THE INFLUENCE OF STAKEHOLDERS' MOTIVATIONS AND BARRIERS ON CONSTRUCTION MATERIAL USE EFFECTIVENESS

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Abstract

Despite all the ecological, economic and social benefits of improving Construction Material Effectiveness (CME: using less construction materials in buildings, while maintaining the quality of materials for future recoverability), the market development for CME strategies (reducing material use, intensifying use (shared or multipurpose use), extending use, reusing, and recycling) is still slow.

A considerable amount of research has investigated the barriers to stakeholders' engagement with these measures. These studies mostly speculate barriers that may possibly exist rather than identifying the barriers that stakeholders have actually found detrimental. Studies which have conducted interviews/surveys usually investigate a limited number of CME strategies (usually recycling), among a limited number of stakeholder groups (mostly contractor), in few phases of a building lifetime (usually construction).

This thesis juxtaposes different CME strategies among various stakeholder groups and building lifecycle phases. A questionnaire was sent to architects, LEED consultants, structural engineers, general contractors, owner/developers, and building operators of recent LEED NC Gold or Platinum certified projects in Metro Vancouver, BC. The goal was to investigate the influence of respondents' motivations and barrier on the practice rate of the strategies.

This study showed that:

- Stakeholders' attitude about the environmental significance of CME strategies does not necessarily result in the higher practice rate of the strategies.

- The amount of effort that is put into implementing CME strategies is related more to motivations (or lack thereof) than to being hindered by barriers.
- The CME strategies are generally less considered in the planning and design phase compared to other studied phases. However, the practice rate of the strategies in this phase had a stronger correlation with environmental motivations.
- The stakeholders’ limited area and time of control and responsibility is a major reason for their lack of interest in implementing many of CME strategies.

The following measures are suggested to motivate stakeholders to consider CME:

- Encouraging multi-stakeholder decision making processes which engages stakeholders from up-stream and down-stream phases;
- Educating stakeholders about personal benefits and lifecycle environmental benefits of CME;
- Sharing the benefits and responsibilities of CME among all the influential stakeholders involved during the life cycle of materials.

Preface

This thesis is original, unpublished, independent work by the author, Zahra.S. H.Teshnizi. The survey questionnaire presented in Chapters 4 and 5 of this thesis was designed, carried out, and analyzed by the author solely, with feedback from the project supervisor (Dr. Raymond Cole) and the committee members (Dr. Michael Meitner and Kathy Wardle). The survey was approved by UBC Behavioural Research Ethic Board - UBC BREB Number H14-00074.

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Glossary

Construction Material Effectiveness (CME):

Construction Material Effectiveness (CME) is defined as using less construction materials in buildings to provide the same expected service and performance while maintaining the quality of materials so that they can be infinitely recovered through natural or industrial cycles.

Strategies:

Strategies for CME, which in this study are limited to reducing use, more intensive use, extending use, reusing, and recycling.

Reduce: Reducing the amount of new materials by optimizing material use through design or reducing waste generation during construction

Intense Use: Increasing the intensity of use of materials by designing for shared and/or multi-purpose use or practicing shared and/or multi-purpose use in the operation phase

Extend Use: Extending the life of materials by designing for maintainability, using durable materials or repairing and upgrading materials/products rather than replacing them with new

Reuse: Reusing materials by incorporating design strategies that facilitate future, designing and constructing with salvaged materials and/or existing building structures or, deconstructing and/or salvaging reusable materials

Recycle: Recycling materials by incorporating design strategies that facilitate future recyclability, using recycled content materials, or recycling CDR waste.

3Rs: Reduce, reuse, and recycle

CDR Waste: Construction, Demolition, and Renovation Waste

Material recovery: Keeping materials in the supply chain through reusing, repairing, upgrading, remanufacturing or recycling of materials/products

Deconstruction:

Dismantling a building into its component parts to maximize salvage, reuse and recycling of building materials

Stakeholders' role or stakeholder groups:

In this study, the stakeholder groups in a construction project are limited to: service providers (architects, structural engineers, LEED consultants, and general construction contractors) and customers (owner/developers and building operators)

Customers: owner/developers and building operators

Practice rate: The practice rate of CME strategies in the construction projects which the respondents to the survey in this study are involved in.

Importance: Perceived importance of CME strategies in the respondents' point of view

Motivations: Motivations that encourage stakeholders of a construction project to implement CME strategies

Barriers: Barriers which impedes stakeholders to implement CME strategies

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Dedications

This thesis is dedicated to my parents who are the source of unending love, strength, and inspiration in my life. It is also dedicated to my brothers who have been my best friends in my life journey. Words cannot express my love and gratitude for family who always have my back in happiness and hardship.

Chapter 1: Introduction

The extraction, manufacturing, and transportation of building materials have considerable environmental, economic and social impacts. It is widely accepted that "more than any other human endeavor the built environment has direct, complex and long-lasting impacts on the biosphere" (Kibert 2008, p.44). The building sector is the largest producer of greenhouse gases, with approximately one third of global energy consumption. Moreover, it consumes more than a third of global resources, including 12% of all the world's fresh water and 40-50% of raw materials use. This amount would be doubled if hidden flows were to be considered[1] (Calkins, 2008; Pacheco-Torgal & Labrincha, 2013; UNEP-SBC, 2009).

The building industry is also a major source of solid waste generation. According to reports from Public Works and Government Services Canada (2000), and Greater Vancouver Regional District[2] (2008), one third of total solid waste in Canada and also in Metro Vancouver, is Construction, Renovation and Demolition (CRD) waste. Based on the report more than half of this waste in Metro Vancouver can readily be recycled and diverted from landfills.

A recent report from the United Nations Environment Programme (UNEP) warns that if the economic growth rate remains coupled to natural resource consumption rate, by 2050 the consumption rate of minerals, ores, fossil fuels and biomass will tripled and reach an estimated 140 billion tons per year (UNEP Working Group on Decoupling, 2011). However, except for

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[1] Hidden flows are emissions which are never enter the economy and are released into the environment during the extraction and production process of materials and products (Calkins, 2009).

[2] Metro Vancouver

biomass (which is the resource for timber and paper), the lack of raw material supply at a global level is not the main reason to change material consumption patterns. It is rather driven by increase in energy requirement and cost of extraction from less pure resources (Acree Guggemos & Horvath, 2003, p. 72; Allwood, Ashby, Gutowski, & Worrell, 2011).

From an environmental standpoint, other than negative impacts of the extraction and waste on the ecosystems (Pacheco-Torgal & Labrincha, 2013), since fossil fuels are the main energy resource of the industry, increase in material use means increase in greenhouse gas emissions. The building industry generates 40-50% of greenhouse gases, of which 10-20 % is emitted during the production and construction phases (Allwood et al., 2011; Asif, Muneer, & Kelley, 2007).

According to Architecture 2030[3] (2011), nearly three quarters of the built environement in the US will be new or renewed by the year 2035, which indicates a crucial responsibility and opportunity for the building industry to deal with considerable amounts of CRD waste generation and raw material consumption.

Green building strategies been developed in response to the worldwide increase of awareness and concern regarding the negative environmental impacts of the building industry (Griffin, Knowles, & Allen, 2010). Green building strategies address material use by promoting less material consumption and waste generation through a combination of improved construction

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[3] Architecture 2030 is "a non-partisan, non-profit research organization developing planning, policy, and design solutions for low-carbon, resilient built environments worldwide (Architecture 2030, n.d.)".

materials maintenance and waste management strategies (reduce, reuse and recycle) (Allwood et al., 2011). Many studies have focused on various environmental and economic benefits of these strategies such as decreasing resource and land use, decreasing dump fees, economic profits from selling salvaged or recyclable materials, and creating local employment opportunities (Amponsah et al. 2012; Kralj 2008; Roth 2005, Begum et al. 2006; Amponsah et al. 2012; Duran, Lenihan, and O'Regan 2006).

To foster these strategies in day-to-day practices, green building/material assessment systems have included these strategies in their performance requirements and credits (Griffin et al., 2010). These assessment systems have different aspirations and different level requirements to extending the useful lifetime of construction materials (International Living Future Institute, 2014; McDonough Braungart Design Chemistry, 2012; U.S. Green Building Council, 2013a, 2013b). Moreover, international, national, provincial, and local policies and regulations are promoting – and in some cases demanding – the reduction of material use and waste generation in the building industry. European Union members are expected to achieve a minimum 70% of construction, demolition, and renovation (CDR) waste reduction (by weight) by 2020 (Pacheco-Torgal, 2014). Mission 2030[4] has set the waste diversion target of 35% by 2015, 50% by 2020, 75% by 2025, and 100% by 2030 (Graton & Lynch, 2012). Metro Vancouver's Solid Waste Management Plan (SWMP) has set even more restrictive targets: 70% waste diversion rate by 2015 and 80% by 2020, and 10% reduction in waste generation by 2020 (Dalal, 2011).

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[4] Mission 2030 is a non-partisan and non-profit initiative to inspire efficiency and reduce CRD waste, from Construction Resource Initiatives Council in Canada.

Some recent studies criticize current strategies that are being promoted for failing to place sufficient emphasis on the waste management hierarchy, i.e. reduce, reuse, and recycle. These studies assert that recycling, which is the least preferred in the hierarchy, is the most supported strategy in current assessment methods, practices and policies. Current recycling practices move material flows toward becoming more impure and losing their quality through time (Sassi, 2004). Allwood et al. (2011) emphasize on the importance of designing material loops that reduce the unnecessary material consumption and processing. Some researchers take a further step and suggest that it is not enough to reduce material consumption, but rather we should move toward construction material flow that keeps material quality through its use and can have positive impacts on the environment rather than merely less negative impacts (McDonough and Braungart 2010; McDonough and Braungart 2013; Birkeland 2008).

In this thesis, *Construction Material Effectiveness* (CME) is defined as using less construction materials in buildings to provide the same expected service and performance while maintaining the quality of materials so that they can be infinitely recovered through natural or industrial cycles. Despite all the potential environmental, economic, and social benefits of CME (Birkeland, 2008; CaGBC, 2013; Cole, 2011; Feige, Wallbaum, & Krank, 2011; Greyson, 2007; Halme, Anttonen, Kuisma, Kontoniemi, & Heino, 2007; Meyer, Distelkamp, & Wolter, 2007), it is yet to be the main priority for the selection of materials in the North American mainstream building practices. The absence of these strategies is even more evident in projects which do not aim to gain any green building certification or status. According to Ding (2014), performance and the appearance of materials are the major focus in traditional design and construction processes. Currently the value of many building materials decreases during their lifetime and they are typically not considered valuable enough to be repaired, upgraded, reused, or recycled.

It is stated in the literature that currently the lack of proper regulations and effective *interaction* and *collaboration* between *stakeholders* are currently more important barriers to green buildings than technological limitations (Griffin et al., 2010). Feige et al. (2011) claims that by changing the stakeholder's behavior in the construction industry, both demand and supply sides of sustainable building solutions and technologies can be advanced.

Many researchers have investigated the stakeholders' barriers to implement CME strategies in their projects (Cole, 2011). However, most of these studies speculate the barriers that may possibly exist rather than interviewing the stakeholders for finding barriers that they actually have faced when they implement the strategies for CME (Griffin et al. 2010, p. 3). Moreover, studies which are based on interviews/surveys usually investigate the barriers of a limited number of stakeholder groups (mostly contractors), in few phases of a building lifetime (usually the construction process) to implement a single CME strategy (mostly waste management strategies) (Begum, Siwar, Pereira, & Jaafar, 2009; Osmani, Glass, & Price, 2008; Rodriguez-Nikl, Kelley, Xiao, Hammer, & Tilt, 2014; Saunders & Wynn, 2004; Teo & Loosemore, 2001).

Very few studies have investigated different stakeholders' *motivation* for implementing CME strategies. A highly diverse range of stakeholders are involved in different stages of construction materials life cycle. These stakeholders have various and sometimes conflicting perceptions, interests, and priorities (Wallbaum, Silva, Cole, Hoballah, & Krank, 2010). A possible explanation for influential stakeholders in construction material flows to not favor the strategies for CME is that they simply might not find enough motivation to prioritize CME sufficiently high enough compared to their other list of responsibilities. In other words the influential stakeholders may not find any personal motivation to implement CME strategies.

