 2.6 below comparing to the onsite method.

Table 2.6: Weight of Waste Components

Calculated Weight (kg)	Onsite	Pre-fabrication		
		Workshop	Site	Total
2 x 4	195.20	35.01	106.28	141.28
2 x 6	127.45	73.48	88.13	161.62
2 x 8	54.68		28.60	28.60
2 x 10	33.34	4.08	13.02	17.11
TJI - Joists	87.54		58.78	58.78
OSB - Floor	186.40		141.94	141.94
OSB - Wall/Roof	272.73	77.90	177.67	255.57
Total Calculated Weight (Kg)	957.35	190.48	614.42	804.90

The pre-fabrication method needs 2" x 6" dimensional woods to support assembling pre-fabricated frames in the jobsite, which causes extra waste that traditional method would not apply. This could be one of the possible reasons why more 2" x 6" wood wastes occur with pre-fabrication method. The other reason is that, due to the fact that the same house model of pre-fabrication is hard to be applied during the research period, the pre-fabrication housing samples have different models which may lead to more 2" x 6" lumber being used for those type of framing than the traditional housing samples' model, Catalina II model. The second reason may affect the rest of comparison items. In addition, pre-fabricated wall panels which are built in the off-site workshop are OSB-wall nailed with studs frame by a large nailing machine with a lot of shooting gun aligned. One of the advantages of pre-fabrication is optimizing small pieces of dimensional wood usage in workshop as well as the OSB-wall. But sometimes the OSB pieces cut by a router for the window or door opening are full of nails behind and cannot be reuse in workshop. These pieces mainly contributed to 40.9% of waste happened in workshop and can explain its high waste amount which is very close to traditional method (Yang, 2007). Figure 2.15 shows the onsite wood waste from the residential construction practice. Figure 2.16 shows a more orderly amount of wood waste from the fabrication shop.


Unsorted wood waste pile


Sorted TJI-Joist wood waste

Figure 2.15: Photographs of Wood Waste (Onsite)


Garbage collection from Pre-Fab Shop


Waste pile from Pre-Fab shop

Figure 2.16: Photographs of Wood Waste (Fabrication Shop)

The Construction Group at the University of Alberta has developed a system based on information, innovation, and applied intelligence for stick-built residential facilities (Manrique *et al*., 2008). Research in this area has been directed toward the incorporation of 3D modeling and material optimization techniques in order to provide automation in construction drawings for panelized framing in the home building industry. Exact take-off lists of materials and cutting patterns are extracted from the generated drawings for nominal lumber, sheathing, and drywall in order to provide added value and enhance the current building practice. With regard to material waste, the current model makes use of combinatorial analyses to generate the optimum amount of cuts and leftovers for nomial lumber, sheathing, and drywall. For example, a material waste rate of less than 1% can be ahcieved for nominal lumber by utilizing diffent combinations with 8, 9, and 12-foot components for a detached single family home (see Figure 2.17). The implementation of this research in the current practice can elevate the quality for manufacturing building components in the home building industry through the developmennt of a method that can be applied at manufacturing shops for the prefabrication of components within a controlled environemnt for future assembly onsite.

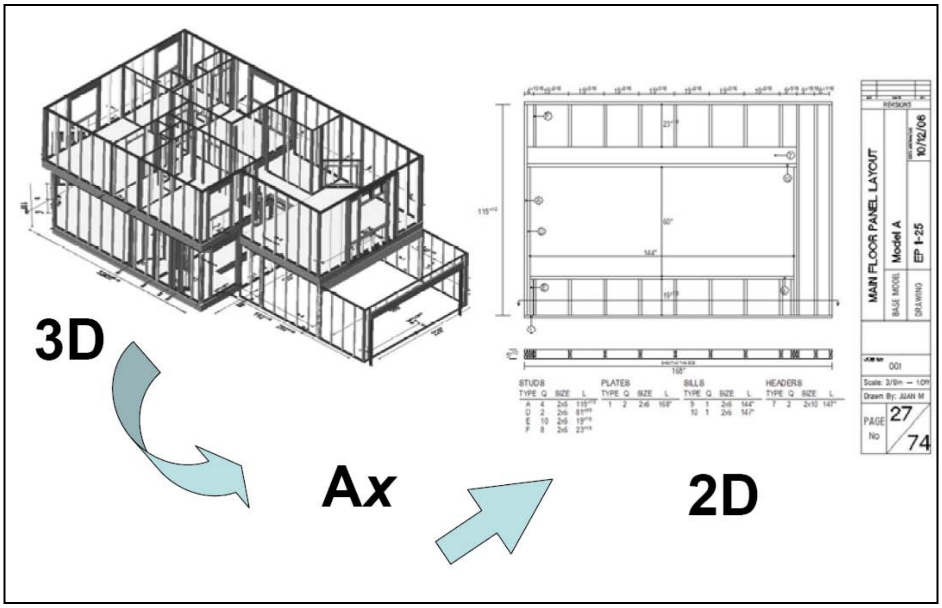


Figure 2.17: Detailed Framing Drawing

2.9 Health and Safety

Health and safety are two issues that impact residential construction from the social, environmental, and economic perspective.

2.9.1 Health

Construction is a hazardous occupation with routine and excessive exposure to many risks such as chemicals, dusts, manual handling, and physical and psychosocial hazards (Murie, 2007). Many of most commonly encountered occupational carcinogens such as solar radiation, crystalline silica, radon, wood dust, diesel exhaust, and mineral fibers are everyday exposures on construction sites (Murie, 2007). An increasing body of evidence has associated house quality with morbidity form infectious diseases, chronic illnesses, injuries, poor nutrition, and mental disorders (Krieger and Higgins, 2002). In Western industrial nations, it is estimated that 4-10% of all head-and-neck cancer cases are caused by occupational exposures with increased risk to those engaged in some blue-collar occupations including woodworkers and construction workers (Brophy *et al*., 2007). Exposures associated with head-and-neck cancer include dust, organic or inorganic agents including iron dust, asbestos cement, paint, polycyclic aromatic hydrocarbons (PAHs), cement dust, varnish, and lacquer. Woodworkers have shown elevated risks for esophageal cancer, gastric cancer and nasal cancer (Brophy *et al*., 2007). The potential problems of construction workers' exposures to diesel exhaust have also been flagged. Construction workers have shown a significant increase risk to cancer with a 2.20 odds ratios (Brophy *et al*., 2007). Construction sites are generally dusty— as powdered bags of cement are emptied for mixing, as wood is sawed, as machinery lumbers across sites, and as pneumatic tools are used on concrete and drywall. There are also fumes from such activities as welding, roofing and paving. Construction workers' lungs are thus multiply exposed to potential toxic hazards. Asbestos and silica are the two best-documented hazards (Ringen *et al*., 1995). Some work-related illnesses appear to be correlated with specific construction trades. Common toxic hazards on the construction site include dusts, metals, solvents and other chemicals. Musculoskeletal Disorders result from injuries. These stem from repetitive tasks and awkward body positions. In building construction, much of the finishing work involves areas either above shoulder height or below knee level (Brophy *et al*., 2007). The prevalence of most musculoskeletal symptoms increases with age. Other health impacts on construction workers include noise-induced hearing loss, skin disorders, and central nervous system disorders (Ringen *et al*., 1995).

2.9.2 Safety

Safety on the jobsite is a significant issue for workers. With the shortage of skilled labor, many young and inexperienced workers enter this field without adequate training. Consequently, the rates of onsite accidents with these young workers are higher when compared to with older, more experienced workers. Experience is a factor in construction injuries, with the rate of injuries decreasing substantially as the length of service increases. Familiarity with the job site is also a consideration. Self-employment and small worksite size also appear to correlate with increased risk of injury (Ringen *et al*., 1995). In addition, site conditions such as inclement weather (temperature, wind, moisture) lead to higher accident rates. With the shift towards factory construction, these weather conditions are mitigated through fabrication in a controlled environment. Likewise, factory construction better lends itself to safe material handling and assembly than conventional methods. For example, the safety risk to workers is lower as these individuals will not generally have to work on an elevated platform or wall in the assembly of wall panel systems. Generally, training of workers is better monitored in a factory environment. Workers can be trained to perform specific tasks with adequate supervision. As well, the general quality of work is shown to be higher in a factory-setting, with less need for re-work. Construction rarely provides steady employment; construction workers are always working themselves out of their jobs. Some assignments may last only a few days to a few months. Thus, a construction worker may have four or more employers a year. Because of bad weather and layoffs between assignments, an individual worker may clock only 1500 hours of work or less yearly in construction, compared with 2000 hours in other industries (Ringen *et al*., 1995). The constantly changing worksite has another marked effect on safety and health. Unlike in an factory setting, where the tasks are often repetitive and controlled by the location of the machinery, the construction site allows, and requires, extensive movement by the worker from place to place. The worker is therefore much more responsible for his or her own protection (Ringen *et al*., 1995). Additionally, the construction workers may have to travel long distances to various work sites.

Construction workers are at great risk of traumatic injury partly because of where they work, for example, from scaffolds and roofs. Roofing may be the most dangerous trade because of the danger of falls (Ringen *et al*., 1995). In conventional onsite built method, half of the framing work, most of the siding and entire roofing are performed at heights. The risk of falling from elevation is quite high. Falls from heights due to inadequate scaffolding or personnel restraints are common causes of serious injuries or fatalities. All of these are entirely predictable and preventable (Murie, 2007). Falls issues are paramount in the onsite house construction industry. By moving towards a factory setting will reduce injury claims such as falls due to floor openings and lifting walls. As well, there is elimination of scaffolds and ladders, which are high sources to injuries, as assembly of panels and modular components are done at ground level in factories. When houses are panelized, walls and floors are built in the factory and roofs are built on the ground with shingles and siding; then the house is assembled using a crane. The operation at heights is reduced by 80%.

Safety on the jobsite is a significant issue for contractors. With the shortage of skilled labour, many young and inexperienced workers enter this field without adequate training. Consequently, the rates of onsite accidents with these young workers are higher when compared to with older, more experienced workers. In addition, site conditions such as inclement weather (temperature, wind, moisture) lead to higher accident rates. With the shift towards factory construction, these weather conditions are mitigated through fabrication in a controlled environment. Likewise, factory construction better lends itself to safe material handling and assembly than conventional methods. For example, the safety risk to workers is lower as these individuals will not generally have to work on an elevated platform or wall in the assembly of wall panel systems.

In conventional onsite built method, half of the framing work, most of the siding and entire roofing are performed at heights, as shown in Figure 2.18. The risk of falling from elevation is quite high.

Framing Siding Roofing

Figure 2.18: Photographs of Onsite Built Method

When houses are panelized, walls and floors are built in the factory and roofs are built on the ground with shingles and siding; then the house is assembled using crane (see Figure 2.19). The operation at heights is reduced by 80%.

Wall panel production | Roof with shingle and siding on ground | Erection

Figure 2.19: Photographs of Panelized Construction

Generally, training of workers is better monitored in a factory environment. Workers can be trained to perform specific tasks with adequate supervision. As well, the general quality of work is shown to be higher in a factory-setting, with less need for re-work.

Falls issues are paramount in the onsite house construction industry. By moving towards a factory setting will reduce injury claims such as falls due to floor openings and lifting walls. As well, there is elimination of scaffolds and ladders, which are high sources to injuries, as assembly of panels and modular components are done at ground level in factories. For the onsite house construction industry, statistics indicate that falls produce more than 50 percent of all claim costs with an average of ~$32,000 and 71 days lost per claim for 2003-2005. Fall categories are shown below based on Worker's Compensation Board (WCB) statistics (WCB, 2009). Hence the potential safety and cost savings benefits of factory construction would be substantial (14 claims/1000 houses = ~ $448,000) (see Figure 2.20).

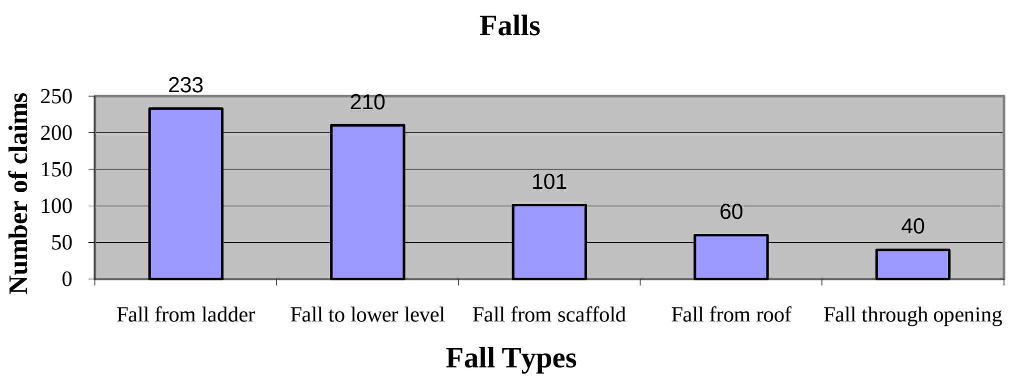


Figure 2.20: Claims Due to Injury

2.10 Sustainability Models and Practices Measurement

This section examines literature related to the development of an evaluation program to measure the effectiveness of organizational practices and operational processes in enhancing sustainability. Partnership for Advancing Technology in Housing (PATH) promotes innovation through three key strategies (PATH, 2008): identify and reduce barriers that impede innovation, including regulatory barriers; disseminate information to speed the development and adaptation of advanced building technologies; and advance housing technology research and foster the development of new technology.

The Organization for Economic Co-operation and Development (OECD) (2003) has identified three primary organizational policy instruments that affect sustainability-enhancing practices: regulatory, economic, and information tools. The criteria for the evaluation of these instruments are environmental effectiveness, economical efficiency, incentives for innovation, administrative costs, and acceptability. The proposed evaluation framework in this research refers to these three instruments in its development.

Evaluation tools are based on a sustainability model—a perspective on the interplay of the social, environmental, and economic domains. There are many sustainability models. Each model provides an overarching view of the social, environmental, and economic perspective. The model shown in Figure 2.21 denotes that the economy is a subset of society (i.e., it only exists in the context of a society), and that many important aspects of society do not involve economic activity (Mann, 2009).

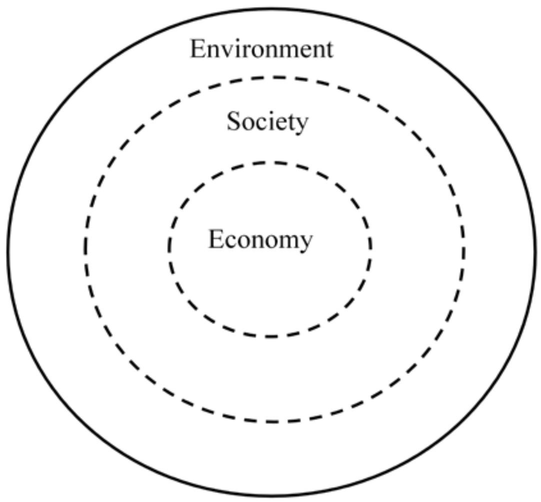


Figure 2.21: Economy, Society and Environment Model

Sustainable development calls for a paradigm shift and a broader view of construction. The traditional engineering benchmark of time, cost, and quality measurements must now include a wider perspective through sustainability indicators such as social, environmental, and economic (SEE) elements. Figure 2.22 illustrates the shift towards the new paradigm. As seen from the figure, the old paradigm can be incorporated into the new SEE paradigm (Projectsmart, 2010). There is a need to look at construction from a different perspective or paradigm. A growing public concern over the harmful consequences of our industrialized societies on our planet and its natural resources has urged society to reexamine their building practices. The figure below is called the "Scope Triangle" which shows the trade-offs inherent in any project between competing objectives. The triangle illustrates the relationship between three primary forces in a project. Time is the available time to deliver the project, cost represents the amount of money or resources available and quality represents the fit-to-purpose that the project must achieve to be a success.

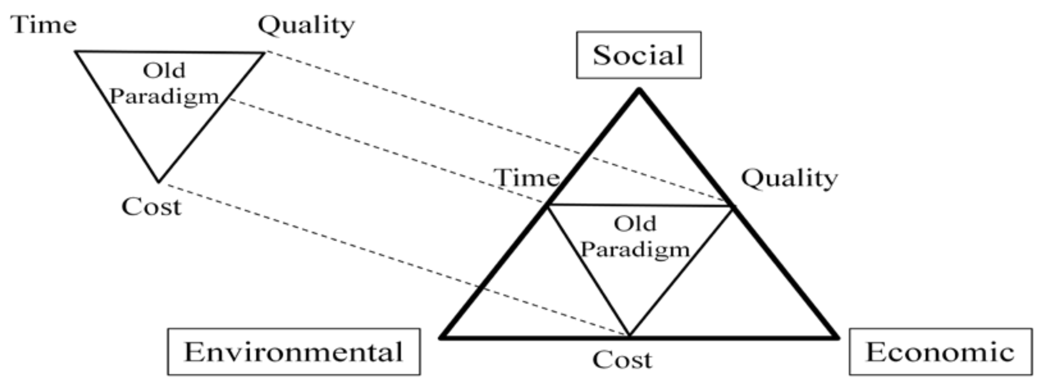


Figure 2.22: Sustainable Development Paradigm Shift

Figure 2.23 shows another sustainability model (Mann, 2009). The strong sustainability circles are presented as a Venn diagram. There is common ground where each of the circles overlap. The area where sustainable development truly occurs within the social, environmental and economic elements is at the center where all three areas overlap. In other words, sustainability lies within the union of the social, environmental, and economic elements.

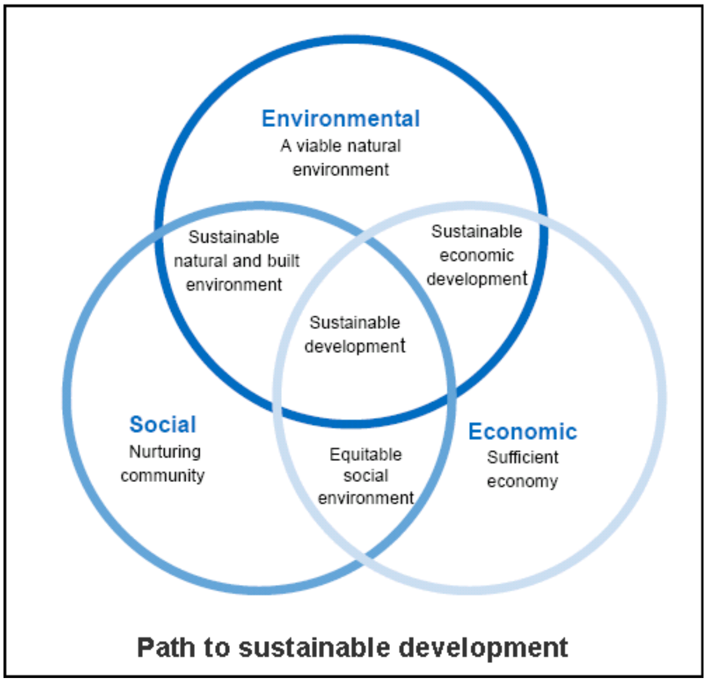


Figure 2.23: Social, Environmental and Economic Sphere

2.10.1 The Natural Step (TNS)

The Natural Step (TNS) is a sustainability measurement tool. TNS (2009) describes and consists of four system conditions: concentrations of substances extracted from the earth's crust; concentrations of substances produced by society; degradation by physical means; and people are not subject to conditions that systematically undermine their capacity to meet their needs and in that society. The Natural Step sustainability principles clearly define the basic criteria for a sustainable society. The A-B-C-D analytical approach (see Figure 2.24) includes four elements, which are repeated as the organization progresses along various pathways towards sustainability.

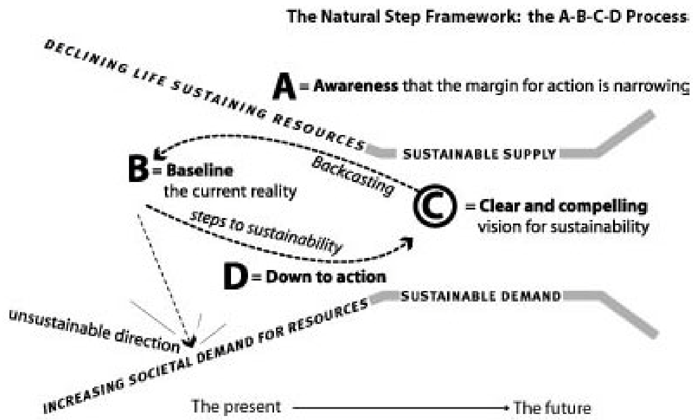


Figure 2.24: Natural Step Framework: the A-B-C-D Process

The first stage involves aligning your organization around a common understanding of sustainability and the "whole-systems" context. The second stage consists of conducting a Sustainability Gap Analysis of the major flows and impacts of the organization, using the Sustainability Principles. In stage 3, stakeholders work together to create a compelling long-term vision for a sustainable enterprise. From this vision, organizations develop a strategy and action plan for moving towards sustainability. Strategies are developed based on looking backwards from a vision of success, a method called "backcasting" from principles. Stage four consists of advising and supporting the execution of specific initiatives by providing appropriate training, techniques, and tools for implementation, followed by measuring progress towards goals and suggesting modifications as needed.

2.10.2 Dow Jones Sustainability Index (DJSI)

The Dow Jones Sustainability Index is another tool used by organizations to assess their sustainability (DJSI, 2009). There are established criteria and associated weightings. There are three sustainability elements and criteria for each element. The Dow Jones Sustainability Index (DJSI) is based on a corporate sustainability assessment. The methodology is based on the application of criteria to assess the opportunities and risks deriving from social, environmental, and economic elements. These criteria consist of both general criteria applicable to all industries and specific criteria applicable to companies in a certain sector and are derived following identification of global and industry challenges. The criteria are built into the corporate sustainability assessment, which quantifies the sustainability performance of a company by assigning a corporate sustainability performance score.

2.10.3 Sustainability Competency & Opportunity Rating & Evaluation (SCORE)

Sustainability Competency & Opportunity Rating & Evaluation is a sustainability self-assessment used to assist organizations in rating their operations with respect to sustainability by focusing the evaluation on organizational practices. It was developed by AXIS Performance Advisors in conjunction with the International Sustainable Development Foundation and the Zero Waste Alliance (2008). This program is used in this research as a basis for the development of the practice rating criteria in the proposed integrated construction practice rating program.

Each practice has three benchmarks of performance. The “incubator” level represents better than status quo and typical performance for those early in their implementation. The “initiative” level represents the performance expected of an organization with a formal sustainability effort. The “integrated” level represents best practice performance in organizations where sustainability is fully integrated, and the organization is actively influencing the behaviour of others outside the organization.

2.10.4 International Organization for Standardization 14000 (ISO 14000)

The most generally applicable and flexible environmental assessment program has been developed by the International Organization for Standardization (ISO). The ISO 14000 series of international environmental management system standards provide guidance on how to manage the environmental impacts of activities, products, and services. An interesting feature of the ISO 14000 standards is their applicability not only to the building being designed, but also to the design process itself.

The first generation of BIM employed by constructors involved the creation of a three-dimensional model based upon the two-dimensional drawings prepared by the designers. The functions for which BIM will be most beneficial to constructors include the preparation of schedules and estimates, tracking and managing changes to the work and shop drawings, and managing site logistics and temporary structures and services, with particular attention to site safety (Aslani *et al.*, 2009).

In the construction industry, a reliable set of construction drawings will set the quality, efficiency, and costs of a project; these three parameters must be the consistent target of an intelligent management system, in combination with construction specifications and constructability issues, different types of designs, schedules, cost controls, and appropriate use of materials and resources, among others. The need for precise information in the Architecture, Engineering and

Construction (AEC) industry has motivated software developers to create sophisticated tools to manage information. In regards to building construction, BIM has the advantage of dealing with information from conceptual stages to final possession and deployment (Penttilä, 2006). Hence, there is tremendous opportunity for BIM to be utilized as an application for green building. This linkage is achievable through development of databases and parametric modeling of building structures. Process documentation for construction activities and their relationship to cost estimates, construction schedules, quantity take-offs, and in this case CO_2 emissions are easily incorporated, manipulated, updated, and depicted through the use of BIM (Goedert and Meadati, 2008). With BIM, homebuilders can simplify the process of gathering relevant information to reduce the economic impact of home construction while producing higher-quality homes. Through the use of parametric modeling, changes during the design stage of the project are updated automatically, affecting information related to cost estimates, quantity takeoffs, construction schedules, and construction drawings, just to mention a few. The data workflow and management in BIM occurs up and downstream, where digital information can manipulate stored information and vice versa (Manrique, *et al*., 2007).

Computer Aided Drafting (CAD) software has evolved considerably to facilitate integration, however, the tools included in these CAD programs lack the specific user components needed for design. The end-user must either develop programmatic codes to bolster his drafting productivity or spend long drafting hours (Staub-French and Khanzode, 2007). Research in construction engineering has been based upon the utilization of 3D modeling techniques to visually present the development of future projects prior to construction. 3D modeling has been applied in particular for constructability purposes (Manrique *et al*., 2007). Sacks and Barak (2005) have stressed the issue of enhancing work productivity for structural engineering designs, as well as the manner in which measuring methods based on 3D modeling can improve modeling time, drafting accuracy, and cost reductions. Teizer *et al*. (2007) have focused on the use of automated 3D sensing at construction sites to detect and track project resources.

In general, two different approaches have been formulated since the introduction of CAD modeling as a drafting solution to support end-users: entity-based modeling and object-based modeling. Entity-based modeling began as a solution to assist CAD designers in drafting elements. However, these elements or "entities" do not have relationships with one another. Many building models have been designed based on the entity-based approach, and the whole building model, therefore, is simply represented by raw graphic entities or primitives (e.g., lines and arcs) which fail to provide rich semantic meaning about the building (Tse *et al*., 2005).

Object-based modeling has been introduced into the field in order to achieve better drafting performance by creating a history that describes how an object was created or modified. This method is known in industry as parametric modeling. New software approaches, disseminated under the name Building Information Modeling (BIM), exploit the principles of parametric modeling to generate changes by making use of object relationships, such that designers need not look after any of the current modifications. Companies such as Graphisoft and Autodesk are adding innovation to their CAD packages by incorporating an intelligent repository into a CAD model. Information generated by the model is classified according to its attributes, such that multi-aspects from the Mechanical, Electrical and Plumbing (MEP) and AEC disciplines can be linked at each stage of the lifecycle of the building facility: scheduling, costing, sustainability, maintainability, acoustics, and energy simulation (Aouad *et al*. 2005).

BIM application stops at the preconstruction phase with a limited amount of research regarding data collection of the construction process. Significant contributions include practical 3D data collection methods and extending the BIM software products to accommodate construction process documentation (Goedart and Meadati, 2008).

Construction executives, managers, designers, and developers of information technology systems for construction can also benefit from the framework as an aid to recognizing the potential synergies when planning with BIM (Sacks *et al*., 2010).

2.11 Mathematical Model Application for Sustainability Rating

A mathematical model is developed based on a linear optimization model approach for a building rating program for houses. The linear optimization model approach is aimed at supporting stakeholders that are faced with making numerous and competing decisions. Linear programming can be applied to various fields of study. It is used most extensively in business and economics, but can also be utilized for some engineering problems. Industries that use linear programming models include transportation, energy, telecommunications, and manufacturing. It has proved useful in modeling diverse types of problems in planning, routing, scheduling, assignment, and design (Wolsey, 1998).

Linear programs are problems that can be expressed in the following form:

$$\begin{aligned} \text{maximize} \quad & c^{\top} x \\ \text{subject to} \quad & Ax \leq b \end{aligned}$$

where **x** represents the vector of variables (to be determined), **c** and **b** are vectors of (known) coefficients and *A* is a (known) matrix of coefficients. The expression to be maximized or minimized is called the *objective function* ($\mathbf{c}^{\mathrm{T}}\mathbf{x}$ in this case). The equations $A\mathrm{x} \leq \mathrm{b}$ are the constraints which specify the objective function is to be optimized (Wolsey, 1998). Linear programming is a considerable field of optimization for several reasons. Many practical problems in operations research can be expressed as linear programming problems. Certain special cases of linear programming such as network flow problems are considered important enough to have generated much research on specialized algorithms for their solution. A number of algorithms for other types of optimization problems work by solving linear programming problems as sub-problems. Historically, ideas from linear programming have inspired many of the central concepts of optimization theory, such as duality, decomposition, and the importance of convexity and its generalizations. Likewise, linear programming is heavily used in microeconomics and company management, such as planning, production, transportation, technology and other issues. Although the modern management issues are ever-changing, most companies would like to maximize profits or minimize costs with limited resources. Therefore, many issues can be characterized as linear programming problems. The standard form is the usual and most intuitive form of describing a linear programming problem (Castro-Lacouture *et al.*, 2009a). It consists of the following four parts:

- A linear function to be maximized

  e.g., Maximize: $c_1x_1 + c_2x_2$

- Problem constraints of the following form

  e.g.,

  $a_{1,1}\mathbf{x}_1 + a_{1,2}\mathbf{x}_2 \leq b_1$

  $a_{2,1}x_1 + a_{2,2}x_2 \leq b_2$

  $a_{3,1}x_1 + a_{3,2}x_2 \leq b_3$

- Non-negative variables

  e.g.,

  $\mathbf{x}_1 \geq 0$

  $\mathbf{x}_2 \geq 0$.

- Non-negative right hand side constants

  $b_i \geq 0$

The problem is usually expressed in matrix form, and then becomes:

Maximize: $c^T x$

Subject to: $Ax \leq b$, $x \geq 0$.

Other forms, such as minimization problems, problems with constraints on alternative forms, as well as problems involving negative variables can always be rewritten into an equivalent problem in standard form.

The rationale for using this approach for the green building rating program is the need to obtain minimum certification scores under numerous environmental criteria at a minimal cost. As such, the model should optimize the selection of points under various competing criteria. There are other constraints affecting the selection criteria as well, such as user preference for areas of focus, for example building materials such as insulated concrete form walls.

Haimes (2004) has noted that there has been significant growth in multi-criteria decision modeling over the past few decades. It should be noted that while in multi-criteria decision analysis the feasible set of discrete alternatives is known beforehand, in multi-objective optimization an infinite number of feasible solutions exist (MacCrimmon, 1973). Chankong *et al*. (1984) have stated that, in the real world, problems often depend upon a score of criteria where the solution is the best compromise between competing factors. It is evident that the multi-criteria decision analysis using linear optimization is the most suitable approach for the objectives and criteria associated with a green building rating program.

In formulating the model, the selection of criteria must take on either 0 or 1, meaning that that the criteria being selected (1) or not (0). Markowitz and Manne's (1957) work on discrete programming problems lend itself to application within the proposed model. In addition, the work of Hoffman and Padberg (1985) on combinatorial and integer optimization provides a background for the development of this model. Hoffman and Padberg (1985) have stated, notably, that "combinatorial optimization problems are concerned with the efficient allocation of limited resources to meet desired objectives when the values of some or all of the variables are restricted to be integral."

Castro-Lacouture *et al*. (2009b) optimization model for the selection of materials using a LEED-based green building rating system with the objective function of minimizing cost while satisfying selection of material criteria is comparable with the Built Green optimization aim in this research of minimizing cost to reach designated certification levels. The use of decision modeling software such as Solver in Microsoft Excel has shown to be resourceful for solving computational problems. Moore and Weatherford (2001) have illustrated numerous optimization modeling examples. The construction industry and the community in general will benefit from an integrated tool that will help optimize the process of material, equipment and systems selection at every stage of the construction project life cycle, making it useful to designers, engineers, contractors, and facility managers (Barnes and Castro-Lacouture, 2009).

2.12 Summary

This chapter commenced with a literature review in the areas of sustainability, CO_2 emissions, green building performance rating programs, construction organizational practice evaluations, material waste, health and safety, BIM, sustainability models, and mathematical models. There is plenty of research in the field on performance rating systems. The literature review on sustainability measurement indicates just how varied the environmental rating of buildings can become. Due to this complexity, most measures of sustainability have been incorporated into labelling or certification programs on performance.

There is a gap in the research literature pertaining to the practice rating. Hence, this gap provides the impetus for this research. In regards to the application of BIM, there is no literature involving the quantification of CO_2 emissions outputs. Work with BIM involves costing and scheduling features. Finally, the use of mathematical optimization was examined. Although there is ample literature on this topic, the work involved in this thesis examined its application as a tool in solving an engineering analysis of costs and sustainability scores.

Chapter 3: Research Methodology

3.1 Introduction

The purpose of this research is to develop a framework for rating the sustainability of residential construction practice in order to identify potential solutions to facilitate changes for residential builders. The researcher believes that a better understanding of the residential construction practice will allow builders to proceed from a more informed perspective in terms of sustainable residential construction. In seeking to understand this residential construction practice, this research involves the development of a three-component framework to address sustainability in terms of a social, environmental, and economic paradigm.

This chapter describes the research methodology and includes discussions around the following: rationale for research approach, description of the research sample and summary of information needed; overview of research design; methods of data collection; analysis of data; ethical considerations; issues of trustworthiness; and limitations of the research. The chapter concludes with a brief summary.

3.2 Rationale for Qualitative Research Design

The research design in this thesis uses a qualitative research strategy as opposed to quantitative research. Among qualitative research categories, exploratory research was selected as opposed to placement of theory and attitudinal research. The qualitative research approach was selected due to the exploratory nature of the information gathered. Exploratory research involves three interrelated objectives: to diagnose situations, screen the alternatives, and discover new ideas (Zikmund, 1997). Qualitative research is grounded in an essentially constructivist philosophical position, in the sense that it is concerned with how the complexities of the socio-cultural world are experienced, interpreted, and understood in a particular context and at a particular time. The intent of qualitative research is to examine a social situation or interaction allowing the researcher to enter the world of others and attempt to achieve a holistic rather than reductionist understanding (Locke *et al.*, 2000). Qualitative methodology implies an emphasis on discovery and description, and the objectives are generally focused on extracting and interpreting the meaning of experience (Denzin and Lincoln, 2003).

Due to the nature of this research, this thesis adopts a case-based, action research method. The case study method involves an in-depth examination of a single instance or event in order to identify underlying principles. The case study research method can be defined as *"an empirical inquiry that examines contemporary phenomena within its real-life context, when the boundaries between phenomenon and context are not clearly evident and in which multiple sources of evidence are used"* (Yin, 1984). Critics of the case study method claim that the study of a small number of samples may not provide sufficient grounds for establishing reliability and universality of the findings (Noor, 2008). These critics also believe that research results based on case studies are "localized" to a specific situation and thus cannot rightly be extrapolated to other situations. Despite these criticisms, case studies have been used continuously by academic researchers with success in carefully planned and crafted studies of real-life situations.

Quantitative and qualitative research can be distinguished based on criteria such as role, relationship between researcher and subject, and scope of findings (Bryman, 1998). With respect to role, quantitative research is fact-finding in nature, based on evidence or records, whereas qualitative research is based on opinions, views, and perceptions. With regard to the relationship between researcher and subject, with quantitative research the relationship is distant, whereas with qualitative research the relationship is close. The scope of findings in quantitative research is nomothetic (founded upon or derived from law), whereas qualitative research is idiographic (pertaining to or involving the study of individual cases or events).

The action research method is a reflective process of progressive problem-solving, assisted or guided by professional researchers, with the aim of improving the environments within which the research is conducted (Susman and Evered, 1978). The action research and case study methods often accompany one another when a new methodology or approach is the subject of the study.

It is this researcher's contention that purely quantitative methods were unlikely to elicit the rich data necessary to address the proposed research purposes. The researcher's view is that a qualitative stance fits within this thesis as it includes the following features: an understanding of the processes by which events and actions take place; developing contextual understanding; facilitating interactivity between the researcher and participants; adopting an interpretive stance; and maintaining design flexibility.

3.2.1 Action Research

Action research is known by many other names, including participatory research, collaborative inquiry, emancipator research, action learning, and contextual action research. Action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to further the goals of social science simultaneously. Thus, there is a dual commitment in action research to study a system and concurrently to collaborate with members of the system in changing it, in what is together regarded as a desirable direction.

Action research differs from other types of research in several ways. One is its focus on turning the people involved into researchers as well. It also has a social dimension—the research takes place in real world situations, aims to solve real problems. A third difference involves the initiating researcher, who, unlike in other disciplines, makes no attempt to remain objective, but openly acknowledges his/her bias to the other participants (O'Brien, 2001).

The action research process can include the following steps. Initially, a problem is identified and data is collected for a more detailed diagnosis. This is followed by a collection of several possible solutions from which a plan of action emerges and is implemented. Data on the results of the intervention are collected and analyzed, and the findings are interpreted in light of how successful the action has been (O'Brien, 2001). In this research, field construction practices resulting in material wastes being generated on construction sites was the impetus for this research. The researcher queried the residential builder, who was the collaborating partner for this work, on this issue and raised material waste as a problem. A detailed field study was conducted providing data for analysis. Following the analysis, possible solution, such a moving from onsite framing to pre-fabrication, detailed framing drawings, and building supplies list were examined. The papers the researcher investigated for these possible solutions are provided in the references.

Overall, this action research is based on addressing the goal of a residential builder to measure his sustainability efforts and provide solutions to improve upon his sustainable residential construction goals in a social, environmental, and economic paradigm.

When is action research used? Action research is used in real situations focused on solving real problems. This is why the researcher adopted this approach for the research.

The methodology in action research allows for several different research tools to be used that are generally common to the qualitative research paradigm. These include keeping a research journal, document collection and analysis, participant observation, interviews, and case studies. All of these tools are utilized in the present research.

3.2.2 Rationale for Case Study Methodology

Within the framework of a qualitative approach, the research was most suited for a case study design. As a form of research methodology, case study is an intensive description and analysis of a phenomenon, social unit, or system bounded by time and place (Berg, 2004). The research in this thesis fits well within the case study because it places the researcher within a setting to address a real-world situation.

To overcome limitations of the case study method, the researcher has clearly documented and compared the homebuilding processes on the industry level and the company level. Homebuilders operate in a variety of different markets and are required to satisfy different regulations in each market; furthermore, each has its own products, business strategies, competitive advantages, and production management system. What these homebuilders have in common, however, is they follow the same basic homebuilding process and face similar challenges. Although the work developed in this research is based on the practice of a particular collaborating company, it can be applied to other homebuilders.

3.3 Research Data Collection

The approach to data collection is fieldwork-based, as opposed to a desktop study. The data collection uses a problem-solving approach (action research) coupled with a case study. Techniques for data collection include focus groups, unstructured personal interviews, field data collection, and field observation.

The focus group was another method to gather information. Staff members from the collaborating research organization formed a group to facilitate sustainability goals. A focus group is essentially a group discussion focused on a single theme (Krueger and Casey, 2000). The goal is to create a candid conversation that addresses, in depth, the selected topic. The underlying assumption of a focus group is that, within a permissive atmosphere that fosters a range of opinions, a more complete and revealing understanding of the issues will be obtained. It must be acknowledged that focus groups, while serving a useful function, are not without disadvantages. Among these disadvantages is “groupthink” as a possible outcome (Fontana and Frey, 2003). Groupthink suggests that individuals would migrate to a consensus or opinion of findings suggesting that individual conclusions may be neglected. Furthermore, logistical difficulties might arise from the need to manage conversation while attempting to extract data. The purpose of focus groups is to augment the information already obtained and to provide additional data to ensure trustworthiness and credibility. To yield the most information and data in this research, purposeful sampling is a method that is typical of case study methodology (Silverman, 2000).The use of multiple data-collection methods is critical in attempting to obtain an in-depth understanding of the goal under this research. This strategy adds breadth and depth to the research. These methods include interviews and field observations. The interview method provides the opportunity for rich and thick descriptions. Further, it gives the researcher an opportunity to clarify statements and probe for additional information. The major benefit of collecting data through individual, in-depth interviews is that they capture a participant's perspective on an experience (Marshall and Rossman, 2006). The interview is a fundamental tool in qualitative research; Kvale (1996) describes the qualitative research interview as an "attempt to understand the world from the subject's point of view, to unfold the meaning of people's experiences..." The interviews in this research were unstructured as opposed to structured. The researcher's reason for using this interview data collection method is that it is a legitimate way to generate data when interacting with people. Although interviews have strengths, there are limitations associated with interviewing. First, not all people are equally cooperative, articulate, and perceptive. Second, interviews require researcher skill. Third, interviews are not neutral tools of data gathering, as they are the result of the interaction between researcher and participant (Rubin and Rubin, 2005). The researcher interviewed many participants including the following: residential builders (office staff including draftsmen, estimators, schedulers, buyers, etc.), field trades (framers, electricians, plumbers, etc.); and government and non-governmental agencies. Field observations were conducted for over 30 houses. Photographs, data collection, and site interviews were part of the field observations.

3.4 Overview of Research Design

The following list summarizes the steps used to carry out this research. Following this list is a more in-depth discussion of each of these steps.

The research design, illustrated in Figure 3.1, is approached through three components. Component 1 involves the development of the integrated construction practice rating program. Component 2 entails the development of an application of BIM for the purpose of automating the quantification of the CO_2 rating parameter. Finally, Component 3 leads to the development of a mathematical linear optimization model for a rating program.

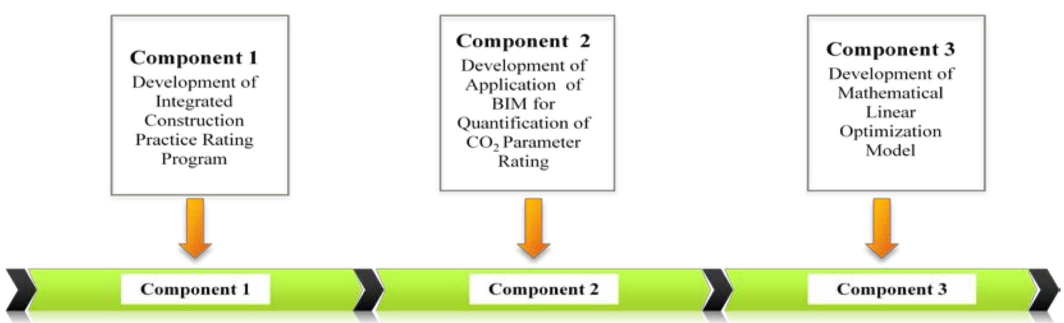


Figure 3.1: Research Component Framework

The research methodology framework is illustrated in Figure 3.2. The framework consists of four elements: inputs, criteria, tools, and outputs. Within the framework, three sustainability rating tools are developed: an integrated construction practice rating program, the application of BIM for quantification of parameter rating, and a mathematical linear optimization model. The framework is bound by the inputs and criteria as shown in Figure 3.2. These inputs and criteria are the constraints, limitations, and user parameters within which the framework tools are developed. As a result of the tools having been developed and implemented within the framework, the outputs include sustainability scores, cost analyses, related construction drawings, and parameter quantification (i.e., CO_2 emissions) rating.

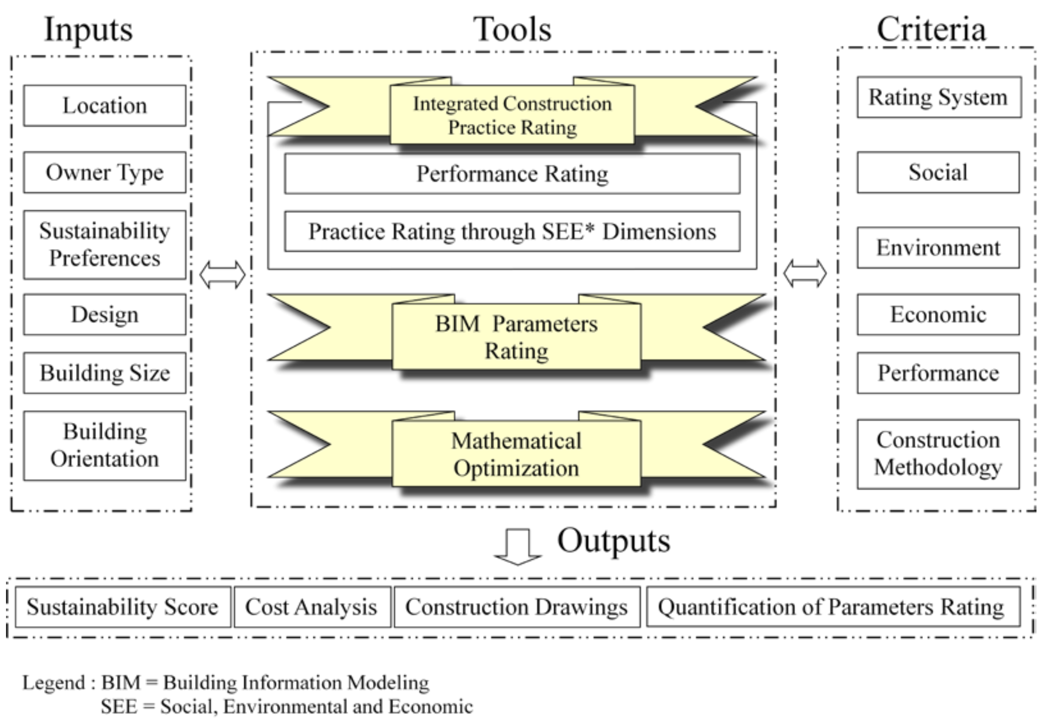


Figure 3.2: Methodology Framework

For instance, in developing the integrated construction practice rating program, which combines performance measurements with the construction practice rating, inputs are processed through the criteria. This process generates a sustainability score. The practice rating program criteria include the set of rating checklists in which points are obtained. In regards to the BIM quantification rating model, the inputs, such as building size, are frontloaded into a BIM, which contains a database of emissions rates. Rates are based on a particular construction methodology (i.e., onsite stick-frame) resulting in an accumulated CO_2 emission amount for a particular input, such as building size. The mathematical linear optimization model is developed to allow stakeholders to analyze their costs from competing environmental categories and make decisions based on preferences from a selection of environmental categories.

The research plan is separated into three distinct components as noted in Figure 3.1. Each of these components is developed through a series of steps interlinked to achieve its objective.

3.4.1 Component 1—Development of the Integrated Construction Practice Rating Program (ICPRP)

The development of the Integrated Construction Practice Rating Program (ICPRP) involves three main steps: Step 1—Performance Rating evaluation; Step 2—Practice Rating development and evaluation; and Step 3—Integrated Construction Practice Rating Program implementation. Each of these three significant steps is used to address the performance rating, then the practice rating, and finally the integration of the performance and practice rating into the ICPRP.

In Step 1, the performance rating component is described and implemented in order to deliver a particular score. Although this component has no direct contribution with respect to research and development, it is important to recognize its contribution in the proposed ICPRP. The performance rating is quantified through the Built Green program. The program is truly a representative sustainability rating program in the sense that it combines measurements of both performance and practice, rather than just one measurement element. In Step 2, the construction practice rating is developed. This step proposes a construction practice rating program based on three elements of sustainability, defined in this thesis as social, environmental, and economic (SEE). The evaluation program is developed based on rating functions and practices of home building companies. This step includes the development of the flow process and evaluation criteria. A description of the scoring system is also provided. The results provide a numerical score that is transposed into a stars qualitative level rating program. In Step 3, the integrated construction practice rating program uses the score from the performance rating and combines it with the practice rating, resulting in a qualitative integrated sustainability score. The description of the ICPRP, complete with the scoring level, is described. A case study will demonstrate the application of this tool for a residential building firm from Edmonton, Alberta, Canada.

3.4.2 Component 2—Development of the Application of BIM for Quantification of CO_2 Parameter Rating

The rationale for this tool is rooted, from the designer's perspective, in the application of BIM. The research aims to utilize BIM in order to facilitate the quantification of the CO_2 footprint generated during the construction process through a series of logical steps, including capture of field data on emissions, 3D CAD drawings, database development, and BIM parametric modeling. The challenges identified include user design criteria constraints for BIM input; development of the BIM database; and the link to the parametric model for analysis. The research approach requires that the designer be cognizant of the translation of the field measurements into an appropriate BIM-structured format for quantification of the CO_2 footprint. The output from the BIM is confirmed in the field study. The following section details the research methodology and approach.

The methodology for this research is shown in Figure 3.3. One aim of the methodology is to illustrate how BIM is embedded within the architectural model used for quantification. The figure shows the relationship and flow among the various constraints and parameters, the model, and the resulting output. The input parameters are established based on design parameters, material availability, and customer requirements. These could include housing style, size, location, finishing, and budget. These input parameters are evaluated within the BIM database against a set of constraints including such criteria as equipment, materials, and related regulations. A 3D parametric model utilized through BIM contains information about rates for CO_2 emissions and cost data. By changing any of the input parameters, such as floor area, for example, the model would rapidly recalculate revised results and store them in a database for further application. In addition, the selection of either an onsite or factory-built construction technique could be addressed separately. The repository for the CO_2 emission baseline and rates is established through field observations and measurements.

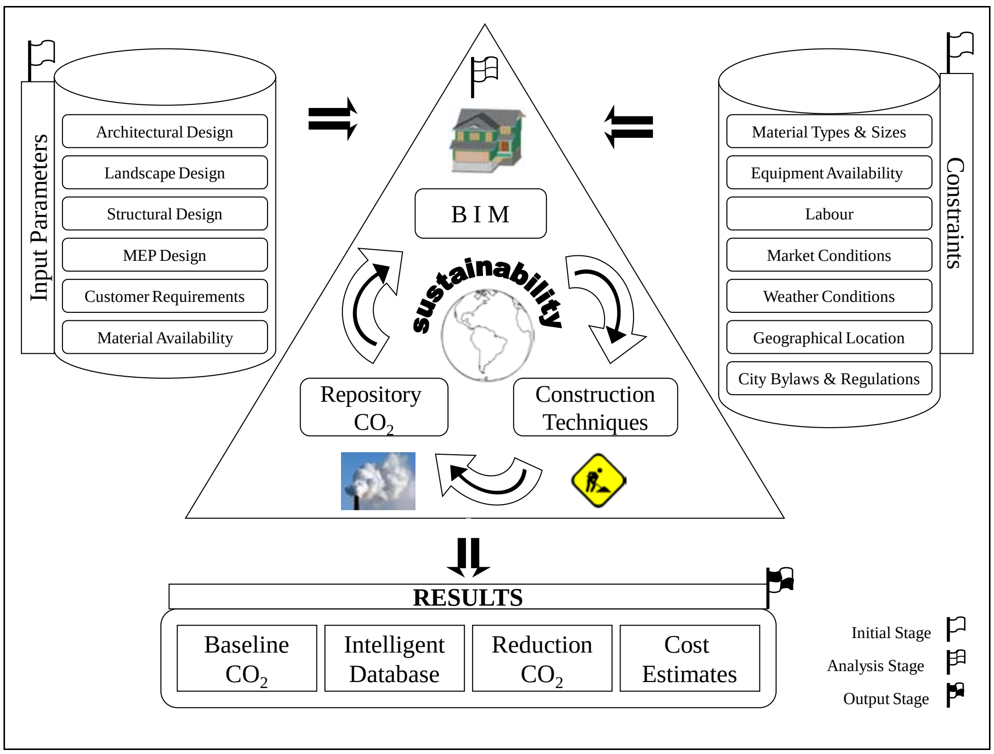


Figure 3.3: CO_2 Framework Methodology

The methodology for this research, as presented in Figure 3.3, begins at the initial stage with the acquisition of sufficient data related to the project, such as architectural, structural, and mechanical designs (e.g., floor plans, finishing materials, elevations, cross sections, beams/columns, types of heating and ventilation systems, etc.). This information is vital to the project since it will determine the nature of the construction process to follow. This information is constrained by rules and bylaws for construction, as well as by the location of the building in terms of material supply and labour, as indicated in the analysis stage. Depending on the construction methodology, (i.e., panelized versus onsite construction), accessibility and equipment allocation may also play an important role in the construction process. The weather conditions will also determine the manner in which activities are performed during construction (e.g., winter versus summer start). This research, however, does not address the impact of weather.

Once the design and construction process has been stipulated and finalized, the BIM will be frontloaded with an intelligent database containing CO_2 emission rates per unit of construction work (this concept is explained later on in this thesis). This database can also be modified to suit the construction methodology to be used. At the output stage, the designers and construction team can modify the output based on the results obtained (i.e., cost estimates and CO_2 emissions). The end result is that stakeholders can arrive at better decisions for the construction of a house by measuring and then reducing its impact on the environment.

The conventional construction process can be broken down into 17 distinct stages, ranging from stake-out to pre-occupancy inspection (Landmark Group of Builders, 2008). The 17 stages are established by the builder by sorting all construction activities into groups. Other builders may have a different number of stages, but, however they are grouped by different builders, all construction activities have been identified here. The Landmark Group's 17 stages have been industry-validated through an external management organization that focuses on Lean construction principles for the house construction process. This external organization, High Performance Solutions Inc., is based in Canada.

The findings from this stage are to set a baseline for environmental sustainability in the house construction industry. These processes should be analyzed together to gain a more accurate and comprehensive perspective which takes into account materials, building techniques, labour, etc., in a holistic manner.

The methodology commences with a review of the house construction process by identifying all activities and stages for wood-frame house production. In order to accurately model the current construction practice, it was necessary to visit a number of construction sites during different stages of the construction process and at different times of the year: during a period from 2007 to 2009, over 30 house construction sites were visited.

The application of BIM for quantification involves four steps: Step 1—Determination of CO_2 Sources; Step 2—Quantification of Parameter (CO_2 Emissions); Step 3—Incorporation of the Quantifications of the Parameter Rating into the 3D model; and Step 4—Integration of the BIM.

Step 1 includes identification of the stages and tasks of the residential construction process. Site visits and expert opinions are also obtained. Step 2 includes the gathering and documentation of CO_2 emissions from equipment, transportation, and onsite operations. Step 3 includes a description of the software utilized in this application, the development of parameter attributes, and a description of building classification systems. Step 4 involves the quantification of CO_2 emissions from building assemblies from the previous step. This step also includes the verification of output results with field data collection.

BIM covers geometry, spatial relationships, quantities, and properties of building components. BIM is utilized to bridge the information loss associated with the transfer of a project from the design team to the construction team and then to the building owner, by allowing each group to add to and reference back to all information acquired during the project. The particular parameter related to the rating of the construction practice used in this section of the methodology is CO_2 emissions. Other parameters for quantification, such as the effect of the construction practice on the human respiratory system, can also be evaluated. In Step 1, construction stages and activities involved in the process of onsite stick-frame construction are identified. Site visits are conducted and expert opinion is gathered and documented. In Step 2, CO_2 measurements and information are obtained, including the types of vehicles and equipment used, activity durations, and labour requirements during the construction process. In Step 3, incorporation of the rating quantifications into the 3D model is initiated. A database is then established and populated with unit rates based on building classification systems. In Step 4, integration of the BIM for the quantification of CO_2 emissions is performed. The use of BIM for the quantification of CO_2 emissions from various construction processes allows the user to generate the information needed by organizations working to enhance current practices.

3.4.3 Component 3—Development of the Mathematical Linear Optimization Model

Linear optimization is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear relationships. More formally, linear programming is a technique for the optimization of a linear objective function, subject to linear equality and linear inequality constraints. Given a polytope and a real-valued affine function defined on this polytope, a linear programming method will find a point on the polytope where this function has the smallest (or largest) value if such point exists, by searching through the polytope vertices (Wolsey, 1998).

The development of the Mathematical Linear Optimization Model entails three main steps. These steps include the following: Step 1—Model Rationale; Step 2—Model Formulation; and Step 3—Implementation and Analysis.

In Step 1, the rationale for developing the mathematical linear optimization model is described. In essence, this approach is used to solve the problem of user-defined preference selection analysis. The aim of the model is to solve for an objective function of minimum cost, incorporating environmental category constraints and user preferences in the selection process. In Step 2, the mathematical linear optimization model is fully developed, incorporating the environmental constraints and user preference for a particular rating program. This step includes the establishment of a database for the unit cost per criterion under consideration. In Step 3, a computer program (MS Excel) is utilized to test and implement this model. This step outputs the results for analysis. Stakeholders can then make decisions with respect to particular environmental categories, informed by the cost analysis information.