This thesis focuses on the influence of different stakeholder groups' motivations and barriers on their ability or interest in implementing CME strategies. By considering the role and influence of each stakeholder group in different stages of construction material flow, the study will provide greater understanding of construction material Life Cycle Analysis (LCA). Assessing life cycle economic and environmental benefits of CME, as necessary as it is (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2012, p. 85), is insufficient for motivating the stakeholders who are involved only in limited phases of a building lifetime. Therefore, studying the factors that relate stakeholders' preferences to CME will potentially encourage the adoption of CME strategies in the mainstream practice.

The primary goal of this study is to find the connection between the implementation of CME strategies and stakeholders' priorities and preferences. The CME is more appealing to the stakeholders if they are not only beneficial for the environment, but also are in line with their individual priorities. Therefore, it is crucial to identify the stakeholders who are expected to implement these strategies and discover the relationship and interactions between these stakeholders in different stages of material flows in which the strategies for CME can be implemented.

Within this overall ambition, the thesis addresses the following questions:

- What are the current practice rates of different CME strategies?
- Who are the influential decision makers, investors and beneficiaries of CME in different stages of construction material flows?
- What is the attitude of key stakeholders toward the importance of CME strategies?
- Does the stakeholders’ awareness of the importance and environmental benefits of CME affect their decision about implementing the strategies?
- What are the primary motivations and barriers of different stakeholder groups for implementing CME strategies? Do different stakeholders have common or conflicting priorities?
- How the stakeholders’ motivations and barriers to CME strategies influence the practice rate of these strategies?

This thesis is organized in five chapters (other than the current chapter – introduction). Chapter 2 reviews the existing literature on environmental material use solutions (including CME) and CME strategies. Chapter 3 reviews the literature on stakeholders’ environmental attitudes and behaviors associated with material related decisions. Chapter 4 explains data collection and sampling methods and Chapter 5 presents the survey results and data analyses. Chapter 6 provides a detailed interpretation of the data analyses and offers a series of suggestions for improving CME in the current construction industry. The chapter concludes by presenting research limitations and future research opportunities.

Chapter 2: Environmental use of material resources

This chapter provides a summary of the literature on environmental material use solutions and an argument as to why this thesis focuses on CME among other suggested solutions. The chapter then presents CME strategies available in the market. The practice rate, importance, motivations, and barriers for these strategies among different stakeholder groups are investigated in the data collection phase of this study (see Chapter 4).

2.1 Environmental material use solutions

Previous work has shown that the current use of material in the building industry is not sustainable (Allwood et al., 2011; Birkeland, 2008) because they are used in an *open system* in which their quality is degraded after their first use and they will be discarded at the end of their first use. In such consumption model *non-regenerative* resources are used and a considerable amount of waste is generated (Worrell et al., 1997). Other studies offering solutions for sustainable material and resource use are presented in Appendix B)

As presented in Table 2.1, the first four solutions aim to reduce the environmental impacts while maximizing the efficiency, whereas, the last three (eco-effectiveness, eco-productivity, regeneration) aim to find possible solutions for creating positive human and environmental impacts throughout the resource flows. These three solutions also have a broader scope and look into all the resources (including material, water, and energy) as a system and eco-productivity and regeneration go beyond building scale and emphasize on the potential synergies between buildings and their larger encompassing context.

Table 2.1 Hierarchy of environmental resource consumption (table by the author)

Solution	Goal
Waste management	Waste reduction, recovery, and safe disposal
Material efficiency	Providing material services with less material production and processing
Resource efficiency	Delivering greater value with less resource input and negative impacts
Eco-efficiency	Maximizing economic and social values while minimizing the negative life cycle ecological impacts
Eco-effectiveness	Using resources in endless technical and biological cycles enabling triple top line growth
Eco-productivity	Generating excess resources and contributing to the ecosystem through resources use
Regeneration	Benefiting human and natural systems through resource use, maintaining or increasing resource quality, and ensuring resource replenishment

This thesis looks into material effectiveness opportunities associated with construction material flow, i.e., strategies for reducing material resource consumption while while keeping the quality of materials so that they can be infinitely recovered through natural or industrial cycles. However, the study does not investigate eco-productivity or regeneration opportunities, i.e. increasing the value of material resources or potential positive ecological influences of construction materials use. This restriction was imposed because the notion of positive ecological impacts of construction material use is yet to be practical, especially with current range of commonly used construction materials.

2.2 CME strategies

This section presents the strategies which are suggested in the literature for construction material effectiveness and is limited to the CME strategies currently being deployed: reducing use, more intensive use, extending use, reusing, and recycling. Since the main goal of this research is to investigate the stakeholders' influence on the implementation of CME strategies, it is important to consider the strategies which are familiar to and are considered practical among the influential stakeholders. In the data collection phase of this study (Chapter 4), the stakeholders' attitude about the strategies which are presented below is investigated.

2.2.1 Reduce use

Reduce use in this study is defined as reducing the amount of new materials used in a building by optimizing material use through design or reducing waste generation during construction. Many studies have investigated methods to reduce waste generation during the construction phase. Guidelines are provided for construction waste reduction in various jurisdictions and suggestions include: using modular and prefabricated systems; using products with less or reusable packaging; accurate and detailed construction documentation; updating the dcouments with changes in projects; accurate material requirement assessment to avoid errors and prevent over-ordering; and proper material storing and handling (Allwood et al., 2011; Birkeland, 2008; Yeheyis et al., 2012).

Previous studies suggest that the design phase has the highest potential for material use and waste generation reduction but that these goals are not typically a priority in the design phase (Osmani, Glass, & Price, 2006; Osmani et al., 2008). Moreover, waste reduction has gained more attention in the construction phase through maximizing waste diversion rather than reducing waste generation (Metro Vancouver, 2011). It seems necessary therefore, to find the reasons why reducing material use is not a high priority in the design and material selection phases.

2.2.2 Intense use

In this study, *intense use* is defined as increasing the intensity of use of materials by designing for shared and/or multi-purpose use or practicing shared and/or multi-purpose use in the operation phase. Compared to other approaches, this strategy may be more difficult for the construction industry to engage. However, as Allwood et al. (2011) emphasize many buildings (houses/offices) are empty more than half of a day and they have considerable potential to be designed for shared and/or multiple use. Designers have a major role for implementing and advancing these strategies; however, their ability and willingness can be greatly affected by the building type and their client's interest.

In a consumerism culture, which grew as a result of industrial revolution, "ownership of goods leading to social status". Thus, there might be less interest in sharing (De Vries, 2008 cited in Allwood et al., 2011). Prettenthaler and Steininger (1999) have identified comfort and prestige as other important advantages of ownership over service use.

2.2.3 Extend use

Extend use is defined as extending the life of materials by designing for maintainability, using durable materials, or repairing and upgrading materials/products rather than replacing them with new ones. Designing for maintainabilty, adaptability, fexibility, and deconstruction are suggested in the literure as effective solutions for extending building components and building lifetime. Suggested techniques include: using durable and easilily reversible connections and faseners; using easily accessible and seperable components, systems, and joints; accurate documentation of building systems; and using materials/products for which maintenance services are available in the region (Addis, 2008; Allwood et al., 2011; de Silva, Dulaimi, Ling, & Ofori, 2004; Sassi, 2008). *Shearing layers of change* by Brand (1995) emphasizes the necessity of designing buildings in a way that different layers, which have different lifetimes, can be separated to facilitate maintenance, flexibility, and adaptability (see Figure 2.1).

The durablity of materials/components/systems has considerable economic and environemtal benefits, as it reduces the need for maintenance and replacement. It also results in the reduction of material use and waste (CaGBC, 2010). However, investment in long-term future benefits is not a current priority or practice in the construction industry. Consequently, a project team may choose less durable materials/products that reduce initial costs and not be concerned that these may create significant extra cost and complication in future (de Silva et al., 2004).

Despite all the benefits of repairing, upgrading, and remanufacturing, the literature identifies various functional and personal reasons for consumers' interest in replacing materials/products, including: improving utility of materials/products, improving expression, and desire for new (Ashby, 2012; van Nes & Cramer 2006). Allwood et al. (2011) suggest that "[t]he business case for repair … is generally weak in developed economies with high labour [sic] costs and where most products are sourced from low labour [sic] cost countries". Personalizing and emotional attachment to products is suggested as a solution that can change consumers attitude toward

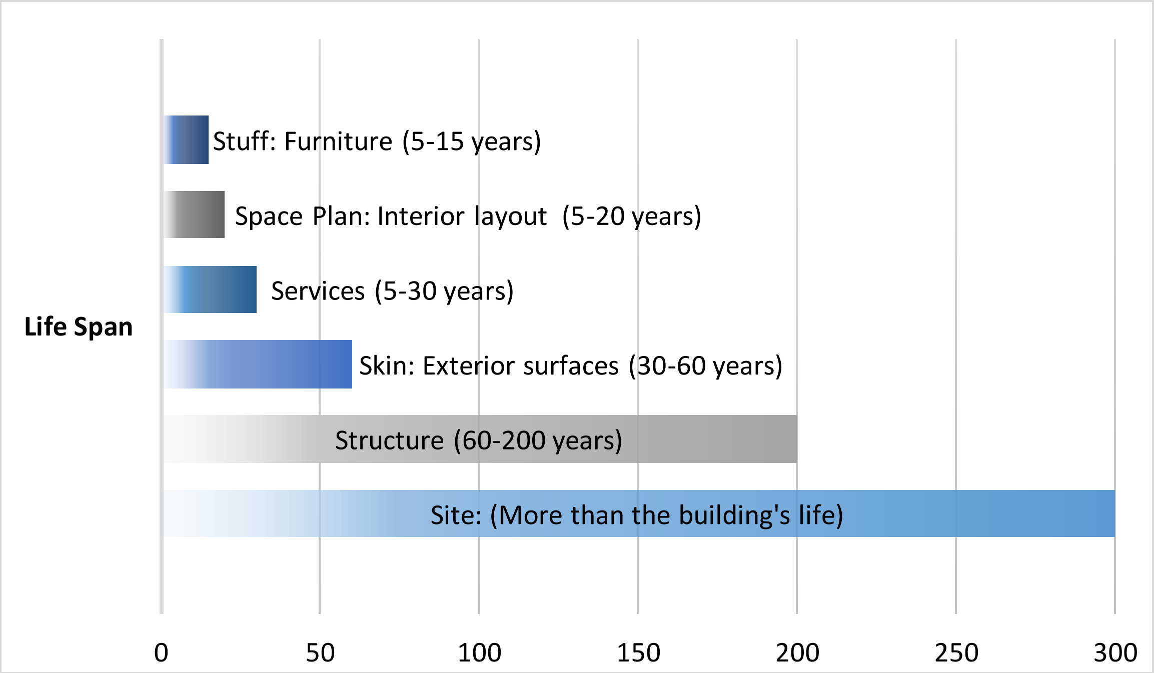

Figure 2.1 Shearing layers of change: The lifespan of different building layers (based on: Brand, 1995)

extending use of material/products (Allwood et al., 2011). This solution, however, is only applicable to those construction materials/products that are visible.

Service providers and manufacturers have a major role in promoting maintenance, upgrade, and remanufacturing services. According to Allwood et al. (2011) whereas independent service providers' primary motivation for such services is profit, the motivation for manufacturers is often neither profit, environment, nor legislations but market recognition (after-sale support), *intellectual property*, and brand protection. On the other hand, customers might find remanufacturing an attractive solution for extending product use, because manufacturers can "add value" to old products which be otherwise thrown away (Allwood et al., 2011). However, for a product to have a successful remanufacturing market, there should be a slow technology improvement (Allwood et al., 2011). If this is the case then technology improvement can be a major barrier for remanufacturing for construction products which have a long lifespan.

2.2.4 Reuse

Reuse is defined in this thesis as reusing materials by incorporating design strategies that facilitate future reusability, designing and constructing with salvaged materials/products, or deconstruction and salvaging reusable materials. An USEPA study states that reuse can reduce energy consumption and greenhouse gas emissions up to 60% more compared to recycling (Ferland, 2006 cited in Gorgolewski, 2008). Despite the environmental and economic benefits of building material/component/structure reuse, it is not yet very common except for materials with heritage, cultural, or aesthetic values (Allwood et al., 2011; Gorgolewski, 2008). The acknowledged barriers to *reuse* include: undeveloped market; insecure supply and demand volumes; lack of price transparency; lack of quality assurance; health and safety legistlations; time pressure; increased design, modification, and recertification costs and complications; and keeping up with fashion (Allwood et al., 2011; Gorgolewski, 2008; Matsumoto, 2009).

Govermental initiatives have been developed to encourage increased salvaging and reuse of materials with heritage value. For instance, in order to preserve heritage houses or at least the materials with heritage value in heritage houses, the City of Vancouver’s Green Demolition Bylaw requires houses which are built before 1940 to divert minimum 75% of their material. Character houses from the same era are required to divert 90% of their construction materials/products (City of Vancouver, 2014).

Designing for maintainabilty, adaptability, fexibility, and deconstruction, which are mentioned in section 2.2.3, have a significant role in facilitating and increasing the potential for materials/products reuse and recycling (de Silva et al., 2004; Kibert, 2008) but these design considerations are currentlly greatly *under-utilized* (Birkeland, 2008, p. 66). Unlike recycling, project teams need to be willing to spend extra time and effort to design for reusability and design with salvaged materials (Gorgolewski, 2008). Therefore, for the success of such design measures, it is necessary to identify designers' motivations for considerong these strategies.

Deconstruction and salvaging construction materials is perceived to be a costly process, due to the high labor costs in developed economies (Gorgolewski, 2008). It is expected that deconstruction and salvaging costs would fall if it became more standardized and common practice (Catalli & Williams, 2001). To make material reuse a common practice, it is crucial to provide incentives for different stakeholders who can influence the implementation of this strategy.

The profitability of salvaging may vary in different regions and for different building types and sizes, depending on various factors such as labor cost, disposal cost, salvage value, availability and accessibility of salvaged materials. Guy & Mclendon (2003) have studied the deconstruction of 6 one and two-story wood-frame houses in Florida and concluded that deconstruction process costs 21% more than demolition. Nonetheless, factoring in the reduced disposal fees and revenues from salvaged materials, deconstruction processes were 37% less costly compared to demolition. Dantata, Touran, and Wang (2005) adjusted the data from Guy & Mclendon (2003) study to the Massachusetts's costs and revenues and discovered that deconstruction could cost

25% higher than demolition in that region because of the higher labor cost, lower demolition cost, and lower salvage material value in Massachusetts compared to Florida. They claim that this cost is even higher when factoring in extra time required for deconstruction.

2.2.5 Recycle

Recycle strategy is defined as recycling materials by incorporating design strategies that facilitate future recyclability, using recycled content materials, or recycling CDR waste. Governments in different regions around the world are becoming more aware of the value of waste as a resource and have set high goals to increase waste diversion rates. Despite the significant improvements in recycling technologies, CDR is still the largest waste stream in most regions that yet has considerably higher diversion potentials (Pacheco-Torgal, 2014).

Recycling is being increasingly supported and encouraged in governmental policies. Ontario, for instance, has mandated waste management plan in construction projects (Yeheyis et al., 2012). Metro Vancouver has defined extra charges for CDR waste, if certain materials are sent to landfills (e.g., corrugated card board, gypsum, or clean wood from 2015) (Greater Vancouver Sewerage and Drainage District, 2013). The City of Vancouver incentivize waste diversion in single and multi-family houses by giving demolition permit prior to building permit so that project teams have enough time for proper deconstruction rather than demolition. They also reduce tipping fees of CDR waste by 50% (in specific transfer stations), if project teams commit to deconstruction and minimum 75% waste diversion in these projects (City of Vancouver, 2014).

Although recycling *is significantly less energy intensive than primary production*, high quality recycling will become increasingly difficult as streams of material available for recycling become more and more composite and impure. This is even more significant considering the increased complexity of mixed-material products, which leads to higher cost of collection and separation, and thus less attraction in recycling (Allwood et al., 2011). As it was argued in section 6.5B.4, in order to increase the recycling potentials, it is important that building components and buildings are designed for recyclability (Birkeland, 2008, p. 72; McDonough & Braungart, 2013; Sassi, 2008).

Despite the necessity of advancing technologies and techniques for design for recyclability, it is equally important to assess and understand different stakeholders' attitude about such measures. If stakeholders are not motivated to use these technologies and techniques, they not likely to consider it as a priority in their projects.

2.2.6 CME strategies in the environmental assessment systems

A short review of requirements for CME in some of the building and material assessment systems, which are developed and used in North America, are provided in Appendix C. Current green building assessment systems and tools are criticized for not sufficiently addressing this issue. Choosing environmental materials/products is yet the most challenging and time consuming tasks for design teams (Kibert, 2008). According to Ding (2012) "… points allocated for sustainable materials selection do not encourage designers and assessors to pay more attention to sustainable building materials as only approximately 9%, 13% and 16% of the total points were allocated respectively in BREEAM, LEED and GreenStar".

Building environmental assessment systems and tools are also questioned in terms of whether they are really incentivizing the most resource efficient solutions. Birkeland (2008, p. 78) argues that current assessment systems are designed to predict the future damage and motivate design professionals and other stakeholders to decrease this damage. “They do not weigh in the cost of inaction or lost opportunity cost or poor design. [Neither do] they … consider the resource required to replace exiting development with green buildings”. Despite all ecological value of retrofitting compared to new construction or maintaining the status quo, our assessment systems do not prioritize retrofitting, as they allow projects to consider a clear land as a start point for assessment rather than considering the existing building as the baseline. Therefore, environmental cost of demolition is seldom taken into consideration in these assessment systems. Consequently, developers typically only consider the personal benefits of new construction, not the overall costs and benefits of their decision for the society and environment (Birkeland, 2008).

Table 2.2 presents a review of material and resource credit distribution in projects certified in Leadership in Energy and Environmental Design (LEED) for New Construction and Major Renovations (NC 1.0) assessment system in Canada. It illustrates that although LEED NC 2009 has been successful in motivating recycling strategy, it has not been sufficiently successful in promoting reducing use, extending use (MRc8), and reusing (MRc1 and 3) (Bulkeley & Gregson, 2009; Todd, Pyke, & Tufts, 2013). Table 2.3 shows that LEED 2009 for Existing Building Operations and Maintenance (EBOM) has also not been very successful in shifting the building operation and maintenance practices toward sustainable purchasing of furniture and construction materials/products or in improving CDR waste management practices in maintenance and renovation phases.

The materials credits in LEED 2009 reward the use of more sustainable products that perform well on a specific performance criterion, but not necessarily on other attributes. This makes it difficult to compare products which have different sustainability features (USGBC, 2015). Moreover, LEED 2009 does not promote resource use reduction and or differentiate between material types when requiring their diversion. Yeheyis et al. (2012) argue that while a project may be able to divert 75% of waste, the remaining waste that is sent to landfill may be more harmful for human and environment.

Table 2.2 LEED Canada for New Construction (NC) 1.0 material and resource credit distribution as of March 31, 2013, from © CaGBC (2013b) Adapted with permission from CaGBC, on behalf of Mark Hutchinson.

Credit	Total	Certified	Silver	Gold	Platinum
MRc1.1 Building reuse, structural (75%)	**6%**	4%	11%	4%	0%
MRc1.2 Building reuse, structural (95%)	**3%**	4%	5%	2%	0%
MRc1.3 Building reuse, nonstructural	**1%**	1%	2%	1%	0%
MRc2.1 Construction Waste Management	**93%**	87 %	91%	95%	100%
MRc2.2 Construction Waste Management	**76%**	61%	76%	80%	91%
MRc3 Materials reuse (5%)	**3%**	3%	3%	3%	9%
MRc3 Materials reuse (10%)	**2%**	1%	2%	2%	4%
MRc4 Recycled content (7.5%)	**98%**	97%	99%	98%	100%
MRc4 Recycled Content (15%)	**78%**	68%	77%	80%	96%
MRc8 Durable Building	**27%**	14%	17%	33%	78%

* The number each rating level is as follows: Certified: 71, Silver: 185, Gold: 244, Platinum: 23, Total: 523

Table 2.3 LEED Canada for Existing Building Operations and Maintenance (EBOM) material and resource credit distribution as of March 31, 2013, from © CaGBC (2013b) Adapted with permission from CaGBC, on behalf of Mark Hutchinson.

Credit	Total
MRc2.2 Sustainable Purchasing: Durable Goods - Furniture	**30%**
MRc3 Sustainable Purchasing: Facility Alterations and Additions	**38%**
MRc8 Solid Waste Management: Durable Goods	**85%**
MRc9 Solid Waste Management: Facility Alterations and Additions	**35%**

* The number each rating level is as follows: Certified: 1, Silver: 3, Gold: 30, Platinum: 6, Total: 40

Recognizing the market improvement and readiness, LEED v4 takes a broader view of sustainable materials and products use by requiring a life cycle approach to design and material selection (Todd, 2013). MR credits in LEED v4 are aimed to precipitate development of LCA tools and databases. These credits also support waste management hierarchy (reduce, reuse, recycle, and waste to energy) with the goal of reducing embodied impacts and increasing overall resource efficiency (U.S. Green Building Council, 2015). However, building reuse and building LCA are alternative options of one credit. Therefore, a reused building is not encouraged to conduct LCA assessment to understand whether it has positive environmental impact during its use phase, compared to constructing a new building.

LEED v4 also has a greater focus on transparency of human and natural health impacts of materials/products over their whole lifetime. It is too early to analyze the impacts of LEED v4 on the material use practices in the market, but since LCA credits in LEED v4 are optional and give projects maximum of 7 points, project teams might decide that striving for these credits is not worth their time and effort. They may prefer to focus on credits which give them more points, such as energy credits. Moreover, LCA credits for materials/products allow project teams to consider a minimum of cradle-to-gate lifespan, which does not take into account the future durability, maintainability, and recoverability of materials/products.

The Living Building Challenge (LBC), on the other hand, emphasizes on the limited time to change human relationship with nature and thus defines a more ambitious building assessment system. In contrast to LEED, which defines green building goals in a *checklist* format (Cole, 2012), LBC claims to be a philosophy that aims to shift our relation with nature toward one that *thinks optimistic* and *holistically* (International Living Future Institute, 2014). LBC aims to transform design and construction processes and focuses on actual results rather than expected performance. The 20 LBC "imperatives" which are all mandatory, are assessed at least after 12 consecutive months of the project operation where performance data has been measured rather than predicted.

In comparison to the LEED systems, LBC not only has higher expectations for waste diversion[5], but also differentiate between types of materials by having different minimum diversion requirements for each material stream[6] (Living Building Institute, 2010). However, LBC does

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[5] Diverted waste includes those that are recycled, reused, salvaged or composted. Incineration or allocation as "alternative daily cover" is not permitted. "Hazardous materials in demolition waste, such as lead-based paint, asbestos, and polychlorinated biphenyls are exempt from percentage calculations" (International Living Future Institute, 2014).

[6] LBC requires 99% diversion rate for metal, 99% for paperboard and card, 100% for soil and biomass, 95% for Rigid Foam, carpet & insulation, and 90% for all other materials (combined weighted average) (Living Building Institute, 2010).

not place emphasize on the quality of waste diversion, i.e. whether it is down-cycled, nor does require projects to consider recoverability and the quality of material recovering as a requirement in their design and material selection processes.

Chapter 3: Stakeholders' attitude towards environmental materials use

This chapter reviews the discussions in the literature regarding the various priorities and environmental attitudes and behaviors of the stakeholders involved in construction projects.

3.1 Stakeholders involved during construction material flow

Rohracher (2001 cited in Griffin et al., 2010) asserts that green buildings are *part of a social-technical system* that causes "functional dependencies and requirements, but also interests, perspectives and the interaction of actors". A highly diverse range of stakeholders are involved in different phases of building life cycle, each of which have various and sometimes conflicting interests, benefits, and responsibilities, which are the *center of attention* of each group (Feige et al., 2011).

Table 3.1 shows the main stakeholders involved in different phases of a building life cycle and their most important concerns. These stakeholders are categorized in three groups: internal (strategic), external (normative), and both internal and external. External (normative) stakeholders are those who can influence or are influenced by a project, but are not directly involved in it. These stakeholders are "both moral actors and the subject of moral action". The scope of normative stakeholders can be as broad as future generations and the environement. On the contrary, internal (strategic) stakeholders are those who are directly working with a project (Feige et al., 2011; Wallbaum et al., 2010).