3.5 Ethical Consideration

In any research study, ethical issues relating to protection of the participants are of vital concern (Marshall and Rossman, 2006). The research process involves volunteer cooperation, and it is a basic premise that participants are informed about the research's purpose. Although it was anticipated that no serious ethical threats were posed to any participants, this research used safe-guards to ensure protection and rights of participants. First, informed consent remained a priority throughout the study. Second, participant interests were considered of primary importance when choices were made regarding the reporting and dissemination of data. The researcher kept required information confidential.

3.6 Analysis of Data and Issues of Trustworthiness (Validation)

The data was collected from field sources and confirmed through expert interviews with personnel in the residential construction industry.

In qualitative research, trustworthiness consists of any efforts by the researcher to address the more traditional quantitative issues of validity (the degree to which something measures what it purports to measure) and reliability (the consistency with which it measures over time). In seeking to establish the trustworthiness of a qualitative research, Guba and Lincoln (1998) use the terms *credibility*, *dependability*, *confirmability* and *transferability,* arguing that the trustworthiness of qualitative research should be assessed differently from quantitative research.

Credibility

The criterion of credibility (or validity) suggests whether the findings are accurate and credible from the standpoint of the researcher, the participants, and the reader. Methodological validity involves consideration of the interrelationship between the research design components—the research purpose, conceptual framework, research questions, and methods. To enhance the research methodology's validity, the researcher gathered data from multiple sources and through multiple methods to yield a fuller and richer picture of the findings. To enhance the validity in this thesis, the researcher reviewed and discussed the findings with professional colleagues as a further way of ensuring that the feedback of the participants was adequately reflected in the findings.

Dependability

Reliability in the traditional sense refers to the extent that research findings can be replicated by other similar work. Qualitative research usually does not cover enough of an expanse of subjects and experiences to provide a reasonable degree of reliability. The more important question becomes one of whether the findings are consistent and dependable with the data collected. Hence the aim in dealing with dependability is not to eliminate inconsistencies but to understand and acknowledge when they occur.

Confirmability

The concept of confirmability corresponds to the notion of objectivity in quantitative research. The implication is that the findings are a result of the research, rather than an outcome of the biases and subjectivity of the researcher.

To achieve this end, the researcher has included journaling, memos, and field notes to illustrate how the data can be traced back to its origins.

Transferability

Transferability implies how the findings can transfer to another particular context. In other words, is there generalizaeability. The researcher attempted to address this issue of transferability through the examination of typical residential construction practices with various industry experts. Depth, richness, and detailed description provide the basis for a qualitative researcher's claim to relevance in some broader context (Schram, 2003).

3.7 Chapter Summary

In summary, this chapter provided a detailed description of the research methodology. A qualitative case study methodology was used to illustrate the development of the evaluation framework. The research design was developed though three components, with a rating tool proposed in each component. Component 1 provides the ICPRP sustainability rating score from two programs, BGRP and the SEE evaluation. Component 2 developed the BIM model. From Component 3, modification and enhancement of particular construction practice activities can be explored. Although the mathematical model uses a particular rating program, the model is adaptable to parameters from other rating programs.

This research contains certain limitations, some of which are related to the common critiques of qualitative research methodology in general and some of which are inherent in the research design. Aside from issues pertaining to subjectivity, a further major limitation was just using one case study. As a result, a critique might be the limited possibility of generalizing this research to other contexts.

Chapter 4: Framework Development and Implementation

4.1 Introduction

The chapter details each of the three stages of the research commencing with the integrated construction practice rating program, followed by the application of BIM for quantification of parameters rating, and concluding with the mathematical optimization model. These three components are not sequential and are independent of each other. The case study approach is utilized in the framework development with the idea that it can be generally applicable within the context of the residential construction industry.

4.2 Development of the Integrated Construction Practice Rating Program[1]

4.2.1 Step 1—Performance Rating Evaluation

This research utilizes the Built Green rating program for output of performance scores that is amalgamated with the organizational practice rating to provide the integrated construction practice score level. The Built Green program consists of two major evaluation elements, the HOT2000 results and the Built Green checklist form. The end results of the rating program evaluation elements provide a scoring. A field sample of the results of these ratings are included in the case study. As mentioned in the methodology section, the performance rating component is applied to deliver a particular performance score. Although this component has no direct contribution with respect to research and development in

[1] A version of this section has been published in The International Journal of Interdisciplinary Social Sciences, Common Ground Publishing Pty Ltd, Melbourne, Australia, 2008

this thesis, it is important to recognize its contribution in the proposed integrated construction practice rating program.

4.2.2 Step 2—Organizational Practice Rating Evaluation

Qualitative Practice Evaluation

The organizational practices and operational processes of a construction firm directly affect its sustainability goals. These practices and processes are thus to be identified and evaluated. This section points to some of these practices and processes. The discussion is referred to later on in the evaluation section. Current sustainable strategies and practices noted by Industry Canada (2008), which are included in the qualitative scoring program, can be divided into the following evaluation elements: Social (e.g., corporate social responsibility, eco-industrial networking); Environmental (e.g., eco-efficiency, ISO 14001 certification, environmental management system); and Economic (e.g., lifecycle management, green supply chain management).

The research in this thesis proposes a sustainability model (see Figure 4.1) with the three SEE elements linked together. Each of the elements carry equal importance (as seen based on their size), are inter-dependent, and don't have a start-end point. The lines connecting the elements indicate their inter-dependency. In other words, any dominance of one element would impact the other two elements. For instance, if the economic element (e.g., profit) is the dominant focus, the social element (e.g., salary) and environmental element (e.g., pollution) would be impacted negatively. The model is encircled resembling a sphere, indicating that within the construction domain, these three elements must be entirely considered. The revolving arrow indicates the sustainability model is not static and will move and adapt to differing sets of circumstances.

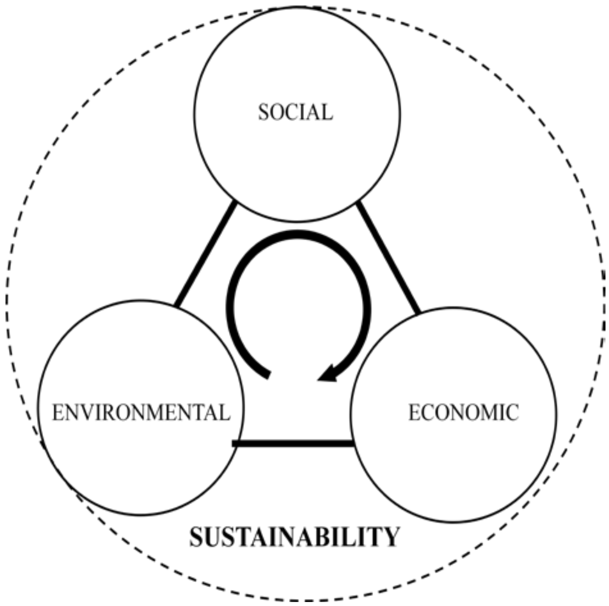


Figure 4.1: SEE Elements Proposed Model

Figure 4.2 illustrates the qualitative evaluation of organization practices and processes that consists of the input stage, evaluation stage, and output stage. The practice evaluation commences with the criteria development through explicit data and implicit knowledge. Following the input stage, the evaluation program is refined through development of the weighting and benchmarking of the criteria. Finally, the output provides the user with feedback on his practice evaluation and scoring.

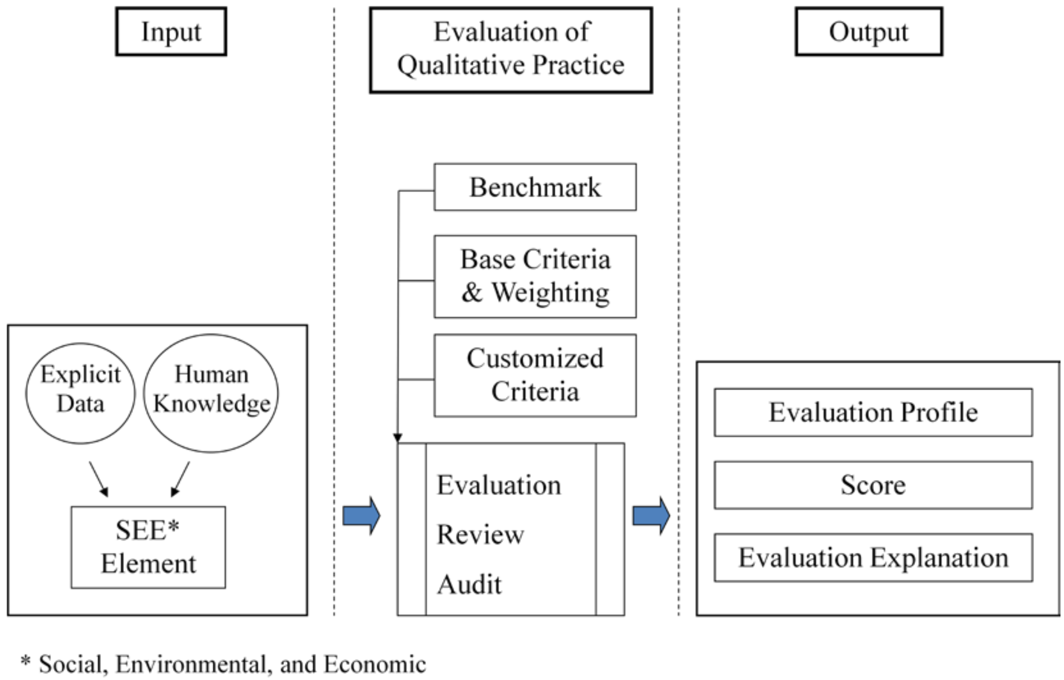


Figure 4.2: Flow Process of Organizational Practices Evaluation

Proposed SEE Elements

The practice evaluation framework is divided into three core elements: Social, Environmental, and Economic. Within the three elements, the structure is further divided into corresponding function levels, and finally according to the subsequent practice level. Refer to Figure 4.3 for a sample schematic illustrating the social element. Figure 4.4 illustrates the environmental element, while Figure 4.5 illustrates the economic element.

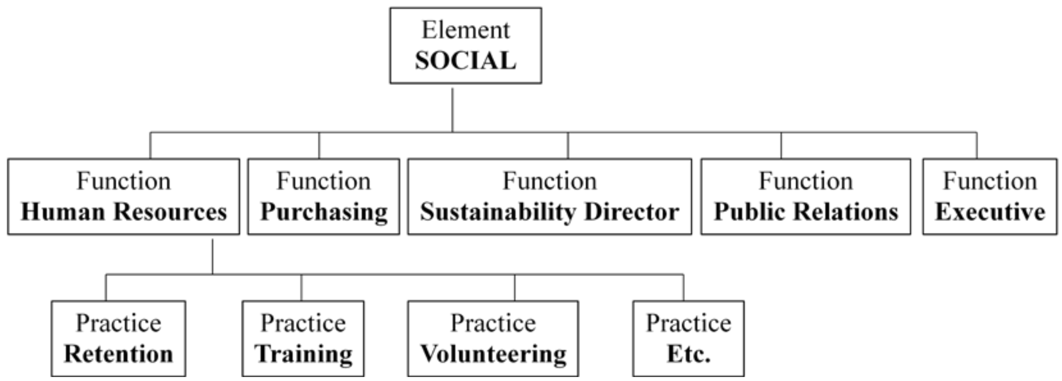


Figure 4.3: Sample of Social Element Evaluation Criteria

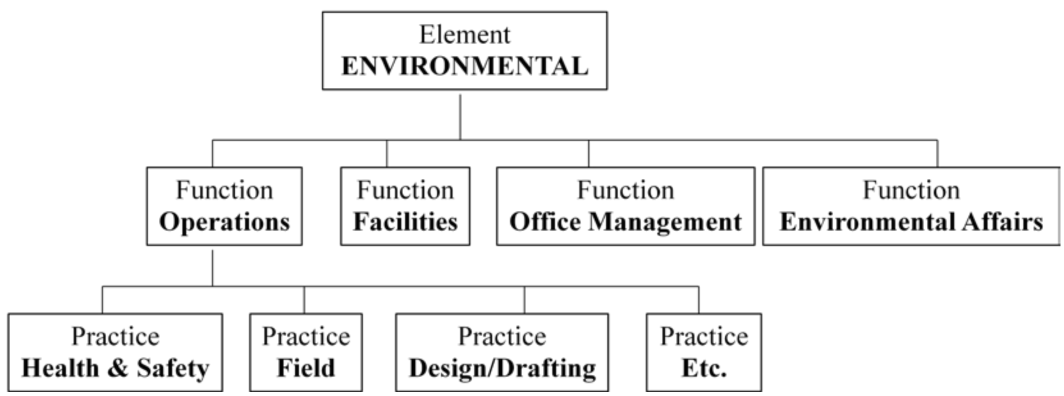


Figure 4.4: Sample of Environmental Element Evaluation Criteria

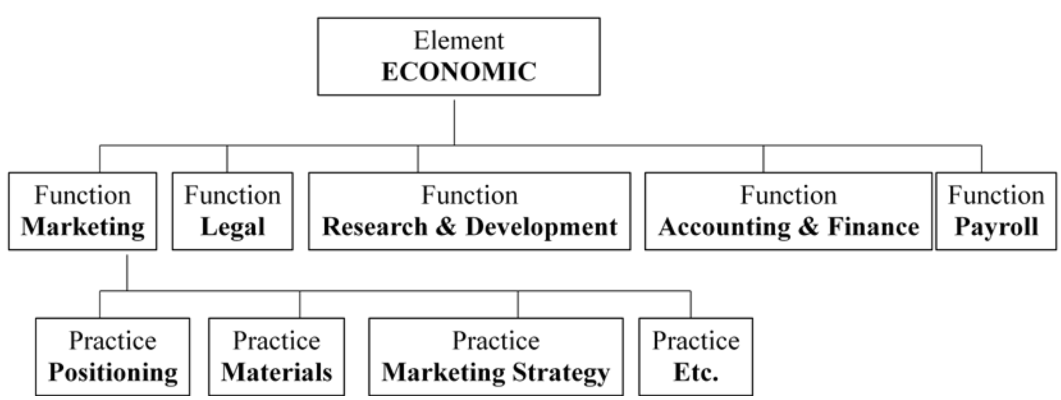


Figure 4.5: Sample of Economic Element Evaluation Criteria

A detailed breakdown of the SEE model with corresponding evaluation form is included in the section below. The development of the criteria is also the means to benchmark the progress of the criteria. As such, the evaluation program rates the criteria on three levels as either ***i***nitiated, ***i***ntermediate, or ***i***ntegrated; hence, the use of the *3**i*** rating notation. Each criteria is scored on whether it obtains a qualitative score of either initiated, intermediate, or integrated. These scores are assigned a numeric value of 1 for initiated, 3 for intermediate, or 5 for integrated. A score of zero (0) is used if the criterion is not considered. Other evaluation programs have similar numeric scoring values. Preiser and Vischer (2005) have outlined a number of principles by which to create and maintain sustainable evaluation programs:

- create an organizational culture that supports evaluation and the use of evaluation results;
- integrate ongoing evaluation into everyday work and processes;
- develop a range of evaluation methods, including the ability to conduct rapid, inexpensive evaluations;
- develop baselines, benchmarks, and comparisons.

Table 4.1 provides a summary of the various functions/departments that are evaluated under the SEE elements of sustainability. These functions/departments are categorized into three elements: social, environmental, economic. The social element includes the following: sustainability director, procurement/purchasing, human resources, senior management/executive, and public relations. The environmental element includes the following: facilities, office management, environmental affairs, and operations. The economic element includes the following: accounting & finance, marketing, research & development, legal and payroll. Within a function or department, there are a sub-set of practices that are denoted.

Table 4.1: SEE Summary

Dimension	Category	Function/Department
Social (S)	S-1-1 & S-1-2	Sustainability Director
Social (S)	S-2-1& S-2-2	Procurement/Purchasing
Social (S)	S-3-1 to S-3-4	Human Resources
Social (S)	S-4-1 to S-4-4	Senior Management/Executive
Social (S)	S-5-1 to S-5-3	Public Relations
Environmental (E)	E-1-1 to E-1-4	Facilities
Environmental (E)	E-2-1 to E-2-3	Office Management
Environmental (E)	E-3-1 to E-3-3	Environmental Affairs
Environmental (E)	E-4-1 to E-4-5	Operations
Economic (C)	C-1-1 to C-1-3	Accounting & Finance
Economic (C)	C-2-1 to C-2-5	Marketing
Economic (C)	C-3-1 & C-3-2	Research & Development
Economic (C)	C-4-1 & C-4-2	Legal
Economic (C)	C-5-1-to C-5-3	Payroll

The following tables (Table 4.2 to Table 4.15) provide a detailed descriptive evaluation of practices in each of the functions within the three elements of sustainability.

The score column can range from 0 to 5 points: Not Applicable (0 Points), Initiated (1 point), Intermediate (3 points), Integrated (5 points). The evaluator will assign a maximum of 5 points for each sub-criterion (hence, a maximum of 15 points per criterion). Designers and residential builders could use this tool when looking for a means to rate their sustainability efforts from the practice perspective.

Table 4.2: Evaluation Form for Sustainability Director under the Social Element

SOCIAL—SUSTAINABILITY DIRECTOR

Cat.	Points	Function/Practice
S-1-1		**Vision**: Have a clear vision for how sustainability relates to your organization's mission 1. Develop a business case for pursuing sustainability 2. Develop interim and long-term vision of your organization's role in a fully sustainable society 3. Get support of leadership to communicate these long-term goals (obtain executive support for pursuing sustainability initiatives)
S-1-2		**Reporting**: Regularly report on the results of sustainability efforts 1. Report to management at least annually about the benefits and costs of sustainability projects 2. Develop and publish an internal sustainability report 3. Report to management and other stakeholders on sustainability performance via a publicly available sustainability report

Table 4.3: Evaluation Form for Purchasing the Social Element

SOCIAL—PURCHASING

Cat.	Points	Function/Practice
S-2-1		**Policy**: Have a purchasing policy related to sustainability 1. Have a formal sustainable or environmentally preferable purchasing policy and waste reduction 2. Have meaningful reinforcement and audit systems for assessing progress toward sustainable purchasing 3. Evaluate major purchases based on sustainability
S-2-2		**Supplier influence**: Choose suppliers based in part on their sustainability performance 1. Switch to electronic billing and payments 2. Send out letters and/or surveys to suppliers to express your commitment to sustainability and your intent to give preference to sustainable suppliers 3. Use contractors that share a commitment to sustainability (e.g., banks, janitorial, landscaping, courier, catering, etc.). Write sustainability criteria and requirements into contract language for all contractors

Table 4.4: Evaluation Form for Human Resources under the Social Element

SOCIAL—HUMAN RESOURCES

Cat.	Points	Function/Practice
S-3-1		**Employee orientation and training**: Provide ongoing sustainability education for all employees 1. Provide training to employees involved with sustainability efforts. Routinely offer training on advanced sustainability practices 2. Adopt learning and knowledge management programs such as intranet, staff meetings, repositories 3. Speak regularly to other groups about your efforts, encouraging them to adopt sustainable practices
S-3-2		**Culture and organizational climate**: Make sustainability "how we do things here" and provide a respectful and productive workplace 1. Develop an empowered culture where employees routinely come up with ways to improve performance; sustainability is one of the areas employees focus on 2. Demonstrate through word and action that sustainability is a core value of the organization 3. Conduct an employee survey at least every two years and act on the results (including such elements as employee involvement, diversity, work/life balance, living wage jobs)
S-3-3		**Volunteering and charities**: Support the communities in which you operate or affect 1. Have programs that encourage employees to donate to charities and to volunteer; encourage charitable participation with matching donations 2. Allow employees to volunteer during paid work time 3. Select certain charities or social/ environmental issue(s) that are strategic to your organization and provide at least 40 hours per person of pro bono services per year
S-3-4		**Talent attraction &retention** 1. Actively recruit from and provide jobs for people from disadvantaged populations (e.g., people with disabilities, minorities, at-risk youth) 2. Develop conflict resolution system and cultural diversity/tolerance program 3. Develop program for handling of grievances and complaints (e.g., whistle-blowing policy and helpline)

Table 4.5: Evaluation Form for Senior Management under the Social Element

SOCIAL—SENIOR MANAGEMENT

Cat.	**Points**	**Function/Practice**
S-4-1		**Executive education**: Provide executives with education on sustainability 1. Expose executives to sustainability through articles, speakers and other methods 2. Provide executives formal training on sustainability and incorporate discussions of its relevance in planning meetings 3. Make sustainability knowledge and commitment a selection and performance criterion for executives
S-4-2		**Commitment**: Demonstrate commitment to sustainability through accountability and resources 1. Require each department work on sustainability initiatives and goals 2. Build sustainability into budgets, reviews, selection criteria, and compensation 3. Integrate sustainability into mission
S-4-3		**Transparency and stakeholder involvement**: Operate in a transparent and involving manner 1. Provide access to complete and accurate performance data to investors, regulators and the public 2. Provide mechanisms to solicit input from all major stakeholder groups 3. Conduct regular, formal assessments of stakeholder expectations and satisfaction levels
S-4-4		**Codes of conduct/compliance/corruption & bribery** 1. Ensure mechanisms are in place to assure effective implementation of your company's codes of conduct 2. Dedicate help desks, focal points, ombudsman, hot lines 3. Enforce disciplinary actions in case of breach, i.e., warning, dismissal, zero tolerance

Table 4.6: Evaluation Form for Public Relations under the Social Element

SOCIAL—PUBLIC RELATIONS

Cat.	Points	Function/Practice
S-5-1		**PR/outreach strategy**: Educate stakeholders about your sustainability efforts 1. Promote sustainability as part of your image to those stakeholders or markets that will care 2. Produce a publicly available formal annual sustainability report which portrays your progress as well as your areas for improvement. 3. Identify your major stakeholders and actively assess their trust, perception and ideas for improvement
S-5-2		**Incident/emergency response and media communications** 1. Provide timely, accurate and complete information to authorities and the public when a crisis does occur; give higher priority to protecting public health and the environment than protecting your short-term financial interests and image 2. Provide access for the media and public about incidents and responses (e.g., via website) 3. Operate with transparency, avoiding the temptation to spin bad news in your favor
S-5-3		**Privacy protection** 1. Develop formal privacy policy (ensure mechanisms in place to ensure effective implementation) 2. Enforce disciplinary actions (i.e., zero tolerance) 3. Communicate to customers on the kind of information collected and its use

Table 4.7: Evaluation Form for Facilities under the Environmental Element

ENVIRONMENTAL—FACILITIES

Cat.	**Points**	**Function/Practice**
E-1-1		**Energy**: Reduce environmental and social impacts associated with energy use through conservation, renewables, and production 1. Conduct energy audit and act on results 2. Have in place systems for monitoring and reducing both from equipment and human behavior 3. Purchase or produce at least 50% renewable energy
E-1-2		**Waste**: Move toward a zero waste facility 1. Conduct waste audit and act on results. Have programs in place for waste reduction (e.g, recycling is more convenient than trash receptacles, monitoring and feedback systems, signage, etc.) 2. Provide incentives for employees and haulers to divert resources from the waste stream 3. Achieve zero waste (at least 90% reduction in solid waste going to the landfill) while directing residual products to the “next best use” whenever practical
E-1-3		**Parking and transportation facilities** 1. Provide free parking for carpoolers, provide bike parking and shower facilities 2. Subsidize bus passes and/or provide other incentives for alternative transportation 3. Choose sites that permit commuting choices, including convenient alternative transportation
E-1-4		**Janitorial**: Use cleaning and pest control products and methods that minimize toxics 1. Ensure that 50% or more by volume are green cleaning products (Green Seal, Green Cross, UGCA or equivalent). For janitorial paper products, source ones with high recycled content 2. Ensure 75% of the cleaning products are green/sustainable and nontoxic pest control methods are used. Apply integrated pest management practices. 3. Ensure 100% of the cleaning products are green/sustainable and nontoxic pest control methods are used

Table 4.8: Evaluation Form for Office Management under the Environmental Element

ENVIRONMENTAL—OFFICE MANAGEMENT

Cat.	Points	Function/Practice
E-2-1		**Office supplies and equipment**: Minimize impacts associated with office supplies, furnishings and equipment 1. Have a program in place for routinely assessing the impacts of purchases and working on finding better options 2. Ensure 80% or more of office supplies and equipment come from sustainable sources (i.e., from a certified sustainable source, 100% post-consumer waste, recyclable, product take-back, etc.) 3. Adopt a paperless policy
E-2-2		**Contract services**: Use contractors that share a commitment to sustainability (e.g., banks, janitorial, landscaping, courier, catering, etc.) 1. Notify all major contractors/suppliers of your commitment to sustainability 2. Implement a program for evaluating contractors on their sustainability practices. Write sustainability criteria and requirements into contract language for all contractors 3. Actively influence contractors not hired directly (e.g., work with building owner or create collaborative purchasing programs with building tenants)
E-2-3		**Transportation**: Actively promote the reduction of climate impacts associated with transportation of people and documents/materials 1. Encourage alternative transportation for commuting through incentives and other means (e.g., paid parking, carshare, etc.). For correspondence freight and business travel, use the lowest impact carrier that will meet the needs of the parties involved 2. Offer incentives to contractors and customers to reduce fossil fuel use 3. Be climate neutral for all organizational transportation and for at least 25% of commuting impacts

Table 4.9: Evaluation Form for Environmental Affairs under the Environmental Element

ENVIRONMENTAL—ENVIRONMENTAL AFFAIRS

Cat.	Points	Function/Practice
E-3-1		**Sustainability management systems** 1. Actively promote industry-wide practices and standards that protect public health and the environment 2. Have an ISO 14001- conformant environmental system 3. Include goals associated with customer and supplier impacts
E-3-2		**Environmental policy/management system** 1. Adopt a corporate environmental policy 2. Measure environmental impacts of products & services 3. Enroll in third party sustainability program (e.g., The Natural Step)
E-3-3		**Sustainability reporting**: Make available and use qualitative and quantitative data on your progress toward sustainability 1. Produce an internal report highlighting accomplishments and areas for improvement 2. Include sustainability reporting as part of existing public reports for liaison and permitting purposes 3. Publish a separate, detailed and audited sustainability report

Table 4.10: Evaluation Form for Operations under the Environmental Element

ENVIRONMENTAL—OPERATIONS

Cat.	Points	Function/Practice
E-4-1		**Health & Safety** 1. Implement occupational health and safety policy into operations 2. Provide employee safety and orientation program for new hires 3. Demonstrate reduction of WCB claims
E-4-2		**Design/Drafting** 1. Utilize BIM to facilitate analysis of designs for parameters (e.g., CO_2 emissions) 2. Standardize framing designs and automate construction drawings 3. Develop 3D models to permit further analyses, such as material quantification for procurement and cost estimation, material waste minimization and generation of material cutting lists
E-4-3		**Field operations** 1. Implement wireless links to submit inspector data 2. Reduce frequency of site visits 3. Formalize recycling efforts on sites and utilize recycling bins (develop systems to collect data on waste generated and material diversion)
E-4-4		**Lean construction** 1. Introduce lean systems concepts to minimize waste in production 2. Consolidate purchasing to control inventory 3. Cross-train employees on construction tasks
E-4-5		**Construction methodology** 1. Evaluate alternative construction practices 2. Implement a CO_2 registry—emissions are examined at every stage of the construction process and develop strategies for reduction 3. Explore industrialization of construction practice (e.g., pre-fabrication, panelization, modular construction)

Table 4.11: Evaluation Form for Accounting & Finance under the Economic Element

ECONOMIC—ACCOUNTING & FINANCE

Cat.	Points	Function/Practice
C-1-1		**Budgets**: Modify your systems so that people are encouraged to optimize the sustainability performance of the entire organization rather than their own budgets 1. Provide a method of accounting for benefits that accrue to different budgets (e.g., capital versus O&M; operations versus customer service dept.) 2. Include sustainability as one of the criteria that should be assessed before money is spent 3. Provide a program to return some of the savings to the departments that created them
C-1-2		**Key performance indicators**: Develop a set of sustainability metrics 1. Develop a set of metrics to assess the benefits and costs of pursuing sustainability 2. Develop a complete set of sustainability metrics for the organization and report on them at least annually 3. Regularly conduct sustainability best-practice studies with other organizations to uncover opportunities for improvement
C-1-3		**Financial analysis**: Use tools to provide a more complete assessment of options which take into account sustainability 1. Include an assessment of risks and intangible benefits when assessing sustainability options 2. Use total cost of ownership (not first cost) and identify externalities related to lifecycle of the product or capital investment 3. Make lifecycle analysis available and take responsibility for all identifiable externalities when making major decisions; avoid discount rates that unfairly impact on future generation

Table 4.12: Evaluation Form for Marketing under the Economic Element

ECONOMIC—MARKETING

Cat.	Points	Function/Practice
C-2-1		**Marketing strategy**: Have a strategy in place that encourages all your customers to choose the more sustainable options 1. Assess market segments for their understanding and opinions about sustainability to identify messages that will resonate with each segment 2. Develop a message that will resonate with each market segment such that it encourages them to make the sustainable choice (e.g., take-back opportunities as a marketing strategy) 3. Develop an aggressive customer education campaign around sustainability to build demand for sustainable products and services
C-2-2		**Product positioning and brand management** 1. Assess all your major products for their sustainability impacts (eliminate or redesign lines with the worst sustainability performance) 2. Seek credible eco-labeling or certification for your products 3. Conduct feedback process with stakeholders
C-2-3		**Internal marketing**: Educate all employees about the organization's sustainability efforts 1. Incorporate sustainability into employee communications on ad hoc basis 2. Communicate at least quarterly via at least two types of media 3. Ensure all employees are fully aware of sustainable activities
C-2-4		**Marketing materials and give-aways** 1. Use high-recycled content paper and soy-based inks when printing 2. Reduce the use of give-aways and choose products that exemplify sustainability 3. Make it easy for customers to eliminate duplicate mailings or get off your mailing list
C-2-5		**Education of public** 1. Help customers understand and reduce energy consumption 2. Promote the concepts of sustainability in you marketing materials to educate your customers 3. Increase web-based communication (paperless) for newsletters

Table 4.13: Evaluation Form for Research & Development under the Economic Element

ECONOMIC—RESEARCH & DEVELOPMENT

Cat.	**Points**	**Function/Practice**
C-3-1		**Affordable housing** 1. Examine practices to explore how to lower the cost of production 2. Seek partnership and joint ventures with other stakeholders 3. Develop rationale and case for subsidies and/or tax deferrals
C-3-2		**Innovations** 1. Invest in product research and development (e.g., spray foam insulation) 2. Increase implementation of new technology practices into operations 3. Establish best practices through industry and stakeholder dialogue

Table 4.14: Evaluation Form for Legal under the Economic Element

ECONOMIC—LEGAL

Cat.	**Points**	**Function/Practice**
C-4-1		**Corporate governance** 1. Establish vision and framework for sustainability that clearly defines the business case for pursuing it 2. Establish executive-level oversight and support of its corporate sustainability strategy with long-term and interim goals 3. Ensure transparency and comprehensive reporting on sustainability
C-4-2		**Risk & Crisis management** 1. Take full responsibility for your actions and move quickly to solutions (risks retained, transferred or avoided) 2. Define risks systematically and use uniform risk analysis framework, i.e. use risk maps and other tools to rank risk on 2D scale (probability and magnitude) 3. Have formal policy to address environmental accidents such as reporting and action plan

Table 4.15: Evaluation Form for Payroll under the Economic Element

ECONOMIC—PAYROLL		
Cat.	**Points**	**Function/Practice**
C-5-1		**Employee compensation**: Link rewards and compensation to sustainability performance 1. Provide a fair living wage to all employees (compare with industry average) 2. Maintain a fair ratio between the highest and lowest paid employee (fair wage mechanism) 3. Provide an award or reward program to encourage sustainability innovations and share cost savings from suggestions
C-5-2		**Employee evaluation** 1. Incorporate sustainability into performance evaluations 2. Examine employee environmental certification credentials 3. Ensure employee performance appraisal systems integrates compliance/codes of conduct
C-5-3		**Executive team and salary** 1. Increase in female manager, executive and shareholder positions 2. Have compensation explicitly tied to social, environmental and governance performance targets 3. Improve diversity representation within management

The score from each criterion is accumulated for each of the three elements. The results would be shown in a tabular format as shown in Table 4.16. The points are then normalized to a maximum of 100 by dividing by each element by 6.75.

Table 4.16: Summary of Accumulated Points under each Element

Element	Points	Normalized Points (divide by 6.75)
Social	/225	/33.3
Environmental	/225	/33.3
Economic	/225	/33.3
Total	/675	/100

The results from the evaluation form provide the practice scoring level ranging from 5 star (highest) to 1 star (lowest). The particular level assessed is based on the accumulated scoring from the evaluation form encompassing the social, environmental, and economic elements of sustainability. The three elements (social, environmental, and economic) each accounts for one third (1/3) of the total score. Table 4.17 illustrates the points required to achieve a particular star level rating. A five-level rating allows for a wider evaluation than a three-level rating. The case study will later demonstrate the application of this evaluation form.

Table 4.17: Practice Score Levels

Total Points	**Practice Score Levels**
81-100	5 star
61-80	4 star
41-60	3 star
21-40	2 star
1-20	1 star

4.2.3 Step 3—Integrated Construction Practice Rating Program

Figure 4.6 illustrates the relationship of the integrated construction practice rating program of both qualitative and quantitative criteria. The framework combines practice criteria with a performance rating program (Mah and Al-Hussein, 2008). As shown, the performance evaluation is based on eight categories from the Built Green program. The practice evaluation is based on the developed SEE model, which is the contribution from this thesis.

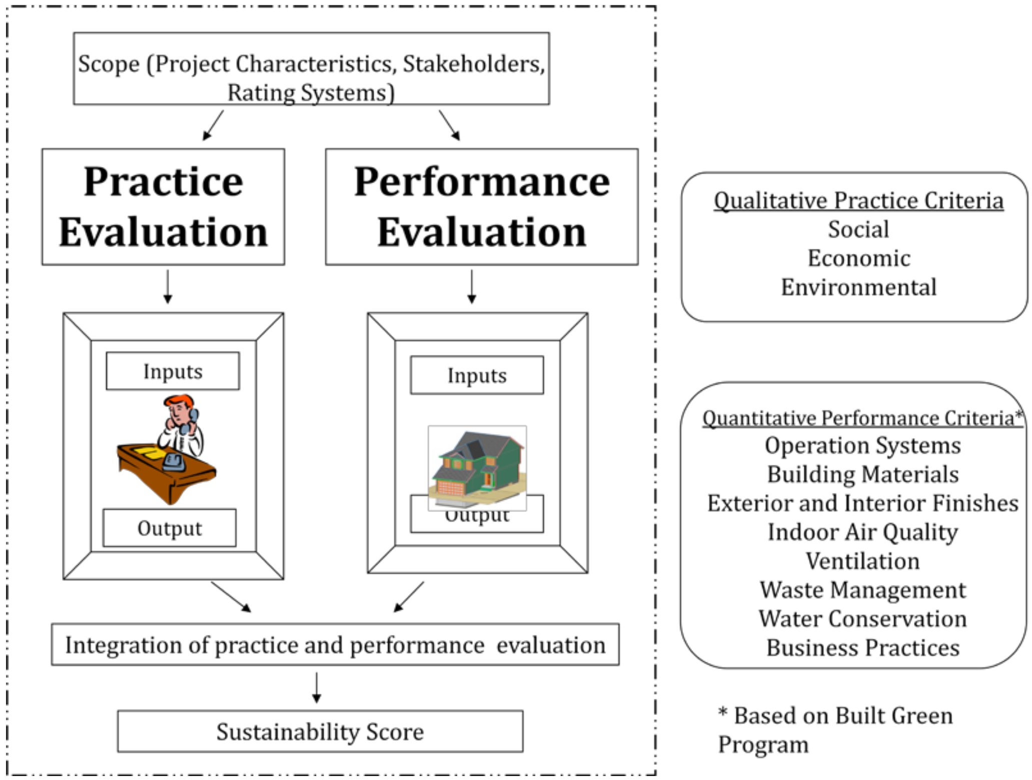


Figure 4.6 Integrated Construction Practice Rating Program

Table 4.18 shows the different performance score, practice score, and integrated sustainability score levels. The performances score is obtained from the Built Green program and ranges from high to low (Platinum is the highest, while Bronze the lowest). The practice score level is obtained from the SEE model and ranges from 5 star (highest) to 1 star (lowest). The integrated sustainability score level is obtained from amalgamating the results from the performance and practice score levels and ranges from A (highest) to E (lowest).

Table 4.18: Integrated Green Building Program Scoring

Performance Score Levels	Practice Score Levels	Integrated Sustainability Score Levels
Platinum	5 star	A
Gold	4 star	B
Silver	3 star	C
Bronze	2 star	D
	1 star	E

Table 4.19 outlines the possible results from amalgamating the performance and practice score levels. For instance, the scenario of obtaining an A level rating is through four possible combinations, such as Platinum performance level with either a 5-star or 4-star practice level (case 1 and 2). The other two scenarios for an A level rating is through a Gold performance level with either a 5-star or 4-star practice level (case 3 and 4). As noted in the table, the other integrated sustainability score levels are determined by matching the appropriate performance score level with the practice score level. In total, there are twenty case scenarios that would provide integrated sustainability score levels A, B, C, D, and E. Providing twenty case scenarios allows for a more practical range of results for the various score levels combinations. A score of A indicates that the evaluation results are *excellent*, followed by a score of B which indicates a *good* result, followed by a score of C which indicates a *fair* result. A score of D would indicate a *poor* rating, while a score of E indicates a *failing* result. The user can use these results to benchmark an organization's current ranking and strive to improve upon them. Likewise, the user could use the results in marketing or promotion of a company's commitment to strong results.

Table 4.19: Integrated Sustainability Score Levels

Case #	Performance + Practice = Sustainability Rating		
	Performance Score Levels	**Practice Score Levels**	**Integrated Sustainability Score Levels**
1	Platinum	5 star	A
2	Platinum	4 star	A
3	Gold	5 star	A
4	Gold	4 star	A
5	Platinum	3 star	B
6	Gold	3 star	B
7	Silver	5 star	B
8	Bronze	5 star	B
9	Platinum	2 star	C
10	Gold	2 star	C
11	Silver	4 star	C
12	Bronze	4 star	C
13	Platinum	1 star	D
14	Gold	1 star	D
15	Silver	3 star	D
16	Bronze	3 star	D
17	Silver	1 star	E
18	Silver	1 star	E
19	Bronze	2 star	E
20	Bronze	1 star	E

4.2.4 Summary

The contribution from this evaluation tool is the integration of an established performance rating system (e.g, Built Green) with the proposed practice evaluation system resulting in the integrated sustainability score. In other words, the contribution is the addition of the practice evaluation to the current performance measurement evaluation. The findings will allow builders to benchmark their current ICPRP score and identify practices that could be modified to strengthen their scores subsequently.

4.3 Development of the Application of Building Information Modeling (BIM) for Quantification of Parameters Rating[2]

The house model that is used for the development of the application of BIM is a Landmark Homes Cambridge II model, which is a two-storey, 1760 ft^2 (163 m^2) size house. This house model was selected as it is one of the most popular built by the company, and the model is within the average industry size and style.

The automation of BIM for quantification of parameters (e.g., CO_2 emissions) related to the rating of the construction practice is developed in this section. A detailed mapping of construction activities is conducted, and the unit emission rates are added within a registry in a classification in BIM, which provides as an output the effects of these activities on sustainability measurements as BIM extracts quantities and types of materials.

4.3.1 Step 1—Determination of Sources of CO_2 Emissions

The residential construction process consists of a number of sub-processes. It commences with site preparation involving topsoil stripping and basement excavation. Site preparation and pre-grading is completed by the land developer prior to the lot being made available to the residential builder. The scope of the site preparation in not included in this research. Following excavation, the foundation contractor uses cast-in-place foundation walls for the basement. Supporting grade beams are formed and poured, followed by backfilling. Piling for the supporting garage grade beam, garage slab, sidewalk and deck are then completed. Once the structural grade beams are set, the framing stage, which includes the framing of

[2] A version of this section has been accepted for publication, Journal of Construction Innovation: Information, Process, Management, Emerald Publications, 2010

floors, walls, and the roof structure of the house and garage, takes place. While heating, plumbing, and electrical systems are roughed-in, roofing, siding, soffit and fascia are installed on the exterior of the structure. The building is then insulated, and drywall is applied to the ceilings and walls. Following interior finishing and painting, the electricians install light fixtures, outlets, switches, etc. The finished flooring is then installed, followed by the plumbing fixtures, door knobs, towel bars, and a myriad of other minor components (Ying, 2008).

Table 4.20 outlines the 17 stages in the residential construction process. Over 30 houses of two similar models (Catalina II and Cambridge II) were observed for the purpose of field data collection with respect to the 17 stages. The Catalina II size is 1696 ft^2 (158 m^2), and the Cambridge II size is 1760 ft^2 (163 m^2). Durations were observed for the tasks and trips, and types of vehicles were noted.

Table 4.20: Stages of Residential Construction

Stages	Description
1	Stake Out
2	Deep Services & Foundation Walls
3	Backfill & Shallow Trenching
4	Capping Shallow Services
5	Framing Main & Second Joists
6	Framing Second & Roof
7	Roofing
8	Siding & Rough-Ins
9	Electrical RI & Slabs
10	Insulation & Boarding
11	Drywall Taping & Texture
12	Stage 1 Finishing & Cabinets
13	Railing & Painting
14	Tile & Vinyl Flooring
15	Hardwood & Stage 2 Finishing
16	Carpet & Finals
17	Touch-Ups & Pre-Occupancy

4.3.2 Step 2—Quantification of Parameter (CO_2)

The quantification methodology utilized in this research categorized construction activities for a single house into 17 stages and measured the CO_2 contributions from each stage's specific activities and its impact on work. Identifying separate stages for data collection produced opportunities to collaborate with various independent contractors in the analysis of the entire scope of work.

Factors such as transportation, equipment, weather, scheduling, and material handling were also taken into account as criteria for quantification. Data was collected through direct detailed field observations and measurements.

Over seventy (70) contractors (trades) are utilized by a Landmark Group of Builders. These trades travel to each of the four main neighbourhoods in the City in which the builder has houses to construct. An address database of these contractors was established based on a municipal address and postal code. The construction site address was based on the postal code of the show home constructed in each of the four areas of the city. With the use of internet applications, Google Maps and Mapquest, the travel distances between the contractor and construction areas was established based on an input of postal codes. The results are shown in Table 4.21. Based on the results, the average distance between a contractor and a particular construction site was 19.9 km (~ 20 km), hence a 40 km round trip calculation was determined.

Table 4.21: Distance Calculations of Contractors to Construction Site

Distance Subtrade to Construction Site (km)						
			West - Parkland	South West - Magrath Manor	South East - Millcreek Meadows	North - Lakeview
SHORT_NAME	**SUB_CITY**	**SUB_POSTCODE**	**T6M 0B7**	**T6R 3S4**	**T6T 1Z7**	**T5Z 3W4**
A & B Concrete Pumpi	Acheson	T7X 5A4	28.6	32.3	39.7	34.1
Alberta Concrete Pum	Edmonton	T6T 1L8	32.2	13.4	7.2	28.3
Alberta Hardwood Flo	Edmonton	T6E 4W8	26.5	7.6	5	20
All Weather Windows	Edmonton	T5S 2K7	22	14.8	22.4	12.2
Artistic Stairs Ltd.	Edmonton	T5S 1E8	16.1	14.3	21.9	17.1
Ashley Fine Floors	Edmonton	T5S 1R5	14.8	14	21.6	18.5
AyA Kitchens & 28400	Edmonton	T5M 1Y6	17.4	15	22.5	15.6
B.R.K. Masonry 28056	Onoway	T0E 1V0	71.4	74.3	81.9	61.3
Budget Waste I 28057	Calgary	T2C 1V5	n/a	n/a	n/a	n/a
Builders Floor centre		T6E 5C5	24.5	5.5	4.3	20.4
Burnco ROCK Pr 28122	Edmonton	T6B 3B4	41.7	15.6	13	17.9
C.D.M Painting & Decorating		T5X 5X5	31.2	24.9	26.4	3.5
Canac	Edmonton	T5L 3H3	23.3	14.6	20.1	10.9
Canadian Closet Solu	Sherwood Park	T8A 0R8	42.6	24.3	21.7	21.7
Certified Automation	Edmonton	T6J 6V7	22.5	7.7	3.5	25.1
CMS Enterprises Inc.	Edmonton	T5A 0C5	31.9	31.1	28.5	9.8
Complete Found 28800	Namao	T0A 2N0	43.6	37.8	34.9	12.1
Connect Home Innovat	Edmonton	T5S 1E5	16.1	14.2	21.7	17.2
Contec Concrete Serv	Edmonton	T5G 1B8	28.2	20.6	17.7	7.2
Cosmic Closets Inc.	Edmonton	T5P 4W2	15.9	13.5	21.1	17.7
Craft D	Spruce Grove	T7X 1M6	29.4	33.1	40.7	35.9
Creative Door	Edmonton	T5S 1E7	16.1	13.8	21.4	17.5
Creative Stone Produ	Edmonton	T5S 2H1	15.3	14.6	22.2	18.2
Davis Heater Service	Edmonton	T6P 1L8	39.3	16.9	14.3	23
Deck F/X Ltd.	Edmonton	T5X 3G3	32.7	27.7	24.8	1.9
Divine Hardwoo 28095	Edmonton	T6E 6W6	27	8	11.6	18.7
Dyand Mechanical Sys	Edmonton	T5M 1W9	23.3	13	20.6	14
Electrical Wiring Services	Edmonton	T5L 2S6	24.6	13.7	19.1	10.5
Elms Weeping Ti 1439	Edmonton	T5T 6W3	10.8	11.7	19.3	23.8
EX/S Cleaning 1450	St Albert	T8N 0J8	25.1	22.7	30.2	10
E-Z-DUZ-IT Cri 28104	Sherwood Park	T8C 1A9	47.8	28	25.6	34.6
First Class El 28158	Edmonton	T6E 0C4	25.9	6.9	5.8	19.1
Gradex Consult 28059	Sherwood Park	T8H 2H3	41.7	23.3	20.9	20
Great Canadian Exteriors	Edmonton	T6E 0C9	27.5	8.4	6	18.3
Great Canadian Roofing	Edmonton	T6E 0C9	27.5	8.4	6	18.3
Habberjam Mechanical	Edmonton	T5X 2N7	32	22.4	25.7	2.9
Igloo Manufacturing	Edmonton	T5S 1Y1	22	14.8	22.4	12.2
K V R Electric Ltd.	Edmonton	T5P 4V4	15.1	12.7	20.3	19
Karjohn Contrac 2037	Edmonton	T5C 0T3	30.1	20.6	17.5	6.8
Kat's Kontracting	Edmonton	T6L 1H8	28.5	9.5	3.4	20.4
Kitchen Craft Cabine	Edmonton	T6J 6V7	22.5	7.7	3.5	24.1
KJay Electric Ltd.	Edmonton	T5S 1J3	15.8	14.8	22.4	17.5
Klewchuk Constructio	Sherwood Park	T8A 5P1	42.2	39.4	13.4	10.5
Lafarge	Edmonton	T5H 3X5	24.3	11.3	14	10
M. T. S. Painting &	Edmonton	T6R 2T1	15.6	6.9	9.2	27
Matrix Wiring Innova	Edmonton	T5S 2P6	15.6	18.7	23.2	11.6
Maxim Glass	Edmonton	T5L 2H7	22.5	15.6	23.2	11.6
MGS Company	Edmonton	T6E 6R7	26.2	7.2	3.1	21.2
NDA Construction Ltd	Edmonton	T5T 5V1	8.2	13.8	22	27.8
Norpen Masonry 28125	Edmonton	T5T 3C2	13.7	12.2	19.8	20.1
Northern Heatin 2327	Morinville	T8R 1C5	45.4	43	50.5	30.6
Overhead Door Compan	Edmonton	T5M 3Z3	20.4	17.1	24.6	14.5
P F Manufacturing	Edmonton	T5S 1H1	15.3	13.4	20.9	17.9
Pals Surveys Ltd.	Edmonton	T5S 1G7	15.8	14.5	22	17.5
Park Lighting Ltd.	Edmonton	T5P 4V4	15.1	12.7	20.3	19
Performance Drywall	Edmonton	T5M 3T3	17.7	15.1	23	15.1
Productive Plum 2565	Edmonton	T6E 0C4	25.9	6.9	5.8	19.1
Rolling Mix Concrete	Edmonton	T5S 2N6	22	14.8	22.4	12.2
Ronco Doors & Distri	Edmonton	T5S 1E9	16.1	14.2	21.7	17.2
Southside Ornamental	Edmonton	T6E 4E1	22.4	8.5	8.8	15.6
Stantec	Edmonton	T5K 2L6	25.4	10.8	13.2	12.2
Stel-Marr Concrete L	Edmonton	T5V 1J1	20.1	16.9	24.3	14.3
Straight "A" Contrac	Beaumont	T4X1W7	33.8	23.7	15	43.1
Sublime Exteriors	Edmonton	T6W 1K8	18.3	4.3	6.4	26.2
Sunrise Excava 28033	St Albert	T8N 5V9	24	21.6	29.1	11.1
Sure Fire Propane Lt	Edmonton	T6P 1L8	39.3	16.9	14.3	23
The Spindle Factory	Edmonton	T5L 2T1	23.2	14.6	22.2	12.6
TNN Maintenance & Cl	Edmonton	T5A 0R6	32.2	21.1	18.2	7.6
Trail Appliances Ltd	Edmonton	T6E 5P3	24.6	5.6	5.1	20.4
Trail Building Suppl	Edmonton	T6E 5V3	26.4	7.4	4.8	19.8
Weiss-Johnson Sheet	Edmonton	T6E 6L9	26.9	7.9	5.3	18
Westek Truss Systems	Edmonton	T5V 1S8	22	14.8	22.4	12.2
Westridge Cabinets	Edmonton	T6E 6W6	27	8	7.2	18.8
WestWorld Computers	Edmonton	T5P 4V4	15.1	12.7	20.3	19
Wood & Energy Store	Edmonton	T5M 1W9	23.3	13	20.6	14
Worrell's Concrete S	Edmonton	T6L 4M8	28.6	13.7	4	24
		Ave=	**25.7**	**16.6**	**18.9**	**18.3**
		Total Ave=	**19.9**			

Figure 4.7 illustrates the locations of various contractors to the North-Lakeview subdivision.

Figure 4.7: Illustration of Contractors Location to a Particular Residential Construction Neighborhood

In addition to the distance calculations, emission rates for various vehicle types were established based on numerous publications and website sources (see Table 4.22). Likewise, equipment CO_2 emission rates were obtained from various sources. Although the sources are cited in the references, they include Ford Motor

Company (2009) and Michigan Occupational Safety and Health Administration (2009) as examples.

Table 4.22: Emission Rates per Vehicle Type and Equipment Type

vehicle	CO2 kg/km	equipment	CO_2 kg/hr
car/van	0.23	compressor	2.68
0.5 t	0.34	generator	2.68
1 t	0.7	excavator/backhoe	40
2 t	0.76	crane	16
3 t	0.82		
concr/5 t	1.16		

Sample Calculations of CO_2 Emissions

The following is a sample calculation of CO_2 emissions from Stage 3 – Backfill and Shallow Trenching. Underground gas line installation CO_2 quantity is obtained by the following calculation which is typical for all tasks. The distance value, and vehicle and equipment emission rates are used in the excel spreadsheet computation.

CO_2 (kg) = (material trip numbers) **x** (vehicle type) **x** (distance)

+ (labour trip numbers) **x** (vehicle type) **x** (distance)

+ (duration) **x** (equipment type)

The distance, vehicle and equipment types are values obtained from lookup tables.

The following is a numeric example:

220 CO_2 [kg] = 1 **x** 1.16 [CO_2 kg/km] **x** 40 [km]

+ 1 **x** 0.34 [CO_2 kg/km] **x** 40 [km]

+ 4 [hr] **x** 40 [kg/hr]

The excel formula would be the following (see Table 4.23):

I20 = D12*F7*C2+F12*F3*C2+C12*I4

Table 4.23 shows the data cells and results (in MS Excel) from the above equation.

Table 4.23: Excel Spreadsheet Illustration of Computations

	A	B	C	D	E	F	G	H	J
1			Distance km		veh	CO_2 kg/km		equipment	CO_2 kg/hr
2			40		van	0.23		compressor	2.68
3					0.5t	0.34		generator	2.68
4					1 t	0.7		excavator/backhoe	40
5					2t	0.76		crane	16
6					3 t	0.82			
7					concr/5 t	1.16			
8									
9	Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO_2 (kg)
10				Trips	Vehicle	Trips	Vehicle	Equipment	
11	3	**Backfill & Shallow Trenching**							
12		Underground gas line installation	4	1	5t truck	1	0.5t truck w/ trailer	1 backhoe	220

The amount of CO_2 [kg/unit] is calculated by taking the CO_2 [kg] from an activity and dividing it by the quantity per unit. For example, in Stage 5, Framing—main floor results in 178.48 CO_2 [kg] which is then divided by 82.3 [m^2] resulting in 2.17 kg/m^2 of emissions. The results are shown in Table 4.24.

Table 4.24: CO_2 Emission Rate for Framing—Main Floor

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO_2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
5	Framing Main & Second Joists										
	Deliver first floor framing package -wall	1	0.5					23.2	linear m of wall	63.1	63.10
	Deliver first floor framing package -floor	1	0.5	5t truck				23.2	m2 of floor	82.3	0.28
	Framing - main floor	13			8	0.5t truck	1 generator, 1 compressor	178.48	m2 of floor	82.3	2.17
	Framing - main floor walls	19			8	0.5t truck	1 generator, 1 compressor	210.64	linear m of wall	63.1	3.34
	Deliver second floor framing package -floor	1	0.5	5t truck				23.2	m2 of floor	82.3	82.30
	Deliver second floor framing package -wall	1	0.5	5t truck				23.2	linear m of wall	63.1	63.10

Excavation of site

Formwork

Formwork delivery

Foundation wall form preparation

Figure 4.8: Photographs of Stage 2—Foundation Site Preparation

During Stage 2—foundation, a significant amount of vehicle and equipment activity was observed. For instance, a truck with a picker is required for delivering and mobilizing the formwork, as shown in Figure 4.8.

Pouring concrete walls

Foundation grade beam installation

Damp Proofing

Winter Heating

Figure 4.9: Photographs of Tasks in Stage 2—Foundation Concrete Work

A concrete truck and concrete pump unit are utilized for pouring the concrete walls, as shown in Figure 4.9. Propane heaters are used in the winter construction period to prevent cracking during the curing of the concrete walls.

Framing interior

Framing garage

Figure 4.10: Photographs of Tasks in Stage 3—Framing

Figure 4.10 shows photographs of the framing in the garage and interior walls. The durations of each of the tasks were established based on field review of over 30 Landmark Homes Catalina II and Cambridge II models. The address table shows the locations where the field review was conducted to determine the durations. Table 4.25 shows the house addresses and models where field observations and recordings were taken.