Table 3.1 Major stakeholders during different building life cycle phases and their main concerns, from © Feige, Wallbaum, & Krank, (2011) Adapted with permission from publisher.

Key stakeholders		**Life cycle phase**	**Main Concerns**
Internal (strategic) stakeholders	Investor (can be end user)	Planning, Concept, Design	Return of investment; Economic feasibility; corporate social responsibility; regulation; personal beliefs; company image
	Manufacturer / Supplier	Construction, Maintenance, Renovation, (Deconstruction)	Energy supply; availability of natural resources; economic feasibility; cost-efficiency; workforce; corporate social responsibility; regulation; personal beliefs; company image
	Banks / Financial Institutions	Planning, Concept, Capital	Return of investment; company image
	Contractors	Construction, Renovation, Deconstruction	Materials and energy supply; economic feasibility; cost-efficiency; workforce; corporate social responsibility; regulation; personal beliefs; company image

Key stakeholders		Life cycle phase	Main Concerns
Internal (strategic) stakeholders	Planners/ Architects/ Interior Designers/ Engineers	Planning, Concept, Design, Construction, (Renovation)	Knowledge; creative and efficient application of technologies; cost-efficiency; corporate social responsibility; regulation; personal beliefs; company image
	End user (can be investor)	Use, Maintenance	Well-being; economic feasibility; lifestyle; personal beliefs; company image
	Building operators and maintenance	Use, Maintenance	High and efficient performance of the building; users comfort
Both internal and external stakeholder	Public authorities	All	Regulations and control; well-being
External (normative) stakeholders	NGO & Civil Society	All	Social equity; access to information; well-being
	Research & Education	All	Technology and knowledge
	Media	All	Democratic share of information
	Environment	All	Permanent degradation
	Future generations	All	Social equity, well-being

Normative stakeholders, such as public authorities, researchers, and NGOs, usually have more interest in sustainable practices and can play a more active role in facilitating and promoting these practices, which should be implemented by strategic stakeholders. However, when authorities act as an strategic stakeholder, they can cause major regulatory barriers for implementation of sustainable solutions (Wallbaum et al., 2010). On the other hand, when strategic stakeholders have the client role, e.g. public authorities for strategic planning projects, investors as clients of designers, end-users as clients of apartments or shops, *financial feasibility* is one of the most important priorities. Therefore, they are usually interested in environmental goals, only if they can "see the return on investment associated with … [these] measures" (Wallbaum et al., 2010). Whereas, end users who are usually not involved in the early phases of the projects, may be more concerned about the health, comfort, and safety issues (Grace K.C. Ding, 2012).

Despite the diversity of stakeholders' values, they are *closely interconnected* and interdependent (Cole, 2011). Therefore, to develop measures that successfully encourage collaboration among stakeholders to achieve sustainability goals, it is crucial to identify all the key stakeholders (including both *Internal* and *external*), understand *value differences* among them, and their influence on each other in every context (Cordano, Frieze, & Ellis, 2004; Grace K.C. Ding, 2012; Maclaren, 1996, p. 188; Wallbaum et al., 2010).

3.2 Stakeholders' environmental attitudes and behaviors

Environmental attitude and behavior studies assert that mere availability of technologies and tools is not enough to promote positive environmental decisions and behaviors. It is equally important to understand people's attitude in order to take measures that incentivize their participation in environmental actions (Feige et al., 2011; Griffin et al., 2010; Joseph, 2006; Rashid, Evans, & Longhurst, 2008). Allwood et al. (2011) argue that "[t]he literature of sustainable consumption is still relatively young, so mainly focused on understanding behaviour [sic] rather than on identifying mechanisms for change."

Ajzen (1993) defines attitudes as "people's evaluations of objects or situations that predispose them to behave in a certain way". Attitudes are shaped over time and change according to a variety of factors such as individual's personal experiences of a situation or object, parents, family, and the community's influence through the imposition of social norms that can invoke a sense of moral obligation (Teo & Loosemore, 2001). Attitudes are also affected by different occupational cultures through peer pressure and defining a member's role and status in that society, and expecting certain behavior (Teo and Loosemore 2001, Robbins 1991). Legislation usually has a relatively weak effect on people's attitudes, because it is difficult for them to understand its specifics and implications due to its often obscure language. However, incentivizing and mass media can increase the influence of legislations on the attitudes (Teo and Loosemore 2001).

Understanding people's attitude helps to identify the effective measures to motivate change (Teo & Loosemore, 2001). *Behavioral intention* indicates how motivated a person is to behave in a certain way. Behavioral intention is affected by personal attitudes, social norms, and perceived ease/difficulty of the behavior. Personal positive or negative attitudes are themselves based upon personal beliefs or knowledge. The social factors relate to an individual's sense of social pressure to behave in a certain way. The perceptual factors relate to an individual’s perception of the ease or difficulty of a behavior which is based on past experiences and anticipated obstacles to doing something (Ajzen, 1993; Teo & Loosemore, 2001).

Some environmental behavior studies suggest that there is not a strong direct relationship between environmental concerns and specific behaviors (Bamberg, 2003). According to Bamberg (2002), for example, *even strong goal intentions* may not result in *actual behavior*. Gibbons et al. (2004) suggest that “unintentional decisions, which are reactions to situational factors, also served to guide behavior along with intentional decisions”. These unintentional decisions might even be contrary to individuals’ attitudes and intentions (cited in Ohtomo & Hirose, 2007). Given the large number of stakeholders involved in the construction related decision makings, situational factors may have even more considerable influence on the environmental behaviors in this industry compared to other daily decisions. The influence of stakeholders’ environmental motivation and their awareness of the importance of CME strategies on the practice rate of the strategies is investigated in the data collection phase of this study (see Chapter 5).

Despite all the advances in using healthy and environmental materials/products in the built environment, there is yet to be enough attention to the role of initial planning, design, and material selection phases in closing material loops. The focus of a majority of construction projects is first on “… the fastest, easiest and most economical way to get the job done” (Gorgolewski, 2008). Stakeholders then consider measures such as reducing resource use or increased recycled content to improve *the green aspects of the chosen material system* (Griffin et al., 2010, p. 5).

Extensive research has been conducted to find personal/psychological and social factors affecting people's environmental interests and behavior relating to resource consumption and waste management. These studies consider waste aversion, heritage value, cultural and personal values as factors that motivate people to extend use or reuse resources. On the other hand fear of hidden defect, comfort and perceived difficulty of the process, and cultural status are considered as social and psychological factors that impede extending use and reusing of resources (see Appendix D).

There are several studies which investigate stakeholders' attitude toward CME strategies. However, none of the existing studies have investigated the attitude of different stakeholders toward different strategies in a comprehensive manner. Most prior works focus on single strategies in one particular stage of a building life cycle - most typically waste reduction measures in the construction phase (Kulatunga, Amaratunga, Haigh, & Rameezdeen, 2006; Osmani et al., 2008; Teo & Loosemore, 2001). Although, construction waste management is an important aspect of imroving the effectiveness of material use, it only covers the end of the life phase of materials life cycle. Whereas, effective waste reduction is not possible if it does not consider the upstream phases – i.e., materials production, design strategies, and construction methods.

There is a trend in waste management research which investigates the attitude of stakeholders about possible waste diversion measures and the ways in which stakeholders' interest and commitment can be improved (Kulatunga et al., 2006; Osmani et al., 2008; Teo & Loosemore, 2001; Yuan & Shen, 2011). Many of these studies focus on one specific stakeholder group, such as contractors, on-site workers, architects, or structural engineers (Begum et al., 2009; Osmani et al., 2008; Rodriguez-Nikl et al., 2014; Saunders & Wynn, 2004; Teo & Loosemore, 2001).

For instance, Osmani et al. (2008) conducted a study of top UK architects' attitude toward the importance construction waste reduction in the design phase. The study showed that despite architects' awareness of the importance of waste minimization, "waste management is not a priority in the design process" and "very few attempts are made to reduce waste during the design process". Architects mostly believed that construction waste is the result site operation and contractors' poor planning, rather than design decisions. Interviewed architects also considered clients' lack of interest as the main reason for poor waste management in the design phase.

Some studies have focused on the attitudes of different construction industry workforce members toward waste management (Kulatunga et al., 2006; Osmani et al., 2008; Teo & Loosemore, 2001). These studies show that despite a positive attitude toward the importance of waste management, there is not enough attention given to waste management in practice. The awareness and acceptance of the importance of waste management is contradicted by an acceptance of "waste as an inevitable by-product of construction activity" (Teo & Loosemore, 2001).

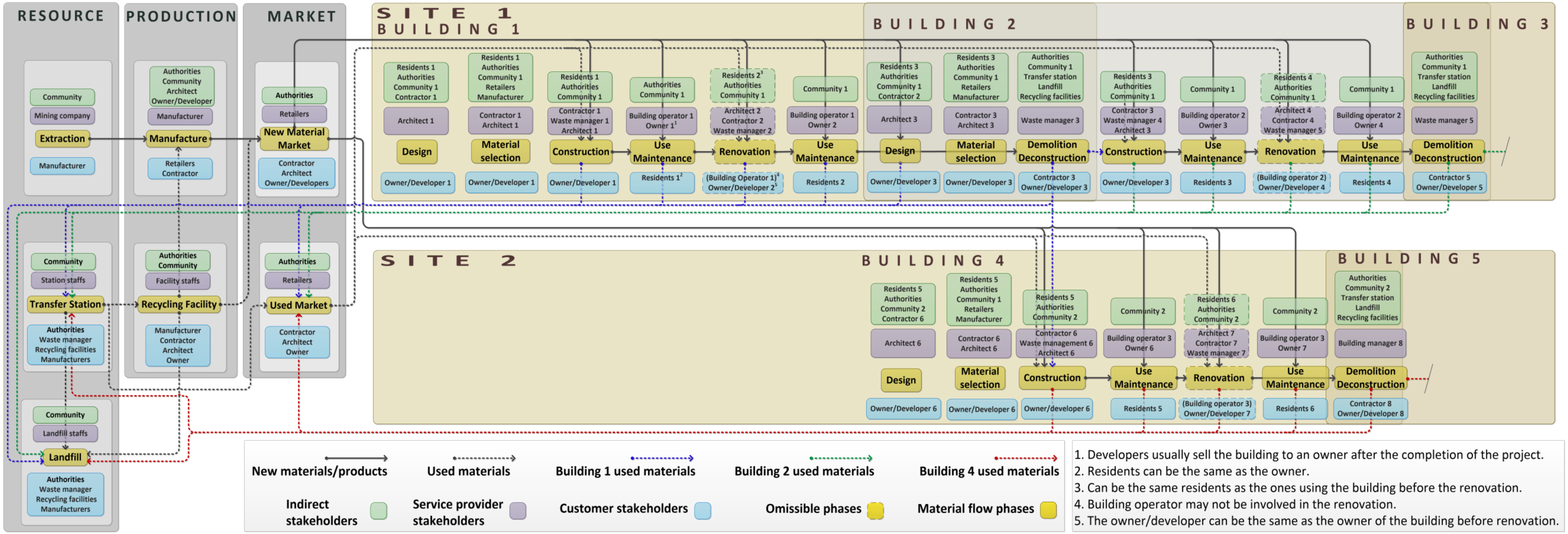
Some researchers have studied different *employee grouping* in one specific stakeholder group. For instance, Lingard, Graham, and Smithers (1997) and Lingard et al. (2000) have compared different attitudes of both site-based and head-office employees of large contractors toward waste management in different regions of Australia. They found that managers stated more concerens about cost, time, or quality issues than environmental issues. Whereas, construction workers had stated a greater concern about environmental issues compared to other project concerns. Nonetheless, operatives believed that main contractors and designers have the full responsibility of waste management. They believed that, despite this responsibility, waste management is a low project priority for project managers and they do not provide appropriate resources and incentives to support this goal and create a sense of collective responsibility. These studies show that "organizations are not a homogenious group". Therefore, it is necessary to investigate stakeholders' perception regarding environmental goals of a project even in an individual level.