Table 4.25: Address of Houses for Catalina II and Cambridge II Models

Address	Model
4911 - 213 STREET NW	Cambridge II
6009 60 Street	Cambridge II
139 - 55 Street SW	Cambridge II
152 - 55 Street SW	Cambridge II
119 - 65 Street SW	Cambridge II
6031 - 4 Avenue SW	Cambridge II
4058 Crowsnest Crescent	Cambridge II
8731 - 180 Avenue NW	Cambridge II
20914 - 92 A Avenue NW	Cambridge II
20723 - 58 AVENUE NW	Cambridge II
539-59 Street SW	Cambridge II
523-59 Street SW	Cambridge II
6711 Speaker Place NW	Cambridge II
1413 37C Ave	Cambridge II
1460-37 B Avenue NW	Cambridge II
3196 Whitelaw Drive NW	Cambridge II
3243 Whitelaw Drive NW	Cambridge II
211 - 55 Street SW	Catalina II
115 - 65 Street SW	Catalina II
116 - 54 Street SW	Catalina II
1905 - 68 Street SW	Catalina II
6816 - 19 A AVENUE SW	Catalina II
17904 - 87 Street NW	Catalina II
9262 - 212 STREET NW	Catalina II
21014 - 92B AVENUE NW	Catalina II
9273 - 208A STREET NW	Catalina II
9270 - 208A Street NW	Catalina II
9266 - 210 STREET NW	Catalina II
5523 - 209 Street	Catalina II
532 - 59 Street SW	Catalina II
5831 - 7 Avenue SW	Catalina II
6816 Speaker Vista NW	Catalina II
3745 - 13 Street NW	Catalina II
1418-37 B Avenue NW	Catalina II
1430-37 B Avenue NW	Catalina II
1436-37 B Avenue NW	Catalina II

Tables 4.46 to Table 4.29 show the results of the average durations for each of the applicable tasks in each of the 17 stages of the residential construction process.

Up to three values for each task were observed, and the standard was used for comparison. The standard was obtained from industry experts. The durations used in the tables are the averages of the 3 observations and the standard. The standard deviation is based on these four values as well. The 3 observations were comparable with the standard for the majority of the tasks. Several of the durations were left blank due to erroneous values recorded.

Table 4.26: Task Durations for Stages 1 to 5

Stage	Tasks	#1	#2	#3	Ave	Standard	Ave with standard	Std Dev
	Stake Out							
1	Stake-Out	1	4	2	2.3	2	2.3	1.3
	First call for underground utility line markout	1	1	0.5	0.8	0.5	0.8	0.3
	Deep Services & Foundation Walls							
	Deep services	5	4		4.5	4	4.3	0.6
	Excavation	7	8		7.5	6	7.0	1.0
	Soil Test	1	0.5	1	0.8	0.5	0.8	0.3
	Cribbing - Footing	7	3	4	4.7	2	4.0	2.2
	Sleeves & "T'	1	0.1	0.25	0.5	1	0.6	0.5
2	Sump Liner	1	1	1	1.0	2	1.3	0.5
	Deliver Wall cribbing material package	1	2	0.5	1.2	1	1.1	0.6
	Cribbing - walls	10	20	12	14.0	12	13.5	4.4
	Mark and inspect foundation	0.25	0.5	0.5	0.4	1	0.6	0.3
	Weeping Tile, Spray	2	1	2	1.7	8	3.3	3.2
	Install electrical panel c/w temp service	3	1	2	2.0	2	2.0	0.8
	City Inspection #1 for foundation	0.5	0.5	0.25	0.4	0.5	0.4	0.1
	Backfill & Shallow Trenching							
	Backfill Foundation	6	4	8	6.0	4	5.5	1.9
	Shallow Services	4	2	4	3.3	4	3.5	1.0
	Precast products	2	1	1	1.3	1	1.3	0.5
3	Window wells	1	1	1	1.0	1	1.0	0.0
	First call for gasline		0.5	0.5	0.5	0.5	0.5	0.0
	Gas Line Site Readiness Inspection	0.25	0.5	0.5	0.4	0.5	0.4	0.1
	Underground gas line installation	3	1	4	2.7	8	4.0	2.9
	Capping & Shallow Services							
	Main floor joists & subfloor package		1	1	1.0	2	1.3	0.6
	Main floor joists & subfloor installation "Capping"	3	2	5	3.3	8	4.5	2.6
4	Install propane basement heater	0.5	1	0.5	0.7	2	1.0	0.7
	Install Gas Meter	0.5	0.5	3	1.3	2	1.5	1.2
	Install natural gas heater in basement	0.5	1	0.5	0.7	1	0.8	0.3
	Electrical Service Inspection	0.25	0.5	0.5	0.4	1	0.6	0.3
	Electrical Meter Installation / Power to panel	0.5	0.5	1	0.7	1	0.8	0.3
	Framing Main & Second Joists							
	Deliver first floor framing package - wall		1	1	1.0	1	1.0	0.0
	Deliver first floor framing package - floor		1	1	1.0	1	1.0	0.0
5	Framing - main floor		8	15	11.5	16	13.0	4.4
	Framing - main floor walls		32	9	20.5	16	19.0	11.8
	Deliver second floor framing package - floor		1	1	1.0	1	1.0	0.0
	Deliver second floor framing package - wall		1	1	1.0	1	1.0	0.0

Table 4.27: Task Durations for Stages 6 to 8

Stage	Tasks	#1	#2	#3	Ave	Standard	Ave with standard	Std Dev
6	**Framing Second & Roof**							
	Interior stairs delivery		1	1	1.0	2	1.3	0.6
	Tarp basement stairs		0.5	0.5	0.5	1	0.7	0.3
	Deliver tubs & showers		1	1	1.0	1	1.0	0.0
	Deliver roof package		1	1	1.0	2	1.3	0.6
	Deliver roof trusses		1	1	1.0	2	1.3	0.6
	Deliver Windows		1	1	1.0	2	1.3	0.6
	Deliver additional lumber		1	1	1.0	2	1.3	0.6
	Framing Second Floor walls		68	6	37.0	20	31.3	32.5
	Framing roof		32	15	23.5	20	22.3	8.7
	Crane the roof		2	2	2.0	2	2.0	0.0
	Crane the tub		0.5	0.5	0.5		0.5	0.0
	Crane the shower		0.25	0.25	0.3		0.3	0.0
	HVAC mark out	2	1	1	1.3	2	1.5	0.6
	Frame Check	3	2	3	2.7	2	2.5	0.6
7	**Roofing**							
	Temp walkways	1	1	2	1.3	2	1.5	0.6
	Safety rails	1	1	2	1.3	2	1.5	0.6
	Mechanical Insulation	1	1	12	4.7	2	4.0	5.4
	Install fireplaces	2	1	2	1.7	2	1.8	0.5
	Cabinet Mark-out	1	1	1	1.0	1	1.0	0.0
	Repair Framing Deficiencies		4	3	3.5	2	3.0	1.0
	Return un-used lumber		1	1	1.0	2	1.3	0.6
	Site clean	1	1	1	1.0	2	1.3	0.5
	Posts & Verandahs	1	1	5	2.3	8	3.8	3.4
	City Inspection #2 for Framing	1	0.25	1	0.8	2	1.1	0.7
	Load Roof shingles	1	1	2	1.3	2	1.5	0.6
	Roofing	10	16	12	12.7	16	13.5	3.0
	Smart Trim Installation		16	5	10.5	8	9.7	5.7
8	**Siding & Rough-ins**							
	Install siding	40	80	80	66.7	48	62.0	21.0
	Eavestrough & downspouts	5	8	4	5.7	8	6.3	2.1
	Delivery masonry / stonetile	0.5	0.5	1	0.7	2	1.0	0.7
	Install masonry / stonetile	8	16	8	10.7	24	14.0	7.7
	Exterior Metal Railing	1	2	2	1.7	2	1.8	0.5
	Heating rough-In	5	4	25	11.3	4	9.5	10.3
	Gasline measurement (plumber)		1	1	1.0	1	1.0	0.0
	Install gasline to furnace		4	2	3.0	2	2.7	1.2
	Gasline inspection	0.5	0.5	1	0.7	1	0.8	0.3
	Connect gasline to furnace and light furnace	1	1	1	1.0	2	1.3	0.5
	Plumbing Rough-in	12	32	24	22.7	16	21.0	8.9

Table 4.28: Task Durations for Stages 9 to 12

Stage	Tasks	#1	#2	#3	Ave	Standard	Ave with standard	Std Dev
9	**Electrical RI & Slabs**							
	Basement floor sand & prep	3	4	2	3.0	2.5	2.9	0.9
	Place sand in garage	1	2	2	1.7	2.5	1.9	0.6
	Adjust teleposts	?	0.1		0.1	2	1.1	1.3
	Pour Basement Floor	4	4	8	5.3	6	5.5	1.9
	Pour garage floor	3	2	8	4.3	6	4.8	2.8
	Electrical Rough-In	20	32	24	25.3	16	23.0	6.8
	Move basement heater to Garage, tarp garage door		1	1	1.0		1.0	0.0
	Structured Wiring	4	6	7	5.7	3	5.0	1.8
	Check all rough-ins	2	2	1	1.7	4	2.3	1.3
	Install heating plenums & Drop Furnace	15	6	8	9.7		9.7	4.7
	Garage Stair		1	1	1.0		1.0	0.0
10	**Insulation & Boarding**							
	Install Insulation & Vapor Barrier		8	8	8.0	8	8.0	0.0
	Install BIBS		1	1	1.0	2	1.3	0.6
	City Inspection #3 - insulation	0.5	0.1	1	0.5	0.5	0.5	0.4
	Load Drywall	2	1	2	1.7	2	1.8	0.5
	Drywall Boarding	40	32	40	37.3	32	36.0	4.6
	Pre-grade	3	4	4	3.7	8	4.8	2.2
	Install frost walls & insulation	8	8	8	8.0	4	7.0	2.0
	Plumbing Pre-Final	4	2	3	3.0	4	3.3	1.0
	Install Garage Door	2	4	3	3.0	2	2.8	1.0
11	**Drywall Taping & Texture**							
	Attic/Bonus Room Floor Insulation	3	2	2	2.3	4	2.8	1.0
	Drywall Taping	40	42	80	54.0	40	50.5	19.7
	Prime Vac	1	1	2	1.3	2	1.5	0.6
	Prime	3	2	3	2.7	4	3.0	0.8
	Texture	3	2	4	3.0	2	2.8	1.0
12	**Stage 1 Finishing & Cabinets**							
	Inspect walls, check window signs		1	1	1.0		1.0	0.0
	Electrical Rough Final	2	4	8	4.7	4	4.5	2.5
	Stage 1 vac	1	1	1	1.0	2	1.3	0.5
	Deliver mantle	0.5	1	1	0.8	0.5	0.8	0.3
	Deliver Stage One finish package	0.5	1	2	1.2	2	1.4	0.8
	Stage 1 Finishing	30	32	40	34.0	24	31.5	6.6
	Deliver Cabinets	1	1	2	1.3	2	1.5	0.6
	Install Cabinets	12	8	12	10.7	16	12.0	3.3

Table 4.29: Task Durations for Stages 13 to 17

Stage	Tasks	#1	#2	#3	Ave	Standard	Ave with standard	Std Dev
13	**Railing & Painting**							
	Install Railing	9	16	12	12.3	16	13.3	3.4
	Paint vac	1	1	2	1.3	2	1.5	0.6
	Inspect finishing, railing & cabinets	1	1	1	1.0		1.0	0.0
	Pour driveway & sidewalks	3	8	8	6.3	5	6.0	2.4
	Parging	2	2	1	1.7		1.7	0.6
	Rough Grade Site	4	3	4	3.7	2	3.3	1.0
	Interior Painting	30	40	80	50.0	40	47.5	22.2
	Exterior painting	6	8	12	8.7	5	7.8	3.1
	Inspect Painting	1	1	1	1.0		1.0	0.0
14	**Tile & Vinyl Flooring**							
	Electrical Final	7	8	8	7.7	8	7.8	0.5
	Granite Counters	2	2	2	2.0	4	2.5	1.0
	Laminate countertops	2	2	1	1.7	2	1.8	0.5
	Structured Wiring Final	3	2	3	2.7	4	3.0	0.8
	Hard flooring vac	1	1	1	1.0		1.0	0.0
	Tile backsplash & tub surrounds	24	36	24	28.0	25	27.3	5.9
	Sheet Vinyl Flooring		8	2	5.0	16	8.7	7.0
15	**Hardwood & Stage 2 FInishing**							
	Laminate Flooring (n/a)							
	Hardwood Flooring - deliver	0.5	1	1	0.8	2	1.1	0.6
	Hardwood Flooring - install	12	16	8	12.0	16	13.0	3.8
	Check hard surface flooring		0.5	1	0.8		0.8	0.4
	Deliver Stage 2 materials - hardware locks	0.5	1	1	0.8	1	0.9	0.3
	Stage 2 Finishing	7	32	8	15.7	8	13.8	12.2
	Mirrors & Shower Doors - delivery/install	2	2	2	2.0	4	2.5	1.0
	Wire shelving	4	2	3	3.0	4	3.3	1.0
	Plumbing Final & pressure test water lines	8	8	8	8.0	8	8.0	0.0
	Carpet Vac	1	1	2	1.3		1.3	0.6
16	**Carpet & Finals**							
	Carpet Flooring - deliver/install	15	8	16	13.0	16	13.8	3.9
	Check carpet		0.5	1	0.8		0.8	0.4
	Heating Final	2	2	4	2.7	2	2.5	1.0
	Furnace & Ductwork Clean	3	2	3	2.7	2	2.5	0.6
	Full Clean	7	10	6	7.7	8	7.8	1.7
	City Final Inspection	0.5	0.5	1	0.7	1	0.8	0.3
	Window Final	2	1	3	2.0	2	2.0	0.8
	Final site & garage clean	1	1	2	1.3	3	1.8	1.0
	Clean & wash basement floor & stairs	1	1	3	1.7		1.7	1.2
	Temp Driveway & level sidewalks	?	1	2	1.5	2	1.7	0.6
	Site Managers Final Inspection	3	2	2	2.3		2.3	0.6
17	**Touch-ups & Pre-occupancy**							
	Paint touch-ups (3rd coat)	8	16	12	12.0	16	13.0	3.8
	Fireplace Start-up	2	2	2	2.0	2	2.0	0.0
	Cabinet Final	3	2	3	2.7	4	3.0	0.8
	Check for all inspection stickers	0.5	1	1	0.8		0.8	0.3
	Re-clean	1	1	2	1.3	2	1.5	0.6
	Do All Repairs			8	8.0		8.0	
	2nd Re-clean	1	1	2	1.3		1.3	0.6
	Blower-door test	1	2	2	1.7		1.7	0.6
	Garbage removal	1	1	2	1.3		1.3	0.6
	Occupancy and Key Turnover	1	1	4	2.0		2.0	1.7

The following tables (Table 4.30 to Table 4.46) show the CO_2 emissions for each stage.

Table 4.30: CO_2 Emissions for Stage 1

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
1	**Stake Out**										
	Stake-Out	2.3			1	0.5t truck		13.6	Ea	1	13.6
	First call for underground utility line markout	0.8			1	van		9.2	Ea	1	9.2

Table 4.31: CO_2 Emissions for Stage 2

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
2	**Deep Services & Foundation Walls**										
	Deep services				2	3t truck		65.6	Ea	1	65.60
		4.3			2	1t truck	1 excavator	228	ea	1	228.00
	Excavation				1	3t truck		32.8	Ea	1	32.80
		7	20	5t truck	2	0.5t truck	1 excavator	1235.2	m3 of soil	298.1	4.14
	Soil Test	0.8			1	0.5t truck		13.6	Ea	1	13.60
	Cribbing - Footing		1	5t truck				46.4	m3 of footing	3.49	13.30
		4	1	concrete mixer	2	0.5t truck	1 generator	84.32	m3 of footing	3.49	24.16
	Sleeves & 'T'	0.6		concrete pump	2	van		18.4	ea	1	18.40
	Sump Liner	1.3			1	1t truck		28	ea	1	28.00
	Deliver Wall cribbing material package	1.1	1	3t truck				32.8	m2 of basement wall	95.13	0.34
	Cribbing - walls		2	3t truck				65.6	m2 of basement wall	18.88	3.47
			3	3t picker				139.2	m2 of basement wall	18.88	7.37
		13.5	1	concrete mixer		0.5t truck	1 generator	164.18	m2 of basement wall	18.88	8.70
	Mark and inspect foundation	0.6		concrete pump	6				ea	1	0.00
	Weeping Tile, Spray				1	1t truck		28	l. ft of wt	128	0.22
		3.3	1	5t truck	1	van	1 gravel spreader	187.6	l. ft of wt	128	1.47
	Install electrical panel c/w temp service	2			1	1.0t		28	ea	1	28.00
	City Inspection #1 for foundation	0.4			1	car		9.2	ea	1	9.20

Table 4.32: CO_2 Emissions for Stage 3

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
	Backfill & Shallow Trenching										
	Backfill Foundation				2	3t truck		65.6	m3 of backfill	62.4	1.05
		5.5			2	1t truck	1 backhoe	276	m3 of backfill	62.4	4.42
	Shallow Services				1	3t truck		32.8	ea	1	32.8
		3.5			1	0.5t truck	1 backhoe	153.6	ea	1	153.6
3	Precast products	1.3	1	5t truck				46.4	m3 of backfill	0.11	421.82
	Window wells	1	1	5t picker			1 generator	30.68	ea	3	10.23
	First call for gasline	0.5		1t truck w/ trailer	1	van		9.2	ea	1	9.2
	Gas Line Site Readiness Inspection	0.4			1	0.5t truck		13.6	ea	1	13.6
	Underground gas line installation	4	1	5t truck	1	0.5t truck w/ trailer	1 backhoe	220	ea	1	220

Table 4.33: CO_2 Emissions for Stage 4

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
	Capping & Shallow Services										
	Main floor joists & subfloor package	1.3	1	5t truck				46.4	m2	82.3	0.56
	Main floor joists & subfloor installation. "Capping"	4.5			2	0.5t truck	1 generator, 1 compressor	51.32	m2	82.3	0.62
	Install propane basement heater		1	5t truck				46.4	ea	1	46.4
4		1	1	5t truck (for propane refill)				840	ea	1	840
	Install Gas Meter	1.5			1	0.5t truck		13.6	ea	1	13.6
	Install natural gas heater in basement	0.8			1	0.5t truck		13.6	ea	1	13.6
	Electrical Service Inspection	0.6			1	0.5t truck		13.6	ea	1	13.6
	Electrical Meter Installation / Power to panel	0.8			1	0.5t truck		13.6	ea	1	13.6

Table 4.34: CO_2 Emissions for Stage 5

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
	Framing Main & Second Joists										
	Deliver first floor framing package -wall	1	0.5					23.2	linear m of wall	63.1	0.36767
	Deliver first floor framing package -floor	1	0.5	5t truck				23.2	m2 of floor	82.3	0.2819
5	Framing - main floor	13			8	0.5t truck	1 generator, 1 compressor	178.48	m2 of floor	82.3	2.16865
	Framing - main floor walls	19			8	0.5t truck	1 generator, 1 compressor	210.64	linear m of wall	63.1	3.33819
	Deliver second floor framing package -floor	1	0.5	5t truck				23.2	m2 of floor	82.3	0.2819
	Deliver second floor framing package -wall	1	0.5	5t truck				23.2	linear m of wall	63.1	0.36767

Table 4.35: CO_2 Emissions for Stage 6

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
6	Framing Second & Roof										
	Interior stairs delivery	1.3	1	1t truck				28	ea	1	28
	Tarp basement stairs	0.7		1t truck w/ trailer	1	0.5t truck		13.6	ea	1	13.6
	Deliver tubs & showers	1	1	3t truck				32.8	ea	1	32.8
	Deliver roof package	1.3	1	3t truck				46.4	m2 of house	82.3	0.56
	Deliver roof trusses	1.3	1	5t truck				46.4	m2 of house	82.3	0.56
	Deliver Windows	1.3	1	5t truck				32.8	ea	1	32.8
	Deliver additional lumber	1.3	1	3t truck				32.8	ea	1	32.8
	Framing Second Floor walls	31.3		3t truck	10	0.5t truck	1 generator, 1 compressor	303.768	linear m	78.9	3.85
	Framing roof	22.3			10	0.5t truck	1 generator, 1 compressor	255.528	m2 of floor area	82.3	3.10
	Crane the roof	2					20 t crane	32	ea	1	32
	Crane the tub	0.5			1	0.5t truck		13.6	ea	1	13.6
	Crane the shower	0.3			1	0.5t truck		13.6	ea	1	13.6
	HVAC mark out	1.5			1	0.5t truck		13.6	ea	1	13.6
	Frame Check	1.5			1	0.5t truck		13.6	ea	1	13.6

Table 4.36: CO_2 Emissions for Stage 7

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
7	Roofing										
	Temp walkways	1.5	1	5t truck				46.4	ea	1	46.4
	Safety rails	1.5			1	van		9.2	ea	1	9.2
	Mechanical Insulation	4			1	0.5t truck		13.6	ea	1	13.6
	Install fireplaces	1.8			1	0.5t truck		13.6	ea	1	13.6
	Cabinet Mark-out	1			1	0.5t truck		13.6	ea	1	13.6
	Repair Framing Deficiencies	3			1	0.5t truck		13.6	ea	1	13.6
	Return un-used lumber	1.3			1	3t truck		32.8	ea	1	32.8
	Site clean	1.3	1	5t truck				46.4	ea	1	46.4
	Posts & Verandahs	3.8				0.5t truck	1 generator, 1 compressor	20.368	ea	1	20.37
	City Inspection #2 for Framing	1.1			1	car		9.2	ea	1	9.2
	Load Roof shingles	1.5	1					46.4	m2 of roof	112.6	0.41
	Roofing	13.5		5t truck w/ crane beam	2	1t truck	1 generator, 1 compressor	128.36	m2 of roof	112.6	1.14
	Smart Trim Installation	9.7			1	1t truck	1 generator, 1 compressor	51.992	ea	1	51.99

Table 4.37: CO_2 Emissions for Stage 8

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
8	Siding & Rough-ins										
	Install siding	62	1		6	0.5t truck		114.4	m2 of wall	199	0.57
	Eavestrough & downspouts	6.3			1	2t truck (1t)		28	ea	1	28
	Delivery masonry / stonetile	1	1	3t truck				32.8	m2 of wall	8.9	3.69
	Install masonry / stonetile	14			6	0.5t truck	1 heater - propane (winter)	81.6	m2 of wall	8.9	9.17
	Exterior Metal Railing	1.8			1	1t truck		28	ea	1	28
	Heating rough-In	9.5			1	3t truck		32.8	ea	1	32.8
	Gasline measurement (plumber)	1			1	0.5t truck		13.6	ea	1	13.6
	Install gasline to furnace	2.7			1	0.5t truck		0.0068	ea	1	0.01
	Gasline inspection	0.8			1	0.5t truck		13.6	ea	1	13.6
	Connect gasline to furnace and light furnace	1.3			1	van		9.2	ea	1	9.2
	Plumbing Rough-in	21			2	0.5t truck		27.2	ea	1	27.2

Table 4.38: CO_2 Emissions for Stage 9

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
9	Electrical RI & Slabs										
	Basement floor sand & prep	2.9	1				gen	54.172	m2 of basement	82	0.66
	Place sand in garage	1.9	1	5t dump truck		0.5t truck		60	m2 of garage	26	2.31
	Adjust teleposts	1.1		5t dump truck	1				ea		
	Pour Basement Floor	5.5	1	5t truck	2	0.5t truck	hand tools	73.6	m3 of basement slab	8.3	8.87
	Pour garage floor	4.8	1	concrete mixer				46.4	m3 of garage slab	2.6	17.85
	Electrical Rough-In	23		concrete pump	2	van		18.4	ea	1	18.4
	Move basement heater to Garage, tarp garage door.	1			1	0.5t truck		13.6	ea	1	13.6
	Structured Wiring	5			1	van		9.2	ea	1	9.2
	Check all rough-ins	2.3	1		1	van		37.2	ea	1	37.2
	Install heating plenums & Drop Furnace	9.7	1	1t van				32.8	ea	1	32.8
	Garage Stair	1		3t truck w/ trailer				32.8	ea	1	32.8

Table 4.39: CO_2 Emissions for Stage 10

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
10	Insulation & Boarding										
	Install Insulation & Vapor Barrier	8	1		1	0.5t truck		41.6	m2 of wall	184	0.23
	Install BIBS	1.3	1	1t van				32.8	ea	1	32.8
	City Inspection #3 - insulation	0.5		3t truck	1	car		9.2	ea	1	9.2
	Load Drywall	1.8	1	5t truck				46.4	m2 of wall	606	0.08
	Drywall Boarding	36		5t picker	4	0.5 truck		54.4	m2 of wall	606	0.09
	Pre-grade	4.8	1		1	1 t truck w/ trailer	1 Bobcat	180.8	m2 of lot area	372	0.49
	Install frost walls & insulation	7	1	5t truck (removal)	1	0.5t truck		41.6	m2 of wall	46	0.90
	Plumbing Pre-Final	3.3	1	1t truck	1	0.5t truck		41.6	ea	1	41.6
	Install Garage Door	2.8		1t truck	1	1 t truck w/ trailer		28	ea	1	28

Table 4.40: CO_2 Emissions for Stage 11

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
11	Drywall Taping & Texture										
	Attic/Bonus Room Floor Insulation	2.8	1	5t truck				46.4	ea	1	46.4
	Drywall Taping	50.5	1	5t cube van	5	0.5t truck		96	m2 of wall/ceiling	606	0.16
	Prime Vac	1.5		1t van	5	0.5t truck		68	m2 of house	163	0.42
	Prime	3			5	van		46	m2 of wall	606	0.08
	Texture	2.8			5	3t van		164	m2 of ceiling	192	0.85

Table 4.41: CO_2 Emissions for Stage 12

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
12	Finishing & Cabinets										
	Inspect walls, check window signs	1			1	0.5t truck		13.6	ea	1	13.6
	Electrical Rough Final	4.5			1	0.5t truck		13.6	ea	1	13.6
	Stage 1 vac	1.3			1	van		9.2	m2 of house	163	0.06
	Deliver mantle	0.8			1	van		9.2	ea	1	9.2
	Deliver Stage One finish package	1.4	1	5t truck				46.4	ea	1	46.4
	Stage 1 Finishing	31.5			1	1t truck/trailer		28	ea	1	28
	Deliver Cabinets	1.5	1	5t truck				46.4	ea	1	46.4
	Install Cabinets	12			2	van		18.4	ea	1	18.4

Table 4.42: CO_2 Emissions for Stage 13

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
13	Railing & Painting										
	Install Railing	13.3			2	1t truck		56	ea	1	56
	Paint vac	1.5			1	0.5t		13.6	m2 of wall	163	0.08
	Inspect finishing, railing & cabinets	1			1	0.5t truck		13.6	ea	1	13.6
	Pour driveway & sidewalks	2			2	1t truck	vibrator (gas), bobcat	141.36	m3 of concrete	4.3	32.87
		2	1	5t concr truck				46.4	m3 of concrete	4.3	10.79
		2	1	1t flat deck for rebar				30.4	m3 of concrete	4.3	7.07
	Parging	1.7	1	sand truck for prep			concrete mixer	13.6	30% of wall area of basement	28	0.49
			1	0.5t truck/trailer				28	30% of wall area of basement	28	1
	Rough Grade Site	3.3	1	1t truck			2 bobcat	178.4	m2 of lot area	372	0.48
	Interior Painting	47.5			5	2t van		152	m2 of wall	414	0.37
	Exterior painting	7.8			1	2t van		30.4	m2 of ext wall	184	0.17
	Inspect Painting	1			1	0.5t truck		13.6	ea	1	13.6

Table 4.43: CO_2 Emissions for Stage 14

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
	Tile & Vinyl Floor ing										
	Electrical Final	7.8			1	2t van		30.4	ea	1	30.4
	Granite Counters	2.5	1	5t truck				46.4	ea	1	46.4
	Laminate countertops	1.8	1	5t cube van				30.4	ea	1	30.4
14	Structured Wiring Final	3		1t truck	1	2t van		30.4	ea	1	30.4
	Hard floor ing vac	1			1	van		9.2	m2 of house	163	0.06
	Tile backsplash & tub surrounds	1	1	5t truck				46.4	ea	1	46.4
		26.3		5t cube van	3	1t truck		84	ea	1	84
	Sheet Vinyl Floor ing	8.7			2	1t van		56	m2 of vinyl floor ing	33	1.70

Table 4.44: CO_2 Emissions for Stage 15

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
	Hardwood & Stage 2 FInishing										
	Laminate Floor ing (n/a)								m2 of floor	50	0
	Hardwood Flooring - deliver	1.1	1	5t truck				46.4	m2 of floor	50	0.93
	Hardwood Flooring - install	13		5t van	2	1t truck		56	m2 of floor	50	1.12
	Check hard surface flooring	0.8			1	1t truck		28	ea	1	28
15	Deliver Stage 2 materials - hardware locks	0.9	1	5t truck				46.4	ea	1	46.4
	Stage 2 Finishing	13.8		5t truck	1	1t truck/trailer		28	ea	1	28
	Mirrors & Shower Doors - delivery/install	2.5			1	1t cube van		28	ea	1	28
	Wire shelving	3.3			1	1t cube van		28	ea	1	28
	Plumbing Final & pressure test water lines	8			1	1t van		28	ea	1	28
	Carpet Vac	1.3			1	0.5t		13.6	m2 of carpet	82	0.17

Table 4.45: CO_2 Emissions for Stage 16

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
	Carpet & Finals										
	Carpet Floor ing - deliver/install	13.8	1		2	1t truck		102.4	m2 of carpet	82	1.25
	Check carpet	0.8	1	0.5t				13.6	ea	1	13.6
	Heating Final	2.5			1	1t van		28	ea	1	28
	Furnace & Ductwork Clean	2.5			1	5t truck		46.4	ea	1	46.4
16	Full Clean	7.8			1	van		9.2	m2 of house	162	0.06
	City Final Inspection	0.8			1	car		9.2	ea	1	9.2
	Window Final	2			1	1t cube van		28	ea	1	28
	Final site & garage clean	1.8			1	1t van		28	m2 of lot area	372	0.08
	Clean & wash basement floor & stairs	1.7			1	1.0t		28	m2 of basement	82	0.34
	Temp Driveway & level sidewalks	1.7	1	5t truck	1	1t truck/trailer	bobcat	74.4	ea	1	74.4
	Site Managers Final Inspection	2.3		5t gravel truck							

Table 4.46: CO_2 Emissions for Stage 17

Stage	Tasks	Duration (hr)	Material		Labour		Installation	CO2 (kg)	Unit	Qty / Model	Amt (kg/unit)
			Trips	Vehicle	Trips	Vehicle	Equipment				
17	Touch-ups & Pre-occupancy										
	Paint touch-ups (3rd coat)	13			2	1t van		56	m2 of wall	414	0.14
	Fireplace Start-up	2			1	0.5t van		13.6	ea	1	13.6
	Cabinet Final	3			1	1t van		28	ea	1	28
	Check for all inspection stickers	0.8			1	van		9.2	ea	1	9.2
	Re-clean	1.5			1	van		9.2	m2 of house	162	0.06
	Do All Repairs	8			1	van		9.2	ea	1	9.2
	2nd Re-clean	1.3			1	0.5t		13.6	ea	1	13.6
	Blower-door test	1.7			1	van		9.2	ea	1	9.2
	Garbage removal	1.3			4	5t		185.6	ea	1	185.6
	Occupancy and Key Turnover	2			1	van		9.2	ea	1	9.2

As shown in Table 4.47, the summary CO_2 emissions for each stage is shown resulting in a total of approximately 10,000 kg of CO_2 emissions.

Table 4.47: Summary of CO_2 Emissions per Stage

Stages	Description	CO_2 (kg)
1	Stake Out	22.8
2	Deep Services & Foundation Walls	2406.9
3	Backfill & Shallow Trenching	847.9
4	Capping Shallow Services	1038.5
5	Framing Main & Second Joists	458.7
6	Framing Second & Roof	878.5
7	Roofing	445.5
8	Siding & Rough-Ins	381.2
9	Electrical RI & Slabs	378.2
10	Insulation & Boarding	476.4
11	Drywall Taping & Texture	420.4
12	Stage 1 Finishing & Cabinets	184.8
13	Railing & Painting	717.4
14	Tile & Vinyl Flooring	333.2
15	Hardwood & Stage 2 Finishing	302.4
16	Carpet & Finals	367.2
17	Touch-Ups & Pre-Occupancy	342.8
	Total	10002.8

As described in the methodology section, the 17 stages required for construction were further broken down into all the tasks required for material installation in combination with labour and equipment use. There is a six-tonne increase in CO_2 emissions during winter construction since basements are heated throughout the process. This was based on one month of continuous 24-hour heating using a propane heater (approximately 66 kg/day). The heaters outputted 100,000 BTUs using 400 liter tanks that were re-filled every three days. Based on field observations and measurements, each of the 17 stages was examined, and CO_2 emissions were quantified. As mentioned earlier, a summary of the CO_2 emissions for each stage is shown in Table 4.47. The totals result from three components: material transportation and related equipment; labour transportation and equipment; and operational installation equipment.

Material transportation and equipment covers the delivery of materials and corresponding equipment for handling. For example, the footing pour requires a trip each from a concrete mixer and a concrete pump truck. Labour travels include daily crew transportation with select vehicle types such as one-tonne trucks. Onsite installation equipment generally includes excavators and generators. Established CO_2 emissions were used for various vehicle types, such as vans, one- and three-tonne trucks and concrete mixer vehicles, with an average travel distance of 40 km per trip. Hence, vehicle CO_2 emission rates were between 0.23 and 1.16 kg/km. A CO_2 emission rate of 2.68 kg/hr for generators and compressors was also used. Likewise, for the purpose of these calculations, it was assumed that a crane contributes 16 kg/hr of CO_2 (Ford Motor Company, 2009; Kaeser Compressors, 2009).

As shown in Table 4.47, over 10,000 kg of CO_2 emissions is released during conventional onsite construction throughout the 17 stages. Specifically, Stage 2 consisting of deep services and foundation walls, contributes 2406.9 kg of CO_2, while Stage 5, consisting of framing the main floor and second-floor joists only, contributes approximately 458.7 kg of CO_2. Table 4.31 shows the various tasks associated with Stage 2 and its corresponding CO_2 emissions by task and by unit rate. The tasks in this stage have been described previously. The data was collected through field observations and construction logs of trips for material delivery, labour, and equipment.

Typical durations for each task were recorded in hours, along with travel counts and equipment type usage for materials, labour and installation. Based on these measurements, the quantification of CO_2 emissions in kilograms was performed. The tasks were also categorized by building unit, such as cubic meter of basement wall, with a corresponding quantity. This would then provide a CO_2 emission per unit rate, such as kg/m^3. For example, the CO_2 emission rate for the basement walls is 3.47 kg/m^3. This rate, along with the other determined rates, would be utilized in the BIM application. Table 4.34 shows the CO_2 emission computations for Stage 5, which involves framing the main floor and second-floor joists.

For this stage, the tasks involved multiple delivery of framing materials and subsequent crew framing of walls and floors. Crew truck types and travel frequencies were recorded as shown on the table. Subsequent CO_2 emissions were calculated, and units of measurement were determined. Consequently, the unit rate of emissions for framing the main floor was determined to be 2.36 kg/m^2 of living space. The CO_2 emission rates determined in this study are based on the construction of two Landmark models houses: Catalina II 158 m^2 (1,696 ft^2) and Cambridge II 163 m^2 (1,760 ft^2). These rates are assumed linear for homes ranging between 140 m^2 (1,500 ft^2) and186 m^2 (2000 ft^2). Again, establishing emission rates per unit of measurement allows for the CO_2 emission quantification of different-sized homes as well as for its incorporation into the BIM program.

4.3.3 Step 3—Incorporating the Quantification of Parameters Rating into the 3D Model

The incorporation of CO_2 quantification rating into a 3B Model can involve a variety of independent software programs. However, this research uses VICO software. The software platform utilized for this research is Constructor 2008, a program developed by Graphisoft (Vico Software, 2008). This CAD platform allows end users to connect 3D models with information such as cost estimates, construction schedules, and building materials. The model is populated with essential information describing each house component including activities, related method of construction, associated cost, and time.

This software uses statements called “recipes” to represent attributes of a building assembly to be incorporated in a 3D model. In this research, these attributes (recipes) include CO_2 footprint emissions and potential score. Constructor 2008, a parametric CAD modeling software, allows for 3D modeling of building components with information and data that is stored, manipulated, and automatically updated through simple commands. For this research, Constructor

2008 was used in combination with Estimator 2008 to obtain the amount of CO_2 emitted when building single family, wood stick-frame dwellings. The Estimator 2008 software uses quantities exported from the 3D model (Constructor 2008) and matches them with prices per unit of work or emissions per unit of work stored in the database. The 3D model shown in Figure 4.11 was used for this analysis. The single family building is a two-storey, wood-frame structure with a total area of 1760 ft^2 (163 m^2).

Recipes for construction activities are created in Estimator and connected to the 3D model in Constructor. The recipe structure allows for quantifying many types of work such us construction of columns, installation of windows and doors, or the CO_2 emissions related to the use of trucks for material transportation, among others. A recipe in Constructor entails a building element or component such as an interior wall. One should note that any platform can be used for this purpose as long as it has an engine-based parametric modeling.

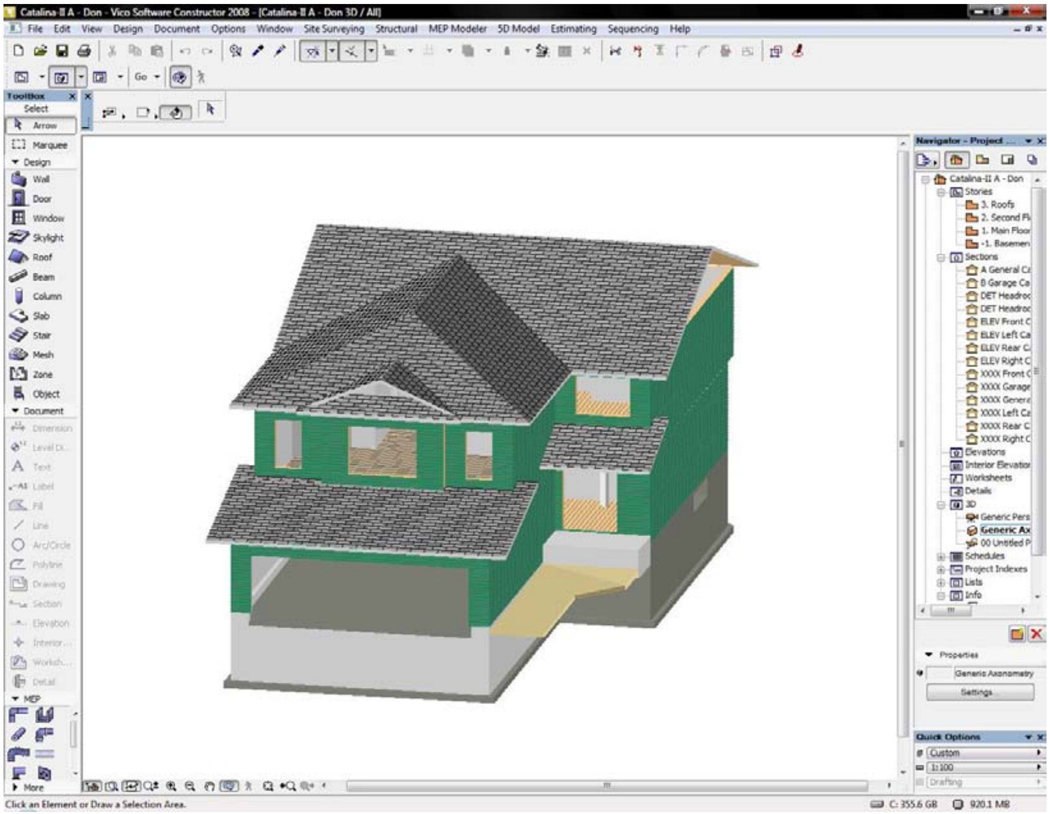


Figure 4.11: 3D Modeling in Constructor 2008

The 3D model can isolate building components of the building structure such as the wood framing (see Figure 4.12 for an illustration of this feature). This figure shows only the main floor framing based on the platform framing method, where the dwelling is composed of walls that run from floor to floor and a platform or floor system in between storeys. Through the use of groups of layers, both the main and second floor are selected for viewing purposes. In addition, the program can display the floor plan in 2D as well, with dimensions and additional notes for further construction.

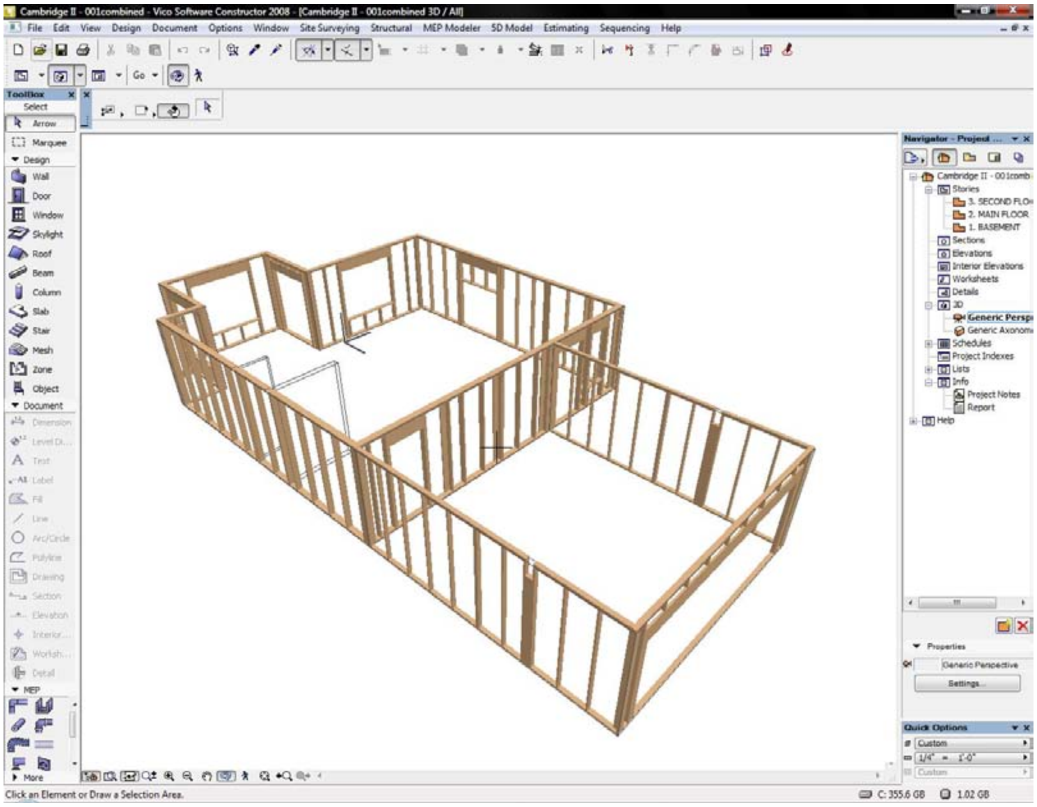


Figure 4.12: 3D Modeling – Framing Design in Constructor 2008

The 3D model has to be completed before calculating the quantity of CO_2 during the construction stage, or cost estimates if required. The physical parameters of the building component quantities are exported to the estimating database, where unit rates for recipes, methods, and resources are stored. A recipe in Constructor entails a building element or component such as an interior wall. As an example, Figure 4.13 shows the typical breakdown of activities and their corresponding CO_2 emissions for wall framing. The top window in Figure 4.13 has the list of recipes for this specific project, the second window from the top has the methods required for this building component, and the bottom window has the resources required for one of the methods. The vertical window on the left hand side of Figure 4.13 shows the classification of the recipes with the American Society for

Testing and Materials (ASTM) E 1557—Uniformat II. This classification system permits the end user to organize and later on to analyze the building by location, such as the amount of CO_2 emitted by constructing the substructure, the facade of the building, or the interior work required to finalize the project.

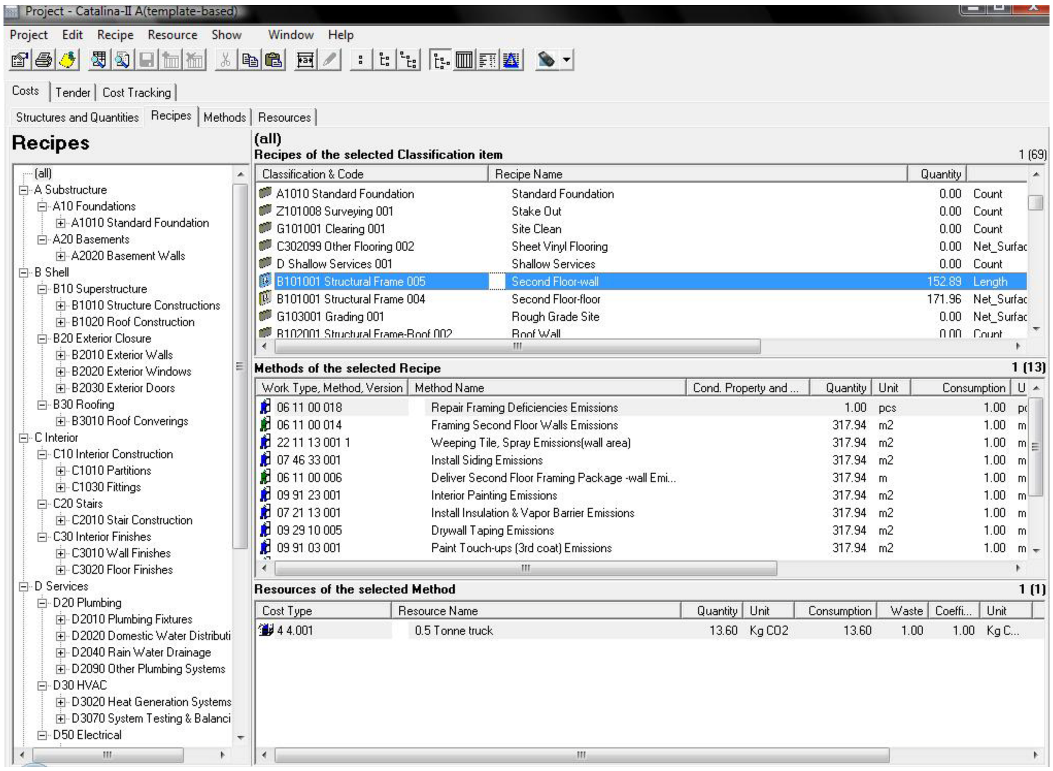


Figure 4.13: Recipes in Constructor 2008

Development of Construction Recipes

One of the main purposes of using construction databases is the scalability from project to project. Projects are in essence unique, but the construction activities required to build similar projects are composed of almost the same type of materials, labour, and equipment. Recipes or building assemblies are the summary of work required to build a specific component of the project. Figure 4.14 illustrates a sample Work Breakdown Structure (WBS) for the house framing stage.

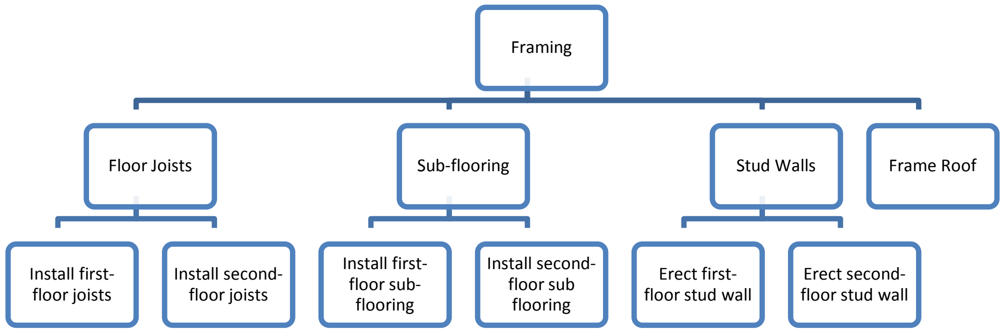


Figure 4.14: Work Breakdown Structure – Framing

Figure 4.15 illustrates the Recipe, Method, and Resource hierarchy that is used in this research. The intent of Figures 4.14 and 4.15 are to illustrate the hierarchical approach for the model. The two shown hierarchies are different in terms of level and complexity.

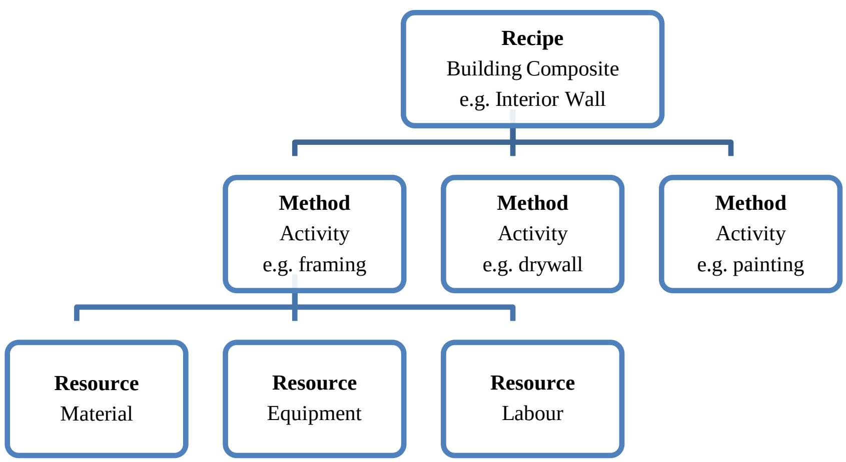


Figure 4.15: Hierarchy for Model

Based on BIM technology, end users can quantify procedures by linking predefined recipes with 3D models, saving time by automating repetitive calculations. As previously mentioned, a recipe is composed of methods for construction; each method is composed of resources. Estimator 2008 works with the same hierarchy: Recipes, Methods and Resources. When developing recipes, the procedure starts by classifying the main recipe with the Uniformat II for building classification according to the location of the building component. The Uniformat II breaks down facilities into eight different locations. The classification system is made of eight components: substructure, shell, interiors, services, equipment and furnishings, special construction and demolition, building siteworks, and general. There are several levels of classification of the Uniformat II. In Estimator 2008, the database has been manipulated to match the breakdown of the Construction Specifications Institute (CSI) Masterformat 2004.

Each method is coded following the classification of the MasterFormat 2004. This code has classified building materials, labour, and equipment for cost estimating into 50 different divisions. Within each method a specific unit of work is quantified; for example, the kilograms of CO_2 emitted by installing the roof on a house by the square footage of the aforementioned activity. Figure 4.16 shows an illustration of the methods used under the recipes in Constructor 2008.

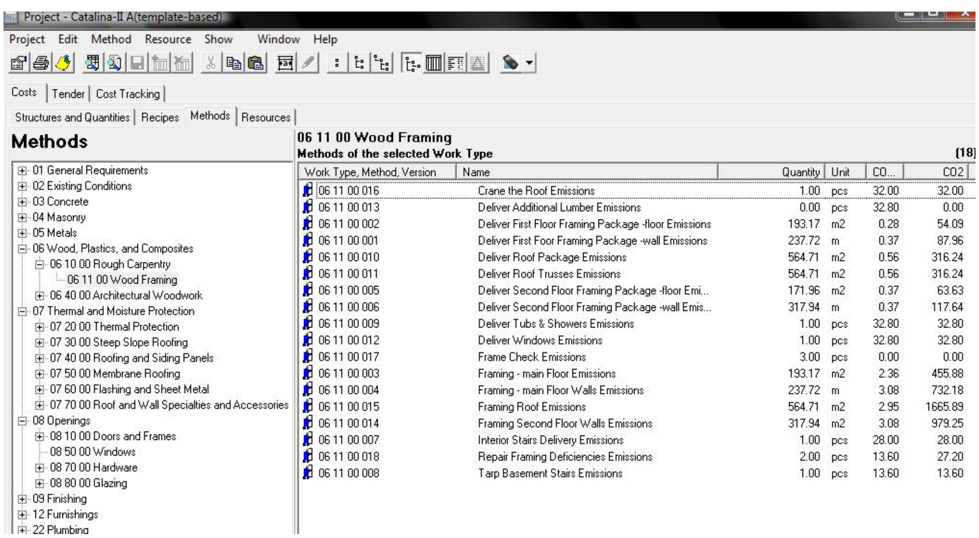
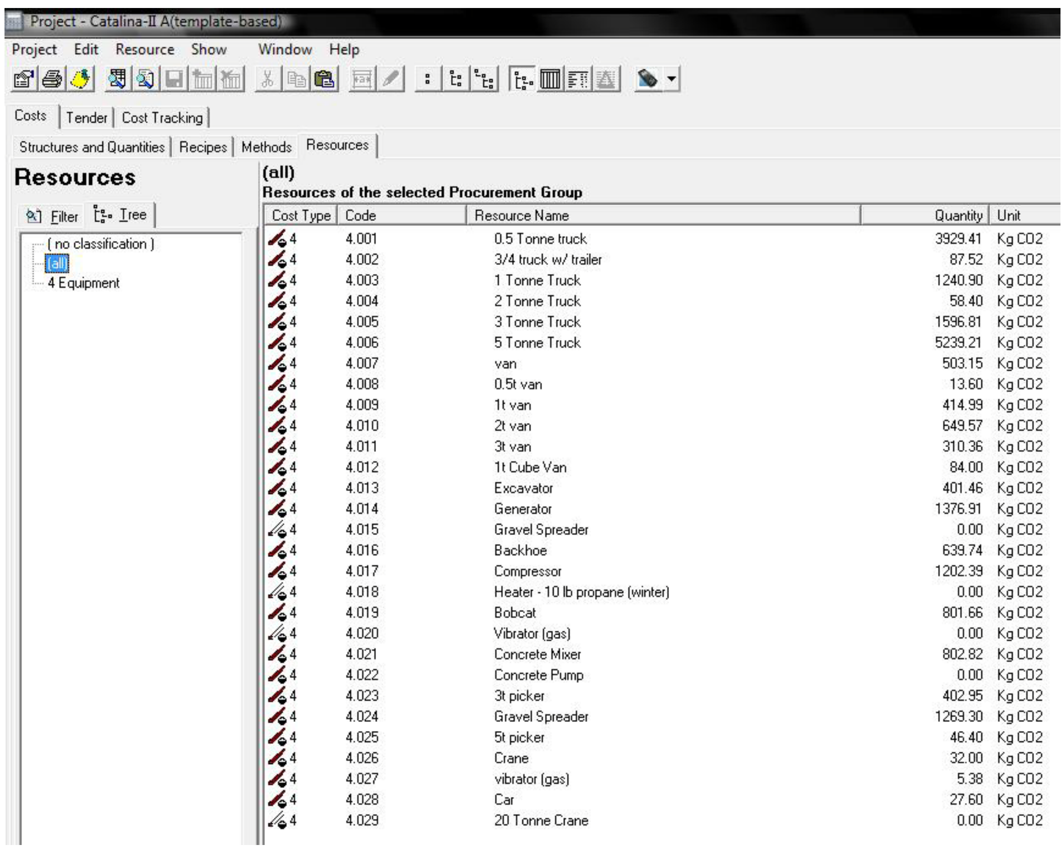


Figure 4.16: Methods in Constructor 2008

The resources in a method are the primary units of work. For example, in order to build a wood wall onsite (using the conventional stick-frame construction method), it is necessary to deliver the materials to the site (Method). A one-tonne truck (Resource: Equipment) is required to deliver materials to the site, dimensional lumber and sheathing are required as main components of the wall (Resource: Material), and two framers are required to put the framing components together (Resource: Labour).