Studying the attitude of one stakeholder group toward a specific strategy without considering their other goals, priorities, responsibilities, and their interaction with other stakeholder groups may not provide an accurate understanding of their interest or their abilitiy to implement that strategy. Stakeholders might consider a material-related strategy important, but the strategy may have a lower priority compared to their other goals and responsibilities in the project – such as time and cost pressures, lack of personal benefits, and managerial attention (Halme et al., 2007, p. 127). Moreover, stakeholders might not be able to implement an environmental-related strategy due to a conflict between their interests with the priorities of other stakeholders.

Very few comparaitive studies have been conducted that investigate the differences between the perspectives of various stakeholder groups and how they can influence each other's ability or interest in implementing materials-related strategies. In one such study, Osmani et al. (2006) compares leading UK architects and contractors' perspectives toward waste management. They found that from architect's point of view, waste reduction is the responsibility of the contractors. Whereas, contractors had a more proactive approach to developing waste management plans to improve on-site waste management. Contractors' considered poorly defined responsibilities which led to confusion as a key barrier for more efficient waste management.

In another multi-stakeholder study, de Silva et al. (2004) compared the attitude of different stakeholders within construction projects regarding improving the maintainability of buildings in Singapore. They found that in contrast to clients, main contractors (including designers and general contractors) are "reluctant to assume further responsibilities and liabilities". For instance, these groups were not willing to provide clients with information about maintainability of products and buildings or "extend defects liability period beyond the current 1 year".

Figure 3.1 shows major stakeholders who are involved throughout a hypothetical construction material flow in two different building sites. The figure depicts limited and changing role, influence, and responsibilities of different stakeholders during different phases of material flow. As an example, 'Building Operator' is sevice provider in 'Use/Maintenance' phase, can be a client in 'Renovation' phase, and typically has no considerable role in 'Design', 'Material Selection' and 'Construction' phases. Despite the complexity of analyzing various stakeholders' attitude toward different CME strategies in a single study, considering stakeholders in their larger context provides a more comprehensive and accurate understanding of their priorities, motivations, and barriers. Such findings can inform policy makers on the motivating factors that can potentially engage and influence a larger group of stakeholders (Cole, 2011; Feige et al., 2011; Lingard et al., 2000; Wallbaum et al., 2010, p. 11).



1. Developers usually sell the building to an owner after the completion of the project.
2. Residents can be the same as the owner.
3. Can be the same residents as the ones using the building before the renovation.
4. Building operator may not be involved in the renovation.
5. The owner/developer can be the same as the owner of the building before renovation.

Figure 3.1 Major stakeholders' involvement during a hypothetical construction material flow

Chapter 4: Data collection

This chapter explains data collection and sampling methods. The result of data collection is presented and analyzed in the next chapter (Chapter 5).

4.1 Data collection method

Developing a data collection method to conduct attitudinal research is a challenging process since the research topic itself is somewhat intangible and *resistant to observe* (Teo & Loosemore 2001, p. 744). Most of the attitudinal studies in the construction industry have used survey questionnaires directed at specific stakeholder groups as their primary data collection method.

The goal of data collection phase in the research presented in this thesis is to identify the key factors which influence different stakeholders' interest in implementing the strategies for CME.

To collect data, a questionnaire survey was sent to different stakeholders of a selected number of building projects. The information about these projects and stakeholder groups associated with them are provided in section 4.2. A web survey (Fluidsurveys[7]) was used to design and distribute the questionnaire. Although a common questionnaire was sent to all the stakeholder groups as a basis of comparison among the stakeholder groups' responses, the survey could be interactively adjusted so as to reflect the respondents' specific role in the projects (see column 2 in Table 4.1).

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[7] http://fluidsurveys.com

To improve the overall survey quality, ease, and clarity and to limit its length, a pilot survey was sent to 10 academic and construction industry experts prior to the main survey in February 2014 and revisions were made as required. The final survey (see Appendix A) asks the respondents 16 questions, which were a combination of multiple choice and rating scale questions in 6 major topics:

- General socio-demographic information (questions 1-4);
- Professional information (questions 5-9);
- Practice rate of strategies for CME in the projects (question 10);
- Attitude toward the importance of these strategies (question 11 and 12);
- Motivations and barriers for implementing strategies for CME (questions 13 and 14); and
- Stakeholders' influence on the implication of strategies for CME (questions 15 and 16).

At the end of the survey an opportunity was provided for the respondents to provide additional comments.

Questions 10-12 and 16 are five-point and questions 13-15 are three-point Likert-type rating scale. The rating scale ranges from 1 (Never) to 5 (Always) in question 10; 1 (Not at all important) to 5 (Very important) in question 11; 1 (Not at all) to 5 (Completely) in question 12; 1 (Has minor influence) to 3 (Has major influence) in questions 12-16. The 'N/A' responses, which is a choice in questions 10-12, were excluded from the analysis.

Although the Likert scale is a common method in the attitudinal studies (Kulatunga et al., 2006; Lingard et al., 2000), the inaccuracy associated with considering equal distances between ordinal values (e.g., Never and Rarely) remains a concern (Jamieson, 2004; Lowell, 2007; Norman, 2010). Thus, it is important to note that the results of this study should not be interpreted as absolute quantitative data but rather as a comparative data set that permits an assessment of relative practice rates, ascribed importance, motivations, and barriers for different strategies for CME.

Questions 10 and 11, ask the respondents about the practice rate and importance of five strategies for CME (see section 2.1) in four phases of the life cycle of a building – planning/design, material selection/construction, use/maintenance and deconstruction/demolition.

Although CME strategies have applicability to different the life cycle phases (Birkeland, 2008, p. 9), they will invariably be implemented in a different ways in each of these phases. Therefore, to prevent false assumptions, misinterpretations and inconsistencies in questions 10 and 11 the strategies for CME are described by their implementation techniques in each phase as it is presented in Table 4.1.

Table 4.1 uses the information collected in section 2.2 to provide a summary of various implementation techniques for CME strategies and the stakeholders involved in each life cycle phase. In the analysis phase (see section 5.2), the responses to these two questions were summarized by averaging the techniques that belong to a same strategy/phase in Table 4.1.

Table 4.1 Implementation techniques for strategies for CME in different life cycle phases of a building

Strategies / Phase	Stakeholder Group(s)[1]	Reduce Use	Intense Use	Extend Use	Reuse	Recycle
Planning/ Design	- Designer - Owner/ Developer	- Reducing unnecessary material consumption[2]	- Designing for shared use - Designing for multipurpose use	- Facilitating maintenance, repair, or upgrade	- Future reusability (DfD) [2]	- Future recyclability (DfD) [2]
Material Selection	- Designer - Contractor - Owner/ Developer	____	____	- Using durable materials	- Using salvaged or upgraded products	- Using high-recycled content materials
Construction	- Contractor - Owner/ Developer	- Minimizing waste generation	____	____	____	____
Use/ Maintenance	- Owner/ Developer (might not be involved in this phase) - Building operator	____	- Shared use - Multipurpose use	- Products repairing and upgrading	____	____
Deconstruction / Demolition	- Contractor - Owner/ Developer	____	____	____	- Building deconstruction - Material salvaging [3]	- Recycling [3]

[1] While a much wider group of stakeholders is involved in each phase, this column only indicates the stakeholders who are studied in this research.

[2] In reality this technique should be also considered in the material selection phase, but to simplify the survey it has only been considered in the planning/design phase

[3] In reality this technique should be also considered in the construction phase, but to simplify the analysis it has only been considered in the deconstruction/demolition phase

Table 4.2 shows different motivations and barriers (for the studied CME strategies) which are asked in questions 13 and 14. These motivating and limiting factors were extracted from the literature review presented in section 2.2, 3.2, and Appendix D).

Table 4.2 Motivations and barriers for different strategies for CME

		Reduce Use	Intense Use	Extend Use	Reuse	Recycle
Motivations	Economic benefits	▨	▨	▨	▨	▨
	Cods & Regulations	▨	▨	▨	▨	▨
	Customer's demand	▨	▨	▨	▨	▨
	Market recognition	▨	▨	▨	▨	▨
	Common practice	▨	▨	▨	▨	▨
	Environmental benefits	▨	▨	▨	▨	▨
	Aesthetic value			▨	▨	
	Heritage value			▨	▨	
Barriers	Budget limits	▨				▨
	Time limits	▨		▨	▨	▨
	Technical facilities	▨	▨	▨	▨	▨
	Lack of knowledge	▨	▨	▨	▨	▨
	Customer's disinterest	▨	▨	▨	▨	▨
	Codes & regulations	▨	▨	▨	▨	▨
	Functional requirements	▨	▨	▨	▨	▨
	Market availability			▨	▨	▨
	Aesthetic requirements			▨	▨	

4.2 Sampling method

Due to the time limits of the data collection phase, the complex materials life cycle and the range of stakeholders involved in material selection and use, had to be simplified (see Figure 3.1). Design, construction, and maintenance of the building were chosen as the key materials life cycle phases (see Figure 4.1) and architects, structural engineers, LEED consultants, general contractors, owner/developers and building operators were selected as the key stakeholders, since they were considered to have a more direct and influential role in material selection and use.

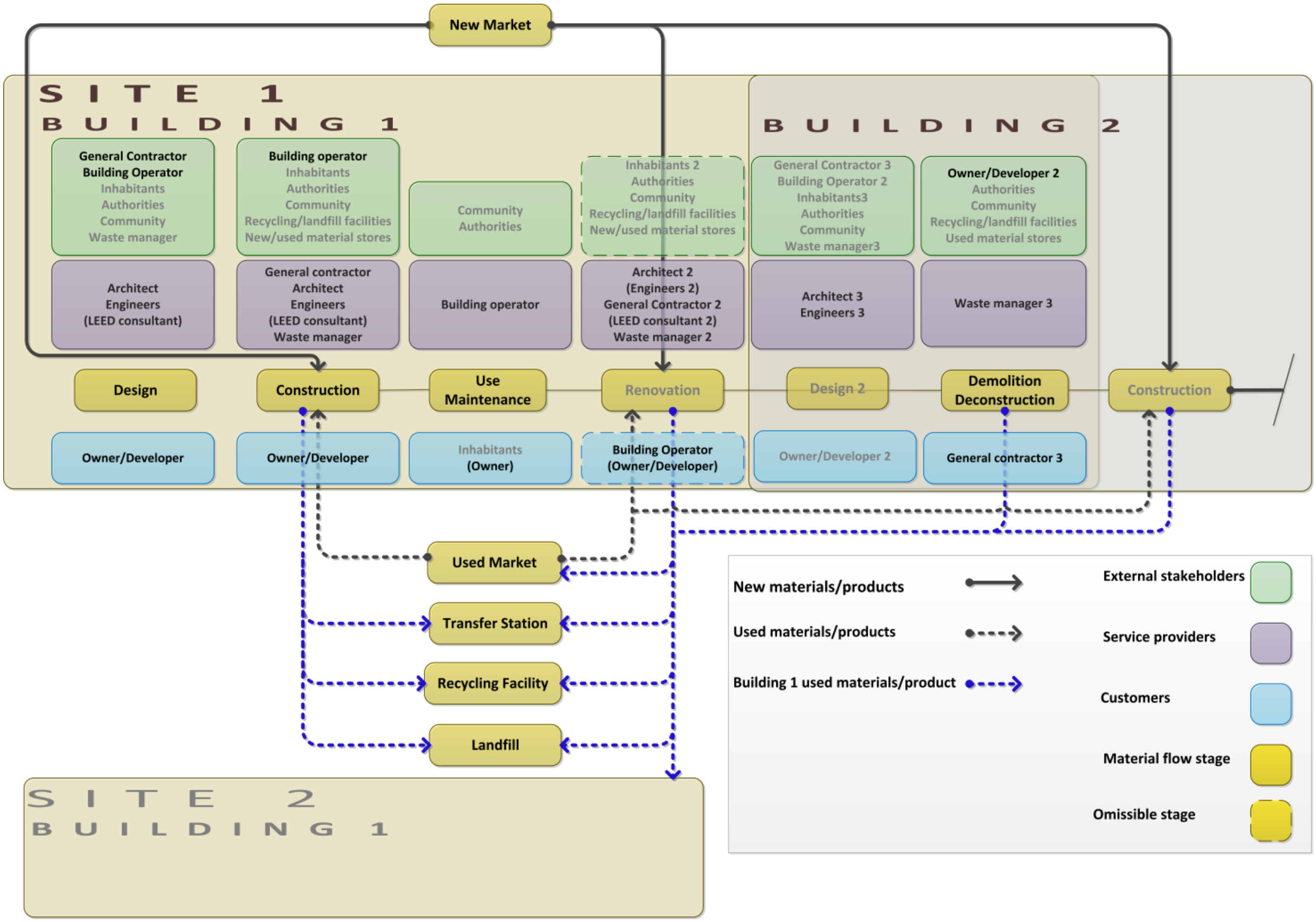


Figure 4.1 Simplified materials life cycle for the data collection phase

One crucial part of every survey study is choosing a representative sample group of participants. Previous studies show that even in environmental and sustainable projects such as those achieving LEED certification, there is less emphasis and success placed on the efficiency of material use compared to the efficiency of other types of resource use, such as water and energy (Ding, 2014; Franzoni, 2011; Kibert, 2008). Therefore, sending the survey to stakeholders associated with random projects in the region may introduce errors in the result, since the respondents might not be familiar with or concerned with CME strategies. To ensure the respondents have a minimum awareness or concern about the strategies, the scope of this research was limited to the stakeholders associated with LEED New Construction and Major Renovation (NC) Gold or Platinum projects. Moreover, in the environmental strategies in these projects are typically both better documented and more publically accessible. However, the questionnaire does not ask specifically about LEED projects but asked for respondents' overall experience with implementing the strategies for CME. Nonetheless, the respondents' involvement in LEED projects increases the chance of them having knowledge and experience of dealing with of CME strategies.

To ensure that all the respondents operate within the same context (e.g., have access to similar construction technologies and building materials and are following similar codes and regulations), the study is limited to the projects which are certified after 2010 in the Metro Vancouver, of British Columbia. Studying recent local projects also faciltated the process of getting the contact information of the involved stakeholders of the projects. It should be noted however, that this sample group is not intended to be a representative of the Metro Vancouver construction industry, but rather representative of a more environmentally aware and leading stakeholder groups within the region.

According to the Canada Green Building Council (CAGBC) (2014), 53 NC LEED Gold and Platinum projects were certified from January 2010 to May 2014. The survey was sent to 143 stakeholders who were involved in these projects, i.e., architects, LEED consultants, structural engineers, general contractor, owner/developer, and building managers. Some of these people were involved in multiple projects included in the study or performed several roles within the selected LEED projects.

A challenging part of the data gathering was to persuade the stakeholders to participate in the survey study because they are all very busy in their respective jobs. It would have made it even more difficult if the survey was sent to the stakeholders who are indirectly involved in the studied projects; such as material manufacturers, policy makers, demolition and waste management subcontractors, recycling facilities, and material distributers. Efforts were therefore made to increase the response rate by, for example, preparing personalized invitation letters and sending two reminder emails with one-week intervals to the participants who had not filled the survey.

The total response rate was 43% (62 out of 143), which is a high rate compared with the norm of 20-30% for questionnaire surveys in the construction industry (Osmani et al., 2006). Out of the 62 received responses (43%), 9 were incomplete and were excluded from some sections of the analysis. Classifying the small sample group based on the respondents' roles (i.e., designers, contractors, and customers) lead to subcategories with even fewer members, e.g., in this study, the contractor and the customer categories only included 10 and 18 members respectively (see Figure 5.1). The relatively small sample group in the study within each of the stakeholder groups (which was selected according to the criteria mentioned in section 4.2), was a major challenge in analyzing the data. Thus the findings about various stakeholder groups' attitudes and preferences will need to be further tested in future research to confirm the accuracy of the results and conclusions.

Chapter 5: Survey results and analysis

The survey responses were analyzed using the Statistical Package for Social Science (SPSS) software. The results of the survey and their analysis are presented in this chapter in the following sub-sections:

- *Demographic and professional information of the respondents:* This section provides a better understanding of the respondents' characteristics.
- *Descriptive and expletory statistics:*
    - Descriptive statistics explores the distribution, the central tendency (mean), and variability (standard deviation) of the responses. The purpose is to juxtapose various life cycle stages, strategies, and stakeholder groups to find the differences between sub-categories.
    - Expletory statistics are inferential analyses to investigate possible correlation between some of the variables. For instance the correlation between different motivations and barriers and the practice rate of different CME strategies will be explored.

These analyses are further discussed and compared with the literature in Chapter 6: (Discussion and conclusion) to find solutions for improving stakeholders' involvement in practicing CME strategies.

5.1 Demographic and professional information of the respondents

Using the responses to questions 1-9, demographic and professional information of the respondents are presented in this section. It should be noted that cumulative percentages are more than 100% in the multiple choice questions.

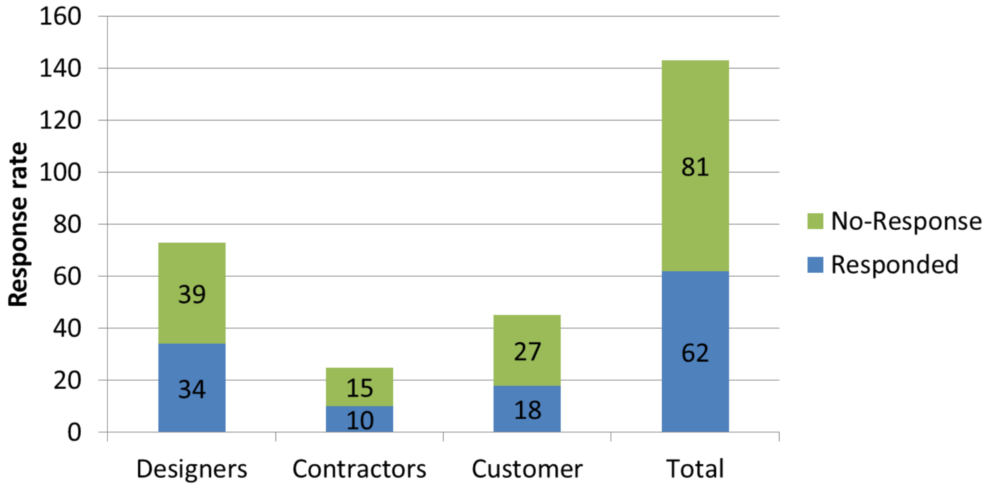


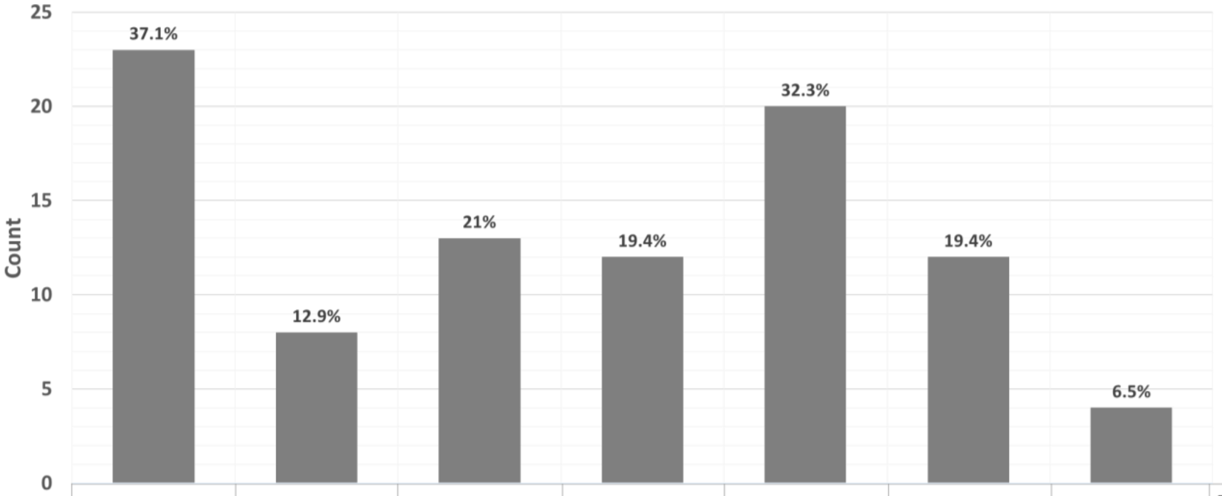
Figure 5.1 Response rate among stakeholder groups

Table 5.1 Stakeholder groups' distribution among the survey respondents (question 5)

Stakeholder groups			Invited		Responded	
			Count	Percentage from total (%)	Count	Response rate (%)
Service Providers	Designers	Architect	31	22 %	16*	52 %
		LEED Consultant	21	15 %	10	48 %
		Structural Engineer	21	15 %	8	38 %
		Total	73	51%	34	47%
	Contractors	General Contractor	25	17 %	10	40 %
	Total		98	69 %	44	45 %
Users	Users	Owner/Developer	30	21 %	11	37 %
		Building operator	15	10 %	7	47 %
	Total		45	31 %	18	40 %
Total			143	-	62	43 %

* 4 of the Architects were also LEED consultant

- Figure 5.1 and Table 5.1 show the distribution of respondents' roles in projects. More than 50% of the respondents are designers: architects, engineers, and LEED consultants.
- According to Figure 5.2, respondents' companies typically have more than one role in projects including: architecture (37%), structural engineering (13%), LEED consultant (21%), general contractor (19%), owner or developer (32%), and building operation (19%).
- Respondents' age varies from 26 to 67, with the mean of 48. The respondents' age distribution is presented in Table 5.2 and Figure 5.3.
- The graduation year of the respondents, ranges between 1969 and 2014, with a mean of 1993 (see Figure 5.4 and Table 5.3).
- The respondents' primary areas of education are architecture (43%), engineering or building sciences (29%), and management or business (18%) (Figure 5.6).



	Architecture	Structural Engineering	LEED Consultant	General Contractor	Owner/Developer	Building operator	Other	**Total**
Frequency	23	8	13	12	20	12	4	**92**
Percentage	37.1%	12.9%	21%	19.4%	32.3%	19.4%	6.5%	**148.4%**

Figure 5.2 The typical role of the respondents' companies (question 5)

Table 5.2 Respondents' age distribution (question 1)

	Age Range	Frequency	Percent
Valid	25 - 35	6	9.7
	36 - 45	20	32.3
	46 - 55	18	29.0
	56 - 65	15	24.2
	66+	1	1.6
	Total	60	96.8
Missing		2	3.2
Total		**62**	**100.0**

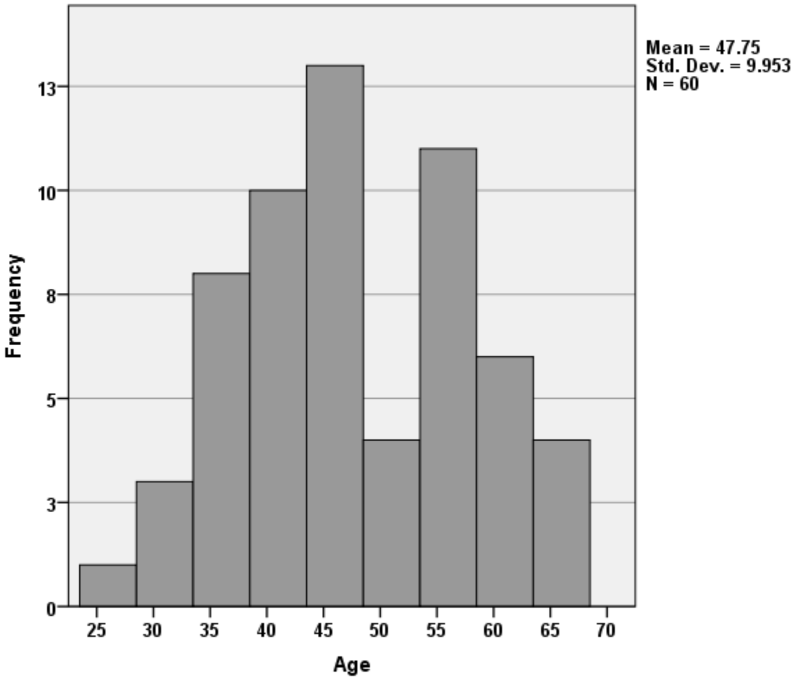


Figure 5.3 Respondents' age distribution (question 1)

Table 5.3 Respondents' graduation year (question 4)