Cost Type	Code	Resource Name	Quantity	Unit
4	4.001	0.5 Tonne truck	3929.41	Kg CO2
4	4.002	3/4 truck w/ trailer	87.52	Kg CO2
4	4.003	1 Tonne Truck	1240.90	Kg CO2
4	4.004	2 Tonne Truck	58.40	Kg CO2
4	4.005	3 Tonne Truck	1596.81	Kg CO2
4	4.006	5 Tonne Truck	5239.21	Kg CO2
4	4.007	van	503.15	Kg CO2
4	4.008	0.5t van	13.60	Kg CO2
4	4.009	1t van	414.99	Kg CO2
4	4.010	2t van	649.57	Kg CO2
4	4.011	3t van	310.36	Kg CO2
4	4.012	1t Cube Van	84.00	Kg CO2
4	4.013	Excavator	401.46	Kg CO2
4	4.014	Generator	1376.91	Kg CO2
4	4.015	Gravel Spreader	0.00	Kg CO2
4	4.016	Backhoe	639.74	Kg CO2
4	4.017	Compressor	1202.39	Kg CO2
4	4.018	Heater - 10 lb propane (winter)	0.00	Kg CO2
4	4.019	Bobcat	801.66	Kg CO2
4	4.020	Vibrator (gas)	0.00	Kg CO2
4	4.021	Concrete Mixer	802.82	Kg CO2
4	4.022	Concrete Pump	0.00	Kg CO2
4	4.023	3t picker	402.95	Kg CO2
4	4.024	Gravel Spreader	1269.30	Kg CO2
4	4.025	5t picker	46.40	Kg CO2
4	4.026	Crane	32.00	Kg CO2
4	4.027	vibrator (gas)	5.38	Kg CO2
4	4.028	Car	27.60	Kg CO2
4	4.029	20 Tonne Crane	0.00	Kg CO2

Figure 4.17: Resources in Constructor 2008

Figure 4.17 shows the resources required for the construction process include vehicles, generators, cranes, compressors, etc., which are used for multiple components (Recipes). In order to perform a correct analysis for the quantification of CO_2 emissions, it is important to determine the amount of emissions per unit of work of each resource. Once these rates are added to each resource and summarized in a method, they are classified under construction recipes.

The recipes are also organized using the location breakdown structure. Figure 4.18 shows how the quantities that came from the 3D model are organized by floor levels. Recipes, methods and resources can also be broken down into areas of a floor level, such as kitchen, master bedroom, and so on. When modeling large projects, this methodology allows end users to verify from which part of the model the information is coming from. The model does not reflect the detailing of the building. This includes issues such as dampness, rotting, etc. which affect the life of the building. The performance measurements, such as a blower door test which is conducted as part of the Built Green rating program, covers this area.

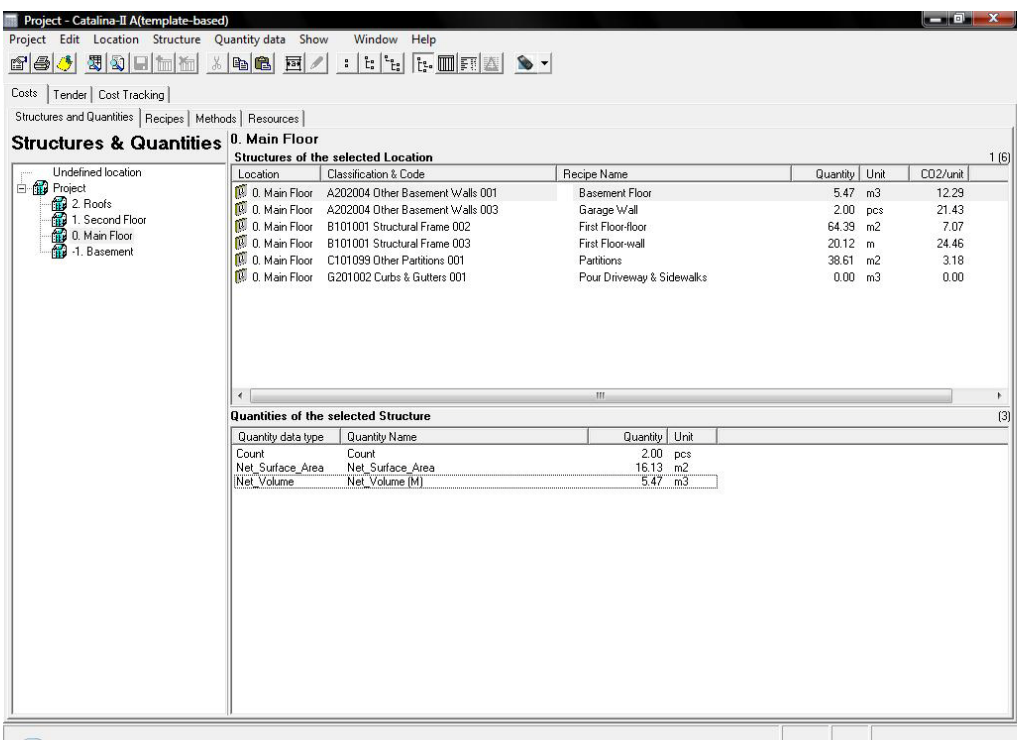


Figure 4.18: Sample Location Breakdown Structure (LBS) in Constructor 2008

4.3.4 Step 4—Integrating the BIM for Quantification of CO_2

This section involves 3D Modeling and Constructor 2008 Quantity Export. For each particular building component, Constructor 2008 quantifies the physical parameters of an element such as height, width, length, area, and volume. Each building component in Constructor has specific Data Quantity Types (DQT). In order to calculate and export the correct quantities to the estimating database, it is necessary to choose the right DQT. For example, if one needs to quantify the amount of drywall required for a certain wall, one has to choose the DQT that quantifies the wall surface area (Net_Surface_Area). Figure 4.19 illustrates this point. It is important to note that every building component provides a different set of DQTs. For instance, a building component such as a wall does not have the same characteristics as a staircase or a window. In the same way, this research used specific DQTs to quantify only those properties that affect the production of CO_2 during the 17 construction stages as described earlier. The flexibility of the software is such that it allows end users to determine which units to measure based on user requirements.

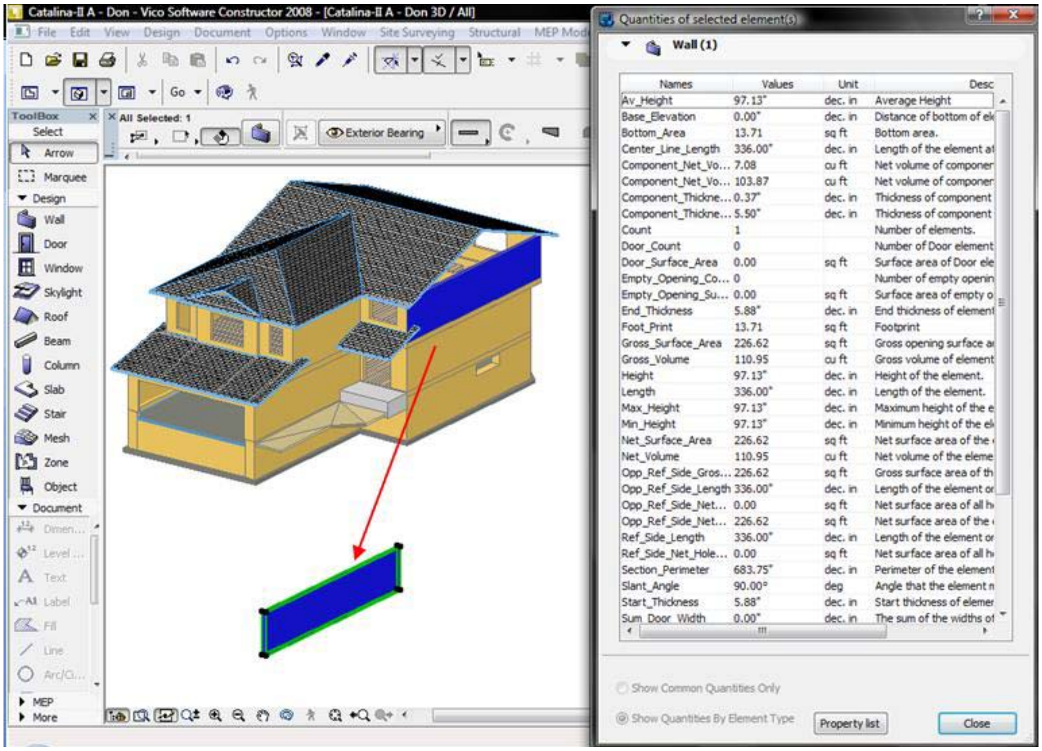
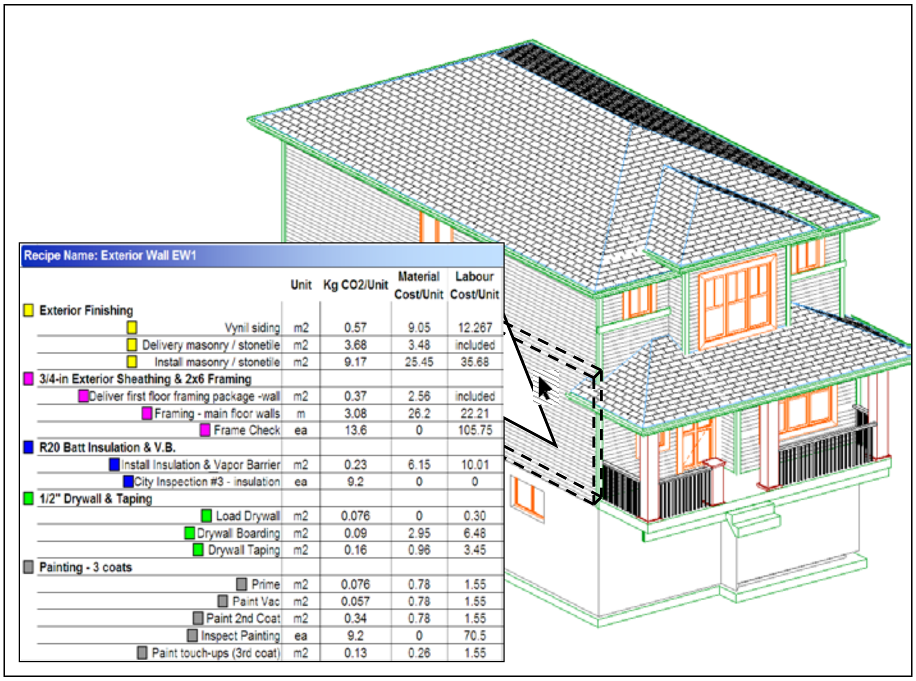


Figure 4.19: Data Quantity Types and Quantities in Constructor 2008

When the 3D model is linked to the estimating database, each building component has to be associated with its own recipe.

Quantification of CO_2 emissions from a building assembly

This research quantifies the output from the 3D model in units of CO_2 emissions instead of dollar amounts. To accomplish this, Constructor 2008 was customized and programmed to output quantities that correlate to kilograms of CO_2 emissions. As mentioned earlier, other parameters could be analyzed; however, this work is focused on CO_2 emissions. For the analysis with BIM, it was necessary to group these tasks into assemblies for construction. For example, Figure 4.20 shows a common assembly of an exterior load-bearing wall.



Recipe Name: Exterior Wall EW1

	Unit	Kg CO2/Unit	Material Cost/Unit	Labour Cost/Unit
Exterior Finishing				
Vynil siding	m2	0.57	9.05	12.267
Delivery masonry / stonetile	m2	3.68	3.48	included
Install masonry / stonetile	m2	9.17	25.45	35.68
3/4-in Exterior Sheathing & 2x6 Framing				
Deliver first floor framing package -wall	m2	0.37	2.56	included
Framing - main floor walls	m	3.08	26.2	22.21
Frame Check	ea	13.6	0	105.75
R20 Batt Insulation & V.B.				
Install Insulation & Vapor Barrier	m2	0.23	6.15	10.01
City Inspection #3 - insulation	ea	9.2	0	0
1/2" Drywall & Taping				
Load Drywall	m2	0.076	0	0.30
Drywall Boarding	m2	0.09	2.95	6.48
Drywall Taping	m2	0.16	0.96	3.45
Painting - 3 coats				
Prime	m2	0.076	0.78	1.55
Paint Vac	m2	0.057	0.78	1.55
Paint 2nd Coat	m2	0.34	0.78	1.55
Inspect Painting	ea	9.2	0	70.5
Paint touch-ups (3rd coat)	m2	0.13	0.26	1.55

Figure 4.20: Example of BIM Exterior Wall Assembly CO_2 Emissions

The assembly is composed of vinyl siding or brick veneer, exterior sheathing and wood studs, thermal insulation, drywall, and final paint. The installation of these components occurs at different stages, but for quantification purposes and CO_2 emission analysis, it was required that the created assembly could read information from the parametric object in the BIM. After the related tasks for construction are obtained and grouped into object assemblies, the BIM transfers the quantities per object into an intelligent database. Based on logical rules and model constraints, the model allows for the instant determination of the CO_2 emissions produced per assembly. The embedded table in Figure 4.18 details the wall assembly.

The information is stored according to the Location Breakdown Structure (LBS) defined in the BIM. The assemblies are classified in the LBS based on location within the building. In this case, the LBS for the 3D model is basement, main floor, second floor, and roof. Each storey in the building is also broken down into areas, such as living spaces, mechanical and service rooms, corridors and so forth.

The LBS is used to classify the building components in different storeys, hence allowing better control over quantities. Constructor 2008 facilitates this process by classifying the model into subsectors that are of importance to the designer. By doing so, one can know how many windows or doors a room on the second floor has by utilizing the LBS manager. Once these criteria are set in the BIM, the quantification of CO_2 emissions and its implications per installed material are stored in the database system. Since the system is based on emission rates per unit of installed material, the CO_2 emission quantification for any other house constructed within the context of the same building technique is also analyzed with accurate results.

As described earlier in this chapter, field studies were conducted to establish appropriate CO_2 emissions rates for building construction activities. These field studies included tracking of task durations, quantification of vehicle trips and notation of vehicle types and equipment types. Then unit rates were derived to correspond with BIM 3D elements. By establishing the unit rates, different sizes and elements were modeled for CO_2 emission output.

The outputs from the BIM model quantification corresponded with the quantities that were computed from the field studies. The benefits of BIM for CO_2 quantification is the efficient automation of CO_2 emissions with varying building sizes and elements. The input user could manipulate and customize the design to meet CO_2 emission goals and other parameters.

4.3.4 Summary

In the application of BIM for quantification of CO_2 emissions, the first step was the identification of construction activities and stages of the residential construction process. Information was then frontloaded into BIM through the establishment of databases. Next, the quantification of CO_2 emissions was automatically obtained from the BIM based on the construction method used in this research. The quantities outputted from BIM corresponded with the field studies' calculations. The use of BIM for quantifying CO_2 emissions from various construction processes, which is not currently available, can provide the information needed by organizations working to enhance current practices. For instance, managers can examine different construction methodologies, such as pre-cast concrete walls, and model the results through BIM. This will then allow them to support better decision-making alternatives. Although site layout and geography influences CO_2 emissions, their overall impact is more significant for building operations rather than construction. Hence, site layout was not considered in this work.

4.4 Development of Mathematical Model Formulation of Rating Program

The purpose of the mathematical model formulation is to develop a linear mathematical optimization model order to establish the minimum cost needed to satisfy a particular certification level based on user priorities for particular categories taken from the Built Green rating program. There are other mathematical models that could have been used; however, the linear optimization model is most suitable and practical in terms of formulation and implementation.

4.4.1 Model Rationale

Castro-Lacouture *et al*. (2009a) developed an optimization model for the selection of materials using the LEED rating system. They proposed a mixed integer optimization model that includes design and budget constraints with an objective function of maximizing credits under LEED. In addition, this model incorporates constraints that are unique to the LEED rating system.

The mathematical model proposed in this thesis is based on a green building rating system similar to the LEED rating system used by Castro-Lacouture *et al*. (2009b). However, in this model, the focus is on cost minimization though the inclusion of the entire eight environmental categories of Built Green, not just material selection under LEED. In addition, it allows for user preferences and incorporates minimum and maximum point requirements per category.

This section proposes a mathematical linear optimization model that enhances the selection of preferred environmental categories. The model considers user-preferences and environmental criteria constraints to address realistic scenarios when attempting to minimize costs. In other words, the model attempts to minimize costs while satisfying user preference and environmental criteria constraints.

4.4.2 Model Formulation

The purpose of the mathematical model formulation is to develop a linear mathematical optimization model in order to establish the minimum cost needed to satisfy a particular level based on user priorities for particular categories taken from the Built Green rating system. In general terms, the methodology will include the mathematical formulation of an objective function and constraints.

The mathematical model for the rating program involves the following steps:

Step 1—Model Formulization Background

The model is based on the Built Green rating program consisting of eight categories and numerous choices under this category. A description of the Built Green program categories was provided in the literature review.

1. Identify the eight categories and options under each category

n_i = number of j options in category i

To illustrate the above formulation, there are 28 options for category 1, 41 options for category 2, 32 options for category 3, etc. See Table 4.48 for the complete breakdown of options per category. Figure 4.21 presents the eight categories under the Built Green rating program and a listing of some of the criteria in a category. Each category will make a contribution to the accumulated points. As noted, each category must contribute a minimum number of points through the selection of criteria.

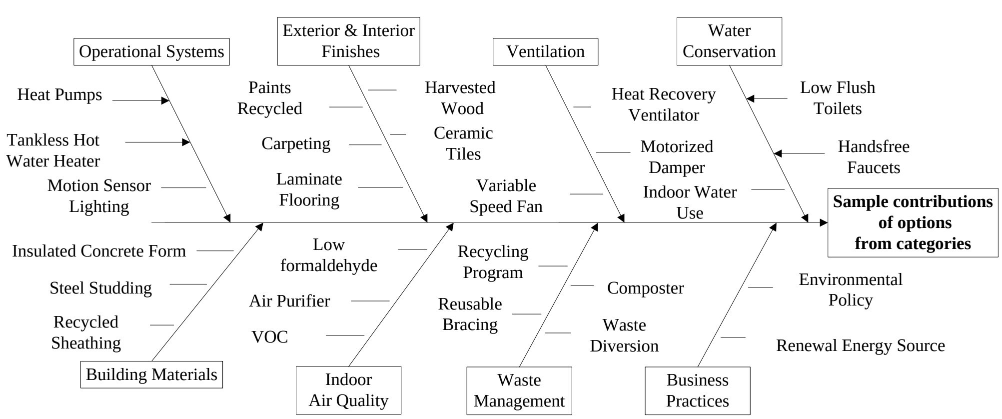


Figure 4.21: Sample Contributions of Options from the Eight Built Green Environmental Categories

Table 4.48 lists the eight categories with the number of options under each. The options range from 10 to 41. The range provides for differing competing choices based on user preferences and cost factors. This will be shown later in the section.

Table 4.48: Eight Environmental Categories and Options per Category

	Built Green Environmental Categories							
	OS (1)	BM (2)	EIF (3)	IAQ (4)	V (5)	WM (6)	WC (7)	BP (8)
Number of Options	28	41	32	27	10	12	17	11

2. Determine the choices for each option

With some options, there could be 1, 2, 3 or 4 choices. The optimization model will either select or not select a k^{th} choice in the j^{th} option in the i^{th} category. Hence if the option is selected, the result is 1, if not selected, the result is 0. Table 4.49 shows a sample case.

α_{ijk} = 0 or 1 depending on selected or not (binary)

α_{ijk} = integer

Table 4.49: Selection of choices in options in each Category

i categories

j options

	OS				BM			EIF			IAQ			V			WM			WC			BP		
	1				2			3			4			5			6			7			8		
1	0	0	1		0			0			0			0			0			0			0	1	0
2	0	0	0		0			0			0			1			0			0	0		0		
3	0	0			0			0			0			1			1	0	0	0	0		0	0	
4	0	0	0		0			0			0			0			0	0		1	0		0		
5	0				0	0		0			0			1			0	0	0	0	0		0		
6	0				0			0			0			0			0			0			0	0	
7	0				0			0			0			0			0			0	0		0		
8	0	0			0			0	0		0			0			0	1		0	0	1	0	0	0
9	0				0			0			0			0			1			1	0		0		
10	0	1			0			0			0			1			0			0			0	1	
11	0	1			0			0			1						0			0			0	0	0
12	0				0			0			0						0	1		0					
13	0				0	1		0			0	0								0					
14	0				0	0		0	1		0	0								0					
15	0				0	1		0			1									0	0				
16	0				0			0	1		1									0	0	0			
17	0				0			0	0	0	1									0					
18	0				0			0			1														
19	0	0	0		0			0			1														
20	0	0	1		0			0			0														
21	0	0			0			0			0														
22	0	0			0			0			0														
23	0				0			0			0														
24	0	0	0		0	0		0	1		1														
25	0				0			0	1		0														
26	0	0	1	0	0			0			1														
27	1				0	0		0			0														
28	0				0			0																	
29					0			0																	
30					0	1		0																	
31					0	0		0																	
32					0			0																	
33					0	0	0																		
34					0	0	0																		
35					0																				
36					0	0																			
37					0																				
38					0	1																			
39					0																				
40					0	1																			
41					1																				

k choices

3. Determine the number of points

The number of points (P_{ijk}) allotted for each choice varies. See Table 4.50 for the points allocation. The points per choice are obtained from the Built Green rating program.

where….

P_{ijk} = points allotted to the k^{th} choice in the j^{th} option in the i^{th} category

Table 4.50: Point per each Choice per Option per Category

	OS				BM			EIF			IAQ			V			WM			WC			BP		
	1				2.0			3			4			5			6			7			8		
1	2	3	4		2			1			1			3			2			1			1	3	5
2	1	2	3		3			1			2			2			4			3	4		3		
3	6	10			1			2			3			3			1	2	4	2	4		1	2	
4	1	2	3		1			1			6			1			2	6		3	6		1		
5	4				1	2		1			2			2			1	2	3	1	2		1		
6	4				1			2			1			2			1			3			1	2	
7	4				1			4			1			2			1			2	3		1		
8	1	2			1			1	2		2			4			1	2		1	2	3	1	2	3
9	2				1			2			1			5			1			3	4		3		
10	1	2			1			1			2			1			3			1			3	5	
11	1	2			1			4			3						2			3			1	3	5
12	2				1			1			1						2	4		3					
13	1				1	2		3			1	2								1					
14	2				1	2		1	2		1	2								2					
15	1				4	6		2			2									2	4				
16	1				1			2	4		2									1	2	3			
17	1				2			1	2	3	2									6					
18	2				1			6			3														
19	4	6	8		2			2			2														
20	4	6	8		2			2			3														
21	2	4			1			2			2														
22	2	4			1			3			1														
23	1				1			2			2														
24	1	2	3		1	2		1	2		2														
25	4				1			2	4		1														
26	1	2	3	4	1			1			2														
27	1				1	2		2			4														
28	1				2			1																	
29					1			2																	
30					1	2		1																	
31					2	4		1																	
32					2			2																	
33					1	2	3																		
34					1	2	3																		
35					1																				
36					1	2																			
37					1																				
38					2	3																			
39					1																				
40					1	4																			
41					1																				

4. Establish database for costs of each criteria (point)

The sources for the cost table are obtained from a local builder's database (Landmark Homes) and/or Built Green website directory of suppliers. Note that some choices have $0 allotted due to building code requirements, which are embedded as part of the Built Green criteria. In other words, there are no additional costs beyond what the builder currently provides. The cost (C_{ijk}) per point is shown in Table 4.51.

where…

C_{ijk} = cost of the k^{th} choice in the j^{th} option in the i^{th} category

Table 4.51: Cost/point per Choice per Option per Category

	OS				BM			EIF			IAQ		V	WM			WC			BP		
	1				2			3			4		5	6			7			8		
1	$500	$500	$500		$1,250			$0			$50		$250	$0			$0			$0	$0	$0
2	$0	$100	$200		$10,000			$0			$250		$50	$0			$50	$50		$0		
3	$2,300	$2,300			$400			$250			$333		$200	$0	$0	$0	$75	$75		$2,000	$1,000	
4	$600	$600	$600		$200			$25			$300		$400	$0	$0		$250	$250		$0		
5	$200				$0	$0		$0			$500		$0	$500	$500	$500	$300	$300		$0		
6	$750				$0			$0			$100		$100	$0			$200			$0	$0	
7	$500				$800			$1,750			$0		$350	$0			$0	$0		$0		
8	$600	$400			$0			$1,750	$1,750		$90		$250	$0	$0		$250	$250	$250	$3,000	$3,000	$3,000
9	$400				$0			$1,000			$800		$250	$0			$333	$250		$5,000		
10	$1,200	$1,200			$0			$0			$0		$0	$33			$800			$0	$0	
11	$165	$165			$0			$875			$0			$150			$1,000			$0	$0	$0
12	$0				$0			$300			$0			$2,500	$2,500		$1,666					
13	$750				$0	$0		$300			$2,000	$1,000					$0					
14	$600				$0	$0		$800	$400		$300	$150					$800					
15	$500				$4,750	$5,000		$300			$0						$2,000	$2,000				
16	$650				$0			$0	$500		$0						$150	$150	$150			
17	$800				$0			$0	$0	$0	$0						$1,167					
18	$125				$0			$917			$500											
19	$700	$700	$700		$150			$0			$0											
20	$3,000	$3,000	$3,000		$0			$1,000			$100											
21	$120	$120			$450			$1,000			$1,000											
22	$196	$196			$350			$2,500			$500											
23	$100				$400			$0			$3,000											
24	$50	$50	$50		$300	$150		$0	$0		$0											
25	$625				$300			$0	$0		$0											
26	$3	$63	$63	$63	$400			$300			$3,500											
27	$0				$1,800	$900		$3,750			$600											
28	$25				$0			$1,000														
29					$75			$1,000														
30					$0	$0		$400														
31					$300	$3,000		$400														
32					$2,000			$500														
33					$800	$600	$533															
34					$1,300	$900	$867															
35					$1,000																	
36					$0	$300																
37					$0																	
38					$2,000	$1,333																
39					$0																	
40					$1,875	$1,875																
41					$0																	

Step 2–Model Optimization

1. Develop formula for the costs in terms of points in each of the categories for a selected certification level under the Built Green rating program

2. Establish objective function

Let C be the set of costs related to cost of the k^{th} choice in the j^{th} option in the i^{th} category (see Table 4.51 for illustration of selection table).

C: C_{111}, C_{112}, … C_{ijk}

Where i = 1, 2, … N for i = 1 to 8

j = 1, 2, … n for {(i = 1, j =1-28), (i = 2, j =1-41), etc.}

k = 1, 2, … m_{ij} for any choice in the j^{th} option in the i^{th} category

Minimize cost (Min C)

$$Min\ C = \sum_{i=1}^{8} \sum_{j=1}^{n_i} \sum_{k=1}^{m_{ij}} C_{ijk} P_{ijk} \alpha_{ijk}$$

n_i = number of j options in category i

m_{ij} = number of k choices in the option j in the category i

α_{ijk} = 1 if the k^{th} choice in the j^{th} option in the i^{th} category is selected

0 if the k^{th} choice in the j^{th} option in the i^{th} category is not selected

C_{ijk} = cost of the k^{th} choice in the j^{th} option in the i^{th} category

P_{ijk} = points allotted to the k^{th} choice in the j^{th} option in the i^{th} category

3. Define criteria and constraints

The eight categories with the number of minimum and maximum points are shown in Table 4.52.

Table 4.52: Built Green Points within Environmental Categories

#	Categories	Min Points	Max Points
1	Operational Systems	10	84
2	Materials	15	72
3	Exterior & Interior Finishes	10	70
4	Indoor Air Quality	15	58
5	Ventilation	6	24
6	Waste Management	7	35
7	Water Conservation	7	50
8	Business Practices	6	30
Total		76	423

Subject to the following constraints:

$$10 \le \sum_{j=1}^{n_1} \sum_{k=1}^{m_{1j}} P_{1jk}\alpha_{1jk} \le 84 \text{ ....[1]}$$

$$15 \le \sum_{j=1}^{n_2} \sum_{k=1}^{m_{2j}} P_{2jk}\alpha_{2jk} \le 72 \text{ ....[2]}$$

$$10 \le \sum_{j=1}^{n_3} \sum_{k=1}^{m_{3j}} P_{3jk}\alpha_{3jk} \le 70 \text{ ....[3]}$$

$$15 \le \sum_{j=1}^{n_4} \sum_{k=1}^{m_{4j}} P_{4jk}\alpha_{4jk} \le 58 \text{ ....[4]}$$

$$6 \le \sum_{j=1}^{n_5} \sum_{k=1}^{m_{5j}} P_{5jk}\alpha_{5jk} \le 24 \text{ ....[5]}$$

$$7 \le \sum_{j=1}^{n_6} \sum_{k=1}^{m_{6j}} P_{6jk}\alpha_{6jk} \le 35 \text{ ....[6]}$$

$$7 \le \sum_{j=1}^{n_7} \sum_{k=1}^{m_{7j}} P_{7jk}\alpha_{7jk} \le 50 \text{ ....[7]}$$

$$6 \le \sum_{j=1}^{n_7} \sum_{k=1}^{m_{7j}} P_{8jk}\alpha_{8jk} \le 30 \text{ ....[8]}$$

The certification levels under Built Green are shown in Table 4.53.

Table 4.53: Built Green Certification Levels

Certification Levels	Points
Platinum	120+
Gold	100-119
Silver	90-99
Bronze	76-89

Let L be the certification levels:

$$L = L_1, L_2, \ldots L_s$$

where s = 1, 2, 3, 4

L_1 = Platinum

L_2 = Gold

L_3 = Silver

L_4 = Bronze

Constraints:

If s =1, then $$\sum_{i=1}^{8}\sum_{j=1}^{n_i}\sum_{k=1}^{m_{ij}} P_{ijk}\alpha_{ijk} \geq 120 \qquad \text{.....[9]}$$

If s =2, then $$100 \leq \sum_{i=1}^{8}\sum_{j=1}^{n_i}\sum_{k=1}^{m_{ij}} P_{ijk}\alpha_{ijk} \leq 119 \qquad \text{.....[10]}$$

If s=3, then $$90 \leq \sum_{i=1}^{8}\sum_{j=1}^{n_i}\sum_{k=1}^{m_{ij}} P_{ijk}\alpha_{ijk} \leq 99 \qquad \text{.....[11]}$$

If s =4, then $$76 \leq \sum_{i=1}^{8}\sum_{j=1}^{n_i}\sum_{k=1}^{m_{ij}} P_{ijk}\alpha_{ijk} \leq 89 \qquad \text{.....[12]}$$

There is a constraint limit of only one *k* choice per option (as shown in equation 13), hence the constraint is set as shown in Table 4.54.

$$0 \leq \sum_{k=1}^{m_{ij}} \alpha_{ijk} \leq 1 \qquad \text{.....[13]}$$

where α_{ijk} = 0 or 1

Table 4.54: Selection Table Constraint for *k* Choices

	OS	BM	EIF	IAQ	V	WM	WC	BP
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	1	1	0	0	0	0	0	1
2	0	0	0	0	1	0	0	0
3	0	0	0	0	1	1	0	1
4	0	0	0	0	0	0	1	0
5	0	0	0	0	1	0	0	0
6	0	0	0	0	0	0	0	1
7	0	0	0	0	0	0	0	0
8	0	0	1	0	0	1	0	1
9	0	0	0	0	1	1	0	0
10	1	0	0	0	1	0	0	1
11	1	0	0	0		0	0	1
12	0	0	0	0		1	0	
13	0	0	0	1			0	
14	0	0	1	1			0	
15	0	0	0	0			1	
16	0	0	0	0			1	
17	0	0	1	0			0	
18	0	0	0	0				
19	0	0	0	0				
20	1	0	0	0				
21	0	0	0	0				
22	0	0	0	0				
23	0	0	0	1				
24	0	0	1	1				
25	0	0	1	1				
26	1	0	0	1				
27	1	0	0	0				
28	0	0	0					
29		0	0					
30		0	0					
31		0	0					
32		0	0					
33		0						
34		2						
35		0						
36		1						
37		0						
38		1						
39		0						
40		1						
41		1						

Step 3—Input User Preferences and Implement in Computer Program

The user inputs the following parameters as shown in Tables 4.55 and 4.56:

1. Certification level desired: s =1, 2, 3, 4

Table 4.55: User Input Desired Certification Level

CERTIFICATION		MIN	MAX
1	PLATINUM	120	423
2	GOLD	100	119
3	SILVER	90	99
4	BRONZE	76	89
	Input #	3	<<input
	Criteria	90	99
CERTIFICATION =		SILVER	result
Actual Points =		92	result
MIN COST =		$3,255	<< solver

user min points perference check	76	OK

In addition to selecting the desired certification level, the user may set categories from which to obtain higher points to obtain the desired level. The constraint is that the user must select a desired minimum point value between the absolute minimum and maximum available for each category.

2. Category preferences

P_{des} for each i^{th} category

Where P_{des} = points desired between minimum and maximum for each i^{th} category.

Hence, P_{desi} will fall within the constraints for minimum and maximum points per category (see Table 4.56).

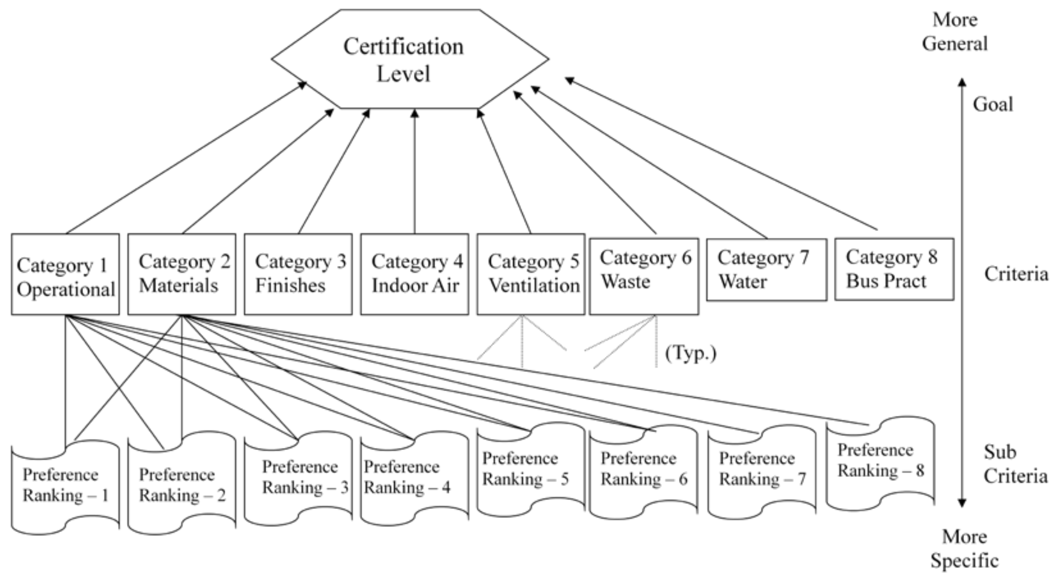


Figure 4.22: Structure of the Preference Selection

Figure 4.22 illustrates the selection structure of the linear optimization model. In general terms, the methodology includes the mathematical formulation of an objective function and its constraints.

Table 4.56: User Preferences per Category (Example)

	OS	BM	EIF	IAQ	V	WM	WC	BP	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**TOTALS**
MIN PTS	10	15	10	15	6	7	7	6	76
	15	18	12	17	8	8	9	8	95
MAX PTS	84	72	70	58	24	35	50	30	423

User Preferences

Table 4.57 illustrates the amount of points required and available to move to higher certification levels with only one category considered for increase in points. To move from Bronze (76 points) to Silver (90 points) an increase of 14 points is required. To move from Bronze (76 points) to Gold (100 points) an increase of 24 points is required. To move from Bronze (76 points) to Platinum (120 points) an increase of 44 points is required. As indicated in Table 4.57, three of the categories (operation systems, building materials and exterior & interior finishes) can singularly achieve the Platinum level. For instance, with only the minimum points obtained in the eight categories, resulting in 76 points, 44 extra points could be reached by increasing just the operation system category. There are five categories that can not be used singularly to achieve Platinum level as they do not have enough available points (44 points).

Table 4.57: User Preferences per Category Scenarios

Certification Level	Points per Category								Total Points	Increase in Points
	Operation Systems (1)	Building Materials (2)	Exterior & Interior Finishes (3)	Indoor Air Quality (4)	Ventilation (5)	Waste Management (6)	Water Conservation (7)	Business Practice (8)		
Min Points =	10	15	10	15	6	7	7	6	76	
Bronze	10	15	10	15	6	7	7	6	76	0
Silver	+14	+14	+14	+14	+14	+14	+14	+14	90	14
Gold	+24	+24	+24	+24	+18	+24	+24	+24	100	24
Platinum	+44	+44	+44	+43		+28	+43		120	44
Max Points =	84	72	70	58	24	35	50	30	423	

Computer program (MS Excel) to implement model

As developed through this section, Microsoft (MS) Excel software was utilized to tabulate the databases and illustrate the model constraints. An advanced version of Solver (V9.6), which is an add-in to MS Excel, was required due to the limitations of 200 adjustable cells of the basic Solver add-in. This mathematical model has 248 adjustable variables, 135 functions, and 1680 dependents.

4.4.3 Implementation and Analysis

The mathematic model allows the user to select the certification level desired and the preference option if chosen. For example, if the Silver level is chosen and only the ventilation category is preferred for point maximization, the minimum cost would be as shown in Table 4.58.

Table 4.58: Minimum Cost for Silver Certification (with only ventilation category maximized)

CERTIFICATION		MIN	MAX
1	PLATINUM	120	423
2	GOLD	100	119
3	SILVER	90	99
4	BRONZE	76	89
	Input #	3	<<input
	Criteria	90	99
CERTIFICATION =		SILVER	result
Actual Points =		94	result
MIN COST =		$6,505	<< solver

user min poi nts perference check	90	OK

The minimum cost to attain the various certification levels is provided in Table 4.59.

Table 4.59: Points per Category to Achieve Particular Certification Level

Certification Level	Points per Category								
	Operation Systems (1)	Building Materials (2)	Exterior & Interior Finishes (3)	Indoor Air Quality (4)	Ventilation (5)	Waste Management (6)	Water Conservation (7)	Business Practice (8)	Total Points
Platinum	12	28	10	17	7	20	7	21	122
Gold	12	28	10	17	7	16	7	6	103
Silver	10	28	10	17	7	8	7	6	93
Bronze	10	15	10	15	7	8	7	6	78

Table 4.60 shows the cost per category to achieve a Silver certification level. The model resulted in a total of 93 points and minimum cost of $3208. As noted in the table, not each category contributed a cost. This is due to the fact that many of the criteria where points could be selected do not have a cost associated with it.

Table 4.60: Cost per Category to Achieve Silver Certification

Certification Level	Costs per Category								
	Operation Systems (1)	Building Materials (2)	Exterior & Interior Finishes (3)	Indoor Air Quality (4)	Ventilation (5)	Waste Management (6)	Water Conservation (7)	Business Practice (8)	Minimum Cost
Silver	$ 2,758	$ -	$ -	$ -	$ 300	$ -	$ 150	$ -	$ 3,208

The case study section in this thesis will provide numerical analysis for other scenario results.

4.4.4 Summary

The aim of the mathematical model is to solve for an objective function of minimum cost while incorporating environmental category constraints and user preferences in the selection process. In other words, the user can analyze different scenarios to determine which options may meet his preferences, while minimizing cost to reach a particular certification level. Although there are numerous mathematical models that could have been utilized, the linear optimization model was the most appropriate for this type of engineering problem based on the nature of the constraints and aim of the model.

The mathematical linear optimization model is fully developed incorporating the environmental constraints and user preference for the Built Green rating program. This includes the establishment of a database for unit cost per criteria under consideration. A computer program (MS Excel) is utilized to test and implement this model. The stakeholders can then make decisions of particular environmental categories for enhancement given the cost analysis information.

Chapter 5: Case Study Implementation and Analysis

A case study was conducted to investigate the practices of an Edmonton residential builder, Landmark Homes (a division of Landmark Group of Builders). Although Landmark Homes historically used the conventional onsite stick-framing construction approach, currently they build a number of their houses using a prefabricated panelized system. In addition, Landmark Homes has implemented a sustainability program called "Landmark Green." The standard house models utilized in this case study are the Catalina II (1696 ft^2) and Cambridge II (1760 ft^2).

5.1 Integrated Construction Practice Rating

The Built Green checklist evaluation for the Cambridge II model resulted in a score of 112 points. This score falls within the Gold certification range of 100-119 points. Table 5.1 shows the points above the minimum for each of the eight environmental categories. The results show that the Business Practices category provided the highest percentage above the minimum required points. This indicates that the Business Practice category offers the best opportunity to maximize points at minimum cost. Conversely, the Waste Management category was not used to obtain addition points above the minimum required as it would result in overall higher costs to earn points. The Cambridge II model house was also run through the HOT2000 program resulting in an EnerGuide score of **77**. The complete output results from both the Built Green checklist and the HOT2000 program are provided in the Appendix E and F.

Table 5.1: Built Green Checklist Score for Case Study

Category	Minimum Points	Case Study Points	Points above Minimum	% above Minimum
Operational Systems	10	15	5	50.0
Building Materials	15	19	4	26.7
Exterior & Interior Finishes	10	16	6	60.0
Indoor Air Quality	15	23	8	53.3
Ventilation	6	9	3	50.0
Waste Management	7	7	0	0.0
Water Conservation	7	9	2	28.6
Business Practices	6	14	8	133.3
Total	76	112		

Hence, based on these two scores (112 points and 77), the case study house would receive the Gold certification. Table 5.2 lists where these two values fall within the various Built Green certification levels. In addition, the figure also shows the other pillar for attaining those certification levels through the EnerGuide rating score.

Table 5.2: Built Green Levels

<table>
<tr><th colspan="3">Certifcation Levels</th><th>Bronze</th><th>Silver</th><th>Gold</th><th>Platinum</th></tr>
<tr><td colspan="3">EnerGuide for New House Rating</td><td>72</td><td>75</td><td>77</td><td>82</td></tr>
<tr><td rowspan="8">Performance Categories</td><td>I</td><td>Operational Systems</td><td rowspan="8">76 Points</td><td rowspan="8">90 Points</td><td rowspan="8">100 Points</td><td rowspan="8">120 Points</td></tr>
<tr><td>II</td><td>Building Materials</td></tr>
<tr><td>III</td><td>Exterior & Interior Finishes</td></tr>
<tr><td>IV</td><td>Indoor Air Quality</td></tr>
<tr><td>V</td><td>Ventilation</td></tr>
<tr><td>VI</td><td>Waste Management</td></tr>
<tr><td>VII</td><td>Water Conservations</td></tr>
<tr><td>VIII</td><td>Business Practices</td></tr>
</table>

Table 5.3 provides the breakdown of accumulated costs to reach a particular EnerGuide rating to meet Built Green certification levels. There is no incurred additional cost to achieve the Bronze level of 72 EnerGuide Rating as the house is constructed to this standard currently. The accumulated cost to attain an EnerGuide rating of 75 (Built Green Silver) is $1600. The accumulated cost to attain an EnerGuide rating of 77 (Built Green Gold) is $2100. Finally, to attain an

EnerGuide rating of 82 (Built Green Platinum) costs $9500. The costs to move from Bronze to Silver amount to $1600, while the costs to move from Silver to Gold is $500, and hence the costs to move from Gold to Platinum is significant at $7400.

Table 5.3: Costs to Achieve Particular EnerGuide Rating

#	Item	Cost	Accumulated Cost	Points	Accumulated Points	Certification Level for EnerGuide
1	R51 Ceiling	$200	$200	0.3	73.1	Bronze
2	Seal House	$400	$600	0.2	73.3	Bronze
3	HRV	$1,000	$1,600	3	76.3	Silver
4	R12 to R20 Basement	$500	$2,100	1.2	77.5	Gold
5	Instant Hot Water (95%)	$800	$2,900	1.1	78.6	Gold
6	90% to 95% Furnace	$700	$3,600	0.6	79.2	Gold
7	Windows 2-p to 3-p	$1,500	$5,100	0.6	79.8	Gold
8	2" SM basement wall ext	$1,600	$6,700	0.4	80.2	Gold
9	2" Rigid ext insulation	$2,800	$9,500	1.3	81.5	Platinum

Figure 5.1 illustrates the accumulated cost impact moving from certification level Bronze to Platinum. The baseline case commences at 72.8 points. As noted, there is a greater increase in costs to move from Gold to Platinum. The cost per point is not linear. Silver certification is achieved at 75 EnerGuide Rating, Gold certification at 77 Rating, and Platinum at 82 Rating. An EnerGuide rating of 81.5 is automatically rounded up to 82, which is the requirement for Platinum certification.

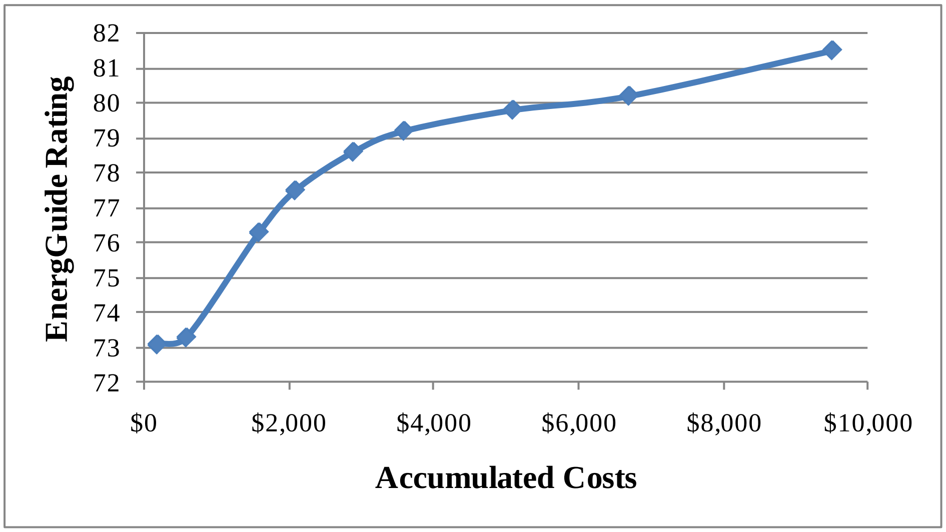


Figure 5.1: Costs to Achieve EnerGuide Rating Points

The practice evaluation results from the case study are shown in Table 5.4.

Table 5.4: Results from Home Builder SEE Evaluation Form

Category		Points	Total
	1		
S-1-1	2		11
	3		
	1		
S-1-2	2		3
	3		
	1		
S-2-1	2		4
	3		
	1		
S-2-2	2		3
	3		
	1		
S-3-1	2		9
	3		
	1		
S-3-2	2		5
	3		
	1		
S-3-3	2		5
	3		
	1		
S-3-4	2		3
	3		
	1		
S-4-1	2		7
	3		
	1		
S-4-2	2		5
	3		
	1		
S-4-3	2		0
	3		
	1		
S-4-4	2		0
	3		
	1		
S-5-1	2		3
	3		
	1		
S-5-2	2		11
	3		
	1		
S-5-3	2		9
	3		
Social Sub-Total =			78

Category		Points	Total
	1		
E-1-1	2		0
	3		
	1		
E-1-2	2		0
	3		
	1		
E-1-3	2		1
	3		
	1		
E-1-4	2		6
	3		
	1		
E-2-1	2		4
	3		
	1		
E-2-2	2		1
	3		
	1		
E-2-3	2		0
	3		
	1		
E-3-1	2		1
	3		
	1		
E-3-2	2		11
	3		
	1		
E-3-3	2		3
	3		
	1		
E-4-1	2		15
	3		
	1		
E-4-2	2		6
	3		
	1		
E-4-3	2		8
	3		
	1		
E-4-4	2		11
	3		
	1		
E-4-5	2		4
	3		
Environmental Sub-Total =			71

Category		Points	Total
	1		
C-1-1	2		0
	3		
	1		
C-1-2	2		3
	3		
	1		
C-1-3	2		1
	3		
	1		
C-2-1	2		0
	3		
	1		
C-2-2	2		6
	3		
	1		
C-2-3	2		1
	3		
	1		
C-2-4	2		10
	3		
	1		
C-2-5	2		5
	3		
	1		
C-3-1	2		9
	3		
	1		
C-3-2	2		15
	3		
	1		
C-4-1	2		7
	3		
	1		
C-4-2	2		3
	3		
	1		
C-5-1	2		6
	3		
	1		
C-5-2	2		0
	3		
	1		
C-5-3	2		4
	3		
Economic Sub-Total =			70

Total =		219

Table 5.5 shows a summary of the practice evaluation based on the SEE elements. The points from the social element are based on 225 total possible points—normalized to 33.3 points. Likewise, the environmental and economic elements have normalized points accounting for 33.3 total points each as well. Hence, for the Social element sub-total of 78 points out of 225 points would result in a normalized point of 11.5 by dividing 78 by 6.75. Likewise, the 71 points from the Environmental element would be 10.5 normalized points by taking 71 and dividing by 6.75. The 70 points from the Economic element results in 10.4 normalized points.

Table 5.5: Summary of Practice Evaluation

Element	Normalized Points	Maximum Points
Social	11.5	33.3
Environmental	10.5	33.3
Economic	10.4	33.3
Total	32.4	100

As noted in Table 5.6, with total points of 32.4, the practice score level would be 2-star. The appendix includes the evaluation form utilized to derive this value. A blank practice evaluation form is also included in Appendix D.

Figure 5.2 illustrates the results from Table 5.5 graphically. The vertical axis represents the points for each element. Each vertical bar grouping represents the actual points achieved compared with the maximum points allotted per SEE element.

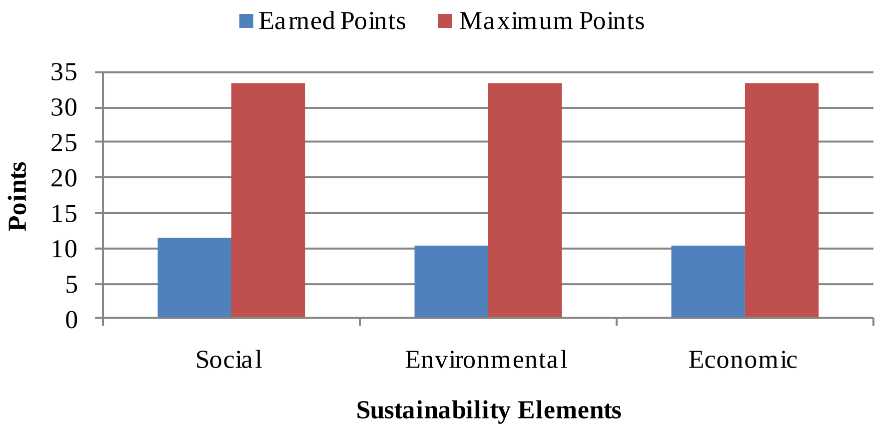


Figure 5.2: Points Earned per SEE Element

Integrated Construction Practice Score Level

The integrated sustainability score level based on Landmark Homes' Built Green performance level and practice evaluation is shown in Table 5.6. Based on a Built Green level of Gold and practice evaluation score of 2-star, the results indicate an integrated sustainability score level of C (Case #10). Based on the score level of C, a residential builder could benchmark this rating and put into place an action plan to improve his score to an A or B score level. This action plan could review the areas in the practice evaluation that the residential builder may want to focus on.

Table 5.6: Landmark Integrated Sustainability Score from SEE Evaluation

Performance Score Levels	Practice Score Levels	Integrated Sustainability Score Levels
Platinum	5 star	A
Gold	4 star	B
Silver	3 star	C
Bronze	**2 star**	D
	1 star	E

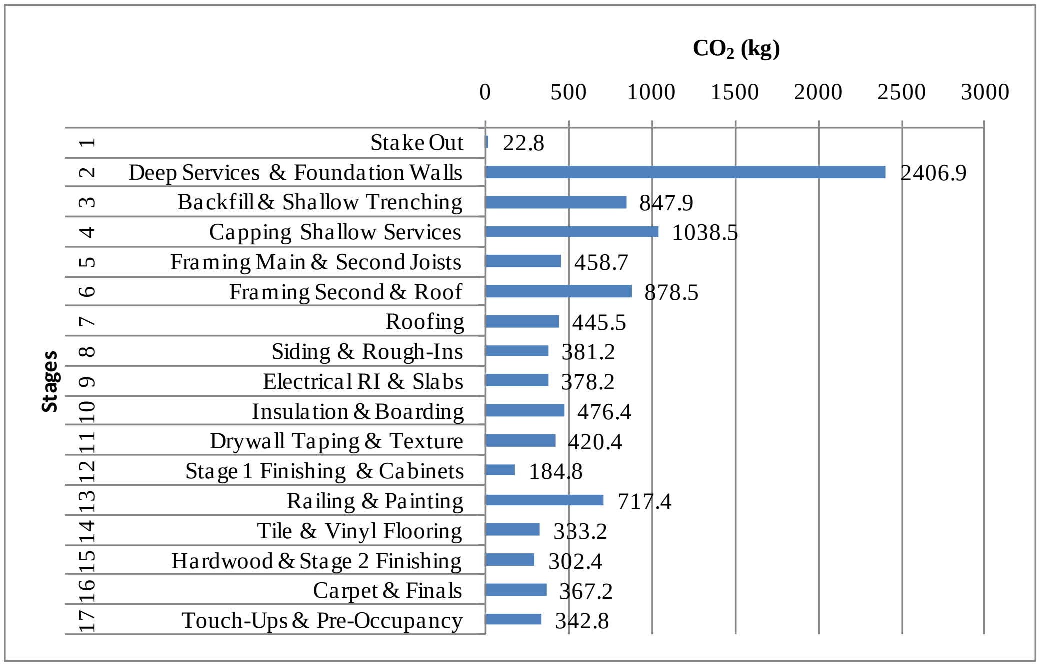
Case #	Performance + Practice = Sustainability Rating		
	Performance Score Levels	Practice Score Levels	Integrated Sustainability Score Levels
1	Platinum	5 star	A
2	Platinum	4 star	A
3	Gold	5 star	A
4	Gold	4 star	A
5	Platinum	3 star	B
6	Gold	3 star	B
7	Silver	5 star	B
8	Bronze	5 star	B
9	Platinum	2 star	C
10	**Gold**	**2 star**	**C**
11	Silver	4 star	C
12	Bronze	4 star	C
13	Platinum	1 star	D
14	Gold	1 star	D
15	Silver	3 star	D
16	Bronze	3 star	D
17	Silver	1 star	E
18	Silver	1 star	E
19	Bronze	2 star	E
20	Bronze	1 star	E

5.2 Application of BIM for Quantification of CO_2 Emissions Parameter

The conventional construction process was broken down into 17 distinct stages, ranging from stake-out to pre-occupancy inspection (Landmark Group of Builders, 2008). The overall emissions from the 17 stages are ~10,000 CO_2 (kg). Table 5.7

shows the breakdown of emissions per construction stage. Stage 2 contributes the most to emissions of all the stages at 23% as shown in Figure 5.3.