		Frequency	Percent
Valid	1965 - 1975	1	1.6
	1976 - 1985	13	21.0
	1986 - 1995	18	29.0
	1996 - 2005	12	19.4
	2006+	9	14.5
	Total	53	85.5
Missing		9	14.5
Total		**62**	**100.0**

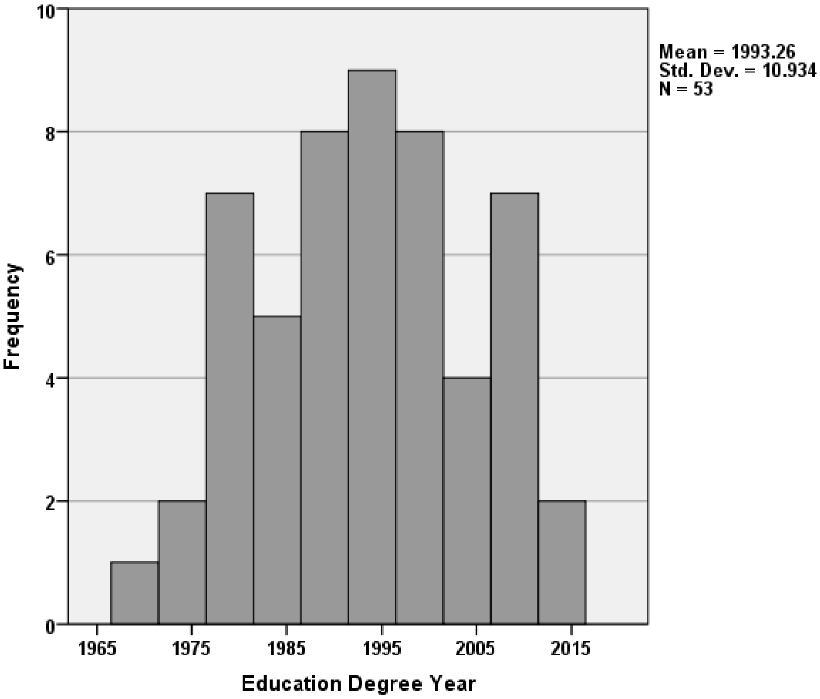


Figure 5.4 Respondents' graduation year distribution (question 4)

- As it is illustrated in Figure 5.5, 75% of the respondents have a bachelor degree or higher in their respective field of study.
- Figure 5.7 shows that the cost of the projects undertaken by the respondents' companies are less than 5 million dollars (42%), 5-15 million dollars (61%), 15-50 million dollars (68%), to more than 50 million dollars (44%)
- Types of projects undertaken by the respondents' companies are institutional (81%), commercial (76%), residential (68%), educational (61%), governmental (58%), and industrial (27%) (Figure 5.8)
- As it can be noticed in Figure 5.9, about 60% of the respondents have stated that less than 50% of their company's projects receive LEED certification.

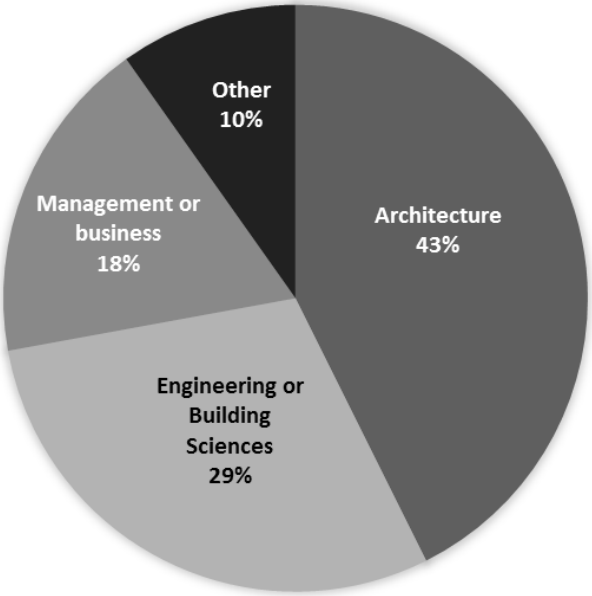


Figure 5.6 Respondents' primary area of education (question 2)

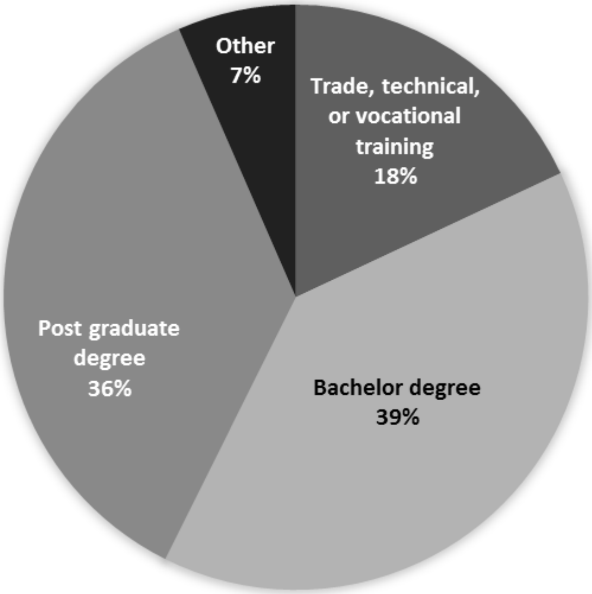
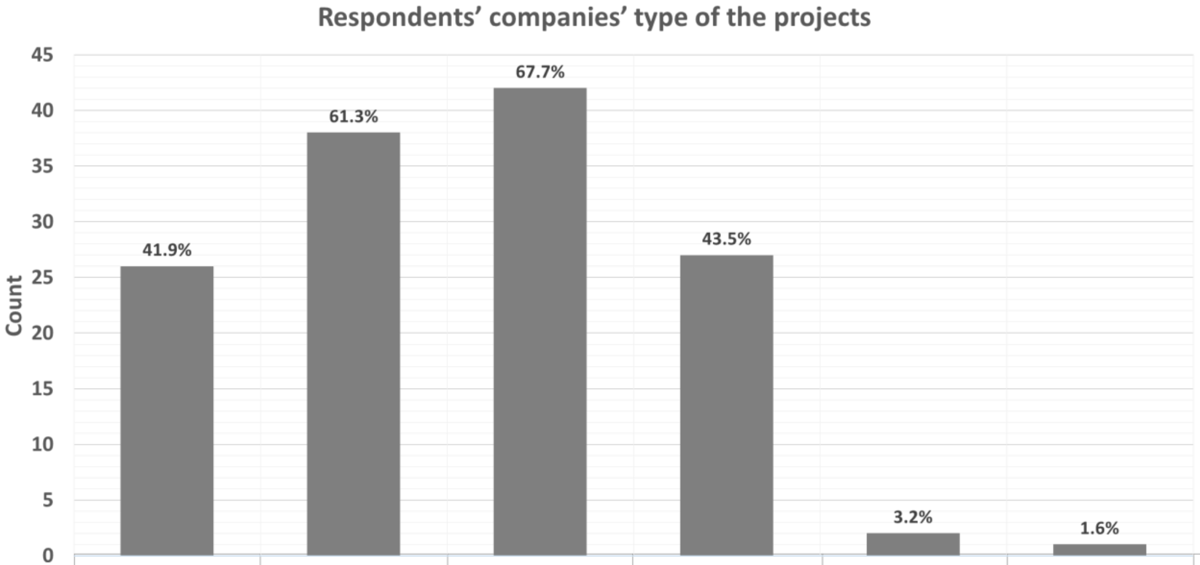
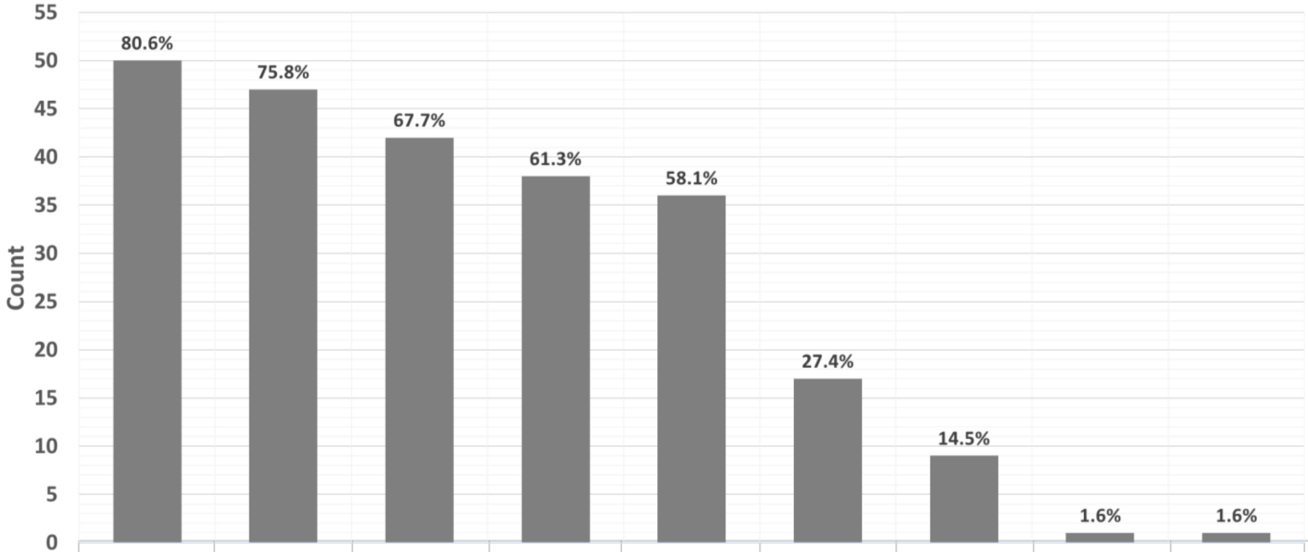


Figure 5.5 Respondents' highest level of education in their primary field of study (question 3)



	Less than 5 million $	5-15 million $	15-50 million $	More than 50 million $	N/A	Missing	Total
Frequency	26	38	42	27	2	1	**136**
Percentage	41.9%	61.3%	67.7%	43.5%	3.2%	1.6%	**219.4%**

Figure 5.7 Cost of the projects undertaken by the respondents' companies (question 7)



	Institutional	Commercial	Residential	Educational	Governmental	Industrial	Other	N/A	Missing	Total
Frequency	50	47	42	38	36	17	9	1	1	**241**
Percentage	80.6%	75.8%	67.7%	61.3%	58.1%	27.4%	14.5%	1.6%	1.6%	**388.7%**

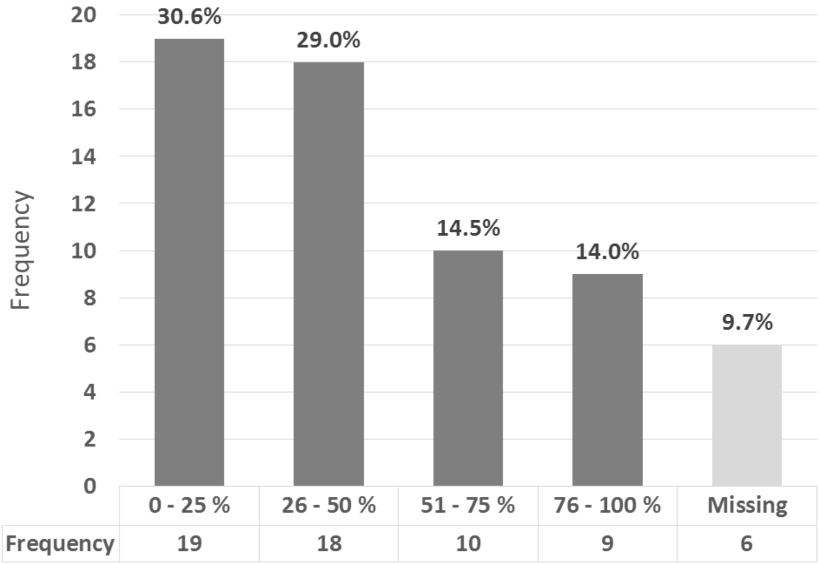
Figure 5.8 Types of the projects undertaken by the respondents' companies (question 8)