Table 5.7: CO_2 Emissions per 17 Construction Stages of Residential Construction



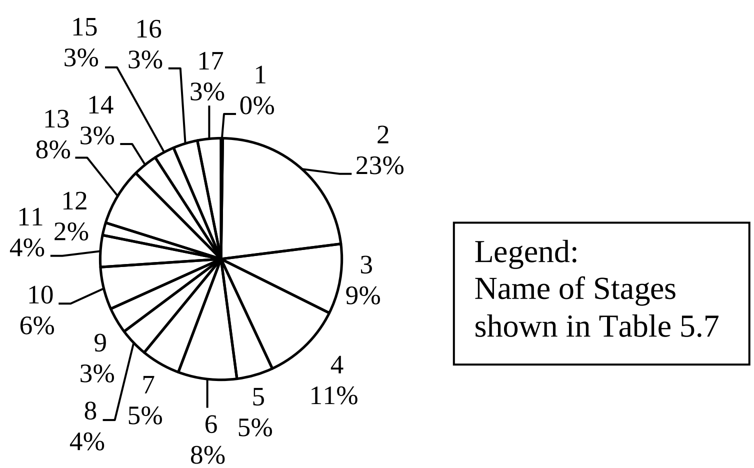


Figure 5.3: CO_2 Percentage Contributions by Stage

The output of quantification of CO_2 emissions were established from BIM. The BIM database houses the CO_2 emission rates based on the ASTM Uniformat and CSI Masterformat classification system. The building assemblies resulted in over 30 recipes, 140 methods, and 320 resource combinations. Figure 5.4 below illustrates the unit rates of CO_2 in kilograms for an exterior wall recipe. This recipe comprises five methods, including exterior finishing, exterior sheathing, 2” x 6” framing, insulation, drywalling and taping, and painting. The resources associated with the methods includes transportation, equipment, and labour. Each recipe in BIM provides CO_2 emissions that accumulate to the overall total of ~10,000 kg of CO_2 emissions which is consistent with the CO_2 emissions determined from the 17 construction stage.

Recipe Name: Exterior Wall EW1

	Unit	Kg CO2/Unit	Material Cost/Unit	Labour Cost/Unit
Exterior Finishing				
Vynil siding	m2	0.57	9.05	12.267
Delivery masonry / stonetile	m2	3.68	3.48	included
Install masonry / stonetile	m2	9.17	25.45	35.68
3/4-in Exterior Sheathing & 2x6 Framing				
Deliver first floor framing package -wall	m2	0.37	2.56	included
Framing - main floor walls	m	3.08	26.2	22.21
Frame Check	ea	13.6	0	105.75
R20 Batt Insulation & V.B.				
Install Insulation & Vapor Barrier	m2	0.23	6.15	10.01
City Inspection #3 - insulation	ea	9.2	0	0
1/2" Drywall & Taping				
Load Drywall	m2	0.076	0	0.30
Drywall Boarding	m2	0.09	2.95	6.48
Drywall Taping	m2	0.16	0.96	3.45
Painting - 3 coats				
Prime	m2	0.076	0.78	1.55
Paint Vac	m2	0.057	0.78	1.55
Paint 2nd Coat	m2	0.34	0.78	1.55
Inspect Painting	ea	9.2	0	70.5
Paint touch-ups (3rd coat)	m2	0.13	0.26	1.55

Figure 5.4: CO_2 Emissions from the Exterior Wall Recipe

Table 5.8 illustrates the GHG, electricity, and natural gas emissions from a typical residential house (Landmark Homes, 2009). The rationale for featuring this table is to illustrate the impact of incorporating sustainable practices into the construction of houses with respect to operating costs. The table illustrates the cost savings by upgrading specifications to meet higher certification levels.

Table 5.8: GHG, Electricity, Natural Gas Estimates for Landmark Homes Models

Model	GHG Emissions (tonnes/yr)			Additional GHG to Upgrade	Electricity Usage (KWh)			Natural Gas Usage (GJ)			Energuide Rating			Annual Savings
	P file	N1	N2	%	P file	N1	N2	P file	N1	N2	P file	N1	N2	N1 to N2
Cartier I A	12.52	10.67	9.42	nil	9313	9300	9094	150.34	113.77	94.75	69	75	78	$530.63
Lougheed I A	12.60	10.65	9.48	nil	9305	9280	9080	152.08	113.55	96.11	68	74	78	$534.66
Garneau I A	11.54	10.07	9.05	nil	9222	9246	9074	131.56	102.31	87.62	70	75	78	$417.23
Glenora I A	10.38	9.67	8.74	nil	9137	9180	9036	109.19	94.80	81.80	73	76	79	$260.85
Lacombe I A	11.79	10.39	9.28	nil	9240	9255	9068	136.54	108.50	92.23	70	75	78	$422.74
Mcleod I B	12.91	11.24	10.04	nil	9335	9336	9114	158.10	124.92	106.89	69	74	77	$490.51
Palliser I A	11.36	10.06	9.01	nil	9205	9225	9051	128.19	102.24	87.03	71	75	78	$392.18
Patricia I A	11.18	9.98	8.98	nil	9190	9217	9049	124.61	100.69	86.34	71	75	78	$364.45
Pearson I A	11.42	10.72	9.41	nil	9231	9310	9100	129.14	114.66	94.54	72	74	78	$329.81
Riel I A	10.48	9.48	8.54	nil	9133	9169	9022	111.28	91.02	77.85	72	76	79	$317.29
Rundle-I A	11.69	10.37	9.29	nil	9232	9253	9068	134.62	108.12	92.47	70	74	78	$402.16
Strathcona-I A	11.22	10.07	9.04	nil	9194	9226	9053	125.55	102.44	87.53	71	75	78	$362.15
Villeneuve-I A	12.07	11.64	9.57	nil	9269	9374	9087	141.92	132.49	97.78	70	72	78	$422.05

As noted earlier in the methodology, the results indicate that Stage 2 (foundation) contributes significantly to CO_2 emissions, as evidenced in Table 5.7. Stage 2 contributes roughly 23 % of the total emissions. However, the study also revealed that this stage provides considerable opportunities to minimize the total emissions produced over the course of construction. One significant potential reduction is based on the season in which construction occurs. The study revealed high heating requirements for construction during the Canadian winter season. In fact, the amount of extra emissions observed during Canadian winter construction (in excess of six tonnes of CO_2) accounted for about two-thirds of the overall construction emissions as calculated in the study. Figure 5.5 shows the drastic increase in CO_2 emissions in winter construction. In fact, the increase is approximately 39% of the winter construction process (Landmark Homes, 2009).

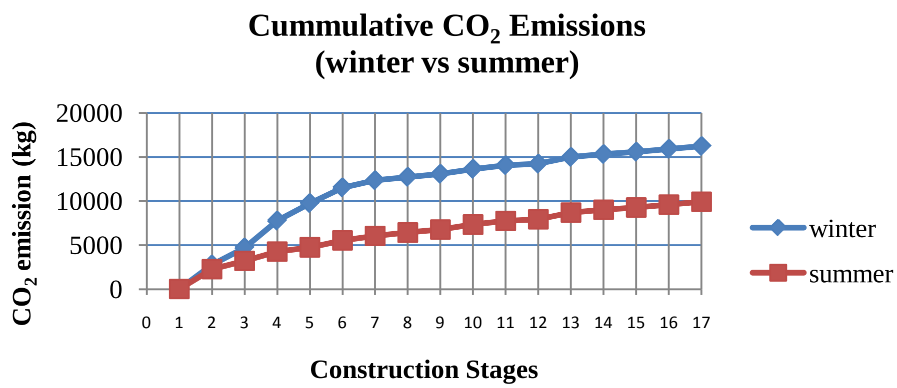


Figure 5.5: Cumulative CO_2 Emissions Comparison - Winter vs. Summer Construction

5.3 Mathematical Analysis

The mathematic model allows the user to select the certification level desired and the preference options if chosen. The model allows the user to select the certification level of Platinum, Gold, Silver or Bronze. As well, the user may select none to all eight of the eight environmental categories as preferences for obtaining points. For example, if the Silver level is chosen and no environmental category is preferred for point maximization, the model would provide a minimum cost of $3208, as shown in the Table 5.9. If no environmental category is chosen, the program solve for the desired certification level at minimum cost through the environmental categories providing the required points.

Table 5.9: Minimum Cost for Silver Certification with User Preference Input

CERTIFICATION		MIN	MAX
1	PLATINUM	120	423
2	GOLD	100	119
3	SILVER	90	99
4	BRONZE	76	89
	Input #	3	<<input
	Criteria	90	99
CERTIFICATION =		SILVER	result
Actual Points =		93	result
MIN COST =		$3,208	<< solver

user min points perference check	76	OK

Table 5.10 shows the actual selection of the various categories and corresponding criteria under each category used for the Table 5.9 results.

Table 5.10: Case Study – Selection Table Sample

	OS				BM			EIF			IAQ			V			WM			WC			BP		
	1				2			3			4			5			6			7			8		
1	0	0	1		1			0			0			0			0			0			0	0	1
2	0	0	0		0			0			0			0			0			0	0		0		
3	0	0			0			0			0			0			0	0	0	0	0		0	1	
4	0	0	0		0			0			0			0			0	0		0	0		0		
5	0				0	0		0			0			0			0	0	0	0	0		0		
6	0				0			0			0			0			0			0			0	1	
7	0				0			0			0			0			0			0	0		0		
8	0	0			0			0	1		0			0			0	1		0	0	0	0	0	1
9	0				0			0			0			1			1			0	0		0		
10	0	1			0			0			0			1			0			0			0	1	
11	0	1			0			0			0						0			0			0	0	1
12	0				0			0			0						0	1		0					
13	0				0	0		0			0	1								0					
14	0				0	0		0	1		0	1								0					
15	0				0	0		0			0									0	1				
16	0				0			0	0		0									0	0	1			
17	0				0			0	1	0	0									0					
18	0				0			0			0														
19	0	0	0		0			0			0														
20	0	0	1		0			0			0														
21	0	0			0			0			0														
22	0	0			0			0			0														
23	0				0			0			1														
24	0	0	0		0	0		0	1		1														
25	0				0			0	1		1														
26	0	0	0	0	0			0	0		1														
27	0				0	0		0			1														
28	0				0			0																	
29					0			0																	
30					0	0		0																	
31					0	0		0																	
32					0			0																	
33					0	0	0																		
34					0	1	1																		
35					0																				
36					0	1																			
37					0																				
38					0	1																			
39					0																				
40					0	1																			
41					1																				

Table 5.11 shows the cost per category to achieve a Silver certification level. The model resulted in a total of 93 points and minimum cost of $3208. As noted in the table, not each category contributed to the cost. This is due to the fact that many of the criteria where points could be selected do not have a cost associated with them.

Table 5.11: Cost per Category to Achieve Silver Certification

Certification Level	Costs per Category								Minimum Cost
	Operation Systems (1)	Building Materials (2)	Exterior & Interior Finishes (3)	Indoor Air Quality (4)	Ventilation (5)	Waste Management (6)	Water Conservation (7)	Business Practice (8)	
Silver	$ 2,758	$ -	$ -	$ -	$ 300	$ -	$ 150	$ -	$ 3,208

The minimum points per category to attain the various certification levels are provided in Table 5.12. These results do not have any user input preferences. The table denotes that the model varies the points up to three categories with the objective function of minimizing costs. In order to obtain a Silver certification, it was cost $3208. These costs come for the operation system ($2758), ventilation

($300), and water conservation ($150) categories. The costs for each category have a corresponding point accumulation associated with it. For instance, the ventilation category cost is $300 will provide an accumulated point in that category of 7 points.

Table 5.12: Points per Category to Achieve Particular Certification Level

Certification Level	Points per Category								
	Operation Systems (1)	Building Materials (2)	Exterior & Interior Finishes (3)	Indoor Air Quality (4)	Ventilation (5)	Waste Management (6)	Water Conservation (7)	Business Practice (8)	Total Points
Platinum	12	28	10	17	7	20	7	21	122
Gold	12	28	10	17	7	16	7	6	103
Silver	10	28	10	17	7	8	7	6	93
Bronze	10	15	10	15	7	8	7	6	78
Min Points =	10	15	10	15	6	7	7	6	76

Table 5.13 highlights the sensitivity of varying points within each category on the minimum cost of achieving the various certification levels. The minimum cost is $1720 with a maximum cost of $11,290.

Table 5.13: Sensitivity of Points per Category on Minimum Cost

Sensitivity of Points per Category on Minimum Cost								
Operation Systems (1)	Building Materials (2)	Exterior & Interior Finishes (3)	Indoor Air Quality (4)	Ventilation (5)	Waste Management (6)	Water Conservation (7)	Business Practice (8)	Minimum Cost
12	16	10	16	6	7	7	7	$ 1,720
19.2	21.6	16	20.2	7.8	9.8	11.3	9.3	$ 2,677
26.4	27.2	22	24.4	9.6	12.6	15.6	11.6	$ 3,634
33.6	32.8	28	28.6	11.4	15.4	19.9	13.9	$ 4,591
40.8	38.4	34	32.8	13.2	18.2	24.2	16.2	$ 5,548
48	44	40	37	15	21	28.5	18.5	$ 6,505
55.2	49.6	46	41.2	16.8	23.8	32.8	20.8	$ 7,462
62.4	55.2	52	45.4	18.6	26.6	37.1	23.1	$ 8,419
69.6	60.8	58	49.6	20.4	29.4	41.4	25.4	$ 9,376
76.8	66.4	64	53.8	22.2	32.2	45.7	27.7	$ 10,333
84	72	70	58	24	35	50	30	$ 11,290

Table 5.14 highlights the sensitivity of varying points within the ventilation category on the minimum cost of achieving the Gold certification levels. The minimum cost is $3973, with a maximum cost of $6458.

Table 5.14: Sensitivity of Points within the Ventilation Category on Minimum Cost of achieving the Gold level

Ventilation Points	Cost
6	$ 3,973
7	$ 4,151
8	$ 4,328
9	$ 4,506
10	$ 4,683
11	$ 4,861
12	$ 5,038
13	$ 5,216
14	$ 5,393
15	$ 5,571
16	$ 5,748
17	$ 5,926
18	$ 6,103
19	$ 6,281
20	$ 6,458

A sensitivity analysis was conducted on the ventilation category which has a minimum point requirement of 6 and a maximum point limit of 20. If the user desires a Silver certification (90 points) with no user preferences (min 76 points based on minimum under each category), the results of the model is a Silver rating with actual points of 95 at a cost of $3208. The effect of the ventilation category is that it contributed 7 points at a cost of $300. If the model conditions are changed to manipulate only the ventilation category by setting the desired points to obtain a Silver rating, the additional cost for the 14 additional points to move from Bronze to Silver would be $3350 (see Table 5.15).

Table 5.15: Ventilation Category Sensitivity

Cost	Points	Ventilation (5)	
		Accumulated Cost	Accumulated Points
$ -	2	$ -	2
$ -	1	$ -	3
$ 50	2	$ 100	5
$ 100	2	$ 300	7
$ 200	3	$ 900	10
$ 250	3	$ 1,650	13
$ 250	4	$ 2,650	17
$ 250	5	$ 3,900	22
$ 350	2	$ 4,600	24
$ 400	1	$ 5,000	25

As well, a sensitivity analysis was conducted on the indoor air quality category, which has a minimum point requirement of 15 and a maximum point limit of 58. If the user desires a Silver certification (90 points) with no user preferences (min 76 points based on minimum under each category), the results of the model is a Silver rating with actual points of 95 at a cost of $3208. The effect of the indoor air quality category is that it contributed 15 points at no cost. If the model conditions are changed to manipulate only the indoor air quality category by setting the desired points to obtain a Silver rating, the additional cost for the 14 additional points to move from Bronze to Silver would be $1430. Hence, if the user prefers this category to maximize points over the ventilation category, there is a savings difference of $1920 to move from a Bronze to Silver certification. Unlike the ventilation category, which has a maximum point limit of 24, the indoor air quality category can further add points for higher certification level (see Table 5.16).

Table 5.16: Indoor Air Quality Sensitivity to Cost and Points for moving from Bronze to Silver

Cost	Points	Indoor Air Quality (4) Accumulated Cost	Accumulated Points
$ -	1	$ -	1
$ -	2	$ -	3
$ -	3	$ -	6
$ -	1	$ -	7
$ -	2	$ -	9
$ -	2	$ -	11
$ -	2	$ -	13
$ -	2	$ -	15
$ -	2	$ -	17
$ -	1	$ -	18
$ 50	1	$ 50	19
$ 90	2	$ 230	21
$ 100	1	$ 330	22
$ 100	3	$ 630	25
$ 150	2	$ 930	27
$ 250	2	$ 1,430	29
$ 300	6	$ 3,230	35
$ 333	3	$ 4,229	38
$ 500	2	$ 5,229	40
$ 500	3	$ 6,729	43
$ 500	1	$ 7,229	44
$ 600	4	$ 9,629	48
$ 800	1	$ 10,429	49
$ 1,000	2	$ 12,429	51
$ 1,000	2	$ 14,429	53
$ 3,000	2	$ 20,429	55
$ 3,500	2	$ 27,429	57

Figures 5.6 and 5.7 graphically illustrate the sensitivity of the both the indoor air quality and ventilation categories on costs with an incremental accumulation of points. As seen in the figures, the ventilation category increases in costs after 3 points, whereas the indoor air quality category increases in costs after 20 points. Hence, it is more economic to accumulate points from the Indoor Air Quality

category as a priority relative to the Ventilation category. The appendix provides the sensitivity to costs and points for each of the eight categories.

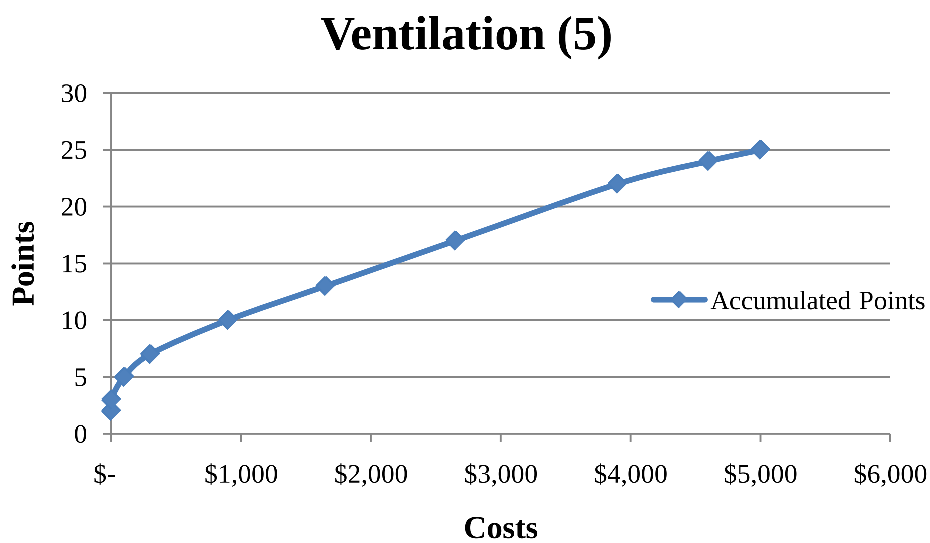


Figure 5.6: Ventilation Category Sensitivity

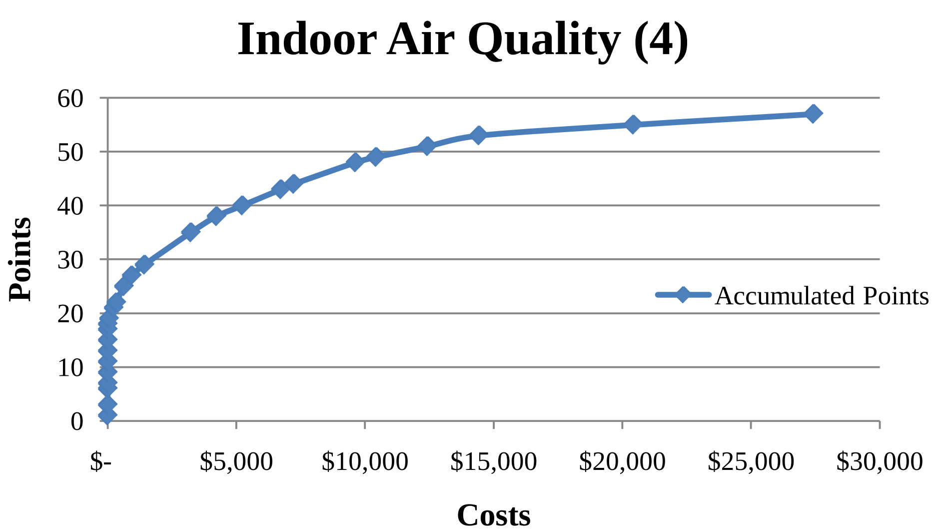


Figure 5.7: Indoor Air Quality Category Sensitivity

5.4 Summary

This case study implemented all three sustainability tools: Integrated Construction Practice Rating Program (ICPRP), BIM, and math optimization model. In the ICPRP, the results were not surprising for Landmark Homes. The builder believed that the company can build a product that meets performance evaluation criteria, which they demonstrated. However, when factoring in their construction practice score which, is a 2-star rating (out of 5 stars), their integrated sustainability score is a C (with A and B levels being higher). Hence, the builder can better measure his sustainability score by adopting the integrated construction rating program developed is this thesis. Landmark Homes can benchmark where they are currently ranked and strive to a higher level of sustainability based on this rating program.

The quantitative performance criteria in this model are modeled based on Built Green's eight evaluation categories. If a different performance evaluation program such as LEED is preferred, the model can be customized to utilize that program's evaluation categories. For instance, the LEED rating program offers different environmental categories and corresponding choices within each that could be formulated in a mathematical model. Hence, this framework allows for the user to select a parameter for any suitable rating program.

In regards to the CO_2 emissions findings, Landmark is exploring a change in construction processes by moving away from onsite stick-frame to factory panelized construction. The aim of this is to reduce CO_2 emissions from construction practice activities. The case study pointed to a rise in CO_2 emissions when the construction season is factored in. Hence, the move to a factory setting would eliminate the need for winter heating. The CO_2 quantification from the BIM was consistent with field studies.

Finally, the mathematical model was developed based on a linear optimization model for a building rating program for houses. A numerical case study for using the linear optimization model approach was implemented. As noted in the case study, some categories do not contribute costs, yet points are obtained from them. This is due to the fact that these criteria are building code requirement that Built Green already credits. This mathematical model exposes a shortcoming of the Built Green rating program, which is the ease with which builders can achieve higher certification levels. A recommendation for this rating program is that there should be higher point requirements for each certification level to truly recognize sustainability efforts in performance.

Chapter 6: Conclusion

6.1 General Conclusion

The significance of this research in rating the sustainability of the residential construction practice is notable, especially considering the contribution of the housing industry to Canada's GDP. The construction industry has tremendous opportunities to enhance sustainable development and provide inroads for innovation. The momentum of green building initiatives has been apparent. Continued openness to change bolsters the advancement of sustainable development and further innovation within the construction industry.

This thesis commenced with the rationale for examining the sustainability of construction practice, a subject which has garnered only limited research attention. In that regard, concerns about rating sustainability are beginning to be addressed in the research through performance and practice evaluations, application of BIM for quantification of parameters related to the construction practice (such as CO_2 emissions) and mathematical optimization modeling.

This research has provided an examination of the state of the art through a review of the literature on green building for residential construction. This has included a broad analysis of CO_2 emissions in construction, various existing rating programs, and sustainability models. The research has described BIM and how it may be applied in sustainability efforts. The introduction of mathematical models was covered in the latter section of the literature review. A detailed background on LEED and Built Green, coupled with the HOT2000 program, concluded the literature review chapter. The thesis then turned to the development of a research framework that comprised three stages. Component 1 of the framework involved the development of an integrated construction practice rating program. The outcome of this component provides stakeholders with a rating of their sustainability level that reflects not only performance measurement but also construction practice rating. The builder now has a benchmark of their sustainability level and can move to a higher level by addressing weaknesses in their construction practice operations. The second component of the research involved the application of BIM for quantification of parameters related to the rating of the construction practice. The CO_2 emission quantification results from BIM were automatically calculated based on parametric modeling. If changes in building dimensions occur, the program allows for automatic updates.

The third component of the research included the development of a mathematical linear optimization model that outputs minimum required costs in order to meet certain certification level criteria. This model was developed to solve a selection preference scenario that stakeholders can address. By utilizing this model, stakeholders would be able to better support their decision-making.

The overall goal of this research is the development of an integrated framework for rating the sustainability of the residential construction practice. Although intended primarily for a North American context, the general approaches described here could apply globally to green building. The focus of the research is on finding solutions in order to effectively rate the sustainability of construction practice, and to allow stakeholders in residential construction to implement the tools developed in this research.

This research has closely investigated the current house construction procedures in order to quantify the associated CO_2 footprint of construction. A field study was performed as the first step to gain a better understanding of current practices. Work measurements related to the quantification of the CO_2 footprint were obtained, and data related to the construction schedule and resource utilization (labour, equipment, and materials) was collected. Based on findings from site visits, potential areas of improvement were identified and recommendations were provided. The environmental CO_2 footprint impact of current house construction practices was also quantified. Equipment operation onsite, transportation to and from the site, and heating for curing concrete during winter were identified as the main sources of gas emissions during construction.

This research is limited by such individual criteria as size, construction methodology, and onsite construction process. The findings will also vary according to the skills of trades personnel onsite as well as by site location.

This thesis quantified the CO_2 emissions of various new detached-house construction stages (from stake-out to pre-occupancy inspection) in Canada. As evidenced through the process of identifying the stages that generate the most CO_2 emissions, better practices and procedures could be used to reduce these emissions. The BIM approach allows for rapid computations of CO_2 emissions from various house sizes, designs, and materials. The use of BIM and the integration of an intelligent database allow end users to calculate CO_2 emissions for different styles of houses built with different construction methodologies. Through the definition of CO_2 rates per unit of material delivered and installed, the quantification of CO_2 emissions per house becomes a much easier task to address. BIM has facilitated the comparison process between two different construction techniques (onsite framing versus off-site framing) through activity definition and by tracking the corresponding CO_2 emissions of each activity. BIM provides managers and decision makers with a useful tool that can be manipulated to support decisions during the design and construction stage.

It is reasonable to expect that, as a result of this research, house construction companies can enhance their current practices. The findings of this research study highlight how the housing industry can contribute to a reduction of CO_2 emissions through the development and adoption of best practice construction concepts. The applications of BIM in sustainability design and analysis will continue to grow. This field study is just one investigation of how innovations in BIM can be implemented in sustainable construction practices.

The contributions of this research to house construction include fostering innovation such as prefabrication in construction practices; reducing CO_2 construction emissions generated from heating during winter construction; improving planning and decision making prior to construction; and having a positive impact on the environment due to reductions of CO_2 emissions and material waste disposal to landfills.

This thesis provided rationale for the development of an evaluation tool to assess environmental scoring on different environmental categories. A mathematical model was developed based on a linear optimization model for a building rating system for houses. A numerical case study was implemented that utilized the linear optimization model approach.

Some categories, although they do not contribute costs, can still earn environmental rating points. This is due to the fact that they are building code requirements for which the Built Green program awards points. This model exposes a shortcoming of the Built Green rating system. That shortcoming is the ease with which builders can achieve higher certification levels. A recommendation is that there should be higher point requirements for each certification level in order to meaningfully recognize sustainability efforts. Sensitivity analyses on each of the eight Built Green Environmental categories can provide the user with useful information regarding the consequences of their user preference category selection.

6.2 Research Contributions and Benefits

The research contributions from this thesis have advanced from the development of a framework for rating the sustainability of the residential construction practice through three specific contributions:

1. Development of an integrated performance and practice evaluation model to assess sustainability efforts of residential builders;
2. Development of an application of BIM for quantification of CO_2 emissions, in a dynamic and efficient manner; and
3. Implementation of a mathematical linear optimization model as a tool to facilitate cost analysis with a rating program.

The integrated construction practice rating program incorporates a comprehensive rating of both performance and practice measurements. Allowing for measurement of the construction practice provides an evaluation of true sustainability efforts. The results discovered in this research point to the shortcoming of programs that rate performance only which is that it is too easy for builders to claim sustainability certification accolades from just one measurement perspective. Prospective owners should demand or challenge builders to reach a higher level of sustainability. With this integrated construction practice rating program, prospective owners would have an alternative or additional rating tool by which to assess the sustainability of builders' operations. Likewise, builders would have another tool by which to measure and enhance their sustainability efforts.

The development of an application of BIM for quantification of a parameter, such as CO_2 emissions, is another specific contribution of this research. In current practice, one of the typical outputs of BIM quantification is the establishment of cost estimating. The research in this area has examined how parametric modeling and BIM may be utilized together in the quantification of the CO_2 emissions generated during the construction practice. Based on classification systems that build hierarchy and assemblies, a location breakdown structure (including the database in which to store the particular method of construction as well as the resource requirements) can facilitate the CO_2 quantification. Specifically, the onsite stick-built construction practice was tracked and CO_2 emissions quantified for activities in 17 construction stages. Through automation, the output from BIM allows the user to determine which activities and what building components are contributing emissions. In addition, this allows builders to change their construction practices in order to address particular activities with high emission amounts. The BIM outputs the activities with CO_2 emissions that the residential builder could identify as a source for reduction of CO_2 emissions. Hence, as indicated by its application in this research, it is observed that BIM can be utilized as an effective sustainability rating tool for CO_2 emissions.

The third contribution from this research is the implementation of a mathematical model as a tool that provides a solution for the selection problems encountered by stakeholders seeking analyses of competing environmental preferences. The model is robust in adopting other rating program criteria. Users are able to manipulate an assortment of variables in order to derive possible outcomes that meet their sustainability goals from selection processing.

The benefits of this research range across academic and industrial spheres. In the academic realm, further research with technologies such as BIM open the door to other applications and to scientific knowledge in building practices and materials development. The proposed ICPRP provides a methodology to rate sustainability on both performance and practice perspectives. From an industry perspective, the construction industry can gain further creditability through adoption of these tools. The research partner in the case study has embraced the work developed in the thesis and hence has a means to improve his practice.

6.3 Limitations and Future Research Work

This research was limited to new onsite construction in the residential construction industry. The integrated framework rating program for residential construction practice developed in this research, it should be noted, provides ratings for stakeholders, not solutions, nor suggestions for improvement. The work in this research could be adopted by governments and other agencies wishing to include construction practice ratings in request-for-proposal contracts. Likewise, future work can be directed toward support measures that can be implemented to enhance sustainability in general, such as legislation requiring the disclosure of rating results for each house construction.

There are opportunities for the utilization of BIM in future work evaluating the factory construction process (pre-fabrication), although this thesis has focused on CO_2 emissions from the onsite construction practice itself. Other applications of BIM could expand in scope to encompass health and safety concerns, or toward utilizing the application of the math model tool to assess CO_2 emissions resulting from different rating programs. Specifically, an opportunity for application of BIM in the area of health and safety could involve respiratory and ergonomics concerns of workers.

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Appendix

A. Math Sensitivity Tables and Graphs

B. Wood and Material Waste Data Forms

C. Wood Waste Field Collection Tables

D. SEE Evaluation Form (Blank)

E. Built Green – Homebuilder Results

F. HOT2000 – Homebuilder Results

G. Landmark – House Specifications

H. Landmark Cambridge Floor Plan

Appendix A: Math Sensitivity Tables and Graphs

Table A.1: Operational Systems and Building Materials Math Sensitivity

Cost	Points	Operational Systems (1) Accumulated Cost	Accumulated Points
$ -	3	$ -	3
$ -	2	$ -	5
$ -	1	$ -	6
$ 25	1	$ 25	7
$ 50	3	$ 175	10
$ 63	4	$ 425	14
$ 100	1	$ 525	15
$ 120	4	$ 1,005	19
$ 125	2	$ 1,255	21
$ 165	2	$ 1,585	23
$ 196	4	$ 2,369	27
$ 200	4	$ 3,169	31
$ 400	2	$ 3,969	33
$ 400	2	$ 4,769	35
$ 500	4	$ 6,769	39
$ 500	4	$ 8,769	43
$ 500	1	$ 9,269	44
$ 600	3	$ 11,069	47
$ 600	2	$ 12,269	49
$ 625	4	$ 14,769	53
$ 650	1	$ 15,419	54
$ 700	6	$ 19,619	60
$ 750	4	$ 22,619	64
$ 750	1	$ 23,369	65
$ 800	1	$ 24,169	66
$ 1,200	2	$ 26,569	68
$ 2,300	10	$ 49,569	78
$ 3,000	6	$ 67,569	84

Cost	Points	Building Materials (2) Accumulated Cost	Accumulated Points
$ -	2	$ -	2
$ -	1	$ -	3
$ -	1	$ -	4
$ -	1	$ -	5
$ -	1	$ -	6
$ -	1	$ -	7
$ -	1	$ -	8
$ -	2	$ -	10
$ -	2	$ -	12
$ -	1	$ -	13
$ -	2	$ -	15
$ -	1	$ -	16
$ -	2	$ -	18
$ -	2	$ -	20
$ -	1	$ -	21
$ -	1	$ -	22
$ -	1	$ -	23
$ -	1	$ -	24
$ 75	1	$ 75	25
$ 150	2	$ 375	27
$ 150	2	$ 675	29
$ 200	1	$ 875	30
$ 300	1	$ 1,175	31
$ 300	1	$ 1,475	32
$ 350	1	$ 1,825	33
$ 400	1	$ 2,225	34
$ 400	1	$ 2,625	35
$ 400	1	$ 3,025	36
$ 450	1	$ 3,475	37
$ 533	3	$ 5,074	40
$ 800	1	$ 5,874	41
$ 867	3	$ 8,475	44
$ 900	2	$ 10,275	46
$ 1,000	1	$ 11,275	47
$ 1,250	2	$ 13,775	49
$ 1,875	4	$ 21,275	53
$ 2,000	2	$ 25,275	55
$ 2,000	3	$ 31,275	58
$ 3,000	2	$ 37,275	60
$ 4,750	6	$ 65,775	66
$ 10,000	3	$ 95,775	69

Table A.2: Exterior & Interior Finishes and Indoor Air Quality Math Sensitivity

Cost	Points	Exterior & Interior Finishes (3)	
		Accumulated Cost	Accumulated Points
$ -	1	$ -	1
$ -	1	$ -	2
$ -	1	$ -	3
$ -	2	$ -	5
$ -	1	$ -	6
$ -	2	$ -	8
$ -	3	$ -	11
$ -	2	$ -	13
$ -	2	$ -	15
$ -	2	$ -	17
$ -	4	$ -	21
$ 25	1	$ 25	22
$ 250	2	$ 525	24
$ 300	1	$ 825	25
$ 300	3	$ 1,725	28
$ 300	2	$ 2,325	30
$ 300	1	$ 2,625	31
$ 400	2	$ 3,425	33
$ 400	1	$ 3,825	34
$ 400	1	$ 4,225	35
$ 500	2	$ 5,225	37
$ 875	4	$ 8,725	41
$ 917	6	$ 14,227	47
$ 1,000	2	$ 16,227	49
$ 1,000	2	$ 18,227	51
$ 1,000	2	$ 20,227	53
$ 1,000	1	$ 21,227	54
$ 1,000	2	$ 23,227	56
$ 1,750	4	$ 30,227	60
$ 1,750	2	$ 33,727	62
$ 2,500	3	$ 41,227	65
$ 3,750	2	$ 48,727	67

Cost	Points	Indoor Air Quality (4)	
		Accumulated Cost	Accumulated Points
$ -	1	$ -	1
$ -	2	$ -	3
$ -	3	$ -	6
$ -	1	$ -	7
$ -	2	$ -	9
$ -	2	$ -	11
$ -	2	$ -	13
$ -	2	$ -	15
$ -	2	$ -	17
$ -	1	$ -	18
$ 50	1	$ 50	19
$ 90	2	$ 230	21
$ 100	1	$ 330	22
$ 100	3	$ 630	25
$ 150	2	$ 930	27
$ 250	2	$ 1,430	29
$ 300	6	$ 3,230	35
$ 333	3	$ 4,229	38
$ 500	2	$ 5,229	40
$ 500	3	$ 6,729	43
$ 500	1	$ 7,229	44
$ 600	4	$ 9,629	48
$ 800	1	$ 10,429	49
$ 1,000	2	$ 12,429	51
$ 1,000	2	$ 14,429	53
$ 3,000	2	$ 20,429	55
$ 3,500	2	$ 27,429	57

Table A.3: Ventilation and Waste Management Math Sensitivity

Cost	Points	Ventilation (5)	
		Accumulated Cost	Accumulated Points
$ -	2	$ -	2
$ -	1	$ -	3
$ 50	2	$ 100	5
$ 100	2	$ 300	7
$ 200	3	$ 900	10
$ 250	3	$ 1,650	13
$ 250	4	$ 2,650	17
$ 250	5	$ 3,900	22
$ 350	2	$ 4,600	24
$ 400	1	$ 5,000	25

Cost	Points	Waste Management (6)	
		Accumulated Cost	Accumulated Points
$ -	2	$ -	2
$ -	4	$ -	6
$ -	4	$ -	10
$ -	6	$ -	16
$ -	1	$ -	17
$ -	1	$ -	18
$ -	2	$ -	20
$ -	1	$ -	21
$ 33	3	$ 99	24
$ 150	2	$ 399	26
$ 500	3	$ 1,899	29
$ 2,500	4	$ 11,899	33

Table A.4: Waste Conservation and Business Practice Math Sensitivity

Cost	Points	Water Conservation (7) Accumulated Cost	Water Conservation (7) Accumulated Points
$ -	1	$ -	1
$ -	3	$ -	4
$ -	1	$ -	5
$ 50	3	$ 150	8
$ 75	4	$ 450	12
$ 150	3	$ 900	15
$ 200	3	$ 1,500	18
$ 250	4	$ 2,500	22
$ 250	3	$ 3,250	25
$ 300	2	$ 3,850	27
$ 333	4	$ 5,182	31
$ 800	1	$ 5,982	32
$ 800	2	$ 7,582	34
$ 1,000	3	$ 10,582	37
$ 1,167	6	$ 17,584	43
$ 1,666	3	$ 22,582	46
$ 2,000	4	$ 30,582	50

Cost	Points	Business Practice (8) Accumulated Cost	Business Practice (8) Accumulated Points
$ -	5	$ -	5
$ -	3	$ -	8
$ -	1	$ -	9
$ -	1	$ -	10
$ -	1	$ -	11
$ -	1	$ -	12
$ -	5	$ -	17
$ -	5	$ -	22
$ 1,000	2	$ 2,000	24
$ 3,000	3	$ 11,000	27
$ 5,000	3	$ 26,000	30

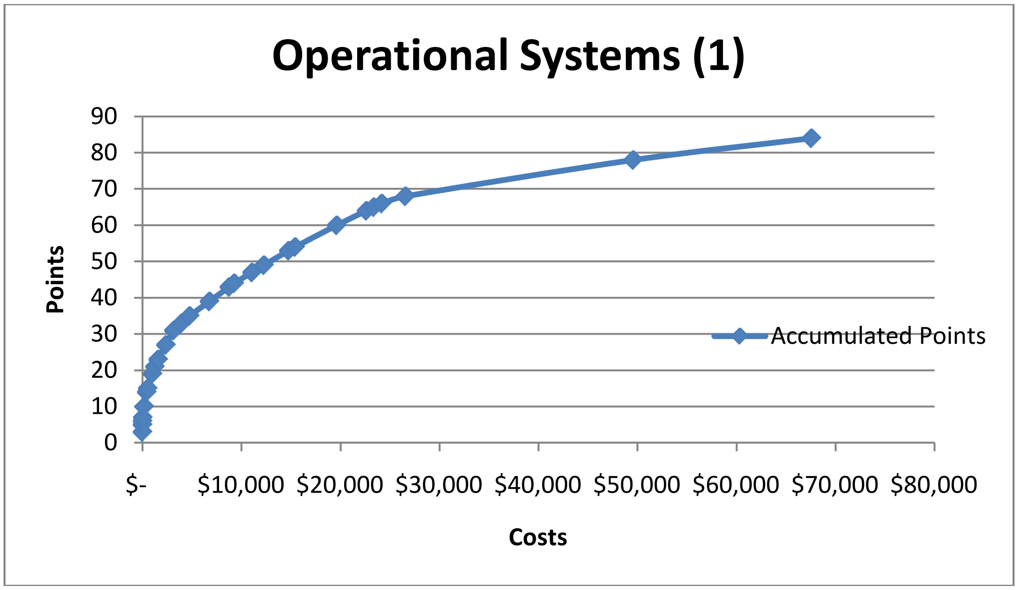

Figure A.1: Operational Systems Accumulated Points vs Costs

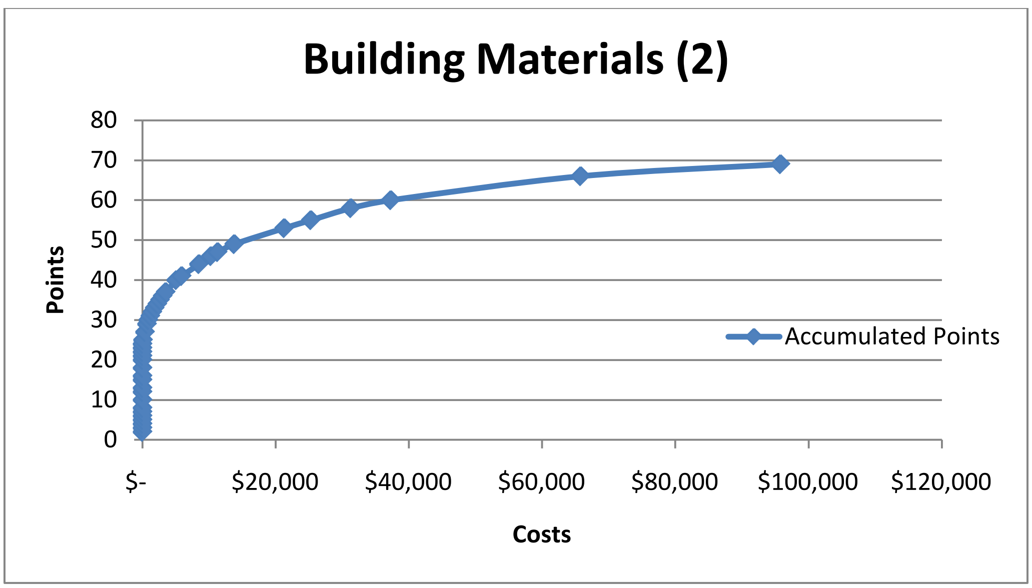

Figure A.2: Building Materials Accumulated Points vs Costs

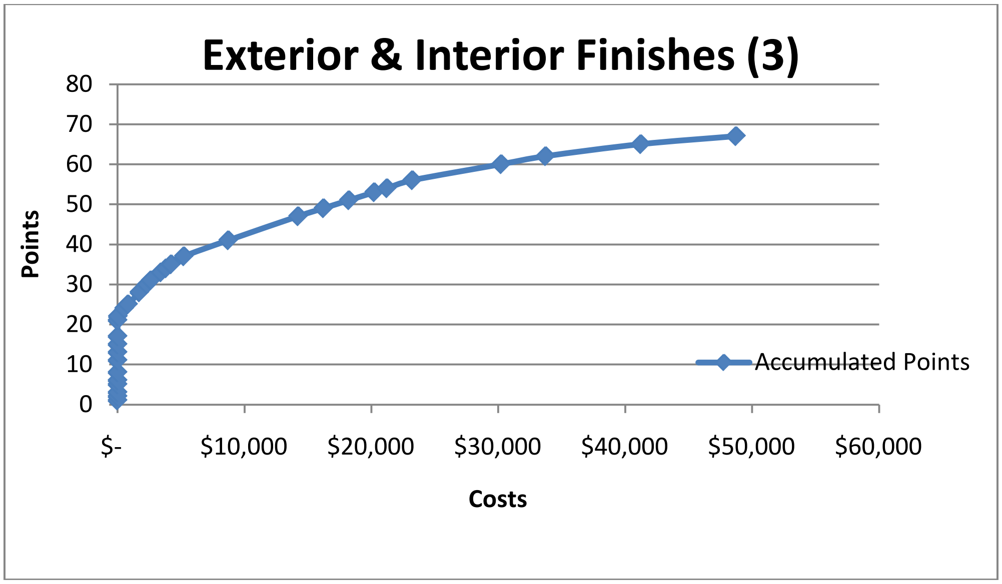

Figure A.3: Exterior & Interior Finishes Accumulated Points vs Costs

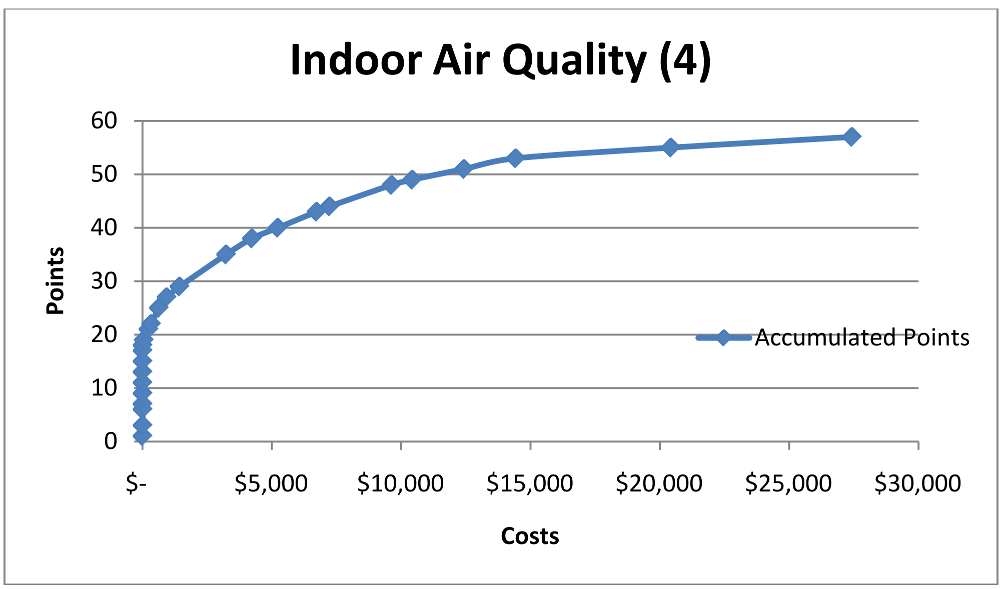

Figure A.4: Indoor Air Quality Accumulated Points vs Costs

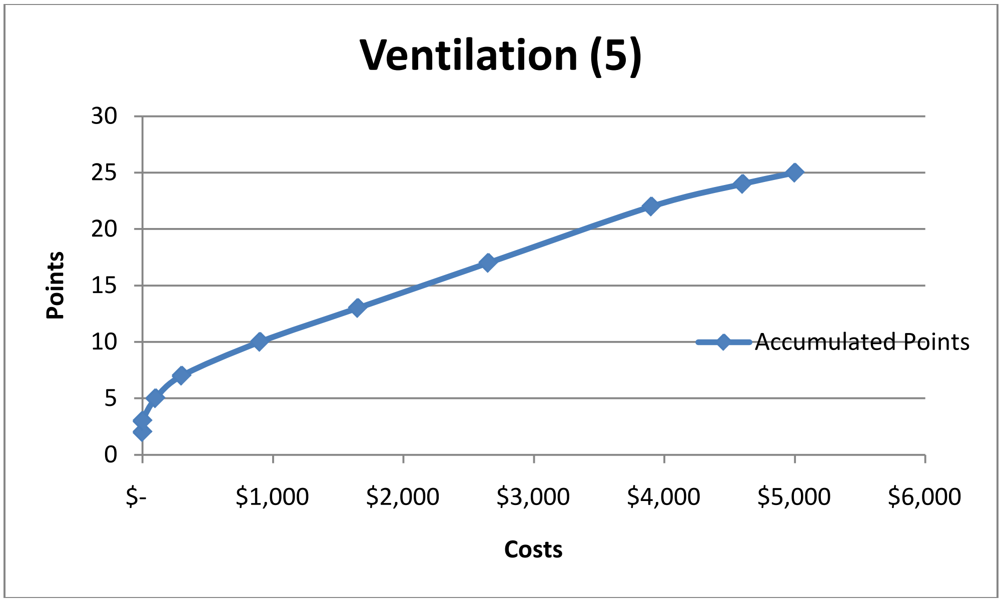

Figure A.5: Ventilation Accumulated Points vs Costs

Figure A.6: Waste Management Accumulated Points vs Costs

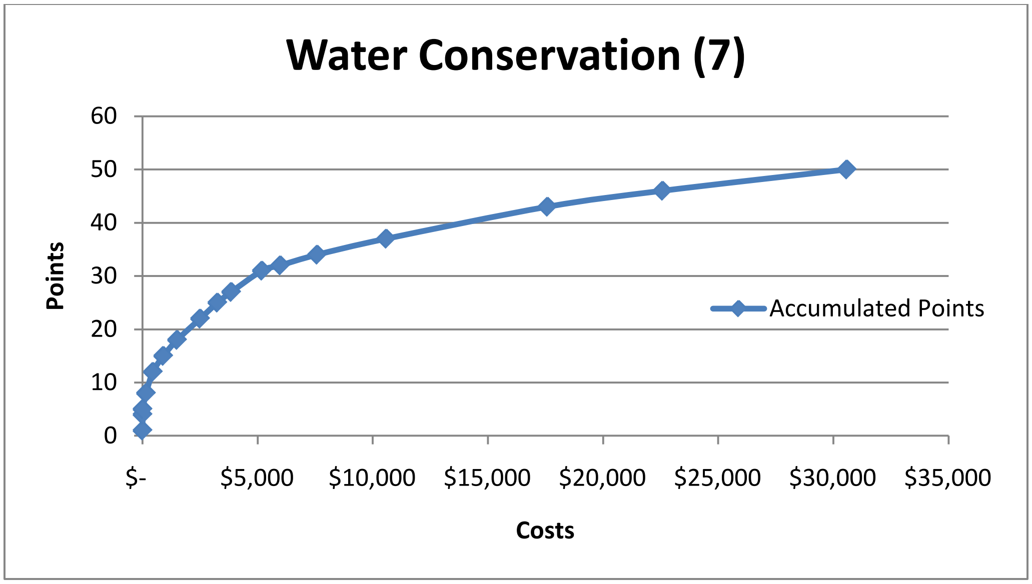

Figure A.7: Water Conservation Accumulated Points vs Costs

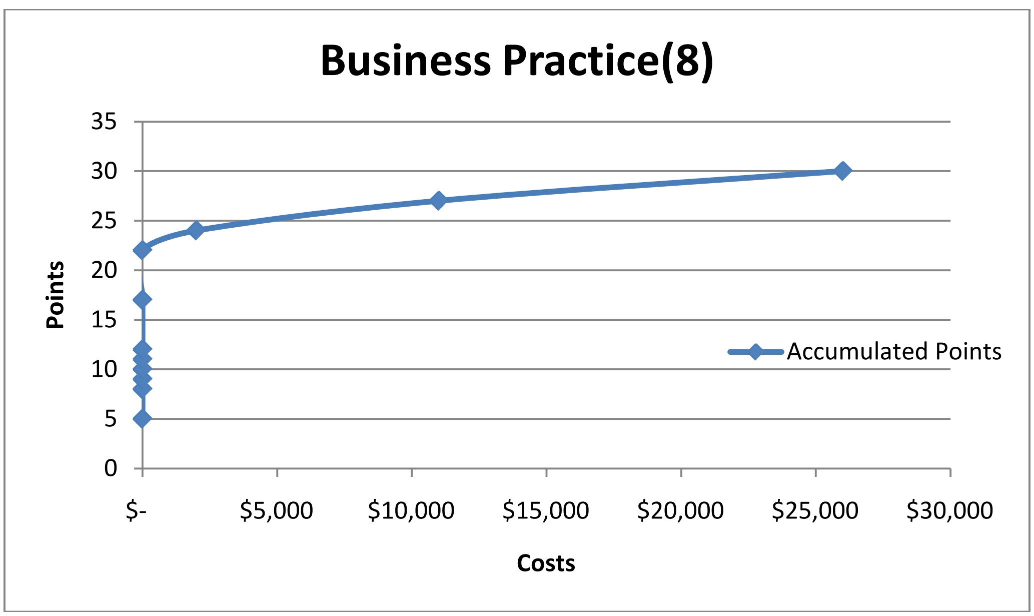

Figure A.8: Business Practice Accumulated Points vs Costs

Appendix B: Wood and Material Waste Data Forms

Table B.1: Wood Pieces Collection Form

Wood	Pieces
2 x 4: > 4" - 1'	
2 x 4: > 1' - 2'	
2 x 4: > 2' - 4'	
2 x 4: > 4' - 6'	
2 x 4: > 6' - 8'	
2 x 4: 8'	
2 x 4: 10'	
2 x 4: 12'	
2 x 4: 14'	
2 x 6: > 4" - 1'	
2 x 6: > 1' - 2'	
2 x 6: > 2' - 4'	
2 x 6: > 4' - 6'	
2 x 6: > 6' - 8'	
2 x 6: 8'	
2 x 6: 10'	
2 x 6: 12'	
2 x 6: 14'	
2 x 8: > 4" - 1'	
2 x 8: > 1' - 2'	
2 x 8: > 2' - 4'	
2 x 8: > 4' - 6'	
2 x 8: > 6' - 8'	
2 x 8: 8'	
2 x 8: 10'	
2 x 8: 12'	
2 x 8: 14'	
2 x 10: > 4" - 1'	
2 x 10: > 1' - 2'	
2 x 10: > 2' - 4'	
2 x 10: > 4' - 6'	
2 x 10: > 6' - 8'	
2 x 10: > 8'	
2 x 12: > 4" - 1'	
2 x 12: > 1' - 2'	
2 x 12: > 2' - 4'	
2 x 12: > 4' - 6'	
2 x 12: > 6' - 8'	
2 x 12: > 8'	

Pieces (floor)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'					
~ 2'					
~ 3'					
~ 4'					
~ 5'					
~ 6'					
~ 7'					
~ 8'					

Pieces (sheathing - wall/roof)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'					
~ 2'					
~ 3'					
~ 4'					
~ 5'					
~ 6'					
~ 7'					
~ 8'					

TJI - Joists	Pieces
4" - 1'	
1'- 2'	
2'- 3'	
3' - 4'	
> 4'	

Table B.2: Wood Pieces Collection Form – House #1

House #1

Wood	Pieces
2 x 4: > 4" - 1'	81
2 x 4: > 1' - 2'	46
2 x 4: > 2' - 4'	22
2 x 4: > 4' - 6'	12
2 x 4: > 6' - 8'	6
2 x 4: 8'	1
2 x 4: 10'	
2 x 4: 12'	
2 x 4: 14'	
2 x 6: > 4" - 1'	92
2 x 6: > 1' - 2'	49
2 x 6: > 2' - 4'	27
2 x 6: > 4' - 6'	2
2 x 6: > 6' - 8'	2
2 x 6: 8'	13
2 x 6: 10'	
2 x 6: 12'	
2 x 6: 14'	
2 x 8: > 4" - 1'	6
2 x 8: > 1' - 2'	14
2 x 8: > 2' - 4'	3
2 x 8: > 4' - 6'	
2 x 8: > 6' - 8'	
2 x 8: 8'	
2 x 8: 10'	
2 x 8: 12'	
2 x 8: 14'	
2 x 10: > 4" - 1'	
2 x 10: > 1' - 2'	6
2 x 10: > 2' - 4'	
2 x 10: > 4' - 6'	
2 x 10: > 6' - 8'	
2 x 10: > 8'	
2 x 12: > 4" - 1'	
2 x 12: > 1' - 2'	
2 x 12: > 2' - 4'	
2 x 12: > 4' - 6'	
2 x 12: > 6' - 8'	
2 x 12: > 8'	

Pieces (floor)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'	1				
~ 2'	2	2			
~ 3'	1	5	2		
~ 4'		8	1		
~ 5'	2				
~ 6'					
~ 7'					
~ 8'		4			

Pieces (sheathing - wall/roof)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'	4				
~ 2'	8	11			
~ 3'	1	11			
~ 4'	9	5		1	
~ 5'	2				
~ 6'					
~ 7'					
~ 8'					

TJI - Joists	Pieces
4" - 1'	12
1'- 2'	18
2'- 3'	3
3' - 4'	1
> 4'	

Table B.3: Wood Pieces Collection Form – House #2

House #2

Wood	Pieces
2 x 4: > 4" - 1'	76
2 x 4: > 1' - 2'	31
2 x 4: > 2' - 4'	20
2 x 4: > 4' - 6'	13
2 x 4: > 6' - 8'	1
2 x 4: 8'	0
2 x 4: 10'	0
2 x 4: 12'	0
2 x 4: 14'	0
2 x 6: > 4" - 1'	89
2 x 6: > 1' - 2'	33
2 x 6: > 2' - 4'	18
2 x 6: > 4' - 6'	5
2 x 6: > 6' - 8'	6
2 x 6: 8'	0
2 x 6: 10'	0
2 x 6: 12'	0
2 x 6: 14'	0
2 x 8: > 4" - 1'	9
2 x 8: > 1' - 2'	5
2 x 8: > 2' - 4'	7
2 x 8: > 4' - 6'	0
2 x 8: > 6' - 8'	2
2 x 8: 8'	0
2 x 8: 10'	0
2 x 8: 12'	0
2 x 8: 14'	0
2 x 10: > 4" - 1'	2
2 x 10: > 1' - 2'	2
2 x 10: > 2' - 4'	3
2 x 10: > 4' - 6'	2
2 x 10: > 6' - 8'	0
2 x 10: > 8'	0
2 x 12: > 4" - 1'	0
2 x 12: > 1' - 2'	0
2 x 12: > 2' - 4'	0
2 x 12: > 4' - 6'	0
2 x 12: > 6' - 8'	0
2 x 12: > 8'	0

Pieces (floor)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'	3				
~ 2'	7	5			
~ 3'	9	2			
~ 4'	1	1			
~ 5'					
~ 6'					
~ 7'					
~ 8'					

Pieces (sheathing - wall/roof)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'	5				
~ 2'	9	9			
~ 3'	15	4			
~ 4'	1	7	6	2	
~ 5'	1				
~ 6'	1	1			
~ 7'					
~ 8'	4				

TJI - Joists	Pieces
4" - 1'	12
1'- 2'	18
2'- 3'	4
3' - 4'	0
> 4'	4

Table B.4: Wood Pieces Collection Form – House #3

House #3

Wood	Pieces
2 x 4: > 4" - 1'	119
2 x 4: > 1' - 2'	58
2 x 4: > 2' - 4'	33
2 x 4: > 4' - 6'	9
2 x 4: > 6' - 8'	7
2 x 4: 8'	6
2 x 4: 10'	1
2 x 4: 12'	
2 x 4: 14'	10
2 x 6: > 4" - 1'	94
2 x 6: > 1' - 2'	50
2 x 6: > 2' - 4'	18
2 x 6: > 4' - 6'	3
2 x 6: > 6' - 8'	9
2 x 6: 8'	2
2 x 6: 10'	
2 x 6: 12'	
2 x 6: 14'	
2 x 8: > 4" - 1'	12
2 x 8: > 1' - 2'	14
2 x 8: > 2' - 4'	5
2 x 8: > 4' - 6'	
2 x 8: > 6' - 8'	
2 x 8: 8'	
2 x 8: 10'	
2 x 8: 12'	
2 x 8: 14'	
2 x 10: > 4" - 1'	5
2 x 10: > 1' - 2'	3
2 x 10: > 2' - 4'	2
2 x 10: > 4' - 6'	
2 x 10: > 6' - 8'	
2 x 10: > 8'	
2 x 12: > 4" - 1'	
2 x 12: > 1' - 2'	
2 x 12: > 2' - 4'	
2 x 12: > 4' - 6'	
2 x 12: > 6' - 8'	
2 x 12: > 8'	

Pieces (floor)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'	5				
~ 2'	9	5			
~ 3'	4	3			
~ 4'	8	2	4		
~ 5'					
~ 6'					
~ 7'	1	2			
~ 8'		1			

Pieces (sheathing - wall/roof)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'	6				
~ 2'	19	9			
~ 3'	11	16	6		
~ 4'	13	11			
~ 5'	4				
~ 6'	1				
~ 7'	1				
~ 8'	1				

TJI - Joists	Pieces
4" - 1'	7
1'- 2'	8
2'- 3'	12
3' - 4'	5
> 4'	9

Table B.5: Wood Pieces Collection Form – House #4

House #4

Wood	Pieces
2 x 4: > 4" - 1'	103
2 x 4: > 1' - 2'	33
2 x 4: > 2' - 4'	36
2 x 4: > 4' - 6'	5
2 x 4: > 6' - 8'	1
2 x 4: 8'	0
2 x 4: 10'	0
2 x 4: 12'	0
2 x 4: 14'	0
2 x 6: > 4" - 1'	168
2 x 6: > 1' - 2'	59
2 x 6: > 2' - 4'	4
2 x 6: > 4' - 6'	12
2 x 6: > 6' - 8'	1
2 x 6: 8'	
2 x 6: 10'	
2 x 6: 12'	
2 x 6: 14'	
2 x 8: > 4" - 1'	16
2 x 8: > 1' - 2'	4
2 x 8: > 2' - 4'	2
2 x 8: > 4' - 6'	1
2 x 8: > 6' - 8'	2
2 x 8: 8'	
2 x 8: 10'	
2 x 8: 12'	
2 x 8: 14'	
2 x 10: > 4" - 1'	12
2 x 10: > 1' - 2'	3
2 x 10: > 2' - 4'	1
2 x 10: > 4' - 6'	5
2 x 10: > 6' - 8'	
2 x 10: > 8'	
2 x 12: > 4" - 1'	
2 x 12: > 1' - 2'	
2 x 12: > 2' - 4'	
2 x 12: > 4' - 6'	
2 x 12: > 6' - 8'	
2 x 12: > 8'	

Pieces (floor)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'	1				
~ 2'	9	2			
~ 3'	1	3			
~ 4'	10	2	1		
~ 5'	1				
~ 6'	1	1			
~ 7'					
~ 8'					

Pieces (sheathing - wall/roof)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'	8				
~ 2'	3	11			
~ 3'	8	7	1		
~ 4'	6	7	2		
~ 5'	1	3			
~ 6'	2	1			
~ 7'	1		3		
~ 8'	1			2	

TJI - Joists	Pieces
4" - 1'	22
1'- 2'	20
2'- 3'	2
3' - 4'	1
> 4'	0

Table B.6: Wood Pieces Collection Form – House #5

House #5

Wood	Pieces
2 x 4: > 4" - 1'	113
2 x 4: > 1' - 2'	33
2 x 4: > 2' - 4'	27
2 x 4: > 4' - 6'	5
2 x 4: > 6' - 8'	9
2 x 4: 8'	5
2 x 4: 10'	0
2 x 4: 12'	0
2 x 4: 14'	0
2 x 6: > 4" - 1'	109
2 x 6: > 1' - 2'	31
2 x 6: > 2' - 4'	15
2 x 6: > 4' - 6'	1
2 x 6: > 6' - 8'	5
2 x 6: 8'	1
2 x 6: 10'	
2 x 6: 12'	
2 x 6: 14'	
2 x 8: > 4" - 1'	13
2 x 8: > 1' - 2'	14
2 x 8: > 2' - 4'	5
2 x 8: > 4' - 6'	
2 x 8: > 6' - 8'	1
2 x 8: 8'	1
2 x 8: 10'	
2 x 8: 12'	
2 x 8: 14'	
2 x 10: > 4" - 1'	1
2 x 10: > 1' - 2'	3
2 x 10: > 2' - 4'	4
2 x 10: > 4' - 6'	1
2 x 10: > 6' - 8'	
2 x 10: > 8'	
2 x 12: > 4" - 1'	
2 x 12: > 1' - 2'	
2 x 12: > 2' - 4'	
2 x 12: > 4' - 6'	
2 x 12: > 6' - 8'	
2 x 12: > 8'	

Pieces (floor)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'					
~ 2'	4				
~ 3'		2			
~ 4'	1	3			
~ 5'					
~ 6'					
~ 7'					
~ 8'	1				

Pieces (sheathing - wall/roof)					
Length	Width				
0	~ 1'	~ 2'	~ 3'	~ 4'	
~ 1'	7				
~ 2'	10	1			
~ 3'	2	3			
~ 4'	3	1		3	
~ 5'	1				
~ 6'	1		1		
~ 7'	1				
~ 8'	1			1	

TJI - Joists	Pieces
4" - 1'	21
1'- 2'	4
2'- 3'	7
3' - 4'	0
> 4'	6

Table B.7: Material Waste Pick-Up Field Form

Material	(%)	Job/Reference #	
Wood (dimensional eg. 2x4)		Address	
Wood (plywood, osb, etc.)		Date	
Drywall		Time In :: Time Out	::
Cardboard (packaging)		Builder	
Metals		Pick Up Type (e.g. framing)	
Concrete		Truck Capacity [yd3]	
Plastics		Truck: Volume/Capacity (%)	
Other		Weight [tonnes] In :: Out	::
Total	100%	Load: Jobs/References #	

Table B.8: Material Waste Pick-Up Field Form Summary

Onsite Construction Material Waste Identification and Quantification						
Reference	#1	#2	#3	#4	#5	Averages
Address	122 Rue Marquet	9131 -205 Strett	20611-91 Avenue	20707-56 Avenue	20532-92 Avenue	
Weight (kg)	970	1060	965			
Volume (cu.m.)	8	8	8			
Material (%)						
Wood (dimensional eg. 2x4)	40	35	45	60	65	**49.0**
Wood (plywood, osb, etc.)	55	35	45	35	30	**40.0**
Drywall	0	0	0	0	0	**0.0**
Cardboard (packaging)	3	1			1	**1.7**
Metals	1	1		1	1	**1.0**
Concrete	0	0	0	0	0	**0.0**
Plastics	0	0	0	1	0	**0.2**
Other	1	28	10	3	3	**9.0**
Total (100%)	100	100	100	100	100	**100.9**

Appendix C: Wood Waste Field Collection Tables

Table C.1: On-site Method Raw Waste Data

Address	122 Rue Marquet	9131 -205 Street	20611-91 Avenue	20707-56 Avenue	20532-92 Avenue
House Model	Catalina II A	Catalina II A	Catalina II A	Catalina II A	Catalina II A
Wood					
2 x 4: > 4" - 1'	81	76	119	103	113
2 x 4: > 1' - 2'	46	31	58	33	33
2 x 4: > 2' - 4'	22	20	33	36	27
2 x 4: > 4' - 6'	12	13	9	5	5
2 x 4: > 6' - 8'	6	1	7	1	9
2 x 4: > 8'	1	0	6	0	5
2 x 4: > 10'	0	0	1	0	0
2 x 4: > 12'	0	0	0	0	0
2 x 4: > 14'	0	0	10	0	0
2 x 6: > 4" - 1'	92	89	94	168	109
2 x 6: > 1' - 2'	49	33	50	59	31
2 x 6: > 2' - 4'	0	0	0	0	0
2 x 6: > 4' - 6'	0	0	0	0	0
2 x 6: > 6' - 8'	0	0	0	0	0
2 x 6: > 8'	0	0	0	0	0
2 x 6: > 10'	0	0	0	0	0
2 x 6: > 12'	0	0	0	0	0
2 x 6: > 14'	0	0	0	0	0

2 x 8: > 4" - 1'	6	9	12	16	13
2 x 8: > 1' - 2'	14	5	14	4	14
2 x 8: > 2' - 4'	3	7	5	2	5
2 x 8: > 4' - 6'	0	0	0	1	0
2 x 8: > 6' - 8'	0	2	0	2	1
2 x 8: > 8'	0	0	0	0	1
2 x 8: > 10'	0	0	0	0	0
2 x 8: > 12'	0	0	0	0	0
2 x 8: > 14'	0	0	0	0	0
2 x 10: > 4" - 1'	0	2	5	12	1
2 x 10: > 1' - 2'	6	2	3	3	3
2 x 10: > 2' - 4'	0	3	2	1	4
2 x 10: > 4' - 6'	0	2	0	5	1
2 x 10: > 6' - 8'	0	0	0	0	0
2 x 10: > 8'	0	0	0	0	0
TJI - Joists					
4" - 1'	12	12	7	22	21
1'- 2'	18	18	8	20	4
2'- 3'	3	4	12	2	7
3' - 4'	1	0	5	1	0
> 4'	0	4	9	0	6

Table C.2: On-site Method Raw Waste Data (Continued)

OSB - Flooring					
1x1 sq ft	1	3	5	1	0
2x1 sq ft	2	7	9	9	4
3x1 sq ft	1	9	4	1	0
4x1 sq ft	0	1	8	10	1
5x1 sq ft	2	0	0	1	0
6x1 sq ft	0	0	0	1	0
7x1 sq ft	0	0	1	0	0
8x1 sq ft	0	0	0	0	1
2x2 sq ft	2	5	5	2	0
3x2 sq ft	5	2	3	3	2
4x2 sq ft	1	1	2	2	3
5x2 sq ft	0	0	0	0	0
6x2 sq ft	0	0	0	1	0
7x2 sq ft	0	0	2	0	0
8x2 sq ft	4	0	1	0	0
3x3 sq ft	2	0	0	0	0
4x3 sq ft	1	0	4	1	0
5x3 sq ft	0	0	0	0	0
6x3 sq ft	0	0	0	0	0
7x3 sq ft	0	0	0	0	0
8x3 sq ft	0	0	0	0	0
4x4 sq ft	0	0	0	0	0
5x4 sq ft	0	0	0	0	0
6x4 sq ft	0	0	0	0	0
7x4 sq ft	0	0	0	0	0
8x4 sq ft	0	0	0	0	0
OSB - Wall/Roof					
1x1 sq ft	4	5	6	8	7
2x1 sq ft	8	9	19	3	10
3x1 sq ft	1	15	11	8	2
4x1 sq ft	9	1	13	6	3
5x1 sq ft	2	1	4	1	1
6x1 sq ft	0	1	1	2	1
7x1 sq ft	0	0	1	1	1
8x1 sq ft	0	4	1	1	1
2x2 sq ft	11	9	9	11	1
3x2 sq ft	11	4	16	7	3
4x2 sq ft	5	7	11	7	1
5x2 sq ft	0	0	0	3	0
6x2 sq ft	0	1	0	1	0
7x2 sq ft	0	0	0	0	0

8x2 sq ft	0	0	0	0	0
3x3 sq ft	0	0	6	1	0
4x3 sq ft	0	6	0	2	0
5x3 sq ft	0	0	0	0	0
6x3 sq ft	0	0	0	0	1
7x3 sq ft	0	0	0	3	0
8x3 sq ft	0	0	0	0	0
4x4 sq ft	1	2	0	0	3
5x4 sq ft	0	0	0	0	0
6x4 sq ft	0	0	0	0	0
7x4 sq ft	0	0	0	0	0
8x4 sq ft	0	0	0	2	1

Table C.3: On-site Waste Analyses

		On-site					**On-site Average**
Address		122 Rue Marquet	9131 -205 Street	20611-91 Avenue	20707-56 Avenue	20532-92 Avenue	
House Model		Catalina II A	Catalina II A	Catalina II A	Catalina II A	Catalina II A	
House Size (sqf.)		1703	1696	1704	1704	1704	1702.20
Wood	**M.F.**						
2 x 4: > 4" - 1'	0.67	81	76	119	103	113	98.40
2 x 4: > 1' - 2'	1.5	46	31	58	33	33	40.20
2 x 4: > 2' - 4'	3	22	20	33	36	27	27.60
2 x 4: > 4' - 6'	5	12	13	9	5	5	8.80
2 x 4: > 6' - 8'	7	6	1	7	1	9	4.80
2 x 4: > 8'	8	1	0	6	0	5	2.40
2 x 4: > 10'	10	0	0	1	0	0	0.20
2 x 4: > 12'	12	0	0	0	0	0	0.00
2 x 4: > 14'	14	0	0	10	0	0	2.00
lb/bf	**1.28**	**299.00**	**229.17**	**557.33**	**258.17**	**333.83**	**335.50 20.39%**

2 x 6: > 4" - 1'	0.67	92	89	94	168	109	110.40
2 x 6: > 1' - 2'	1.5	49	33	50	59	31	44.40
2 x 6: > 2' - 4'	3	0	0	0	0	0	0.00
2 x 6: > 4' - 6'	5	0	0	0	0	0	0.00
2 x 6: > 6' - 8'	7	0	0	0	0	0	0.00
2 x 6: > 8'	8	0	0	0	0	0	0.00
2 x 6: > 10'	10	0	0	0	0	0	0.00
2 x 6: > 12'	12	0	0	0	0	0	0.00
2 x 6: > 14'	14	0	0	0	0	0	0.00
lb/bf	**2.00**	**134.83**	**108.83**	**137.67**	**200.50**	**119.17**	**140.20**
							13.31%
2 x 8: > 4" - 1'	0.67	6	9	12	16	13	11.20
2 x 8: > 1' - 2'	1.5	14	5	14	4	14	10.20
2 x 8: > 2' - 4'	3	3	7	5	2	5	4.40
2 x 8: > 4' - 6'	5	0	0	0	1	0	0.20
2 x 8: > 6' - 8'	7	0	2	0	2	1	1.00
2 x 8: > 8'	8	0	0	0	0	1	0.20
2 x 8: > 10'	10	0	0	0	0	0	0.00
2 x 8: > 12'	12	0	0	0	0	0	0.00
2 x 8: > 14'	14	0	0	0	0	0	0.00
lb/bf	**2.64**	**34.00**	**48.50**	**44.00**	**41.67**	**59.67**	**45.57**
							5.71%
2 x 10: > 4" - 1'	0.67	0	2	5	12	1	4.00
2 x 10: > 1' - 2'	1.5	6	2	3	3	3	3.40

2 x 10: > 2' - 4'	3	0	3	2	1	4	2.00
2 x 10: > 4' - 6'	5	0	2	0	5	1	1.60
2 x 10: > 6' - 8'	7	0	0	0	0	0	0.00
2 x 10: > 8'	8	0	0	0	0	0	0.00
lb/bf	**3.37**	**9.00**	**23.33**	**13.83**	**40.50**	**22.17**	**21.77**
							3.48%
Weight (kg)		**351.13**	**326.22**	**523.41**	**444.52**	**408.12**	**410.68**
		42.35%	**39.89%**	**39.24%**	**41.47%**	**55.61%**	**42.90%**

Table C.3: On-site Waste Analyses (Continued)

TJI - Joists							
4" - 1'	0.67	12	12	7	22	21	14.80
1'- 2'	1.5	18	18	8	20	4	13.60
2'- 3'	2.5	3	4	12	2	7	5.60
3' - 4'	3.5	1	0	5	1	0	1.40
> 4'	4	0	4	9	0	6	3.80
kg/bf	**1.36**	**46.00**	**61.00**	**100.17**	**53.17**	**61.50**	**64.37**
Weight (kg)		**62.56**	**82.96**	**136.23**	**72.31**	**83.64**	**87.54**
		7.54%	**10.14%**	**10.21%**	**6.75%**	**11.40%**	**9.14%**
OSB - Flooring							
1x1 sq ft	1	1	3	5	1	0	2.00
2x1 sq ft	2	2	7	9	9	4	6.20
3x1 sq ft	3	1	9	4	1	0	3.00
4x1 sq ft	4	0	1	8	10	1	4.00
5x1 sq ft	5	2	0	0	1	0	0.60
6x1 sq ft	6	0	0	0	1	0	0.20
7x1 sq ft	7	0	0	1	0	0	0.20
8x1 sq ft	8	0	0	0	0	1	0.20
2x2 sq ft	4	2	5	5	2	0	2.80
3x2 sq ft	6	5	2	3	3	2	3.00
4x2 sq ft	8	1	1	2	2	3	1.80
5x2 sq ft	10	0	0	0	0	0	0.00
6x2 sq ft	12	0	0	0	1	0	0.20
7x2 sq ft	14	0	0	2	0	0	0.40
8x2 sq ft	16	4	0	1	0	0	1.00
3x3 sq ft	9	2	0	0	0	0	0.40
4x3 sq ft	12	1	0	4	1	0	1.20
5x3 sq ft	15	0	0	0	0	0	0.00
6x3 sq ft	18	0	0	0	0	0	0.00
7x3 sq ft	21	0	0	0	0	0	0.00
8x3 sq ft	24	0	0	0	0	0	0.00
4x4 sq ft	16	0	0	0	0	0	0.00
5x4 sq ft	20	0	0	0	0	0	0.00
6x4 sq ft	24	0	0	0	0	0	0.00
7x4 sq ft	28	0	0	0	0	0	0.00
8x4 sq ft	32	0	0	0	0	0	0.00
kg/sq.ft	**1.41**	**158.00**	**88.00**	**220.00**	**139.00**	**56.00**	**132.20**
Weight (kg)		**222.78**	**124.08**	**310.20**	**195.99**	**78.96**	**186.40**
		26.87%	**15.17%**	**23.25%**	**18.28%**	**10.76%**	**19.47%**

Table C.4: On-Site Delivered Material Analyses

		On-site					On-site Average
Address		122 Rue Marquet	9131 -205 Strett	20611-91 Avenue	20707-56 Avenue	20532-92 Avenue	
House Model		Catalina II A	Catalina II A	Catalina II A	Catalina II A	Catalina II A	
House Size		1703	1696	1704	1704	1704	1702.20
Wood	M. F.						
2 x 4 x 92 5/8"	8.29	200	242	200	200	200	208.40
2 x 4 x 104 5/8"	16.96						
2 x 4 x 8'	8	45	0	45	42	51	36.60
2 x 4 x 10'	10	30	30	30	30	30	30.00
2 x 4 x 12'	12						
2 x 4 x 14'	14	112	111	112	104	112	110.20
2 x 4 x 16'	16						
2 x 4 x 18'	18						
lb/bf	**1.28**	**3886.00**	**3860.18**	**3886.00**	**3750.00**	**3934.00**	**3863.24**
		4974.08	**4941.03**	**4974.08**	**4800.00**	**5035.52**	**2247.70**
							14.47%
2 x 6 x 92 5/8"	8.29	250	250	250	250	250	250.00
2 x 6 x 104 5/8"	16.96						
2 x 6 x 8'	8	2	2	2	2	8	3.20
2 x 6 x 10'	10	70	70	70	70	70	70.00
2 x 6 x 12'	12	12	12	12	12	12	12.00
2 x 6 x 14'	14	101	101	101	101	101	101.00
2 x 6 x 16'	16						
2 x 6 x 18'	18	1	1	1	1	1	1.00
lb/bf	**2.00**	**4364.50**	**4364.50**	**4364.50**	**4364.50**	**4412.50**	**4374.10**
		8729.00	**8729.00**	**8729.00**	**8729.00**	**8825.00**	**3976.45**
							25.60%
2 x 8 x 92 5/8"	8.29						
2 x 8 x 104 5/8"	16.96						
2 x 8 x 8'	8	13	13	13	13	13	13.00
2 x 8 x 10'	10	2	2	2	2	2	2.00

2 x 8 x 12'	12	20	20	20	20	20	20.00
2 x 8 x 14'	14	2	0	0	0	0	0.40
2 x 8 x 16'	16	22	22	22	22	22	22.00
2 x 8 x 18'	18						
lb/bf	**2.64**	**744.00**	**716.00**	**716.00**	**716.00**	**716.00**	**721.60**
		1964.16	**1890.24**	**1890.24**	**1890.24**	**1890.24**	**865.92**
							5.57%
2 x 10 x 92 5/8"	8.29						
2 x 10 x 104 5/8"	16.96						
2 x 10 x 8'	8	2	2	2	2	2	2.00
2 x 10 x 10'	10	13	13	13	13	13	13.00
2 x 10 x 12'	12	8	8	8	8	8	8.00
2 x 10 x 14'	14						
2 x 10 x 16'	16						
2 x 10 x 18'	18						
lb/bf	**3.37**	**242.00**	**242.00**	**242.00**	**242.00**	**242.00**	**242.00**
		815.54	**815.54**	**815.54**	**815.54**	**815.54**	**370.70**
							2.39%
Weight (kg)		**7492.17**	**7443.55**	**7458.57**	**7379.45**	**7530.14**	**7460.78**
							48.03%

Table C.3: On-site Delivered Material Analyses (Continued)

TJI - Joists							
kg/bf	**1.36**	**907.00**	**928.00**	**916.00**	**932.00**	**916.00**	**919.80**
Weight (kg)		**1233.52**	**1262.08**	**1245.76**	**1267.52**	**1245.76**	**1250.93**
							8.05%
OSB - Flooring							
8x4 sq ft	**32**	**60**	**60**	**60**	**60**	**60**	**60.00**
kg/sq.ft	**1.41**	**1920.00**	**1920.00**	**1920.00**	**1920.00**	**1920.00**	**1920.00**
Weight (kg)		**2707.2**	**2707.2**	**2707.2**	**2707.2**	**2707.2**	**2707.20**
							17.43%
OSB - Wall/Roof							
8x4 sq ft	**32**	**158**	**155**	**158**	**155**	**158**	**156.80**
kg/sq.ft	**0.82**	**5056.00**	**4960.00**	**5056.00**	**4960.00**	**5056.00**	**5017.60**
Weight (kg)		**4145.92**	**4067.20**	**4145.92**	**4067.20**	**4145.92**	**4114.43**
							26.49%
Total Calculated Weight (Kg)		**15578.81**	**15480.03**	**15557.45**	**15421.37**	**15629.02**	**15533.34**
Waste Weight (Kg)		**829.17**	**817.80**	**1333.92**	**1071.97**	**733.90**	**957.35**
Wastage (%)		**5.32%**	**5.28%**	**8.57%**	**6.95%**	**4.70%**	**6.16%**

Appendix D: SEE Evaluation Form (Blank)

SEE Evaluation Form

Points: Not Applicable (O Point), Initiated (1 point), Intermediate (3 points), Integrated (5 points)

Assign a maximum of 5 points for each sub-criteria (hence, maximum of 15 points per criteria)

SOCIAL—SUSTAINABILITY DIRECTOR

Cat.	Points	Function/Practice
S-1-1		**Vision**: Have a clear vision for how sustainability relates to your organization's mission 1. Develop a business case for pursuing sustainability 2. Develop interim and long-term vision of your organization's role in a fully sustainable society 3. Get support of leadership to communicate these long-term goals (obtain executive support for pursuing sustainability initiatives)
S-1-2		**Reporting**: Regularly report on the results of sustainability efforts 1. Report to management at least annually about the benefits and costs of sustainability projects 2. Develop and publish an internal sustainability report 3. Report to management and other stakeholders on sustainability performance via a publicly available sustainability report

SOCIAL—PURCHASING

Cat.	Points	Function/Practice
S-2-1		**Policy**: Have a purchasing policy related to sustainability 1. Have a formal sustainable or environmentally preferable purchasing policy and waste reduction 2. Have meaningful reinforcement and audit systems for assessing progress toward sustainable purchasing 3. Evaluate major purchases based on sustainability
S-2-2		**Supplier influence**: Choose suppliers based in part on their sustainability performance 1. Switch to electronic billing and payments 2. Send out letters and/or surveys to suppliers to express your commitment to sustainability and your intent to give preference to sustainable suppliers 3. Use contractors that share a commitment to sustainability (e.g., banks, janitorial, landscaping, courier, catering, etc.). Write sustainability criteria and requirements into contract language for all contractors

SOCIAL—HUMAN RESOURCES

Cat.	Points	Function/Practice
S-3-1		**Employee orientation and training**: Provide ongoing sustainability education for all employees 1. Provide training to employees involved with sustainability efforts. Routinely offer training on advanced sustainability practices 2. Adopt learning and knowledge management programs such as intranet, staff meetings, repositories 3. Speak regularly to other groups about your efforts, encouraging them to adopt sustainable practices
S-3-2		**Culture and organizational climate**: Make sustainability "how we do things here" and provide a respectful and productive workplace 1. Develop an empowered culture where employees routinely come up with ways to improve performance; sustainability is one of the areas employees focus on 2. Demonstrate through word and action that sustainability is a core value of the organization 3. Conduct an employee survey at least every two years and act on the results (including such elements as employee involvement, diversity, work/life balance, living wage jobs)
S-3-3		**Volunteering and charities**: Support the communities in which you operate or affect 1. Have programs that encourage employees to donate to charities and to volunteer; encourage charitable participation with matching donations 2. Allow employees to volunteer during paid work time 3. Select certain charities or social/ environmental issue(s) that are strategic to your organization and provide at least 40 hours per person of pro bono services per year
S-3-4		**Talent attraction & retention** 1. Actively recruit from and provide jobs for people from disadvantaged populations (e.g., people with disabilities, minorities, at-risk youth) 2. Develop conflict resolution system and cultural diversity/tolerance program 3. Develop program for handling of grievances and complaints (e.g., whistle-blowing policy and helpline)

SOCIAL—SENIOR MANAGEMENT

Cat.	**Points**	**Function/Practice**
S-4-1		**Executive education**: Provide executives with education on sustainability 1. Expose executives to sustainability through articles, speakers and other methods 2. Provide executives formal training on sustainability and incorporate discussions of its relevance in planning meetings 3. Make sustainability knowledge and commitment a selection and performance criterion for executives
S-4-2		**Commitment**: Demonstrate commitment to sustainability through accountability and resources 1. Require each department work on sustainability initiatives and goals 2. Build sustainability into budgets, reviews, selection criteria, and compensation 3. Integrate sustainability into mission
S-4-3		**Transparency and stakeholder involvement**: Operate in a transparent and involving manner 1. Provide access to complete and accurate performance data to investors, regulators and the public 2. Provide mechanisms to solicit input from all major stakeholder groups 3. Conduct regular, formal assessments of stakeholder expectations and satisfaction levels
S-4-4		**Codes of conduct/compliance/corruption & bribery** 1. Ensure mechanisms are in place to assure effective implementation of your company's codes of conduct 2. Dedicate help desks, focal points, ombudsman, hot lines 3. Enforce disciplinary actions in case of breach, i.e., warning, dismissal, zero tolerance

SOCIAL—PUBLIC RELATIONS

Cat.	Points	Function/Practice
S-5-1		**PR/outreach strategy**: Educate stakeholders about your sustainability efforts 1. Promote sustainability as part of your image to those stakeholders or markets that will care 2. Produce a publicly available formal annual sustainability report which portrays your progress as well as your areas for improvement. 3. Identify your major stakeholders and actively assess their trust, perception and ideas for improvement
S-5-2		**Incident/emergency response and media communications** 1. Provide timely, accurate and complete information to authorities and the public when a crisis does occur; give higher priority to protecting public health and the environment than protecting your short-term financial interests and image 2. Provide access for the media and public about incidents and responses (e.g., via website) 3. Operate with transparency, avoiding the temptation to spin bad news in your favor
S-5-3		**Privacy protection** 1. Develop formal privacy policy (ensure mechanisms in place to ensure effective implementation) 2. Enforce disciplinary actions (i.e., zero tolerance) 3. Communicate to customers on the kind of information collected and its use

ENVIRONMENTAL—FACILITIES

Cat.	Points	Function/Practice
E-1-1		**Energy**: Reduce environmental and social impacts associated with energy use through conservation, renewables, and production 1. Conduct energy audit and act on results 2. Have in place systems for monitoring and reducing both from equipment and human behavior 3. Purchase or produce at least 50% renewable energy
E-1-2		**Waste**: Move toward a zero waste facility 1. Conduct waste audit and act on results. Have programs in place for waste reduction (e.g, recycling is more convenient than trash receptacles, monitoring and feedback systems, signage, etc.) 2. Provide incentives for employees and haulers to divert resources from the waste stream 3. Achieve zero waste (at least 90% reduction in solid waste going to the landfill) while directing residual products to the "next best use" whenever practical
E-1-3		**Parking and transportation facilities** 1. Provide free parking for carpoolers, provide bike parking and shower facilities 2. Subsidize bus passes and/or provide other incentives for alternative transportation 3. Choose sites that permit commuting choices, including convenient alternative transportation
E-1-4		**Janitorial**: Use cleaning and pest control products and methods that minimize toxics 1. Ensure that 50% or more by volume are green cleaning products (Green Seal, Green Cross, UGCA or equivalent). For janitorial paper products, source ones with high recycled content 2. Ensure 75% of the cleaning products are green/sustainable and nontoxic pest control methods are used. Apply integrated pest management practices 3. Ensure 100% of the cleaning products are green/sustainable and nontoxic pest control methods are used

ENVIRONMENTAL—OFFICE MANAGEMENT

Cat.	Points	Function/Practice
E-2-1		**Office supplies and equipment**: Minimize impacts associated with office supplies, furnishings and equipment 1. Have a program in place for routinely assessing the impacts of purchases and working on finding better options 2. Ensure 80% or more of office supplies and equipment come from sustainable sources (i.e., from a certified sustainable source, 100% post-consumer waste, recyclable, product take-back, etc.) 3. Adopt a paperless policy
E-2-2		**Contract services**: Use contractors that share a commitment to sustainability (e.g., banks, janitorial, landscaping, courier, catering, etc.) 1. Notify all major contractors/suppliers of your commitment to sustainability 2. Implement a program for evaluating contractors on their sustainability practices. Write sustainability criteria and requirements into contract language for all contractors 3. Actively influence contractors not hired directly (e.g., work with building owner or create collaborative purchasing programs with building tenants)
E-2-3		**Transportation**: Actively promote the reduction of climate impacts associated with transportation of people and documents/materials 1. Encourage alternative transportation for commuting through incentives and other means (e.g., paid parking, carshare, etc.). For correspondence freight and business travel, use the lowest impact carrier that will meet the needs of the parties involved 2. Offer incentives to contractors and customers to reduce fossil fuel use 3. Be climate neutral for all organizational transportation and for at least 25% of commuting impacts

ENVIRONMENTAL—ENVIRONMENTAL AFFAIRS

Cat.	Points	Function/Practice
E-3-1		**Sustainability management systems** 1. Actively promote industry-wide practices and standards that protect public health and the environment 2. Have an ISO 14001- conformant environmental system 3. Include goals associated with customer and supplier impacts
E-3-2		**Environmental policy/management system** 1. Adopt a corporate environmental policy 2. Measure environmental impacts of products & services 3. Enroll in third party sustainability program (e.g., The Natural Step)
E-3-3		**Sustainability reporting**: Make available and use qualitative and quantitative data on your progress toward sustainability 1. Produce an internal report highlighting accomplishments and areas for improvement 2. Include sustainability reporting as part of existing public reports for liaison and permitting purposes 3. Publish a separate, detailed and audited sustainability report

ENVIRONMENTAL—OPERATIONS

Cat.	Points	Function/Practice
E-4-1		**Health & Safety** 1. Implement occupational health and safety policy into operations 2. Provide employee safety and orientation program for new hires 3. Demonstrate reduction of WCB claims
E-4-2		**Design/Drafting** 1. Utilize BIM to facilitate analysis of designs for parameters (e.g. CO_2 emissions) 2. Standardize framing designs and automate construction drawings 3. Develop 3D models to permit further analyses, such as material quantification for procurement and cost estimation, material waste minimization and generation of material cutting lists
E-4-3		**Field operations** 1. Implement wireless links to submit inspector data 2. Reduce frequency of site visits 3. Formalize recycling efforts on sites and utilize recycling bins (develop systems to collect data on waste generated and material diversion)
E-4-4		**Lean construction** 1. Introduce lean systems concepts to minimize waste in production 2. Consolidate purchasing to control inventory 3. Cross-train employees on construction tasks
E-4-5		**Construction methodology** 1. Evaluate alternative construction practices 2. Implement a CO_2 registry—emissions are examined at every stage of the construction process and develop strategies for reduction 3. Explore industrialization of construction practice (e.g., pre-fab panelization, modular construction)

ECONOMIC—ACCOUNTING & FINANCE

Cat.	Points	Function/Practice
C-1-1		**Budgets**: Modify your systems so that people are encouraged to optimize the sustainability performance of the entire organization rather than their own budgets 1. Provide a method of accounting for benefits that accrue to different budgets (e.g., capital versus O&M; operations versus customer service dept.) 2. Include sustainability as one of the criteria that should be assessed before money is spent 3. Provide a program to return some of the savings to the departments that created them
C-1-2		**Key performance indicators**: Develop a set of sustainability metrics 1. Develop a set of metrics to assess the benefits and costs of pursuing sustainability 2. Develop a complete set of sustainability metrics for the organization and report on them at least annually 3. Regularly conduct sustainability best-practice studies with other organizations to uncover opportunities for improvement
C-1-3		**Financial analysis**: Use tools to provide a more complete assessment of options which take into account sustainability 1. Include an assessment of risks and intangible benefits when assessing sustainability options 2. Use total cost of ownership (not first cost) and identify externalities related to lifecycle of the product or capital investment 3. Make lifecycle analysis available and take responsibility for all identifiable externalities when making major decisions; avoid discount rates that unfairly impact on future generation

ECONOMIC—MARKETING

Cat.	Points	Function/Practice
C-2-1		**Marketing strategy**: Have a strategy in place that encourages all your customers to choose the more sustainable options 1. Assess market segments for their understanding and opinions about sustainability to identify messages that will resonate with each segment 2. Develop a message that will resonate with each market segment such that it encourages them to make the sustainable choice (e.g., take-back opportunities as a marketing strategy) 3. Develop an aggressive customer education campaign around sustainability to build demand for sustainable products and services
C-2-2		**Product positioning and brand management** 1. Assess all your major products for their sustainability impacts (eliminate or redesign lines with the worst sustainability performance) 2. Seek credible eco-labeling or certification for your products 3. Conduct feedback process with stakeholders
C-2-3		**Internal marketing**: Educate all employees about the organization's sustainability efforts 1. Incorporate sustainability into employee communications on ad hoc basis 2. Communicate at least quarterly via at least two types of media 3. Ensure all employees are fully aware of sustainable activities
C-2-4		**Marketing materials and give-aways** 1. Use high-recycled content paper and soy-based inks when printing 2. Reduce the use of give-aways and choose products that exemplify sustainability 3. Make it easy for customers to eliminate duplicate mailings or get off your mailing list
C-2-5		**Education of public** 1. Help customers understand and reduce energy consumption 2. Promote the concepts of sustainability in you marketing materials to educate your customers 3. Increase web-based communication (paperless) for newsletters

ECONOMIC—RESEARCH AND DEVELOPMENT

Cat.	Points	Function/Practice
C-3-1		**Affordable housing** 1. Examine practices to explore how to lower the cost of production 2. Seek partnership and joint ventures with other stakeholders 3. Develop rationale and case for subsidies and/or tax deferrals
C-3-2		**Innovations** 1. Invest in product research and development (e.g,. spray foam insulation) 2. Increase implementation of new technology practices into operations 3. Establish best practices through industry and stakeholder dialogue

ECONOMIC—LEGAL

Cat.	Points	Function/Practice
C-4-1		**Corporate governance** 1. Establish vision and framework for sustainability that clearly defines the business case for pursuing it 2. Establish executive-level oversight and support of its corporate sustainability strategy with long-term and interim goals 3. Ensure transparency and comprehensive reporting on sustainability
C-4-2		**Risk & Crisis Management** 1. Take full responsibility for your actions and move quickly to solutions (risks retained, transferred or avoided) 2. Define risks systematically and use uniform risk analysis framework, i.e. use risk maps and other tools to rank risk on 2D scale (probability and magnitude) 3. Have formal policy to address environmental accidents such as reporting and action plan

ECONOMIC—PAYROLL

Cat.	Points	Function/Practice
C-5-1		**Employee compensation**: Link rewards and compensation to sustainability performance 1. Provide a fair living wage to all employees (compare with industry average) 2. Maintain a fair ratio between the highest and lowest paid employee (fair wage mechanism) 3. Provide an award or reward program to encourage sustainability innovations and share cost savings from suggestions
C-5-2		**Employee Evaluation** 1. Incorporate sustainability into performance evaluations 2. Examine employee environmental certification credentials 3. Ensure employee performance appraisal systems integrates compliance/codes of conduct
C-5-3		**Executive team and salary** 1. Increase in female manager, executive and shareholder positions 2. Have compensation explicitly tied to social, environmental and governance performance targets 3. Improve diversity representation within management

The points from each criteria are accumulated for each of the three elements.

Element	Points	Normalized Points (divide by 6.75)
Social	/225	/33.3
Environmental	/225	/33.3
Economic	/225	/33.3
Total	/675	/100

Appendix E: Built Green – Homebuilder Results

BUILT GREEN™ CHECKLIST 2009

Effective January 1st, 2009

To select points, click on boxes and select point value from drop-down list

Builder: Landmark Homes House Address:

Section 1: 15 Section 2: 19 Section 3: 16 Section 4: 23 Section 5: 9 Section 6: 7 Section 7: 9 Section 8: 14 = TOTAL POINTS: 112

I. OPERATIONAL SYSTEMS

This section awards points for construction methods and types of products that contribute toward lower energy consumption as well as alternative heating and electrical systems.

Minimum 10 Points Required

1-1	Zoning from a HVAC source utilizing two or more thermostatically controlled zones or zoning from separate systems programmed through separate thermostats. (2 zones = 2 points, 3 zones = 3 points, 4 zones = 4 points.) Efficiency can be significantly improved by only heating or cooling when occupants are present and by only heating/cooling to the exact desired temperature. Different desired temperatures can be set in each room or space and an individual zone can be turned off when not occupied. This type of system results in a dramatic reduction of energy consumption and operating costs.		2, 3 or 4
1-2	Install high efficiency, sealed combustion heating appliance with a minimum 92% AFUE (1 point), 94% AFUE (2 points) or 95% AFUE and above (3 points). (Not for electric heat.) High efficiency furnaces or boilers, such as condensing systems, reduce energy consumption and consequently fossil fuel reliance. Because AFUE takes into account efficiency losses during start-up and cool down its rating is slightly lower.	3	1, 2 or 3
1-3	Install ground or water source heat pumps (10 points) or air source heat pumps (6 points) for heating and cooling. Heat pumps can significantly reduce primary energy use for building heating and cooling. The renewable component displaces the need for primary fuels, which, when burned, produce greenhouse gases and contribute to global warming. Please Note: Cool climate heat pump systems are often more efficient due to the costs of electricity however cold climate heat pump systems are often not as efficient as typical boiler/furnace natural gas systems.		6 to 10
1-4	Install power vented domestic hot water (DHW) tank system (1 point), sealed combustion 2 pipe tank system (2 points), or condensing DHW tank system (3 points) Hot water heater is direct vented with a closed combustion system. All air for combustion is taken directly from the outside. A direct system utilizes a co-axial vent pipe (pipe inside a pipe) draws combustion air in through the outer pipe, and exhausts the products of combustion through the inner pipe. A power vented heater exhausts air out of the building via a positive exhaust during main burner operation. Both systems eliminate the need for conventional chimneys or flue systems.	3	1, 2 or 3
1-5	Install instantaneous “tankless” hot water heater. A tankless water heater does not have a storage tank to keep heated all day, or a pilot light; it burns gas only when you need hot water. This eliminates standby heat loss and its higher efficiency will save on utility costs.		4
1-6	Install high efficiency (AFUE 90 or better) boiler domestic hot water system.		4
1-7	Install geoexchange DHW heating system to supply a minimum of 25% of the peak DHW heating load and 70% of the total DHW energy load. A geoexchange system uses the earths constant temperature to heat water for the home.		4
1-8	Install drainwater heat recovery units on the main drainage stack. 3 foot stack (1 point), 6 foot stack (2 points) Drainwater heat recovery units transfer the heat from waste water to incoming water. This reduces the amount of energy needed for the DHW system.		1 or 2
1-9	Sealed combustion fireplace with electronic ignition if gas fueled. Sealed combustion fireplaces involve a double-walled special vent supplied by the manufacturer that normally vents through a sidewall in a horizontal position. The unit must be Sealed Combustion meaning that combustion gasses can not enter the home even if the home becomes depressurized.	2	2
1-10	Install an EPA or CSA certified high-efficiency wood stove or pellet stove with a minimum efficiency of 72% (1 point) or 85% (2 points). State-of-the-art wood and pellet stoves are among the cleanest burning heating appliances and deliver a high overall efficiency. EPA and CSA certified stoves ensure reduced emissions.		1 or 2
1-11	Install fireplace fan kit to circulate warm air into room (1 point per fan, maximum 2 points). A fan kit allows the heat generated by a fireplace to be transferred into the home more effectively.	1	1 or 2

1-12	All windows in home are ENERGY STAR labeled or equivalent for the climatic zone of home. ENERGY STAR labeled windows save energy by insulating better than standard windows, making the home more comfortable all year round, reducing outside noise and can result in less condensation forming on the window in cold weather.	2	2
1-13	Electric range is self cleaning and/or Convection based Ranges that self clean or have convection are better insulated and sealed, performing at or less than 500 kwh (520 kwh for convection) when rated by EnerGuide.		1
1-14	Refrigerator is an ENERGY STAR labeled product. An ENERGY STAR label for refrigerator indicates the product has met strict requirements to reduce energy consumption.		2
1-15	Dishwasher is an ENERGY STAR labeled product. An ENERGY STAR label for a dishwasher indicates the product has met strict requirements to reduce energy consumption.		1
1-16	Clothes washer or combo washer dryer is an ENERGY STAR labeled product. An ENERGY STAR label for a clothes washer indicates the product has met strict requirements to reduce energy consumption.		1
1-17	Clothes dryer has an energy performance "auto sense" dry setting which utilizes a humidity sensor for energy efficiency.		1
1-18	Home is built "Solar Ready" following Canadian Solar Industries Association (CANSIA) guidelines. Designing a home to be solar ready will make the addition of panels in the future much easier. Contact the Canadian Solar Industries Association for more info: www.cansia.ca.		2
1-19	Install active solar hot water heating system. Sized for 30% of DHW load (4 points), 50% (6 points), 80% (8 Points)		4, 6,8
1-20	Install photovoltaic electrical generation system. Sized for 30% of electric load (4 points), 50% (6 points), 80% (8 points). A photovoltaic system will greatly reduce the reliance on fossil fuel energy and reduce greenhouse gas emissions. System capacity must be verified by professional installer or engineer.		4, 6, 8
1-21	50% (2 points) or 100% (4 points) of electricity used during construction of home is generated by wind power or equivalent green power certificate.		2 or 4
1-22	50% (2 points) or 100% (4 points) of electricity used by homeowner during first year of occupancy is generated by wind power or equivalent green power certificate. (prepaid by builder)		2 or 4
1-23	A properly supported and wired ceiling fan and a wall mounted switch roughed in for future installation. Intended to allow for future temperature equalization.	1	1
1-24	Install interior motion sensor light switches. 1 point per switch to a maximum of 3 points. Motion sensor switches prevent lights from remaining on in rooms that are unoccupied. This helps reduce electricity consumption. Switches on closet doors and pantries are also acceptable.	2	1 to 3
1-25	Install central, computerized control systems capable of unified automation control of lighting loads. Lighting and automation control systems prevent lights from remaining on in rooms without occupants, thereby reducing electricity consumption.		4
1-26	Minimum 25% (1 point), 50% (2 points), 75% (3 points) or 100% (4 points) of interior and exterior light fixtures are fluorescent, compact fluorescent light bulbs or LEDs. Fluorescent, compact fluorescent and LED lamps use 50% less energy than standard lamps and last up to ten times longer.		1 to 4
1-27	Minimum 50% of recessed lights use halogen bulbs. Halogen bulbs are slightly more energy efficient, last longer and provide a more effective task light than conventional bulbs.		1
1-28	Air tight, insulation contact-rated recessed lights are used in all insulated ceilings, or insulated ceilings have no recessed lights. Prevents heated air from exhausting through ceiling. Air tight light fixtures lead to a more airtight, energy efficient home.	1	1
	TOTAL SECTION POINTS	**15**	

II. BUILDING MATERIALS

This section deals with building components that make up the structure of the home. Items involve alternatives to using large dimensional lumber, products with a recycled component, utilizing wood products that come from sustainably managed forests and reducing the overall amount of lumber used.

Minimum 15 Points Required

2-1	Insulated Concrete Form (ICF) system used for foundation walls. Insulating Concrete Forms (ICF) are hollow building elements made of plastic foam that are assembled, often like building blocks, into the shape of a buildings exterior walls. The ICFs are filled with reinforced concrete to create structural walls. Unlike traditional forms, the ICFs are left in place to provide insulation and a surface for finishes.		2
2-2	Insulated Concrete Form (ICF) system used for main house walls. See description in 2.1.		3
2-3	Non-solvent based damp proofing (seasonal application). Water based damp proofing products use water as a thinner. Oil based damp proofing gives off a number of volatile organic compounds (VOCs) as the solvent evaporates after application. These VOCs can be a strong irritant and can add to air pollution.		1
2-4	Steel studding made from a minimum of 75% recycled steel is used to replace a minimum of 15% of wood studs in the home.	1	1
2-5	Exterior and interior wall stud spacing at 19.2" on-center (1 point) or 24" on-center (2 points) . Increasing stud spacing reduced the thermal performance of homes while saving materials.	2	1 or 2
2-6	Use of insulated headers / lintels (either manufactured or site built insulated headers) with minimum insulation value of R10. Headers can either be insulated on site or can be a pre-manufactured product (often insulated with a foamed plastic).		1
2-7	Install manufactured insulated rim/band joist, or build on-site built header wrap detail for continuous air barrier. Rim and band joists can either be insulated on site or can be pre-manufactured (often insulated with a foamed insulation).		1
2-8	Elimination of headers at non-bearing interior and exterior walls. It is not necessary to use the additional wood involved in header construction if the opening is less than 4' wide and is non-load bearing. For more details on Optimum Value Engineering framing principles see www.buildingscience.com.		1
2-9	Use of header hangers instead of jack studs. Using metal header hangers instead of jack studs allows for savings in wood use. For more details on Optimum Value Engineering framing principles see www.buildingscience.com.		1
2-10	Elimination of cripples on hung windows. For hung window openings, cripples are only necessary for siding or gypsum board attachment. For more details on Optimum Value Engineering framing principles see www.buildingscience.com.		1
2-11	Elimination of double plates, using single plates with connectors by lining up roof framing with wall and floor framing. Stack framing principles might allow for reduced wood usage. For more details on Optimum Value Engineering framing principles see www.buildingscience.com.		1
2-12	Use of two stud corner framing with drywall clips or scrap lumber for drywall backing instead of studs. Drywall clips can be used instead of a third corner stud allowing for reduced wood usage. For more details on Optimum Value Engineering framing principles see www.buildingscience.com.		1
2-13	Deck or veranda surfaces (1 point) and/or structure (1 point) made from a third-party certified sustainably harvested wood source. Wood must come from a sustainably harvested source with certification from Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI), or Canadian Standards Association's Sustainable Forest Management Standard (CAN/CSA-Z809-02).		1 or 2
2-14	Deck or veranda surfaces (1 point) and/or structure (1 point) made from a third-party certified sustainable concrete. Concrete produced from aggregates derived from a pit or quarry with a valid reclamation plan approved by Materials and Resources Canada or the governing provincial body.	2	1 or 2
2-15	Structural insulated panel system used for at least 75% of roof (4 points) and/or 75% of walls (6 points). Reduces thermal migration and controls air leakage – keeps heating and cooling costs to a minimum compared to a conventionally framed wall.		4 or 6
2-16	Dimensional lumber from a third-party certified sustainably harvested source used for floor framing. Saves old growth forests by using trees form a second generation forests.		1
2-17	Dimensional lumber from a third-party certified sustainably harvested source used for wall framing. Saves old growth forests by using trees form a second generation forests.	2	2

2-18	Dimensional lumber from a third-party certified sustainably harvested source used for roof framing. Saves old growth forests by using trees form a second generation forests.	1	1
2-19	Use manufactured wood products for floor systems instead of dimensional lumber. Engineered wood floor systems saves old growth forests by using components from second generation forests and the use of recycled materials.	2	2
2-20	Reduce dimensional lumber use by using engineered product for all load bearing beams & columns. Engineered products include wood products, concrete and recycled steel.	2	2
2-21	Reduce dimensional lumber use by using engineered products for all exterior window and door headers. Engineered products include wood products, concrete and recycled steel.		1
2-22	Finger-jointed plate material and/or engineered plate material used for all framing plates. Use of recycled materials saves old growth forests.		1
2-23	Reduce dimensional lumber use by using engineered stud material for 10% of structural stud wall framing. Use of engineered lumber products saves old growth forests by using components from second generation forests and the use of recycled materials.		1
2-24	Finger-jointed studs for 90% of non-structural (1 point) and/or 90% of structural (1 point) wall framing. Use of recycled materials saves old growth forests.		1 or 2
2-25	Recycled and/or recovered content gypsum wallboard, minimum of 15% recycled content.		1
2-26	Recycled content exterior wall sheathing (minimum 50% pre- or post-consumer).		2
2-27	Use rain screen system separating cladding from the wall sheathing with a drainage plane (2 point), 60% or more recycled content (additional 1 point). Use of recycled content polypropylene, steel or aluminium rain screen strapping may replace the traditional use of wood strapping on rain screen systems.		1 or 2
2-28	Advanced sealing package, non HCFC expanding foam around window and door openings and all exterior wall penetrations. Controls air leakage and keeps heating and cooling costs to a minimum.	2	2
2-29	All sill plates sealed with foam sill gaskets or a continuous sandwiched bead of acoustical sealant. Controls air leakage and keeps heating and cooling costs to a minimum.	1	1
2-30	All insulation used in home is certified by a third-party to contain a minimum recycled content: 40% (1 point) or 50% (2 points).	1	1 or 2
2-31	Install site applied spray foam to insulate entire rim joist area (1 point), Garage to Bonus room floor (2 points) and/or house walls (2 points). Spray insulations provide excellent air sealing and insulation value. Spray foam must be fire protected and some types cannot come in contact with heating ducts or lines. Consult supplier or installer for further information.		2 or 4
2-32	Replace exterior wood sheathing with insulating sheathing and structurally required metal bracing. Using less materials when possible saves the forest reserves, reduces thermal migration and controls air leakage and keeps heating and cooling costs to a minimum compared to a conventional wall.		2
2-33	Install R5 (1 point), R8 (2 points) or R12 (3 points) above building code required under entire basement slab. Insulation installed under the basement slab will reduce the downward heat transfer into the ground below the slab, especially when hydronic in-slab heating is installed. Insulation under the slab can reduce temperature swings in the heated space and respond quicker to new changes in thermostat settings.		1,2 or 3
2-34	Install Exterior Insulations system using extruded Polystyrene (XPS) on exterior of foundation, 1.5" R7.5 (1 point), 2" R10 (2 points), or 3" R15 (3 points) Insulation on the outside of a foundation system reduced energy loss		1, 2 or 3
2-35	Overhead garage door is made of 75% or greater recycled material.		1
2-36	Attached garage overhead door is insulated with R8 to R12 (1 point) or greater than R12 (2 points).	1	1 or 2
2-37	Attached garage is fully insulated. A fully insulated garage serves an additional insulating capacity for any walls encapsulated by it, further slowing heat loss through those walls.		1
2-38	Builder uses passive solar design shading devices for home. Permanent horizontal and/or vertical exterior shading devices for glazing (2 points), computer controlled devices (additional 1 point). Excludes interior blinds.		2 or 3
2-39	Install 100% recycled content carpet underlayment.	1	1
2-40	Install finished concrete interior floors instead of other types of finished floors (tile, carpet, hardwood, etc). For 300-500 ft² (1 point), 501-1000 ft² (2 points), 1001-1500 ft² (3 points), 1501+ ft² (4 points). Not applicable in unfinished basement areas. Using the concrete itself as a finished floor where concrete is being used regardless (for in floor heat or basement slabs) provides a durable floor with less material usage.		1 to 4
2-41	Install weather-stripped and insulated (R15 minimum) manufactured interior attic hatch (1 point), or no interior attic access (1 point)	1	1
	TOTAL SECTION POINTS	**19**	

III. EXTERIOR and INTERIOR FINISHES

This section focuses on the finish materials used both inside and outside of the home. The items listed include using longer lasting products, products with recycled content and products that are harvested from third-party certified sustainably managed forests.

Minimum 10 Points Required

3-1	Exterior doors with a minimum of 15% recycled and/or recovered content. Recycled or recovered content ensures we keep our landfill use to a minimum. Not including overhead garage doors (see 2-33).		1
3-2	Interior doors with a minimum of 15% recycled and/or recovered content.	1	1
3-3	Interior doors made from third-party certified sustainably harvested wood. Uses trees from forests managed sustainably, that prevent clear cutting and replant trees in areas from which they've been harvested.		2
3-4	All exterior doors manufactured from fiberglass. Fiberglass doors insulate better than steel skinned or wood doors, have a longer lifespan, do not warp, twist or crack, and therefore reduce landfill use.	1	1
3-5	Exterior window frames contain a minimum of 10% recycled content. Reusing materials such as plastics reduces landfill usage and may not be biodegradable.		1
3-6	Exterior window frames made from third-party certified sustainably harvested wood. Uses trees from forests managed sustainably, that prevent clear cutting and replant trees in areas from which they've been harvested.		2
3-7	Natural cementitious stone/stucco/brick or fiber cement siding – complete or combination thereof for 100% of exterior cladding. Strong, long lasting, fireproof material.		4
3-8	Recycled or reclaimed exterior cladding material. 1/3 of exterior (1 point), 2/3 or more of home (2 points). Recycled brick blocks etc, intent is to replace siding materials, primarily exterior finish materials.		1 or 2
3-9	Fiber cement fascia and soffit. Fiber cement fascia and soffit, made with recycled content from sawmill waste and Portland cement, is a strong, long lasting and fireproof material.		2
3-10	Recycled and/or recovered-content fascia and soffit (minimum 50% pre- or post-consumer). Recycled and/or recovered-content fascia and soffit reduces the amount of new material used in production by gluing up mill scraps into large pieces, which conserves natural resources and reduces landfill usage.		1
3-11	Recycled and/or recovered-content siding (minimum 50% pre- or post-consumer). Recycled and/or recovered-content siding reduces the amount of new material used in production by gluing up mill scraps into large pieces, which conserves natural resources and reduces landfill usage.		4
3-12	Exterior trim materials are made from alternatives to solid lumber. Trim materials manufactured from OSB uses a laminating process to make larger pieces from smaller pieces or strands of wood. The process saves old growth forests by using trees from forests managed sustainably, that prevent clear cutting and replant trees in areas from which they've been harvested.		1
3-13	Exterior trim materials have recycled and/or recovered-content (minimum 50%). Recycled and/or recovered-content trim materials reduce the amount of new material used in production by gluing up mill scraps into large pieces, which conserves natural resources and reduces landfill usage.	3	3
3-14	All exterior trim is clad with pre-finished metal (1 point over wood backings, 2 points without wood backings). Trim clad with pre-finished metal is a durable long lasting product that requires no maintenance and reduces waste in landfills due to long life of product.		1 or 2
3-15	Deck or veranda surfaces made from low maintenance materials - deck surfaces do not need maintenance of any kind, including painting, for a minimum of 5 years. Materials that last longer reduce landfill usage and tend to require little to no maintenance, saving replacement costs and reducing energy use.	2	2
3-16	Minimum 25-year manufacturer warranty roofing material (2 points plus 1 point for each additional 5 years). A 25-year roof system saves homeowners money in replacement costs, and reduces the use of landfills due to the longevity of the product.	2	2 or more
3-17	Minimum 25% recycled-content roofing system (1 point underlay and 2 points roofing finish). Recycled content roofing material reduces the use of new resources and waste in landfills.		1 to 3
3-18	Domestic wood from reused/recovered or re-milled sources, 500 ft² minimum for flooring or all cabinets or all millwork. Reused, recovered or re-milled sources eliminate the need for new resources, saving energy, transportation costs, and forestry from depletion.		6
3-19	Natural or recycled-content carpet pad made from textile, carpet cushion or tire waste (rebond still qualifies). Natural or recycled-content carpet pad is a good use of reusable resources.	2	2

3-20	Install carpet that has a minimum of 50% recycled content. Recycled-content carpet is a good use of renewable resources, lessens off-gassing and improves air quality.		2
3-21	Install a minimum of 300 ft² of laminate flooring.		2
3-22	Bamboo, cork or hardwood flooring used in home, minimum of 300 ft² installed. Products must be third-party certified from sustainably managed forests or certified sustainable sources. Cork flooring comes from stripping the bark off cork oak, which regenerates itself. The cork tiles are moisture, rot and mould resistant, providing a floor that can last over 30 years. Bamboo flooring is a good use of natural resources because it is fast growing, durable and flexible. All hard floorings promote better indoor air quality by not trapping contaminates.	3	3
3-23	All ceramic tile installed in home has a minimum of 25% recycled-content. Reduces landfill usage.		2
3-24	MDF and/or finger jointed casing and baseboard used throughout home (1 point), and all jambs (1 point) Medium Density Fiberboard (MDF) casing is created from sawdust and glues, utilizing all wood waste to create usable product.	1	1 to 2
3-25	Solid hardwood trim from third-party certified sustainably harvested sources approved for millwork and/or cabinets (2 points per application – maximum of 4 points). This process saves old growth forests by using trees from forests managed sustainably, that prevent clear cutting and replant trees in areas from which they've been harvested.		2 or 4
3-26	Paints or finishes with minimum of 20% recycled content. Paints or finishes made form recycled content are environmentally friendly because recycling paint reduces the hazardous waste in landfills.		1
3-27	Domestically sourced natural granite, stone or recycled glass (30% of content) countertops in 100% of the kitchen. Natural product is more durable, easy to clean and maintain, resistant to heat and scoring. By quarrying and sourcing in Canada, the environmental cost of shipping is greatly reduced. Foreign stone cut or polished in Canada is not acceptable.		2
3-28	Natural granite, stone, recycled glass or concrete countertops for all other countertop areas. Natural product is more durable, easy to clean and maintain, resistant to heat and scoring.	1	1
3-29	100% agricultural waste or 100% recycled wood particle board used for shelving. Products such as wheat board are made from agricultural waste.		2
3-30	PVD finish on all door hardware. Physical Vapour Disposition provides a more durable product. No toxic wastes are produced making it.		1
3-31	PVD finish on all faucets. Physical Vapour Disposition provides a more durable product. No toxic wastes are produced making it.		1
3-32	Install only Type 1 or 2 grade door hardware with lifetime mechanical and coating warranty. High quality, durable Type 1 and 2 hardware will not require replacing for life of home.		2
	TOTAL SECTION POINTS	16	

IV. INDOOR AIR QUALITY

This section focuses on the quality of the air within the finished home. Products listed here include materials that are low in VOC's, products made from all natural materials as well as various air cleaning and ventilation systems.
Minimum 15 Points Required

4-1	Install pleated media filter on HVAC system with minimum MERV 7 rating. MERV rating system specifies allowable amounts and practical sizes that a filter must catch. The higher the MERV rating, the smaller and greater number of particulates are caught, providing better indoor air quality.	1	1
4-2	Install electrostatic air cleaner on HVAC system. Permanent washable air filter that traps and removes airborne particles from the air before being circulated through the furnace and into the home.		2
4-3	Install electronic air cleaner on HVAC system. An electronic air cleaner offers a superior level of filtration by using advanced, 3-stage filtration technology to trap and filter airborne particles like dust, cat dander and smoke. It works by placing an electric charge on airborne particles, and then collecting the charged pollutants like a magnet. The air cleaner cells can be washed in your dishwasher or sink.		3
4-4	Install HEPA filtration system in conjunction with an HVAC system. HEPA stands for High-Efficiency Particle Arresting. HEPA filtration offers the highest particulate removal available - 99.97% of particles that pass through the system including dust, cat dander, certain bacteria, pollens and more. The system is connected to the cold air return of the forced air heating/cooling system which provides a whole house filtration system.		6
4-5	Install ultraviolet air purifier on HVAC system. Ultraviolet (UV) air treatment systems kill mould spores and certain live, airborne bacteria passing by the lamp to prevent them from being re-circulated into the air of the home.		2
4-6	Install thermostat that indicates the need for the air filter to be changed or cleaned. This feature displays filter maintenance reminders on the thermostat. Regular furnace maintenance is required to keep your mechanical equipment running efficiently and problem free as well as ensuring a healthy indoor air environment.	1	1
4-7	Install hardwired carbon monoxide detector outside main sleeping areas. Carbon monoxide detectors warn against high levels of toxic carbon monoxide.	1	1
4-8	Power vacuum all HVAC ducting prior to occupancy by homeowner. This process helps eliminate pollutants that drop into the HVAC ducting during the construction process from being circulated into the home.	2	2
4-9	Central vacuum system vented to exterior & central vacuum system has Carpet and Rug Institute (CRI) IAQ approval. A central vacuum system collects dust centrally, while exhausting to the exterior so that dust mites and bacteria do not have the opportunity to re-circulate. The result is cleaner, healthier air. Note: install far enough from air intake areas, see manufacturer's installation guidelines.		1
4-10	All insulation in the home is third-party certified or certified with low or zero formaldehyde. Formaldehyde is colorless gaseous organic compound, water soluble, with a characteristic pungent and stifling smell. Products with low formaldehyde emission levels will improve indoor air quality of homes and long term owner health.	2	2
4-11	Low formaldehyde sub floor sheathing (less than 0.18 ppm). Formaldehyde is colorless gaseous organic compound, water soluble, with a characteristic pungent and stifling smell. Products with low formaldehyde emission levels will improve indoor air quality of homes and long term owner health. Industry Standard ANSI A208.1-1999 sets a 0.20 ppm limit. Built Green™ requires a 10% better level of performance at 0.18 ppm. Products using Phenol Formaldehyde, or PMDI or MDI will meet this standard without testing.	3	3
4-12	Low formaldehyde underlayment is used in home (less than 0.18 ppm). Low formaldehyde (phenol) and formaldehyde-free binders (PMDI) are available and becoming more common. FSC certified OSB is becoming more common, reducing environmental impacts on air, water, social quality.	1	1
4-13	Low formaldehyde particle board/MDF (less than 0.18 ppm) = 1 point, or zero formaldehyde particle board/MDF (2 points) used for cabinets. Urea formaldehyde-free fiberboard can be used in the same way as conventional fiberboard, but with the added caution of greater potential for water damage.		1 or 2
4-14	Low formaldehyde particle board/MDF (less than 0.18 ppm) = 1 point, or zero formaldehyde particle board/MDF (2 points) for shelving. Urea formaldehyde-free fiberboard can be used in the same way as conventional fiberboard, but with the added caution of greater potential for water damage.		1 or 2
4-15	All interior wire shelving is factory coated with low VOC / no off gassing coatings Vinyl coating on conventional shelving units and site built MDF shelving offgas VOCs.	2	2
4-16	Water-based urethane finishes used on all site-finished wood floors. Water-based epoxy finish (generally referred to as epoxy-modified finish) differs from its solvent-based counterpart in that the epoxy resin is itself the catalyst for an acrylic or urethane resin.		2

4-17	All wood or laminate flooring in home is factory finished. Installing a pre-finished floor eliminates the time, the dust and the odours associated with the on-site sanding and finishing of an unfinished product.	2	2
4-18	Water-based lacquer or paints are used on all site built and installed millwork, including doors, casing and baseboards. (less then 200 grams/litre of VOC's) Water based interior finish products reduces VOC off-gassing which improves indoor air quality.		3
4-19	Interior paints used have low VOC content (less than 200 grams/litre of VOCs). Volatile Organic Compounds (VOCs) are a class of chemical compounds that can cause short or long-term health problems. A high level of VOCs in paints/finishes off-gas and can have detrimental effects to a buildings indoor air quality and occupant health.		2
4-20	Interior paints used have no VOC's in base paint prior to tint. Volatile Organic Compounds (VOCs) are a class of chemical compounds that can cause short or long-term health problems. A high level of VOCs in paints/finishes off-gas and can have detrimental effects to a buildings indoor air quality and occupant health.	3	3
4-21	Natural linoleum in place of any vinyl sheet flooring. Linoleum installed with low VOC adhesives (low VOC standard is less than 150 grams per litre). Natural linoleum is made from natural linseed and other abundant renewable materials.	2	2
4-22	All ceramic tiles are installed with low VOC adhesives and plasticizer-free grout (low VOC standard is less than 150 grams per litre). Most adhesives are still based on SB latex which releases large quantities of VOCs. The volatile solvents are used to emulsify (or liquefy) the resin that acts as the bonding agent. However, water-based adhesives emit far less VOCs than their conventional solvent based counterparts. There are three types of low-VOC formulas: water-based (latex and acrylics); reactive (silicone and polyurethane); and exempt solvent-based (VOC-compliant solvents). While all three technologies yield low- or zero-VOC caulks, sealants, and adhesives, their performance is slightly different.	1	1
4-23	All vinyl flooring in home is replaced by hard surface flooring. Hard surface flooring is generally more durable and improves the Indoor Air Quality within a building. Carpets collect dust, dust mites and other allergens which when disturbed become airborne particulates, directly affecting the health of the occupants.		2
4-24	Carpet and Rug Institute (CRI) IAQ label on all carpet used in home. To identify carpet products that are truly low-VOC, CRI has established a labeling program. The CRI Indoor Air Quality Carpet Testing Program green and white logo displayed on carpet samples in showrooms informs the consumer that the product type has been tested by an independent laboratory and has met the criteria for very low emissions.	2	2
4-25	Carpet and Rug Institute (CRI) IAQ label on all underlay used in home. The adhesives used to install carpets and the latex rubber by some manufacturers to adhere face fibers to backing materials generate volatile organic compounds (VOCs). Carpets also cover large surfaces within an interior environment and can provide "sinks" for the absorption of VOCs from other sources.		1
4-26	Natural material based carpet in all living areas. Natural wool carpets are durable and use less secondary backing materials and chemicals. Off-gassing is typically caused by the secondary backings and chemical additives in synthetic carpets, for controlling mildew, fungus, fire and rot.		2
4-27	All carpet in home is replaced by hard surface flooring. Hard surface flooring is generally more durable and improves the Indoor Air Quality within a building. Carpets collect dust, dust mites and other allergens which when disturbed become airborne particulates- directly affecting the health of the occupants.		4
	TOTAL SECTION POINTS	23	

V. VENTILATION

This section covers the mechanical ventilation systems in the home, including filtrations and heat recovery.

Minimum 6 Points Required

*** Platinum Level Note* Platinum level homes must use item 5-9 " Ventilation system is installed according to CSA Standard F326, as recommended by the Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI)." as well as 6 additional points from this section.**

5-1	All ductwork joints and penetrations sealed with low toxic mastic or aerosolized sealant system. Duct mastic is a preferred flexible sealant that can move with the expansion, contraction, and vibration of the duct system components. A high quality duct system greatly minimizes energy loss from ductwork. The system should be airtight, sized and designed to deliver the correct airflow to each room.		3
5-2	Programmable ENERGY STAR thermostat with dual set back and continuous fan setting. A set back thermostat regulates the heating/cooling system to provide optimum comfort when the house is occupied and to conserve energy when it is not.	2	2
5-3	Install HVAC appliance with variable speed fan (ECM). A variable speed fan motor (ECM or DC powered) is designed to vary its speed based on the homes heating and air conditioning requirements. Working in conjunction with the thermostat, it keeps the appropriate air temperature circulating through the home, reducing temperature variances in the home. It also provides greater air circulation and filtration, better temperature distribution, humidity control, higher efficiency and quiet performance.	3	3
5-4	Install motorized damper on fresh air inlet (must be interlocked with furnace system). A constantly open fresh air supply (passive air) wastes energy. Positive control of this air will assure building comfort, safety and energy efficiency.		1
5-5	Install all ventilation fans (bath or in-line type) to meet or exceed the Energy Star requirements Energy Star fans have to meet standards for efficiency, and sound transmission, providing quiet and effective ventilation fans. www.oee.nrcan.gc.ca/energystar/english	2	2
5-6	Install a programmable time or humidistat controlled ventilation fan meeting the Energy Star requirements for efficiency and sound level A programmable timer ensures necessary, regular, automatic mechanical ventilation of the home.	2	2
5-7	Install passive Heat Recovery Ventilator (HRV) and verify balanced installation. A Heat Recovery Ventilator (HRV) is an air exchanger that exhausts humid, stale, polluted air out of the home and draws in fresh, clean outdoor air into the home. Invisible pollutants produced by common household substances, plus dust and excess humidity that get trapped in today's houses, can increase your risk of chronic respiratory illness and your homes risk of serious structural damage. A passive HRV unit does not have its own internal fan and is 100% furnace assisted. It works by tying the exhaust side of the unit to the supply air plenum which forces air to exhaust from the home and at the same time fresh air enters from outside through the unit and into the cold air return duct work.		2
5-8	Install an active Heat Recovery Ventilator or Energy Recovery Ventilator (HRV or ERV) and verify balanced installation. A Heat Recovery Ventilator (HRV) is an air exchanger that exhausts humid, stale, polluted air out of the home and draws in fresh, clean outdoor air into the home. Invisible pollutants produced by common household substances, plus dust and excess humidity that get trapped in today's houses, can increase your risk of chronic respiratory illness and your homes risk of serious structural damage. Much like the HRV, the ERV recovers heat; however, it also recuperates the energy trapped in moisture, which greatly improves the overall recovery efficiency. In dry climates and humidified homes the ERV limits the amount of moisture expelled from the home. In humid climates and air conditioned homes, when it is more humid outside than inside, the ERV limits the amount of moisture coming into the home.		4
5-9	Ventilation system is installed according to CSA Standard F326, as recommended by the Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI). www.hrai.ca		5
5-10	All bath fans used throughout home have a noise level of 1 sone or less Installing quiet fans will encourage use for home ventilation.		1
	TOTAL SECTION POINTS	9	

VI. WASTE MANAGEMENT

This section deals with the handling of waste materials on the construction site and encourages recycling.
Minimum 7 Points Required

6-1	Comprehensive recycling program for building site including education, site signage and bins. A comprehensive recycling program that is strictly followed significantly reduces the amount of waste ending up in landfills. Currently it is estimated that up to 50% of landfill waste is construction related.		2
6-2	Collection of waste materials from site by a waste management company that is a current member of a provincial recycling council or equivalent association and verifies that a minimum of 10% of the materials collected from the construction site have been recycled. Not only does this reduce overall waste of product, it ensures that as much product as possible is being utilized for the production of future resources.		4
6-3	Suppliers and trades recycle their own waste, including leftover material and packaging (1 point per trade - maximum 4 points). Trades being responsible for recycling and removal of waste not only reduces landfill waste, but also promotes a cleaner and safer working environment.	4	1 to 4
6-4	Minimum 25% (2 points) or 50% (6 points) by weight of waste materials collected from construction site is diverted from waste stream. Trades being responsible for recycling and removal of waste not only reduces landfill waste, but also promotes a cleaner and safer working environment.	2	2 or 6
6-5	Use of recycled materials derived from local construction sites (1 point for each different product used, to max. of 3). Products recycled from the construction site, such as mulched wood cut offs or mulched gypsum are often useable as either clay/soil water retention additives or for organic burning.		1 to 3
6-6	Trees and natural features on site protected during construction. The protection of existing trees and other natural features such as streams, ponds and other vegetation reduces environmental and ecosystem impact. Many of these features can be protected simply by following good waste management procedures.		1
6-7	Metal or engineered durable form systems used for concrete foundation walls. The use of metal forming systems reduces the requirement of lumber, a limited resource.	1	1
6-8	Concrete used in home has a minimum supplementary cementing material of 25% (1 point) or 40% (2 points) within the scope of proper engineering practices. For every one ton of Portland cement generated, eighth tenths of a ton of carbon dioxide is produced. Supplementary cementations products include fly ash, blast furnace slag as well as metakaolin.		1 or 2
6-9	Reusable bracing is used for framing. The use of reusable bracing for framing reduces the requirement of lumber, a limited resource.		1
6-10	Install recycling center with two or more bins. By installing built in recycling centers, which can be as simple as labeled containers (paper, cardboard, cans, plastics, etc), homeowners are more likely to utilize the pre-existing facilities and thus contribute to the reduction in landfill waste.		3
6-11	Provide composter to homeowner. Providing a composter promotes a reduction in wastes heading to the landfill by giving homeowners an option for organic waste such as food leftovers.		2
6-12	Existing dwellings onsite are recycled or moved instead of demolished (recycled 2 points, moved 4 points).		2 or 4
	TOTAL SECTION POINTS	7	

VII. WATER CONSERVATION

This section encourages a reduction in the amount of water used in the home or in individual units within multi-story buildings.

Minimum 7 Points Required

7-1	CSA approved single flush toilet averaging 1.6 GPF or less installed in all bathrooms (1 point)	1	1
7-2	Install a dual flush or pressure assisted toilet in one or more bathrooms (3 points for first, 1 additional point for each after) Dual flush toilets offer a choice between two water levels for every flush; at minimum should use, 1.6 GPF (6 LPF) or 0.8 GPF (3 LPF).	3	3 or more
7-3	Install a 1.28 GPF toilet in one or more bathrooms (2 points for first, 1 additional point for each after) 1.28 GPF (Gallon per Flush) is general considered the new standard in water efficiency		2 or more
7-4	Install manufactured non-electric composting toilet (3 points each, max of 6 points). A composting toilet uses no water and is odourless. It uses a biological processes to break down the human excrement into organic compost material.		3 or 6
7-5	Insulate the hot water lines with flexible pipe insulation, first three feet of the water lines (1 point) or all hot water lines (2 points). Minimizing the heat loss in the water line will decrease the initial water wasted by delivering hot water faster.	1	1 or 2
7-6	Install hot water recirculation line with insulted hot water lines and pump system. Having the hot water re-circulated from the hot water source to the fixture points will decrease the initial water wasted by delivery the hot water faster. Pump should be on program or timer to reduce stand-by losses.		3
7-7	Install low flow faucets for all kitchen faucets and lavatories (2 points), all showers & tub/showers (additional 1 point). Reduces water consumption by lowering the flow rate. Showers must use 9.8 L/min (2.2 imp. Gal/min) or less. Faucets, both kitchen and bath, must use 8.3 L/min (1.8 imp. Gal./min) or less.	3	2 or 3
7-8	Install hands free lavatory faucets. 1 point per faucet/unit. Battery powered electronic sensor minimizes the spread of germs and saves water.		1 per unit
7-9	Provide front loading clothes washer (3 points), or Condensing Combination wash/dry unit (4 points) Front loading clothes washers conserve water by design, as they are only required to fill up the washing compartment 1/3 full to effectively wash clothing. Additionally they use up to 75% less environmentally damaging laundry detergent, AND they also conserve electrical or gas energy by significantly reducing drying time for clothes with a more thorough spin cycle.		3 or 4
7-10	Install water saving dishwasher that uses less than 26.0 L/water per load. Water saving dishwasher use technology to reduce both the amount of water required as well as electrical energy requirements. The EnerGuide appliance directory put out by Natural Resources Canada has a comprehensive listing of all manufacturers and models of dishwashers and other appliances with water usage and energy efficiency ratings.		1
7-11	Install efficient irrigation technology that utilizes automatic soil moisture-based sensor technology at minimum Show storm water management plan & design; water efficient irrigation systems, sensors, regulators, micro drip feed systems etc.		3
7-12	Install permeable paving materials for all driveways and walkways. Permeable paving allows for storm water to flow back into the ground rather than into the storm sewers.		3
7-13	Provide a list of drought tolerant plants and a copy of the local municipality water usage guide to homebuyers with closing package. Most municipalities provide a guide that gives the water requirements of various plants and grasses. When properly designed, landscaping choices can significantly contribute to water conservation.	1	1
7-14	Builder supplies a minimum of 8" of topsoil or composted yard waste, as finish grading throughout site. Compared to subsoil materials, topsoil usually has higher aggregate stability, lower bulk density, and more favorable pore size distributions which leads to higher hydraulic conductivity, water holding capacity, and aeration porosity.		2
7-15	Builder incorporates water wise landscaping or xeriscaping in show home or customer home (customers 50% of lawn 2 points, 100% 4 points). Xeriscaping (or drought resistant landscaping) plans and options can be obtained from professional landscaping contractors, and once a xeriscaping landscape is in place, it requires no manual watering. (Rain barrel usage, astro turf ineligible.)		2 or 4
7-16	Builder attaches water barrel with insect screen to downspout. Water barrel should also have a drain spout and overflow spout (1 point per barrel - maximum of 3 barrels). Supplying a water barrel encourages homeowners to use rainwater for landscaping needs and therefore save on potable water.		1, 2 or 3
7-17	Install grey water system collecting waste from sinks, shower and/or kitchen to capture and treat for use in toilets or irrigation (6 pts), rough-in for future grey water system (3 points) By reusing waste water, consumption can be drastically reduced. Rough-in must include clearly identified grey water drain stack, separated from sewer line.		6
	TOTAL SECTION POINTS	9	

VIII. BUSINESS PRACTICE

This section deals more with manufacturers and builders office and business practices.

Minimum 6 Points Required

8-1	Products used for home are manufactured within 800 km (1 point for each product - maximum of 5). Products made closer to the location of use will have less embodied energy. Basically this means that the shorter the transportation distance the less energy used in moving the product. Less energy used means fewer emissions.	5	1 to 5
8-2	Builder provides Built Green™ homeowner manual, completed Built Green™ checklist and educational walkthrough with sale or possession.	3	3
8-3	Builders office and show homes purchase a minimum of 50% (1 point) or 100% (2 points) solar, wind or renewable energy. Wind energy is a cleaner way to provide energy. Lower CO2 emissions will benefit the environment.		1 or 2
8-4	Manufacturers and/or suppliers purchase 50% or more solar, wind or renewable electricity. Wind energy is a cleaner way to provide energy. Lower CO2 emissions will benefit the environment.		1
8-5	Builder has written an environmental policy which defines their commitment (must include an office recycling program and energy efficient lighting). A statement of commitment helps to emphasize priority and ultimately define a corporate culture.	1	1
8-6	Manufacturer and/or supplier has written an environmental policy which defines their commitment (must include an office recycling program and energy efficient lighting). (1 point per supplier/manufacturer - maximum of 2 points).		1 or 2
8-7	Builder has written an environmental policy which prioritizes milestones for future net zero housing developments.		1
8-8	Builders' company vehicles are hybrid or bio-diesel vehicles (1 point per vehicle - maximum of 3 points). A commitment to the environment shouldn't stop at construction. Using a hybrid vehicle produces lower harmful emissions. Diesel construction vehicles converted to bio-diesel reduce fuel consumption by up to 75%.		1 to 3
8-9	Environmental certification for builders place of business (building, office, etc). Many commercial buildings have been rated with various energy efficiency standards. Does your company work within an ENERGY STAR, EnerGuide for Houses (EGH), EnerGuide for New Houses (EGNH), REAP or LEED (or other certification standard) certified office building?		3
8-10	Builder agrees to construct and label a minimum of 50% of all homes to the Built Green™ standard per calendar year (3 points for 50%, 5 points for 100%).	5	3 or 5
8-11	Contracted trades and/or suppliers have successfully taken and maintained Built Green™ Builder Training status (1 point per trade organization, Max 5).		1 to 5
	TOTAL SECTION POINTS	**14**	
	TOTAL CHECKLIST POINTS	**112**	

Appendix F: HOT2000 – Homebuilder Results

HOT2000

Natural Resources CANADA
Version 10.50

File: to code Cambridge II.HSE
Application Type: EnerGuide for New Houses

Weather Library: C:\H2KV10~2\Dat\Wth100.dir

Weather Data for EDMONTON, ALBERTA

Builder Code: Cambridge II

Data Entry by: Dave T
Date of entry: 03/07/2009
Company:

Client name: ,
Street address:

City:
Postal code:

Region:
Telephone:

GENERAL HOUSE CHARACTERISTICS

House type:	Single Detached		
Number of storeys:	Two storeys		
Plan shape:	Other, 7-8 corners		
Front orientation:	North		
Year House Built:	2000-		
Wall colour:	Default	**Absorptivity:**	0.40
Roof colour:	Medium brown	**Absorptivity:**	0.84
Soil Condition:	Normal conductivity (dry sand, loam, clay)		
Water Table Level:	Normal (7-10m/23-33ft)		

House Thermal Mass Level: (A) Light, wood frame

Effective mass fraction 1.000

Occupants :
2 Adults for 50.0% of the time
2 Children for 50.0% of the time
0 Infants for 0.0% of the time

Sensible Internal Heat Gain From Occupants: 2.40 kWh/day

HOUSE TEMPERATURES

Heating Temperatures

Main Floor: 21.0 °C

Basement: 19.0 °C

TEMP. Rise from 21.0 °C: 2.8 °C

Basement is- Heated: YES **Cooled:** NO **Separate T/S:** NO
Fraction of internal gains released in basement : 0.150

Indoor design temperatures for equipment sizing

Heating: 22.0 °C

Cooling: 24.0 °C

WINDOW CHARACTERISTICS

Label	Location	#	Overhang Width (m)	Header Height (m)	Tilt deg	Curtain Factor	Shutter (RSI)
South							
Bed 2	second Floor	1	0.46	0.15	90.0	1.00	0.00
Bonus Room 2	second Floor	1	0.46	0.76	90.0	1.00	0.00
Window - 4	First Floor	1	0.61	0.40	90.0	1.00	0.00
Southeast							
Master Bed	second Floor	1	0.46	0.15	90.0	1.00	0.00
Window - 1	First Floor	1	0.00	0.00	90.0	1.00	0.00
East							
Ensuite	second Floor	1	0.46	0.15	90.0	1.00	0.00
Window - 2 copy	Foundation - 1	1	0.00	0.00	90.0	1.00	0.00
North							
Bed 3	second Floor	1	0.46	0.15	90.0	1.00	0.00
Bonus Room 1	second Floor	1	0.46	0.49	90.0	1.00	0.00
Window - 5	First Floor	1	1.22	0.40	90.0	1.00	0.00
West							
Window - 2	Foundation - 1	1	0.00	0.00	90.0	1.00	0.00
Southwest							
Window - 3	First Floor	1	0.00	0.00	90.0	1.00	0.00

Label	Type	#	Window Width (m)	Window Height (m)	Total Area (m^2)	Window RSI	SHGC
South							
Bed 2	2 Pane slider	1	1.24	1.24	1.55	0.522	0.4793
Bonus Room 2	2 Pane slider	1	1.24	1.55	1.93	0.533	0.4973
Window - 4	2 Pane slider	1	1.85	1.55	2.87	0.548	0.5214
Southeast							
Master Bed	2 Pane slider	1	1.55	1.24	1.93	0.533	0.4973
Window - 1	2 Pane Picture	1	1.83	1.52	2.79	0.592	0.5815
East							

Ensuite	2 Pane slider	1	1.24	1.24	1.55	0.522	0.4793
Window - 2 copy	2 Pane slider	1	1.37	0.61	0.84	0.497	0.4270
North							
Bed 3	2 Pane slider	1	1.24	1.24	1.55	0.522	0.4793
Bonus Room 1	2 Pane slider	1	1.24	1.55	1.93	0.533	0.4973
Window - 5	2 Pane slider	1	0.63	1.55	0.98	0.503	0.4402
West							
Window - 2	2 Pane slider	1	1.37	0.61	0.84	0.497	0.4270
SouthWest							
Window - 3	SldDr	1	1.85	2.16	4.00	0.727	0.4193

WINDOW CODE SCHEDULE

Name	Internal Code	Description (Glazings, Coatings, Fill, Spacer, Type, Frame)
2 Pane slider	223224	Double/double with 1 coat, Low-E .10 (soft), 13 mm Argon, Insulating, Slider with sash, Vinyl, RE* = -7.783, Eff. RSI= 0.52
2 Pane Picture	223204	Double/double with 1 coat, Low-E .10 (soft), 13 mm Argon, Insulating, Picture, Vinyl, RE* = 2.410, Eff. RSI= 0.58
SldDr	743245	DG + 1 Heat Mirror 88, Low-E .35 (hard2), 13 mm Argon, Insulating, Patio door, Reinforced vinyl, RE* = -0.353, Eff. RSI= 0.72

* Window Standard Energy Rating estimated for assumed dimensions, and Air tightness type: CSA - A3; Leakage rate = 0.550 m^3/hr/m

BUILDING PARAMETER DETAILS

CEILING COMPONENTS

	Construction Type	Code Type	Roof Slope	Heel Ht.(m)	Section Area (m^2)	R. Value (RSI)
2nd Floor	Attic/hip	STDCLG	6.000/12	0.23	72.84	6.78
Bonus Room	Scissor	2203501000	6.000/12	0.23	25.92	4.92
Fireplace	Attic/gable	STDCLG	3.996/12	0.23	0.56	5.18
Master Bed	Attic/hip	STDCLG	5.004/12	0.23	4.19	5.56

CEILING CODE SCHEDULE

Name	Internal Code	Description (Structure, typ/size, Spacing, Insull, 2, Int., Sheathing, Exterior, Studs)
2203501000	2203501000	Wood frame, 38x89 mm (2x4 in), 600 mm (24 in), RSI 4.9 (R 28) Batt, None, 12 mm (0.5 in) gypsum board, N/A, N/A, N/A

MAIN WALL COMPONENTS

Label	Lintel Type	Fac. Dir	Number of Corn.	Number of Inter.	Height (m)	Perim. (m)	Area (m^2)	R. Value (RSI)
Bonus room Gable Type: stdwall	101	N/A	2	0	0.69	5.49	3.76	2.95
First Floor Type: Landmark wall	101	N/A	7	0	2.46	33.41	82.18	3.98
second Floor Type: stdwall	101	N/A	11	0	2.46	42.82	105.35	3.02
Floor Header - 1 Type: Std Rims		N/A	4	4	0.30	33.41	10.18	3.74

WALL CODE SCHEDULE

Name	Internal Code	Description (Structure, typ/size, Spacing, Insull, 2, Int., Sheathing, Exterior, Studs)
Std Rims	1800300020	Floor header, N/A, N/A, RSI 3.5 (R 20) Batt, None, N/A, None, Hollow metal/vinyl cladding, N/A

EXPOSED FLOORS

Label	Floor Code Type	Area (m^2)	R. Value (RSI)
Bed 2 Cantileve	Std exposed floor	1.90	4.54
Bonus Room	Std exposed floor	21.74	4.54
Fireplace	Std exposed floor	0.56	4.54
Master Cantileve	Std exposed floor	0.65	4.54

DOORS

Label	Type	Height (m)	Width (m)	Gross Area (m^2)	R. Value (RSI)
Door - 2 **Loc: First Floor**	Solid wood	2.06	0.94	1.93	0.39
Door - 3 **Loc: First Floor**	Solid wood	2.06	0.84	1.72	0.39

USER-DEFINED STRUCTURE CODES SCHEDULE

Name	Description
11stdwall	no interior finish
11Landmark wall	
21STDCLG	standard test ceiling
31Std exposed floor	

FOUNDATIONS

Foundation Name:	Foundation - 1		
Foundation Type:	Basement	**Volume:**	158.4 m^3
Data Type:	Library	**Opening to Main Floor:**	0.00 m^2
Total Wall Height:	2.36 m	**Non-Rectangular**	
Depth Below Grade:	1.98 m	**Floor Perimeter:**	33.41 m
		Floor Area:	67.08 m^2
Interior wall type:	BWall	**R-value:**	1.62 RSI
Exterior wall type:	User specified	**R-Value:**	0.00 RSI
Number of corners :	7		
Lintel type:	N/A		
Added to slab type :	User specified	**R-Value:**	0.00 RSI
Floors Above Found.:	Fav52	**R-Value:**	1.00 RSI

Exposed areas for: Foundation - 1
Exposed Perimeter: 33.41 m

Configuration: BCIN_4
- concrete walls and floor
- interior surface of wall insulated from top of wall to 0.6 m below grade
- first storey is non-brick veneer or bricks thermally broken from basement's concrete walls

FOUNDATION CODE SCHEDULE

Interior Wall

Name	Code	Description (Fram., Spac., Studs, Ins/fram., Xtra ins, Int)
BWall	210K01	38x89 mm (2x4 in) wood, 400 mm (16 in), 2 studs, N/A, None, 12 mm (0.5 in) gypsum board

Floors Above Foundation

Name	Internal Code	Description (Structure, typ/size, Spacing, Insul1, 2, Int., Sheathing, Exterior, Drop Framing)
Fav52	4513008300	Composite wood joist, 38x302 mm (2x11.875 in), 600 mm (24 in), None, None, Carpet &

underpad, Waferboard/OSB 15.9 mm (5/8 in), None, No

BASEMENT FLOOR HEADER COMPONENTS

Label	Lintel Type	Fac. Dir	Number of Corn.	Number of Inter.	Height (m)	Perim. (m)	Area (m^2)	R. Value (RSI)
Floor Header - 2 Type: Std Rims	N/A	N/A	4	4	0.30	33.41	10.18	3.74

Basement Floor Header Code Schedule

Name	Internal Code	Description (Structure, typ/size, Spacing, Insul1, 2, Int., Sheathing, Exterior, Studs)
Std Rims	1800300020	Floor header, N/A, N/A, RSI 3.5 (R 20) Batt, None, None, None, Gypsum + Non insul. strapping, No

Lintel Code Schedule

Name	Code	Description (Type, Material, Insulation)
101	101	Double, Wood, Same as wall framing cavity

ROOF CAVITY INPUTS

Gable Ends		**Total Area:**	0.06 m^2
Sheathing Material	Plywood/Part. bd 9.5 mm (3/8 in)		0.08 RSI
Exterior Material:	Hollow metal/vinyl cladding		0.11 RSI
Sloped Roof		**Total Area:**	114.68 m^2
Sheathing Material	Plywood/Part. bd 12.7 mm (1/2 in)		0.11 RSI
Exterior Material:	Asphalt shingles		0.08 RSI
Total Cavity Volume:	70.6 m^3	**Ventilation Rate:**	0.50 ACH/hr

BUILDING ASSEMBLY DETAILS

Label	Construction Code	Nominal (RSI)	System (RSI)	Effective (RSI)
CEILING COMPONENTS				
2nd Floor	STDCLG	6.98	7.17	6.78
Bonus Room	2203501000	4.91	4.97	4.92
Fireplace	STDCLG	6.98	7.12	5.18
Master Bed	STDCLG	6.98	7.16	5.56
MAIN WALL COMPONENTS				
Bonus room Gable	stdwall	3.15	2.95	2.95
First Floor	Landmark wall	3.64	3.97	3.98
second Floor	stdwall	3.15	3.03	3.02
Floor Header - 1	Std Rims	3.50	3.74	3.74
EXPOSED FLOORS				
Bed 2 Cantileve	Std exposed floor	6.24	4.54	4.54
Bonus Room	Std exposed floor	6.24	4.54	4.54
Fireplace	Std exposed floor	6.24	4.54	4.54
Master Cantileve	Std exposed floor	6.24	4.54	4.54
FLOORS ABOVE BASEMENTS				
Foundation - 1	Fav52	0.00	1.00	1.00

BUILDING PARAMETERS SUMMARY

ZONE 1 : Above Grade

Component	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ	% Annual Heat Loss
Ceiling	103.51	103.51	6.13	7598.05	5.70
Main Walls	201.47	176.73	3.37	28812.73	21.62
Doors	3.66	3.66	0.39	5505.92	4.13
Exposed floors	24.85	24.85	4.54	2889.43	2.17
South Windows	6.35	6.35	0.54	6927.24	5.20
Southeast Windows	4.72	4.72	0.57	4877.70	3.66
East Windows	1.55	1.55	0.52	1736.87	1.30
North Windows	4.46	4.46	0.52	5000.55	3.75
Southwest Windows	4.00	4.00	0.73	3227.20	2.42
		ZONE 1 Totals:		**66575.68**	**49.96**

INTER-ZONE Heat Transfer : Floors Above Basement

Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ
67.08	67.08	1.002	10779.04

ZONE 2 : Basement

Component	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ	% Annual Heat Loss
Walls above grade	12.73	11.06	-	3956.06	2.97
East windows	0.84	0.84	0.50	755.89	0.57

West windows	0.84	0.84	0.50	755.89	0.57
Basement floor header	10.18	10.18	3.74	1572.02	1.18
Below grade foundation	133.26	133.26	-	25240.61	18.94
		ZONE [illegible]		[illegible]	24.22

Ventilation

House Volume	Air Change	Heat Loss MJ	% Annual Heat Loss
612.86 m^3	0.235 ACH	34411.293	25.82

AIR LEAKAGE AND VENTILATION

Building Envelope Surface Area: 486.00 m^2

Air Tightness Level is Average (4.55 ACH @ 50 Pa)

Terrain Description	**Height**	**m**
@ Weather Station : Open flat terrain, grass	Anemometer	10.0
@ Building site : Suburban, forest	Bldg. Eaves	6.2

Local Shielding: **Walls:** Heavy
Flue : Light

Leakage Fractions- **Ceiling:** 0.200 **Walls:** 0.650 **Floors:** 0.150

Estimated Equivalent Leakage Area @ 10 Pa:	1011.49 cm^2
Normalized Leakage Area @ 10 Pa:	2.0812 cm^2/m^2
Estimated Airflow to cause a 5 Pa Pressure Difference:	65 L/s
Estimated Airflow to cause a 10 Pa Pressure Difference:	101 L/s
ELA used to calculate Estimated Airflows:	404.60 cm^2

F326 VENTILATION REQUIREMENTS

Kitchen, Living Room, Dining Room	3 rooms @ 5.0 L/s: 15.0 L/s
Utility Room	1 rooms @ 5.0 L/s: 5.0 L/s
Bedroom	1 rooms @ 10.0 L/s: 10.0 L/s
Bedroom	1 rooms @ 5.0 L/s: 5.0 L/s
Bathroom	1 rooms @ 5.0 L/s: 5.0 L/s
Basement Rooms	: 10.0 L/s

CENTRAL VENTILATION SYSTEM

System Type: Fans w/o HR
Manufacturer:
Model Number:

Fan and Preheater Power at :	Watts
Fan and Preheater Power at :	Watts
Preheater Capacity:	Watts
Sensible Heat Recovery Efficiency at	%
Sensible Heat Recovery Efficiency at	%
Total Heat Recovery Efficicency in Cooling Mode	%
Low Temperature Ventilation Reduction:	%
Low Temperature Ventilation Reduction: Airflow Adjustment	(%)

Vented combustion appliance depressurization limit: 5.00 Pa.

Ventilation Supply Duct

Location:	Basement	**Type:**	Flexible
Length:	4.9 m	**Diameter:**	6.0 mm
Insulation:	4.0 RSI	**Sealing Characteristics:**	Sealed

Ventilation Exhaust Duct

Location:	Basement	**Type:**	Flexible
Length:	4.9 m	**Diameter:**	6.0 mm
Insulation:	4.0 RSI	**Sealing Characteristics:**	Sealed

Operating schedule for

Month	% of Time	Added Vent. Rate (L/s)	Month	% of Time	Added Vent. Rate (L/s)
Jan	0.00	0.00	Jul	0.00	0.00
Feb	0.00	0.00	Aug	0.00	0.00
Mar	36.33	5.69	Sep	0.00	0.00
Apr	95.63	14.99	Oct	100.00	15.68
May	0.00	0.00	Nov	29.15	4.57
Jun	0.00	0.00	Dec	0.00	0.00

SECONDARY FANS & OTHER EXHAUST APPLIANCES

	Control	Supply (L/s)	Exhaust (L/s)
Dryer	Continuous	-	1.20

Dryer is vented outdoors

AIR LEAKAGE AND VENTILATION SUMMARY

F326 Required continous ventilation:	50.000 L/s (0.29 ACH)
Central Ventilation Rate (Balanced):	15.677 L/s (0.09 ACH)
Total house ventilation is Balanced	
Gross Air Leakage and Ventilation Energy Load:	32616.309 MJ
Seasonal Heat Recovery Ventilator Efficiency:	0.000 %
Estimated Ventilation Electrical Load: Heating Hours:	274.921 MJ
Estimated Ventilation Electrical Load: Non-Heating Hours:	0.496 MJ
Net Air Leakage and Ventilation Load:	34548.754 MJ

SPACE HEATING SYSTEM

Primary Heating Fuel:	Natural Gas
Equipment:	Condensing furnace/boiler
Manufacturer:	
Model:	
Calculated* Output Capacity:	15.00 kW

* Design Heat loss X 1.00 + 0.5 kW

AFUE:	91.00
Steady State Efficiency:	93.60
Fan Mode:	Auto
ECM Motor:	No
Low Speed Fan Power:	0 watts
High Speed Fan Power:	291 watts

DOMESTIC WATER HEATING SYSTEM

Primary Water Heating Fuel:	Natural gas
Water Heating Equipment:	Direct vent (sealed)
Energy Factor:	0.562
Manufactuer:	
Model:	

Tank Capacity =	189.12 Litres	**Tank Blanket Insulation**	0.00 RSI
Tank Loacation:	Basement		
Pilot Energy =	0.00 MJ/day	**Flue Diameter**	0.00 mm

ANNUAL DOMESTIC WATER HEATING SUMMARY

Daily Hot Water Consumption:	225.00 Litres
Hot Water Temperature:	55.00 ℃
Estimated Domestic Water Heating Load:	17377 MJ
Primary Domestic Water Heating Energy Consumption:	30582.00 MJ
Primary System Seasonal Efficiency:	56.82%

ANNUAL SPACE HEATING SUMMARY

Design Heat Loss at -34.00 ℃ (23.81 Watts / m3):	14590.38 Watts
Gross Space Heat Loss:	133267.42 MJ
Gross Space Heating Load:	132350.97 MJ
Usable Internal Gains:	32265.79 MJ
Usable Internal Gains Fraction:	24.21 %
Usable Solar Gains:	24353.71 MJ
Usable Solar Gains Fraction:	18.27 %

Auxilary Energy Required:	75731.48 MJ
Space Heating System Load:	75731.47 MJ
Furnace/Boiler Seasonal efficiency:	86.78 %
Furnace/Boiler Annual Energy Consumption:	79367.37 MJ

BASE LOADS SUMMARY

	kwh/day	**Annual kWh**
Interior Lighting	3.40	1241.00
Appliances	9.00	3285.00
Other	7.60	2774.00
Exterior Use	4.00	1460.00
HVAC Fans		
HRV/Exhaust	0.21	76.50
Space Heating	1.10	400.34
Space Cooling	0.00	0.00
Total Average Electrical Load	25.31	9236.85

FAN OPERATION SUMMARY (kWh)

Hours	**HRV/Exhaust Fans**	**Space Heating**	**Space Cooling**
Heating	76.4	400.3	0.0
Neither	0.1	0.0	0.0
Cooling	0.0	0.0	0.0
Total	76.5	400.3	0.0

ENERGUIDE FOR HOUSES ENERGY CONSUMPTION SUMMARY REPORT

Estimated Annual Space Heating Energy Consumption	= 87268.95 MJ	= 24241.37 kWh
Ventilator Electrical Consumption: Heating Hours	= 274.92 MJ	= 76.37 kWh
Estimated Annual DHW Heating Energy Consumption	= 30582.00 MJ	= 8495.00 kWh
ESTIMATED ANNUAL SPACE + DHW ENERGY CONSUMPTION	= 118125.87 MJ	= 32812.74 kWh
ENERGUIDE RATING (0 to 100)	73	
EnerGuide Required Ventilation Capacity	0.01 L/s	

Estimated Greenhouse Gas Emissions 10.866 tonnes/year

ESTIMATED ANNUAL FUEL CONSUMPTION SUMMARY

Fuel	Space Heating	Space Cooling	DHW Heating	Appliance	Total
Natural Gas (m3)	2303.54	0.00	820.79	0.00	3124.33
Electricity (kWh)	476.71	0.00	0.00	8760.14	9236.84

ESTIMATED ANNUAL FUEL CONSUMPTION COSTS

Fuel Costs Library = Embedded

RATE	Electricity (Ottawa08)	Natural Gas (Ottawa08)	Oil (Ottawa08)	Propane (Ottawa08)	Wood (Sth Ont)	Total
$	988.14	1803.66	0.00	0.00	0.00	2791.81

Fuel Costs Library Listing

Filename = Embedded

Record # 1 Fuel: Electricity

Rate ID = Ottawa08 Hydro Rate Block

Rate Block	kWhr	Dollars Per kWhr	Charge ($)
Minimum	0.0		9.540
1	600.0	0.0926	
2	99999.0	0.1016	

Record # 2 Fuel: Natural Gas

Rate ID = Ottawa08 Gas Rate Block

Rate Block	m3	Dollars Per m3	Charge ($)
Minimum	0.0		14.000

1	30.0	0.5338	
2	85.0	0.5277	
3	170.0	0.5229	
4	99999.0	0.5194	
Record # 3	Fuel: Oil		
Rate ID = Ottawa08	Oil Rate Block		
Rate Block		Dollars	Charge
	Litre	Per Litre	($)
Minimum	0.0		0.000
1	99999.0	1.1750	
Record # 4	Fuel: Propane		
Rate ID = Ottawa08	Propane Rate Block		
Rate Block		Dollars	Charge
	Litre	Per Litre	($)
Minimum	0.0		0.000
1	99999.0	0.7200	
Record # 5	Fuel: Wood		
Rate ID = Sth Ont	Cord Rate		
Rate Block		Dollars	Charge
	Cord	Per Cord	($)
Minimum	0.0		0.000
1	99999.0	210.0000	

MONTHLY ENERGY PROFILE

Month	Energy Load (MJ)	Internal Gains (MJ)	Solar Gains (MJ)	Aux. Energy (MJ)	HRV Eff. %
Jan	21556.1	2853.7	2398.0	16304.4	0.0
Feb	17420.9	2582.9	2850.6	11987.4	0.0
Mar	15529.7	2865.2	3475.1	9189.4	0.0
Apr	10178.0	2777.0	2628.7	4772.3	0.0
May	5939.8	2874.6	1928.7	1136.4	0.0
Jun	3781.9	2639.8	1060.3	81.8	0.0
Jul	2145.7	1711.2	434.5	0.0	0.0
Aug	3595.7	2657.4	918.7	19.7	0.0
Sep	5916.1	2790.6	1892.1	1233.5	0.0
Oct	10567.8	2879.1	2480.2	5208.6	0.0
Nov	15780.6	2775.4	2245.7	10759.5	0.0
Dec	19938.5	2858.8	2041.1	15038.6	0.0
Annual	132351.0	32265.8	24353.7	[illegible]	0.0

FOUNDATION ENERGY PROFILE

			Heat Loss (MJ)		
Month	Crawl Space	Slab	Basement	Walkout	Total
Jan	0.0	0.0	2815.1	0.0	2815.1
Feb	0.0	0.0	2068.3	0.0	2068.3
Mar	0.0	0.0	1585.3	0.0	1585.3
Apr	0.0	0.0	823.3	0.0	823.3
May	0.0	0.0	196.0	0.0	196.0
Jun	0.0	0.0	14.1	0.0	14.1
Jul	0.0	0.0	0.0	0.0	0.0
Aug	0.0	0.0	3.4	0.0	3.4
Sep	0.0	0.0	212.6	0.0	212.6
Oct	0.0	0.0	898.3	0.0	898.3
Nov	0.0	0.0	1856.1	0.0	1856.1
Dec	0.0	0.0	2594.6	0.0	2594.6
Annual	0.0	0.0	13067.0	0.0	13067.0

FOUNDATION TEMPERATURES & VENTILATION PROFILE

	Temperature (Deg °C)			Air Change Rate		Heat Loss
Month	Crawl Space	Basement	Walkout	Natural	Total	(MJ)
Jan	0.0	16.4	0.0	0.322	0.329	6303.8
Feb	0.0	15.7	0.0	0.300	0.307	4885.9
Mar	0.0	15.5	0.0	0.259	0.300	4265.7
Apr	0.0	15.8	0.0	0.205	0.300	2710.6
May	0.0	16.3	0.0	0.162	0.169	1054.1
Jun	0.0	17.5	0.0	0.125	0.132	539.0
Jul	0.0	18.3	0.0	0.099	0.106	361.7

Aug	0.0	18.1	0.0	0.105	0.112	472.0
Sep	0.0	17.1	0.0	0.153	0.160	1025.1
Oct	0.0	16.9	0.0	0.201	0.300	2820.5
Nov	0.0	16.9	0.0	0.266	0.300	4320.7
Dec	0.0	16.7	0.0	0.306	0.313	5652.0
Ann	0.0	[illegible]	0.0	0.208	0.235	[illegible]

SPACE HEATING SYSTEM PERFORMANCE

Month	Space Heating Load (MJ)	Furnace Input (MJ)	Pilot Light (MJ)	Indoor Fans (MJ)	Heat Pump Input (MJ)	Total Input (MJ)	System Cop
Jan	16304.4	17087.1	0.0	310.3	0.0	17397.4	153.4
Feb	11987.4	12562.9	0.0	228.1	0.0	12791.0	138.6
Mar	9189.4	9630.6	0.0	174.9	0.0	9805.5	153.4
Apr	4772.3	5001.4	0.0	90.8	0.0	5092.2	148.4
May	1136.4	1191.0	0.0	21.6	0.0	1212.6	153.4
Jun	81.8	85.7	0.0	1.6	0.0	87.3	148.4
Jul	0.0	0.0	0.0	0.0	0.0	0.0	152.4
Aug	19.7	20.6	0.0	0.4	0.0	21.0	153.4
Sep	1233.5	1292.7	0.0	23.5	0.0	1316.2	148.4
Oct	5208.6	5458.7	0.0	99.1	0.0	5557.8	153.4
Nov	10759.5	11276.0	0.0	204.8	0.0	11480.8	148.4
Dec	15038.6	15760.6	0.0	286.2	0.0	16046.8	153.4
Ann	[illegible]	[illegible]	0.0	1441.2	0.0	80808.6	0.9

MONTHLY ESTIMATED ENERGY CONSUMPTION BY DEVICE (MJ)

	Space Heating		DHW Heating		Lights &	HRV &	Air
Month	Primary	Secondary	Primary	Secondary	Appliances	FANS	Conditioner
Jan	17087.1	548.7	2691.5	0.0	2678.4	310.3	0.0
Feb	12562.9	495.6	2453.4	0.0	2419.2	228.1	0.0
Mar	9630.6	548.7	2705.9	0.0	2678.4	213.8	0.0
Apr	5001.4	531.0	2578.4	0.0	2592.0	190.0	0.0
May	1191.0	548.7	2606.3	0.0	2678.4	21.6	0.0
Jun	85.7	531.0	2455.7	0.0	2592.0	1.6	0.0
Jul	0.0	548.7	2475.9	0.0	2678.4	0.0	0.0
Aug	20.6	548.7	2477.2	0.0	2678.4	0.4	0.0
Sep	1292.7	531.0	2425.3	0.0	2592.0	23.5	0.0
Oct	5458.7	548.7	2547.5	0.0	2678.4	206.3	0.0
Nov	11276.0	531.0	2514.1	0.0	2592.0	235.0	0.0
Dec	15760.6	548.7	2650.8	0.0	2678.4	286.2	0.0
Ann	79367.4	6460.3	30582.0	0.0	31536.0	1716.6	0.0

ESTIMATED FUEL COSTS (Dollars)

Month	Electricity	Natural Gas	Oil	Propane	Wood	Total
Jan	88.49	298.56	0.00	0.00	0.00	387.04
Feb	78.85	231.43	0.00	0.00	0.00	310.28
Mar	85.76	194.81	0.00	0.00	0.00	280.57
Apr	82.65	128.25	0.00	0.00	0.00	210.91
May	80.34	75.58	0.00	0.00	0.00	155.92
Jun	77.34	57.70	0.00	0.00	0.00	135.03
Jul	79.73	57.02	0.00	0.00	0.00	136.75
Aug	79.74	57.33	0.00	0.00	0.00	137.07
Sep	77.95	74.22	0.00	0.00	0.00	152.18
Oct	85.55	134.44	0.00	0.00	0.00	219.99
Nov	83.92	214.83	0.00	0.00	0.00	298.75
Dec	87.81	279.50	0.00	0.00	0.00	367.30
Ann[illegible]	988.14	1803.66	0.00	0.00	0.00	2791.81

The calculated heat losses and energy consumptions are only estimates, based upon the data entered and assumptions within the program. Actual energy consumption and heat losses will be influenced by construction practices, localized weather, equipment characteristics and the lifestyle of the occupants.

Appendix G: Landmark – House Specifications

Landmark

Version Feb 20 2010

CONCRETE WORK

Footings:
- 18 x 8" (nominal), 32 MPA Type 50 concrete

Telepost pads:
- As per engineering drawings

Foundation walls
- As per engineering drawings

Garage
- Grade beam or full wall & footing

Basement floor:
- 3" (nominal) thick concrete slab
- 20 MPA concrete
- Over 6 mil poly on a minimum of 6" (nominal) compacted sand

Front steps:
- Precast, as per standard model
- Number of risers as per plan

Weeping tile
- Continuous around perimeter of basement walls
- Covered with minimum 6" washed rock

NOTE: If the drainage requirements for a lot are such that the weeping tile and the water runoff from the roof are required to be connected to the storm sewer, the cost of bringing in the extra storm sewer line to the house and the connection of the rain water leaders is payable by the Purchaser

Damp proofing
- On exterior and interior basement foundation walls

Driveway
- DURAMIX, reinforced with 10mm rebar grid over compacted sand.
- Driveway width: full width of garage
- Driveway length: 28 feet maximum

NOTE: Any additional concrete required if the house is set further back from the front of the lot is the responsibility of the Purchaser.

Sidewalk
- 4 ft wide sidewalk, poured to front step, as per standard model
- Supported on piles or foundation walls

NOTE: Driveway and sidewalk surfaces are cure sealed

Garage floor
- 4" (nominal) thick, DURAMIX, reinforced with 10mm rebar grid at 24" on centre over compacted sand
- Supported on 4 piles and doweled to the grade beam or foundation walls
- Garage floor has hand trowel finish

FRAMING MATERIAL

Floor joists
- Floor systems designed and engineered as per plan

Subfloor
- 23/32" tongue and groove
- Glued and screwed

Underlay
- 3/8" underlay in linoleum areas

Exterior walls
- 2 x 6 framing at 24" on centre
- Sill plate gasket under all exterior wall bottom plates

Exterior wall sheathing
- 3/8" OSB

Interior walls
- Partition walls - 2 x 4 framing at 24" on centre
- Mechanical walls - 19.2" on centre

Exterior garage walls
- 2 x 6 framing at 24" on centre

Basement perimeter walls
- Steel studs at 24" on center

Roof Trusses
- Manufactured engineered design

Roof sheathing
- 3/8" OSB

Stairs
- 1 inch plywood for treads

Deck nailer - 2 x 8 treated
- **Laminated beam engineered header installed over garage door**

All interior framing materials are treated with a non-toxic fire retardant spray

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ROOFING

30 year 3 tab asphalt shingles, with roof vents as required

SITE WORK

Rough Grading
- Lot will be rough-graded according to the grading plan set for the subdivision by the municipality
- An approved rough grade certificate will be obtained and provided to the Homeowners
- Homeowners are responsible for maintaining the grade of the lot once the rough grade is approved by the municipality
- Final grade approvals are the responsibility of the Purchaser

Soil tests
- The Builder shall only be responsible for rough grading and levelling of the lot but shall not be responsible for supplying top soil or for terracing or filling or for the installation of retaining walls of any description unless same are specifically set out in this Agreement. The Builder shall not be responsible for any depressions or holes caused by the settling of fill used in backfilling any excavation or utility trench and shall assume no responsibility

- Topsoil is not included

Retaining walls (if required):

- If the final plot plan indicates that retaining walls or wing walls may be required, an allowance will be charged. Any unused portion of the allowance will be credited after rough grade approval. Any shortfall will be charged after rough grade approval.

Window wells

- Installed on basement windows as grading requires
- Complete with 8" (nominal) gravel base and drain pipe

Plotting the home

- Landmark Homes (Edmonton) Inc. is responsible for plotting the home on the lot to conform to all designed grading, site design regulations and engineering design requirements as required by the municipality and the developer for the subdivision.

whatsoever for any loss or damage caused by water or any other substances entering onto or travelling through any part of the Lands either on the surface of the lands or through any depression or utility trench.

- The Builder is responsible to conduct soil tests. The Purchaser acknowledges the lot may require special engineering to achieve soil bearing capacity. The Purchaser shall be responsible for any additional costs.

WINDOWS AND EXTERIOR DOORS

Basement windows

- Double glazed Low-E PVC basement windows, as per plan

Windows

- White triple-glazed Low-E argon filled PVC insulated slides throughout except as noted (gliders, single hung; and picture units, sizes as on standard plan)
- Standard window grills on front elevation windows only; choice of colours: Brass, Pewter OR White

Hinges and hardware for exterior doors

- Satin Chrome

Front exterior door

- Insulated fibreglass 6 panel
- Sidelight, if applicable, Low-E, double glazed
- With painted frame

Garage to house Door

- Embossed fibreglass insulated

Nook Door

- Double glazed Low-E sliding patio doors OR double glazed full glass single door (as per plan)

Garage overhead door

- Series 297 or equivalent
- White steel insulated, 16' x 7' (R-9.3)
- With painted frame and brickmould

NOTE: Additional charge for colours other than white.

Garage Door Opener

- Liftmaster elite series door opener or equivalent
- Comes with two remotes
- Includes exterior keypad

EXTERIOR FINISH

Siding

- Vinyl siding

Fascia

- 8" pre-finished aluminum

Soffit

- Pre-finished aluminum
- 44 mm non-vented aluminum soffit in areas of home encroaching within 1.2 m of property line

Louvers and shutters

- As per plan

Eavestroughs

- Pre-finished 4" or 5" (depending on model) aluminum eaves and downspouts

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HEATING AND VENTILATION

Furnace

- 95% high efficient two stage furnace (direct vent) with ECM Motor
- Power humidifier
- 7 day programmable thermostat with dual setback
- Professional furnace and duct cleaning before possession

Duct work

- Galvanized steel

Range Hood

- 6" duct vented to outside

Heat recovery ventilator

- Heat recovery ventilator in mechanical room with timer
- Switch located next to thermostat

Dryer vent

- One 4" dryer vent with hood (complete with vent kit to exterior)

Registers

- White heat registers and cold air return grills

ELECTRICAL AND ROUGH-INS

Service Panel

- 100 AMP panel with capacity for 60 circuits
- Plug-in on island, location to be determined by electrician

NOTE: Location of the power service panel is at the discretion of the Builder

Specialty Wiring (telephone and cable TV)

- 1 Cat5E wire and 1 RG6 wire terminated with live faceplates as per plan
- Telephone: Cat5E wires connected at the structured wiring panel
- Cable TV: RG6 wires connected at the structured wiring panel

Weatherproof receptacles

- GFI protection for all exterior weather-proof outlets (2 outlets)
- GFI protection for all bathrooms

Laundry room receptacles

- One 110 volt
- One 220 volt

Garage receptacles

- One 220 volt

Lighting fixtures

- 50 cents per square foot of finished area
- Four potlights included in kitchen area of 2 storey models. Bungalow & Bi-level models to have 2 extra ceiling outlets and no potlights
- $200 allowance for compact fluorescent lights. This only applies to light bulbs and cannot be applied to lighting allowance

Switches and plugs

- White Decora plates and plugs
- Three timer switches for bathroom fans
- Two dimmer switches
- Freezer plug in garage

Rough-ins

- Dishwasher rough-in
- Security system wiring in place for: 1 future keypad, 1 future motion detector, future door contacts on all exterior passage/patio doors
- Central vacuum - rough-in piping dropped into the basement (not consolidated). Additional charge to move to the garage and consolidate with plug.
- 2 pre-wires for future ceiling fans

Range Hood

- Two speed fan vented as per plan
- Rough in for Interlock Air Switch

NOTE: If the Purchaser chooses to install a fan with more than 300 CFM`s, the heating system must be reviewed to ensure proper fresh air supply and furnace size. Any increase in the cost of the heating system or any electrical relays required due to this installation is the responsibility of the Purchaser

Carbon Monoxide Detector

- 1 Combination Smoke Detector/Carbon Monoxide detector as per building code location.

INTERIOR DECOR COLLECTIONS

Landmark Homes offers 3 Distinctive Packages

- Urban Sophistication
- Casual Comfort
- Timeless Classics

Each package includes selections for plumbing fixtures, bathroom hardware, interior door hardware, baseboard and casing.

PLUMBING

Kitchen

- Sink: double compartment, undermount, stainless steel sink
- Faucet: Chrome

Main Bath

- Vanity sink: white china basin
- Vanity faucet: Chrome
- Tub: white one-piece fibreglass, complete with tub surround
- Tub faucet: Chrome with Pressure Balance Valve
- Water closets: 4.8 litre high efficiency toilet

Main floor half bath

- Sink: white vitreous china pedestal sink, as per plan
- Faucet: Chrome
- Water closets: 4.8 litre high efficiency toilet
- No cabinet

Ensuite

- Vanity sink: white china basin
- Vanity faucet: Chrome
- Tub: white one-piece fibreglass, complete with tub surround
- Tub faucet: Chrome handle with Pressure Balance Valve
- Water closets: 4.8 litre high efficiency toilet
- Soaker tub with Chrome faucet, as per plan
- Shower as per plan

Domestic Hot Water

- Direct vent high efficiency tankless hot water heater

Lawn service

- Two non-freeze hose bibs

Laundry

- One set of hot and cold laundry taps, with washer drain

Water lines

- Home run system with programmable hot water recirculating to second floor as required by model
- Shut off valves on toilets and sinks

Dishwasher

- Rough-in

Rough in for 3-piece bath in basement

INSULATION AND DRYWALL

Walls

- R20 (RSI 3.5) spray applied 2 lb polyurethane foam

Ceilings

- R40 (RSI 7.0) blown in over CGSB poly

Garage walls and ceiling

- Insulated with R12 spray applied 2 lb polyurethane foam, drywalled and fire taped
- Ceilings under bonus room floor drywalled

Ceilings

vapour barrier in the attic area

- R34 in sloped area
- R28 spray applied 2 lb polyurethane foam under the area built over the garage

Cantilevered Walls

- R28 spray applied 2 lb polyurethane foam under cantilevered areas
- 1/2`` exterior grade drywall on walls cantilevered within 1.2 m of property line

Basement perimeter walls

- R20 fiberglass batt insulation (where possible) complete with CGSB poly extending from floor to ceiling

Garage

- R20 spray applied 2 lb polyurethane foam in common walls between garage and house ONLY

- 1/2 " ceiling density drywall on all ceilings in the garage attics
- 1/2 " drywall on other ceilings

Walls

- 1/2" drywall on all walls
- 1/2" drywall on the garage to house partition wall

Corners

- Square drywall corners throughout

Ceiling texture

- White spray texture

Basement stairwell drywalled all the way down (no taping)

CABINETS AND COUNTERTOPS

Kitchen & Vanity Cabinets

- Cabinet Door Style - choice of:

(a) Oak - Landmark Homes standard stain choices
(b) Maple - Landmark Homes standard stain selections
(c) Thermofoil-vinyl wrap - Landmark Homes standard colours

- Exposed end-panels are veneer, to match cabinet stain colour
- Top moulding on upper cabinets
- Also included: a) one bank of pot drawers (one regular drawer above two-deep drawers); b) 24"-deep & staggered cabinet above fridge; c) staggered range cabinet d) microwave shelf, as per plan
- Drawers on rollers
- No vanity in half bath on main floor

Kitchen & Island Countertops

- Stone, c/w double 1/4 bevel edge. Choice of Landmark standard stone selections
- Comes with ceramic tile backsplash

Bathroom Countertops

- Postformed laminate with no-drip edge and backsplash
- Banjo countertop in main bath (as plan allows)
- One laminate selection only for all bathrooms. Stock colours only. Colours not stocked will be subject to extra charge.
- Matte surface finish. Other finishes subject to extra charge

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BATHROOM ACCESSORIES

Paper holder

- Chrome finish (Chosen with Interior Decor Collection)

Towel Bars

- Chrome finish (Chosen with Interior Decor Collection)
- 1 per bathroom

Robe Hook

- Chrome finish (Chosen with Interior Decor Collection
- 1 Robe Hook in Ensuite

Shower

- Chrome finish rod over tub

Mirrors

- 5 mm polished plate glass the width of the vanity and 36" high

Shower Door (as per plan)

- Chrome
- Complete with modesty lines for shower stalls only

INTERIOR FINISH

Interior passage and closet doors

- Paint grade solid core with ballbearing hinges
- Choice of Style: Camden OR Avalon OR Provincial OR Stanford OR Colonial OR Santa Fe OR Rockport

Shelving (Wire Shelving)

- 4 shelves in linen closet
- 1 shelf in each bedroom
- 4 shelves in the pantry (if pantry is in standard plan)
- Wire shelf and rod - Freeslide
- 3 recycle bins

Door and window casings

- Casual Comfort and Timeless Classics Interior Decor Collection: 3" wide, LM295 profile MDF paint grade. Urban Sophistication Interior

Door headers

- Casual Comfort and Timeless Classics Interior Decor Collections Only: 4 1/2 " LM450 full cap crown mould on outside top of doors open to hallways, including the foyer closet. Urban Sophistication Interior Decor Collection: Does not include interior door header to common areas.
- Casual Comfort and Timeless Classics Interior Decor Collections: Front Door - Fluted casing and header. Urban Sophistication Only: Front Door - 3" 423 MDF casing and 4" 425 MDF header.

Knobs and locks

- Satin Nickel Levers (Chosen with Interior Decor Collection)

Decor Collection: 423 MDF paint grade

Baseboards

- Casual Comfort and Timeless Classics Interior Decor Collection: 3" wide, LM295 profile, MDF paint grade. Urban Sophistication Interior Decor Collection: 4" 425 MDF paint grade

- Master bedroom and all bathrooms: privacy
- Other rooms: passage
- Deadbolts: on front, rear and garage/house doors
- Front Door: Ashford Gripset Satin Nickel Finish

Door stops

- Wall mounted spring type - satin chrome

RAILING

Stair railing

- Choice of Paint Grade Hardwood or Natural Stained Oak (no combinations)
- Wood bracket for main-to-upper-floor handrail
- Choice of 1 3/8" inch spindles
- Handrail cap is "A" Type Flat Rail (2 3/8")
- Shoe is 4" flat
- Spindles and railing are one colour only; additional colour is an extra charge.

PAINTING

Walls

- Choice of one colour for walls and one colour for trim
- 1 coat primer and 2 coat finish Zero VOC paint
- Selected brands of paint, dark colours, very light or pure white are subject to additional charge per room.

Interior doors and woodwork

- Latex primer and finish paint

NOTE: Since wood is a natural product, a stained finish will vary in colour and texture. Stain is absorbed at different rates and cannot be a totally uniform colour.

- Basement stairs painted (below basement door)

FLOORING/TILE

Tub Surround

- 12" of tile around the top and 3" of tile down the side of one piece bath tub and/or shower

Shower stall (if in approved plan)

- 12" of tile above the shower - Builders Series
- 3" on sides of shower

Kitchen Backsplash

- From counter to cabinets

Lino

- Builders Series

Hardwood / Cork

- As per standard model floor layout
- Standard is Pre-finish hardwood satin or matte finish or cork in Landmark Homes standard species and stain selection

Carpet

- Trackless 40 oz. Shaw Carpet or equivalent, with 7-year quality assurance, scotchguard or equivalent protected, anti-static protection
- 7.2 lb. density underlay
- Stair stringer carpeted on carpeted stairs

FIREPLACE & MANTEL

Fireplace box

- Direct vent gas fireplace comes with fan kit
- Electronic ignition - no pilot light
- Black front
- Box raised 6" from the floor

Mantel

- From Wood & Energy Store
- Choice of WE05, WE21 (Transitional), and WE09 (Traditional) Paint Grade OR Natural Stained Oak, WE22 (Contemporary) Available in Paint Grade only.

Corner fireplaces, as per plan

- Paint grade trim

Tile hearth on floor

- Builder Series
- Square cut with angle corners
- 12 inches on the floor

NOTE: Raised hearth is an extra charge to the Purchaser

APPLIANCES

- No appliances are included as part of the standard specifications package
- Cabinet layouts have been designed to accommodate standard-size appliances as follows

Standard Appliance Measurements

- Fridge: 35 1/4" W; 69 3/5" H; 27" D
- Range: 30 1/4" W
- Dishwasher: 24 1/4" W
- Microwave: 22 3/4" - 27 3/4" W (depending on plan); 13 3/4" H; 18" D
- It is the Purchaser's responsibility to arrange for delivery and installation of their appliances AFTER they take possession of the house.

LEGAL/MORTGAGE

1. Landmark Homes (Edmonton) Inc. will

- Pay for interest costs on mortgage draws
- Pay the Purchaser's legal fees and

6. LAND HELD IN TRUST

- In the event that the Builder conveys title to the Lands to the Purchaser prior to the full registration fees of title transfer to Purchaser's name as well as disbursement fees of such transfer if the Builder's solicitor is retained (no credit will be given to Purchaser if Builder's solicitor is not retained)

- Not pay interest costs on personal line of credit or cash transactions

NOTE: Only a Builder-approved mortgage specialist can be used

NOTE: All mortgages are draw mortgages unless specified otherwise by Landmark Homes

2. CMHC premiums, if any, are the responsibility of the Purchaser

3. PAYMENTS DUE

- Payment shall be due pursuant to Paragraph 5 notwithstanding that the title to the land may not be registered in the name of the Builder or the Purchaser at the time such payment is due.

4. ASSIGNMENT OF MORTGAGE PROCEEDS

- The Purchaser agrees to execute all documents required by the Mortgagee and/or its solicitor and to fulfil any and all conditions imposed by the Mortgagee to advance the mortgage proceeds to the Builder. Mortgage documents must be at the office of the builder's solicitor in executed form the earlier of 26 days from Landmark's acceptance of Schedule "C", or 14 calendar days prior to possession date. For the purpose of better carrying out the assignment of mortgage proceeds, the Purchaser appoints the Builder to be their lawful attorney with full power and authority to endorse and present for payment for its own account all cheques payable either to the Purchaser or to the Purchaser and the Builder jointly issued by any mortgage company named in any mortgage registered against the Land or issued by any mortgage company solicitor and representing payment of the proceeds of any such mortgage. The Purchaser specifically acknowledges and agrees that this Power of Attorney has been given for valuable consideration and is irrevocable.

5. MORTGAGE FUNDS

- The Purchaser agrees that they will not interfere, hold back or otherwise restrict the payment of the purchase price, provided however, that if the Purchaser shall instruct any Mortgagee to withhold mortgage proceeds for any reason whatsoever, then the entire balance of the purchase price shall be immediately due and payable by the Purchaser to the Builder at the option of the Builder and the unpaid balance shall bear interest at the rate prescribed in Clause 5 of this Agreement.

payment of the purchase price, including the advancement of all mortgage proceeds, the Purchaser agrees that they hold title to the Lands prior to the full payment of the purchase price as trustee for the Builder and for the account and benefit of the Builder, such conveyance of the Land being for convenience and financing purposes only, and the Builder shall be the beneficial owner of the Lands, it being agreed that and understood that the Purchaser is without any discretionary power of any kind in dealing with the Lands without prior consent of the Builder until the completion of this Agreement and payment of all monies owed hereunder. As security, the Purchaser shall deliver to the Builder or the Builder's solicitor a registerable Transfer of Land in favour of the Builder or the Builder's nominee, and execute such further documents, conveyances and assurances as may be necessary as security for payment of the monies to be paid by the Purchaser pursuant to the terms of this Agreement. Should the Purchaser fail to pay the monies to be paid or fail to observe the terms of this Agreement, and such failure to pay or default continues for seven (7) days after notice to the Purchaser of the Purchaser's default, the Builder, in addition to any other recourse it may have, may register the said Transfer of Land.

7. BUILDER'S LIENS

- Should a Builder's Lien holdback be required, such holdback shall be held by the Builder's solicitors in trust which may be released by such solicitor on the 46th day after total completion or the date of issuance of a Certificate of Substantial Performance by the Builder, provided only that no liens have been registered.

8. DOCUMENT TIMELINES

- Failure to comply with the purchaser performance timelines identified in this agreement is a breach of contract.

ARCHITECTURAL CONTROLS/PLOTTING THE HOUSE

- Architectural controls apply to all subdivisions. The designated agency by the developer has the final authority to approve a plan for construction on the selected lot.

BUILDER WARRANTY

1. Builder Warranty

- 12 month Builder Service Program on components found to be defective in materials

- Builder Service Program does not cover maintenance items

- The program is transferable for the period of or installation from the date of possession. Date of possession is defined as the date that the house is transferred to the Purchaser.

- 24 month Builder Service Program on mechanical and building envelope materials and installation found to be defective within 24 months from the date of possession.
- Please refer to the Landmark Homes (Edmonton) Inc. Homecare Manual for complete details on coverage

the warranty

2. Structural Warranty

- 5 year structural warranty as per the Alberta New Home Warranty

3. Appliances, if any

- Appliances are covered by the manufacturer`s warranty. If appliances are included in the contract, they are for the convenience of the Purchaser. Landmark Homes (Edmonton) Inc. provides no warranty on appliances

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SITE VISIT POLICY

In addition to the stipulations in Clause 11 of the Purchase Agreement, Purchasers must abide by the following policies

- Appointments for site visits must be arranged in advance
- When visiting the Builder`s construction site, the Purchaser must, at all times, be accompanied by one of the Builder`s employees.
- The Purchaser is entitled to a maximum of three (3) site visits during the construction of the home.
- Only those persons named on the Purchase Agreement may be present during any site visit.
- No pets are permitted on the construction site
- Neither the purchaser(s) nor the purchaser(s) ` agents are allowed to do any work on the site prior to the turnover date.
- Failure to comply with the Builder`s Site Visitation Policy is a breach of contract

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GST REBATES

GST on the home will be re-calculated at closing. If the final purchase price of the home + lot is between $350,000 and $450,000, GST will be calculated on a declining basis. If the final purchase price of the home + lot is greater than $450,000, no GST rebate will apply. GST rebates are calculated in accordance with federal taxation laws.

GENERAL

PERSONAL INFORMATION OF PURCHASERS

- The Builder recognizes and respects the importance of privacy. Personal information that the Builder collects will be used for the purpose of properly constructing, arranging financing and conveying title to the dwelling house, as well as providing warranty service. By signing the Purchase Agreement and this accompanying schedule, the Purchaser authorizes the Builder, the Land Titles Office, the Purchaser`s financial institution, the Builder`s lawyers, the Purchaser`s lawyers or any other organization or service provider working with the Builder to exchange personal information when necessary for these purposes.

SEASONAL WORKS

- Seasonal work may not be completed at the time of possession. Such work includes sidewalks/driveways, exterior trim painting, rough grade, parging, manufactured stone, brickwork and window well rock. Seasonal work is completed as weather permits.

NOTES

- All construction shall meet or exceed the current revision of the residential building standards and all other applicable codes. In cases where the specifications do not comply with applicable code requirements, the code
- Due to site conditions and procedure, specifications and dimensions can vary within reasonable limits while still exceeding the residential national building code.
- Window sizes may vary according to the manufacturer chosen
- The location of gas and power meters is chosen at the Builder`s discretion, taking into account site conditions, and to minimize the cost of such services
- Any specific requests for the location of the gas and power meters may be subject to an extra cost. Landmark Homes (Edmonton) Inc. will advise if request may be accommodated
- NO VERBAL AGREEMENTS ARE ACCEPTED

IMPORTANT INFORMATION ABOUT EXTRAS AND CHANGES

- Any selections and upgrades allowed by Landmark Homes (Edmonton) Inc. must be finalized within 21 days following the date of acceptance by Landmark Homes (Edmonton) Inc.

- I/We understand that should I/we not have completed our changes/extras/ selections/upgrades within the above noted time frame, Landmark Homes (Edmonton) Inc. reserves the right to terminate this agreement and retain any deposits paid to cover the costs shall prevail.

- LANDMARK HOMES (EDMONTON) INC. reserves the right to incorporate equivalent material where manufacturer's products become readily unavailable or discontinued (errors or omissions excepted).

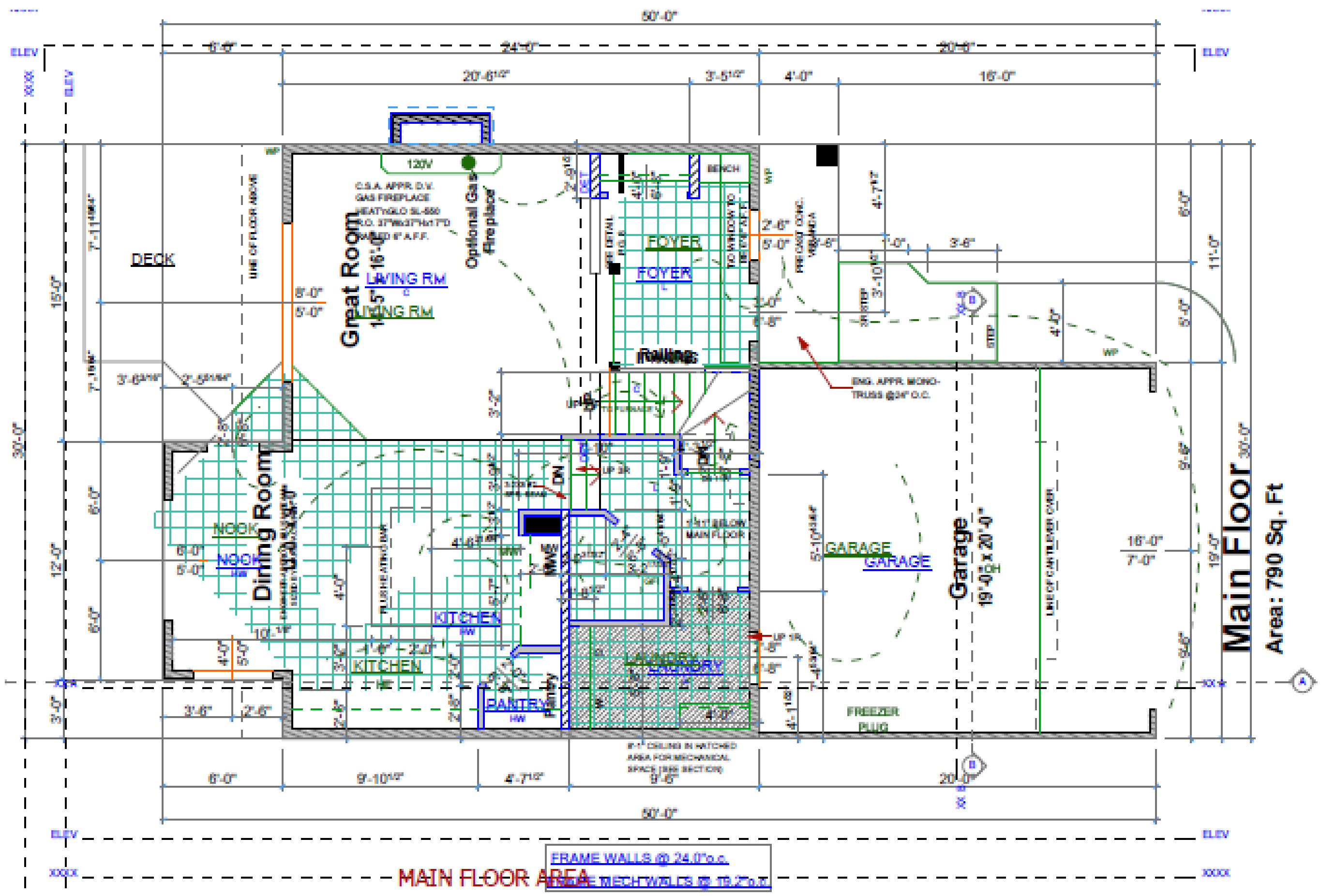
associated with processing the file to the point of cancellation.

UNREGISTERED OR UNSERVICED LAND

- In the case of unregistered land, the Purchaser understands that the Builder will hold the contract price for thirty days from the time the contract is signed by Landmark Homes (Edmonton) Inc.

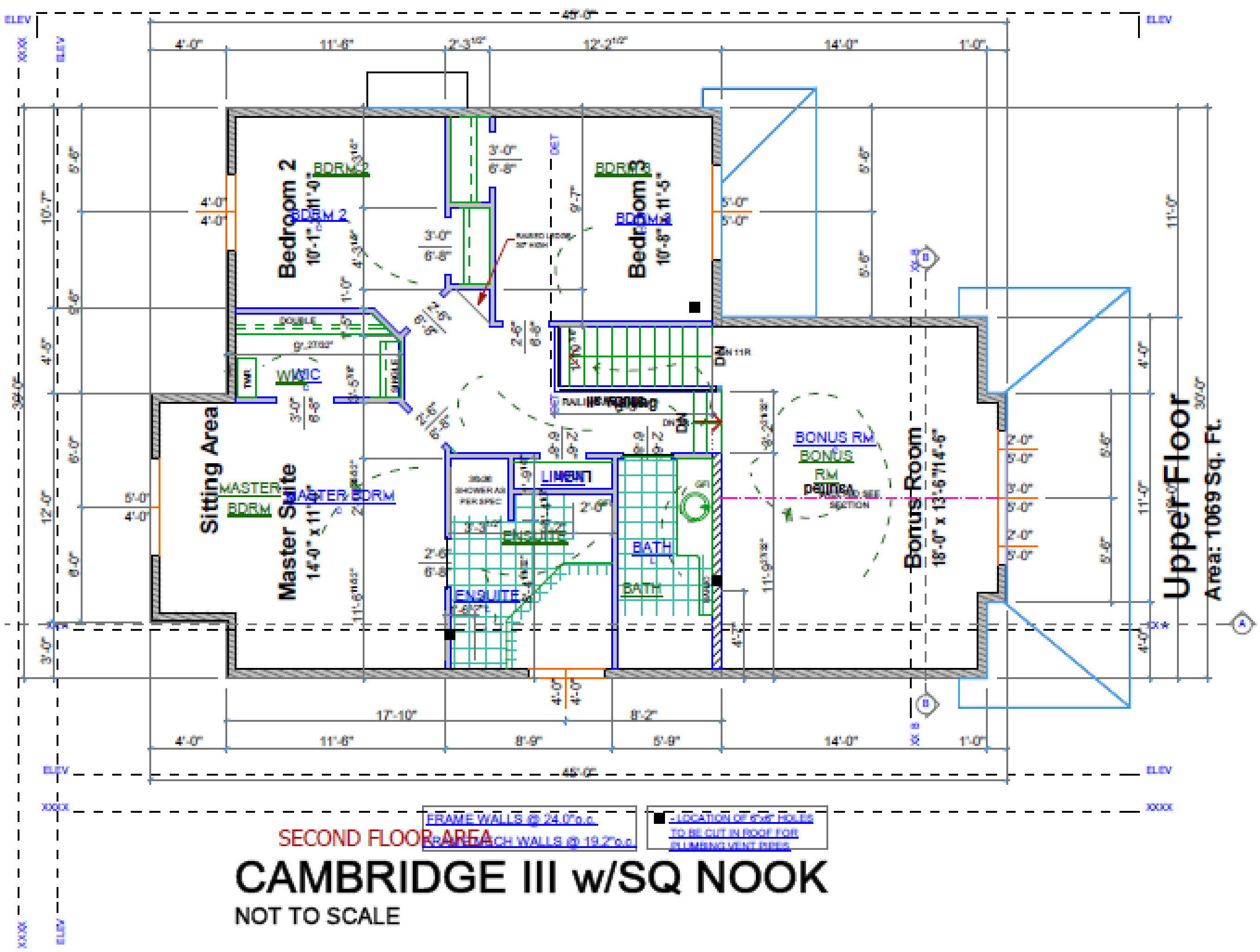
- Should the land remain unregistered at the 30th day, Landmark Homes (Edmonton) Inc. reserves the right to adjust the base price of the home for increases that occurred within the 30 days. The Purchaser will have the option to pay the difference or to cancel the contract without penalty.

Appendix H: Landmark Cambridge Floor Plan



CAMBRIDGE III w/SQ NOOK

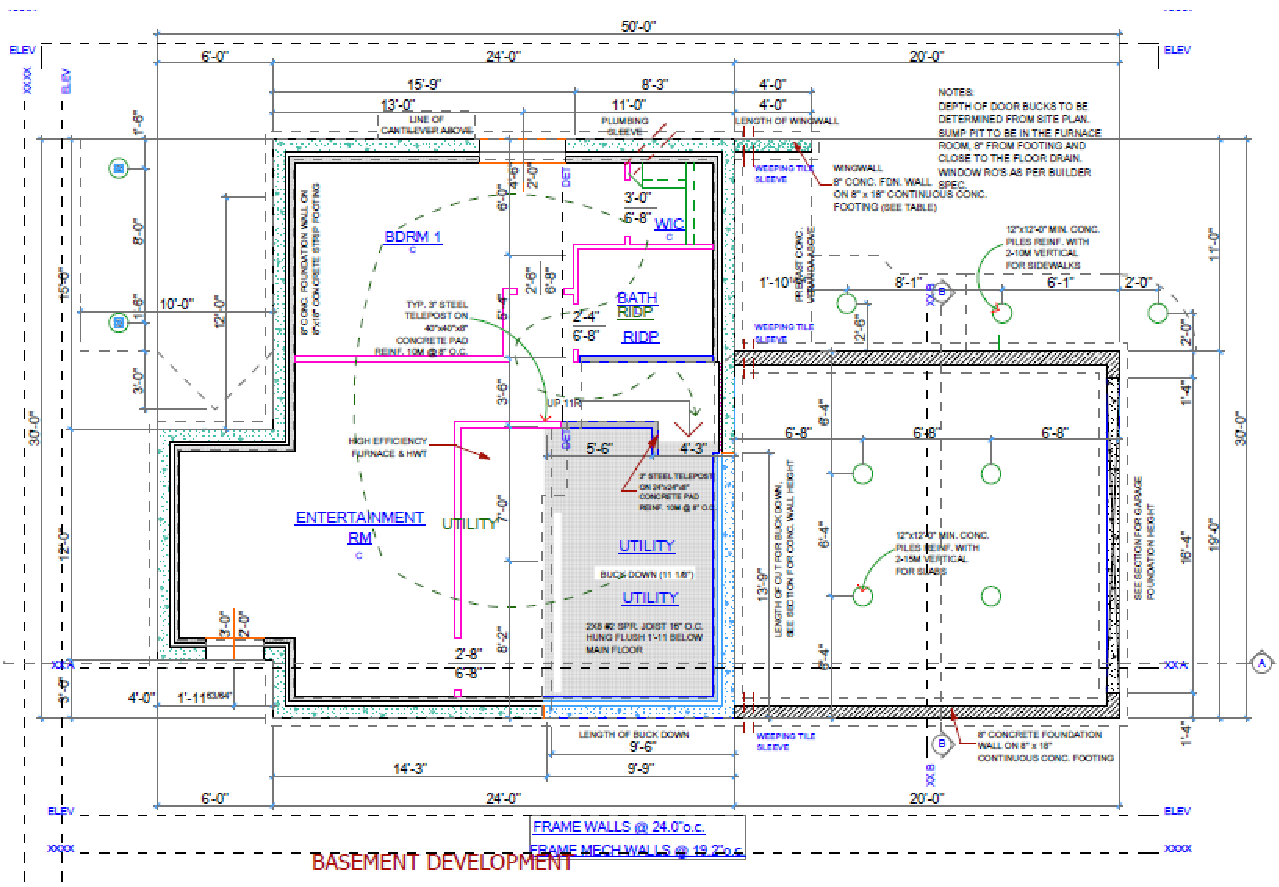
NOT TO SCALE



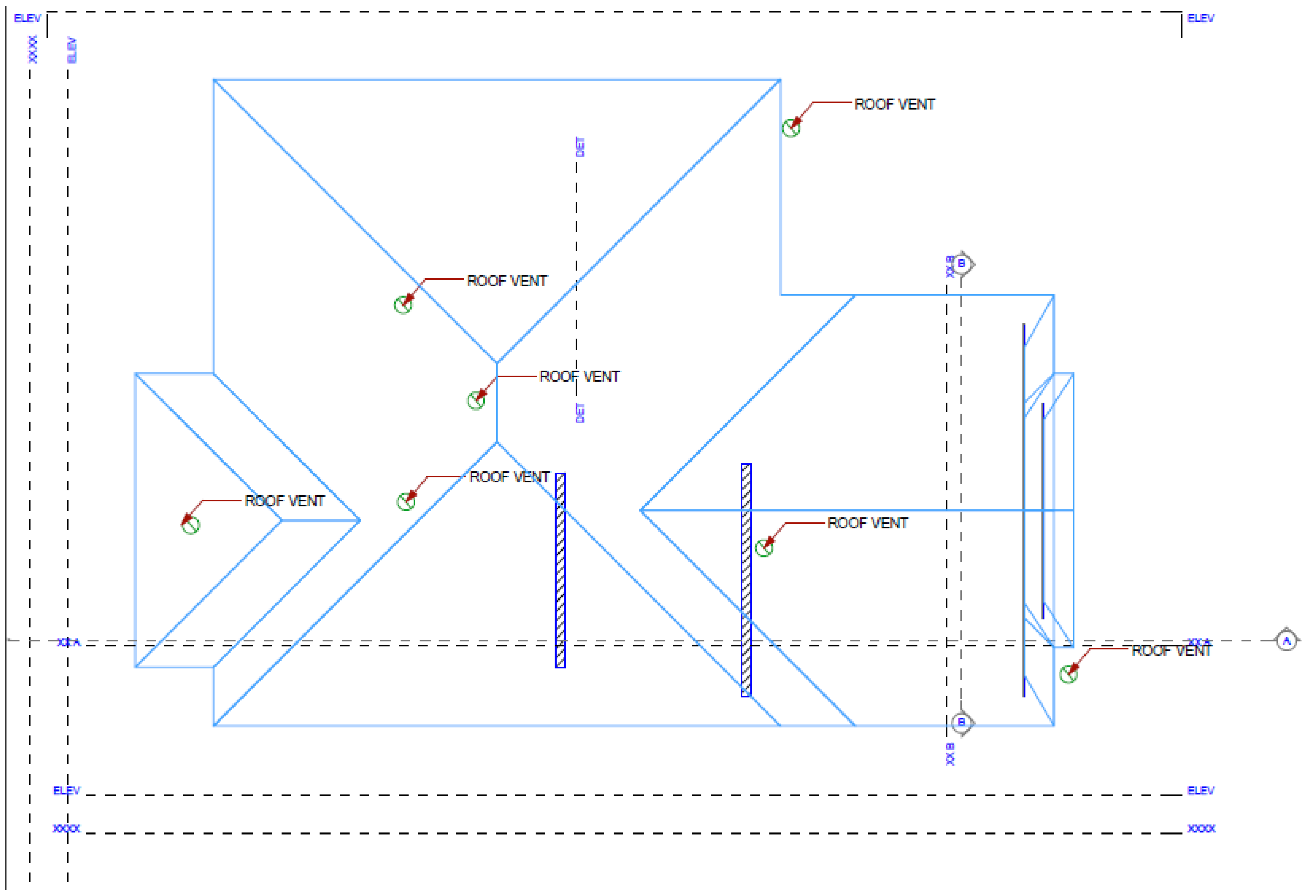
SECOND FLOOR AREA

CAMBRIDGE III w/SQ NOOK

NOT TO SCALE



BASEMENT DEVELOPMENT



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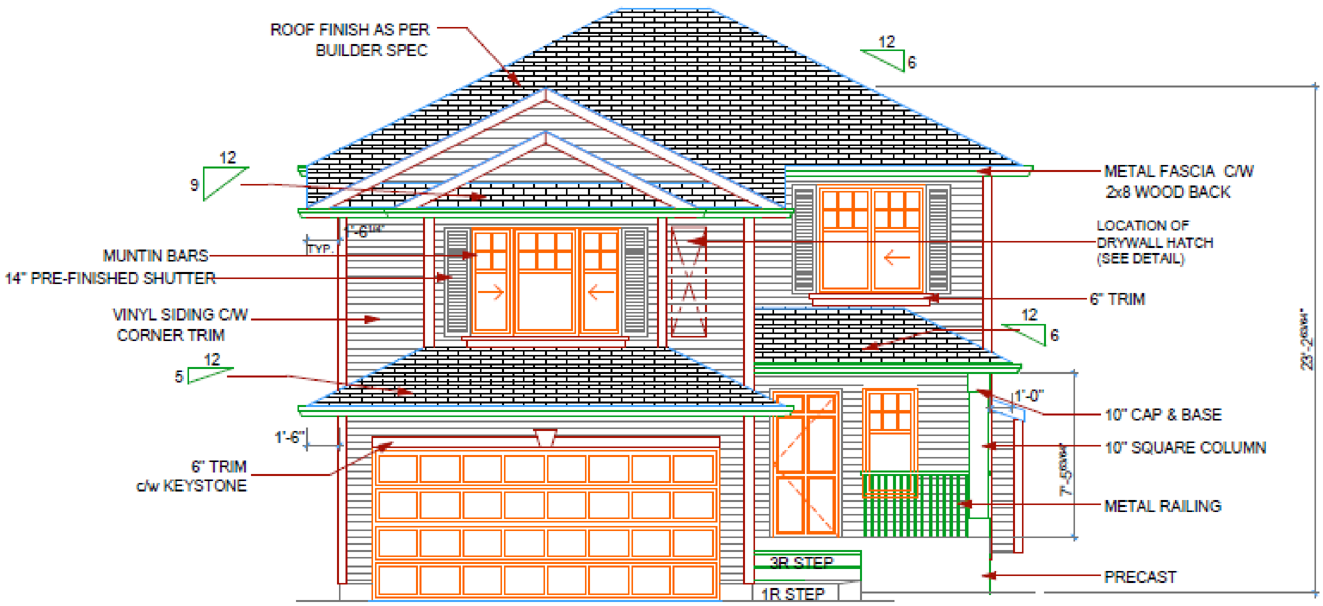
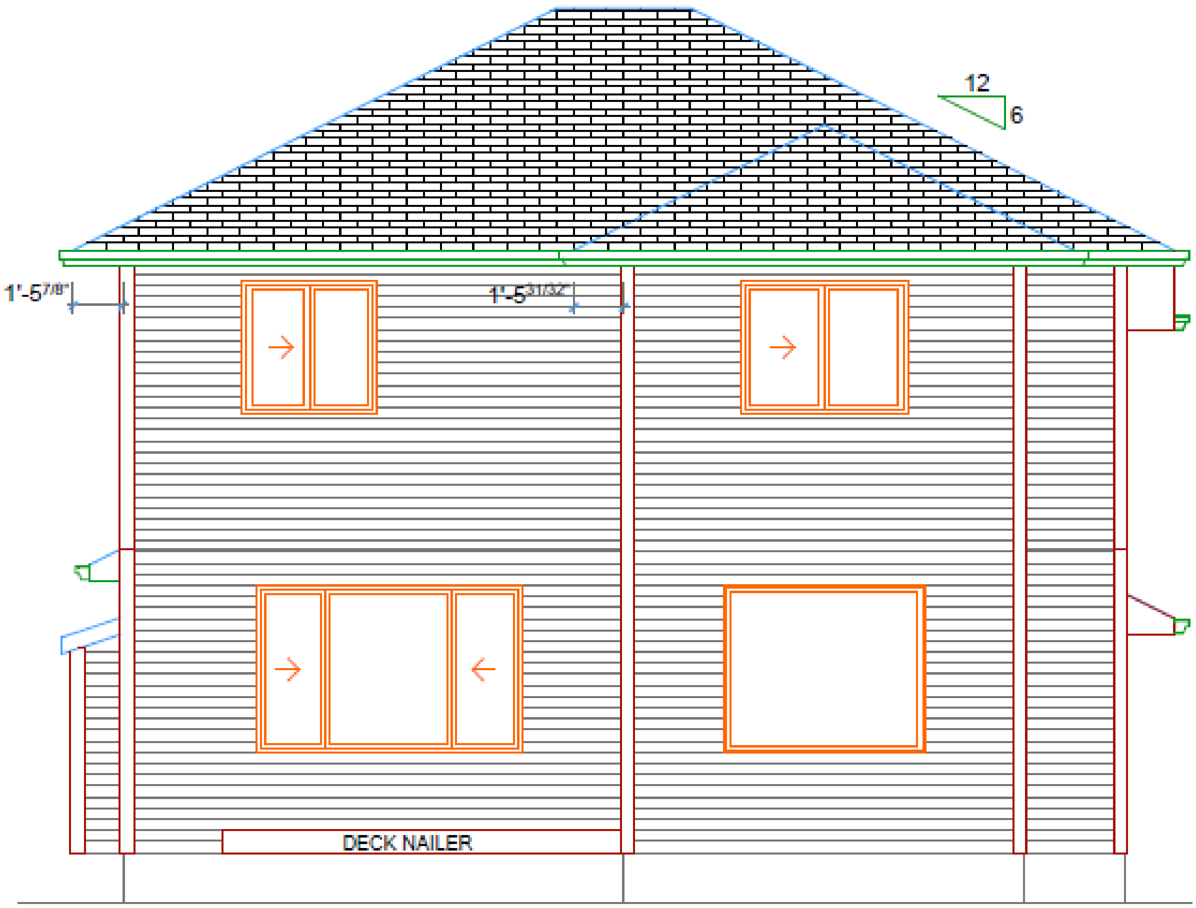
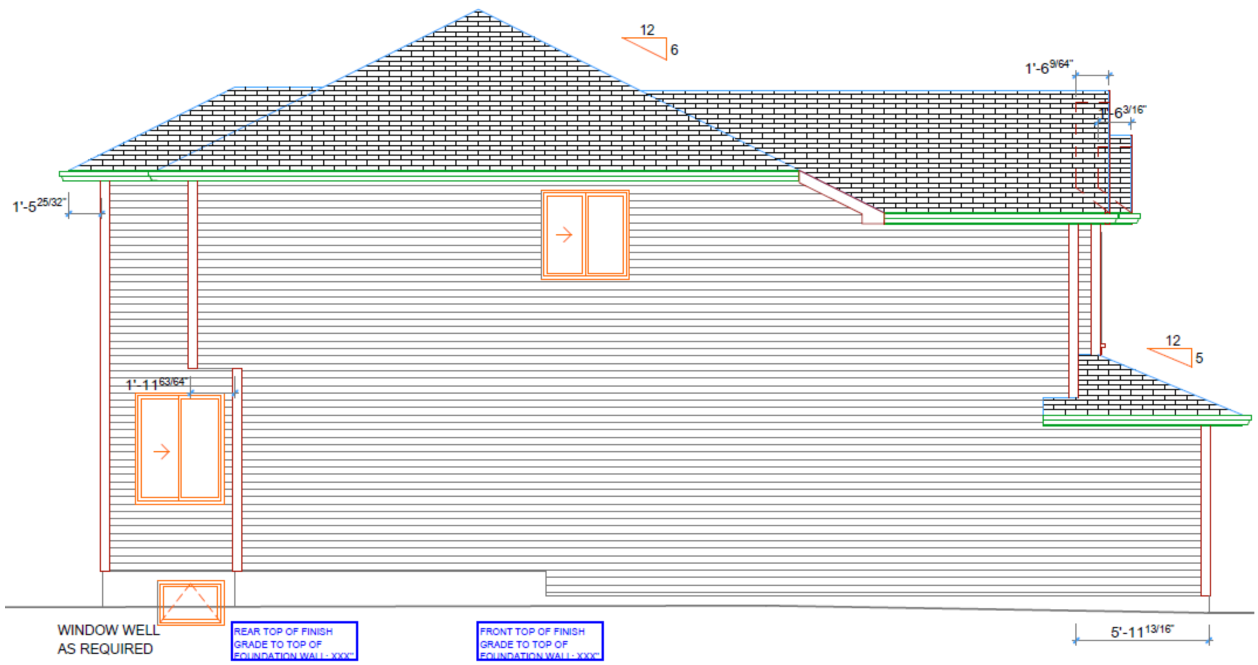
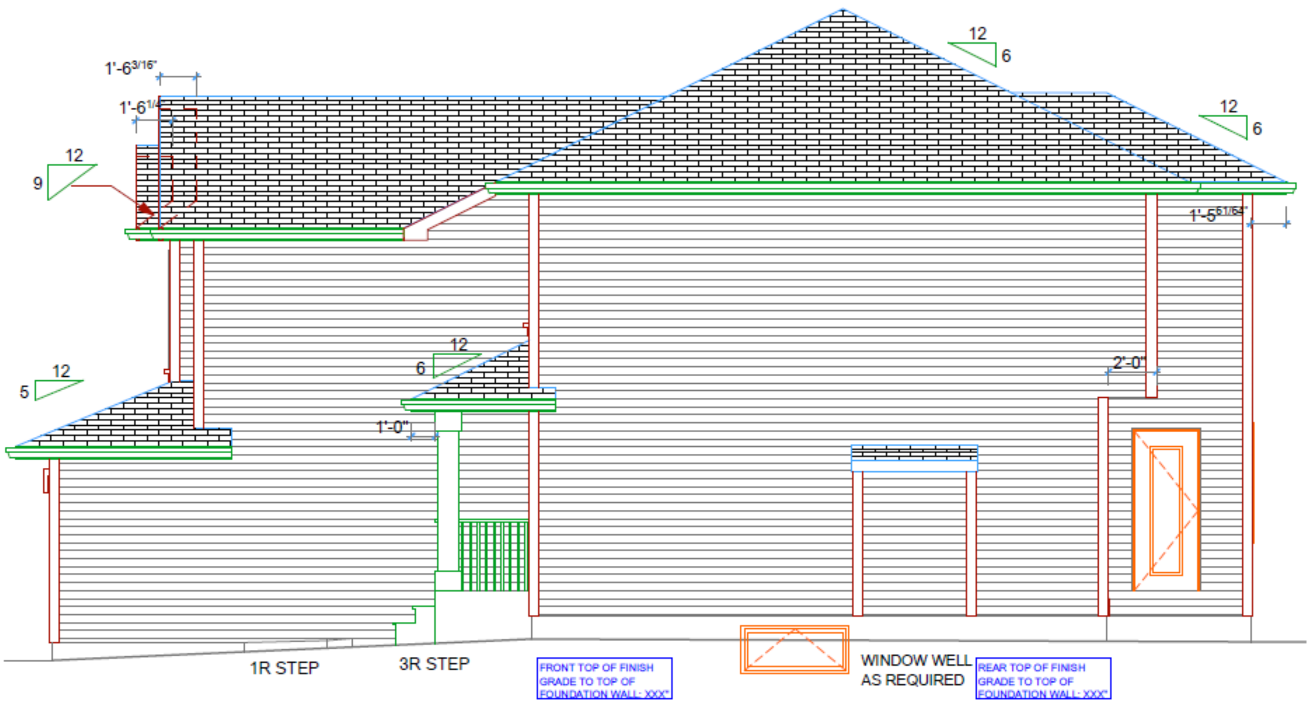
XXXX
XXXX

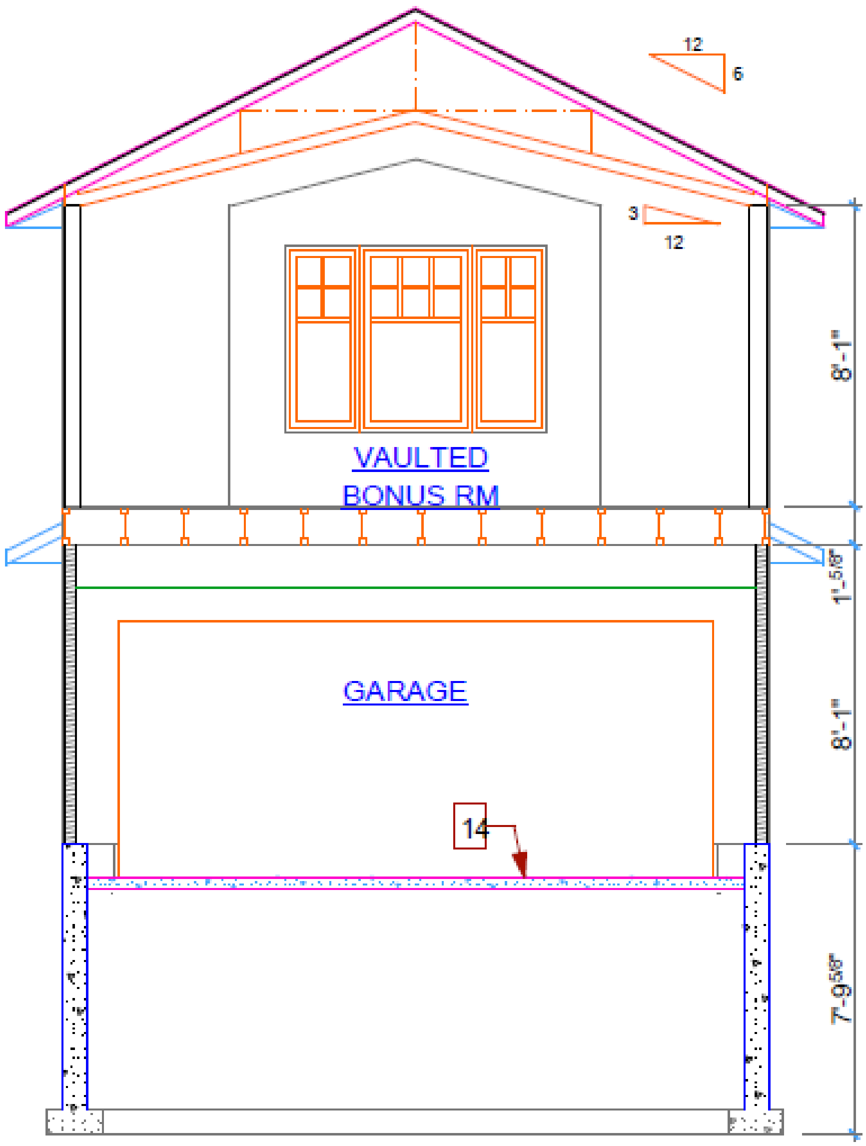

ROOF FINISH AS PER
BUILDER SPEC
12
6
12
9
METAL FASCIA C/W
2x8 WOOD BACK
LOCATION OF
DRYWALL HATCH
(SEE DETAIL)
MUNTIN BARS
TYP.
14" PRE-FINISHED SHUTTER
6" TRIM
VINYL SIDING C/W
CORNER TRIM
12
6
12
5
1'-0"
10" CAP & BASE
1'-6"
10" SQUARE COLUMN
6" TRIM
c/w KEYSTONE
METAL RAILING
3R STEP
1R STEP
PRECAST



REAR ELEVATION


12
6
1'-6 9/64"
1'-6 3/16"
1'-5 25/32"
12
5
1'-11 53/64"
WINDOW WELL
AS REQUIRED
REAR TOP OF FINISH
GRADE TO TOP OF
FOUNDATION WALL - XXX"
FRONT TOP OF FINISH
GRADE TO TOP OF
FOUNDATION WALL - XXX"
5'-11 13/16"


1'-6 3/16"
1'-6 1/4
12
9
12
6
12
6
1'-5 61/64"
12
6
12
5
2'-0"
1'-0"
1R STEP
3R STEP
FRONT TOP OF FINISH GRADE TO TOP OF FOUNDATION WALL: XXX"
WINDOW WELL AS REQUIRED
REAR TOP OF FINISH GRADE TO TOP OF FOUNDATION WALL: XXX"



GARAGE SECTION B-B