5.2 Descriptive and expletory statistics

5.2.1 Practice rate vs. importance of CME strategies

The descriptive statistics of questions 10 and 11 are presented in Table 5.4. The table includes the number of responses, their mean, and standard deviation. Since each respondent is involved in a specific set of building lifetime phases, they might not be well aware of the strategies used in the other phases that they are not directly involved. Thus, in question 10 related to the practice of the strategies for CME in different phases of a building life cycle, stakeholders are only asked about the stages that they are involved:

- *Designers* were asked about the strategies in the design and material selection/construction.
- *Contractor*s were asked about material selection/construction and deconstruction/demolition phases.
- *Owners/developers* were questioned about all the stages



	0 - 25 %	26 - 50 %	51 - 75 %	76 - 100 %	Missing
Frequency	19	18	10	9	6

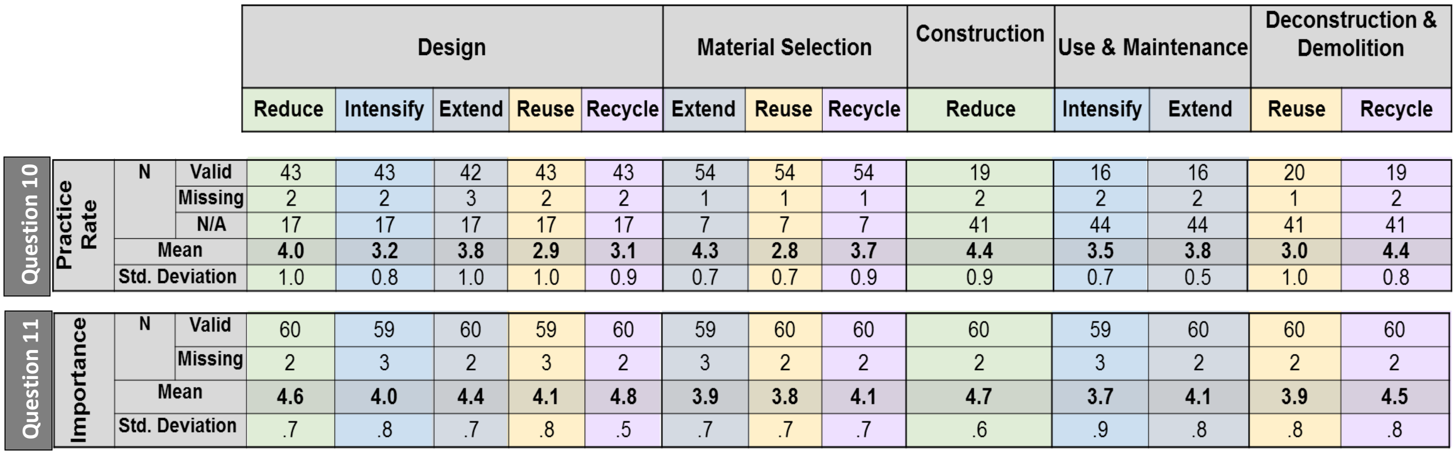
Figure 5.9 The percentage of the projects which have received LEED certification among all the projects of the respondents' companies (question 9)

- *Building operators* are only asked about use/maintenance, since they are typically involved only in this phase.

However, in question 11 all the stakeholders are asked to express their opinion about the importance of the strategies for CME in all the phases of building lifetime, to establish the importance of the strategies (or lack thereof) from the different stakeholders’ perspective regardless of their direct involvement in practicing those strategies.

Figure 5.10 uses the responses to questions 10 and 11 to compare the average practice rate of different strategies with their perceived importance. Here, although both of questions 10 and 11 are five-point Likert-type rating scale, the rating labels are not the same (from Never (1) to Always (5) in question 10 and from Not important at all (1) to Very important (5) in question 11). This labeling difference may have caused discrepancies in the respondents’ choices between these two sets of questions. Thus the arguments in the comparison of the practice rate and perceived importance should be interpreted with caution.

Table 5.4 Descriptive statistics for questions 10 and 11: practice rate and importance of CME strategies (questions 10 and 11)



				Design					**Material Selection**			**Construction**	**Use & Maintenance**		**Deconstruction & Demolition**	
				Reduce	**Intensify**	**Extend**	**Reuse**	**Recycle**	**Extend**	**Reuse**	**Recycle**	**Reduce**	**Intensify**	**Extend**	**Reuse**	**Recycle**
Question 10	**Practice Rate**	**N**	**Valid**	43	43	42	43	43	54	54	54	19	16	16	20	19
			Missing	2	2	3	2	2	1	1	1	2	2	2	1	2
			N/A	17	17	17	17	17	7	7	7	41	44	44	41	41
		Mean		**4.0**	**3.2**	**3.8**	**2.9**	**3.1**	**4.3**	**2.8**	**3.7**	**4.4**	**3.5**	**3.8**	**3.0**	**4.4**
		Std. Deviation		1.0	0.8	1.0	1.0	0.9	0.7	0.7	0.9	0.9	0.7	0.5	1.0	0.8
Question 11	**Importance**	**N**	**Valid**	60	59	60	59	60	59	60	60	60	59	60	60	60
			Missing	2	3	2	3	2	3	2	2	2	3	2	2	2
		Mean		**4.6**	**4.0**	**4.4**	**4.1**	**4.8**	**3.9**	**3.8**	**4.1**	**4.7**	**3.7**	**4.1**	**3.9**	**4.5**
		Std. Deviation		.7	.8	.7	.8	.5	.7	.7	.7	.6	.9	.8	.8	.8

N/A = not applicable;
Scores are obtained from 5-poin Likert scale questions with the following choices:
Question # 10: 1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Often, 5 = Always
Question # 11: 1 = Not important at all, 2 = Somewhat unimportant, 3 = Neutral, 4 = Somewhat important, 5 = Very important

Table 5.5 Pearson correlation between the importance of the strategies and their practice rate

Strategy	Phase	Pearson Correlation	p	Number of Cases
Reduce Use	Design	.29	.055	43
	Construction	.16	.52	19
Intense Use	Design	***.56***	***.001***	43
	Use	.43	.11	15
Extend Use	Design	***.52***	***.01***	42
	Material Selection	.003	.98	54
	Use	.35	.2	15
Reuse	Design	***.49***	***.01***	43
	Material Selection	***.39***	***.003***	54
	Deconstruction	***.50***	***.024***	20
Recycle	Design	.24	.13	44
	Material Selection	***.56***	***.001***	54
	Deconstruction	***.65***	***.003***	19

It is noticeable in Figure 5.10 that, with the exception of ‘extend use/material selection’, the stated importance of all of the strategies is greater than their practice rate. The Pearson correlation coefficient test was conducted to measure the strength of the relationship between respondents’ perception of the importance of the strategies and their practice rate. Pearson correlation coefficient can take a real value between -1 and 1. A negative value indicates an inverse correlation (negative relationship). To conduct Pearson correlation coefficient test, it is assumed that the two variables are continuous. The results of the test which are presented in

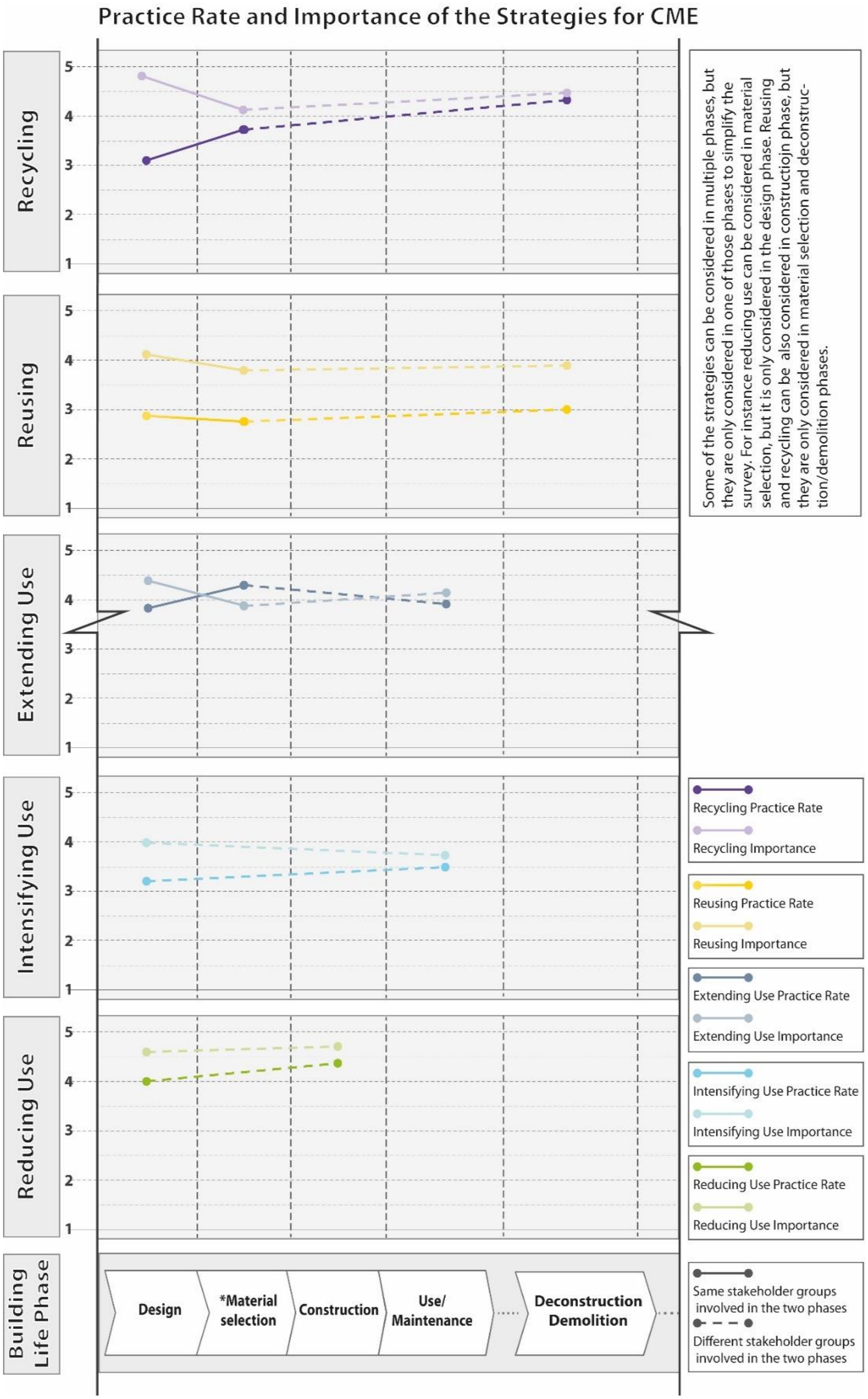
Table 5.5, indicates that there is not always a significant relationship between the two variables (see Figure 5.10):

- In some cases, such as recycle/design, most of the respondents considered them to be important strategies, but do not necessarily practice/implement them consistently.
- In other cases, such as ‘extend use/material selection,’ even the respondents who do not consider them as important responded that that they regularly practice them. This may be due to high customer’s demand.
- There is a correlation between the importance and practice rate for the reuse strategies. This may be because reuse is a voluntary action, so those who consider them to be important are the ones who practice them more.
- Since the use phase does not have enough respondents (18 respondents), the results might not be accurate for this phase. With the available data, Pearson test does not support a correlation between the importance and practice rate of the strategies in the use phase.

Section 5.2.5, 5.2.7, and 5.2.8 investigates the influence of various motivating and limiting factors on the stakeholders’ willingness to implement these strategies.

5.2.2 The influence of LEED assessment system on CME

Figure 5.11 illustrates the responses to question 12, in which about 60% of the respondents believe that they deploy almost or completely the same practice in their LEED vs. non-LEED projects in terms of strategies for CME. This response is perhaps an indicator of the positive influence of the LEED rating system on respondents' willingness to adopt LEED as standard practice of the industry.



Some of the strategies can be considered in multiple phases, but they are only considered in one of those phases to simplify the survey. For instance reducing use can be considered in material selection, but it is only considered in the design phase. Reusing and recycling can be also considered in constructiojn phase, but they are only considered in material selection and deconstruction/demolition phases.

Figure 5.10 The relationship between the practice rate of different CME strategies and their importance in the respondents' point of view during different phases of a building's lifetime.

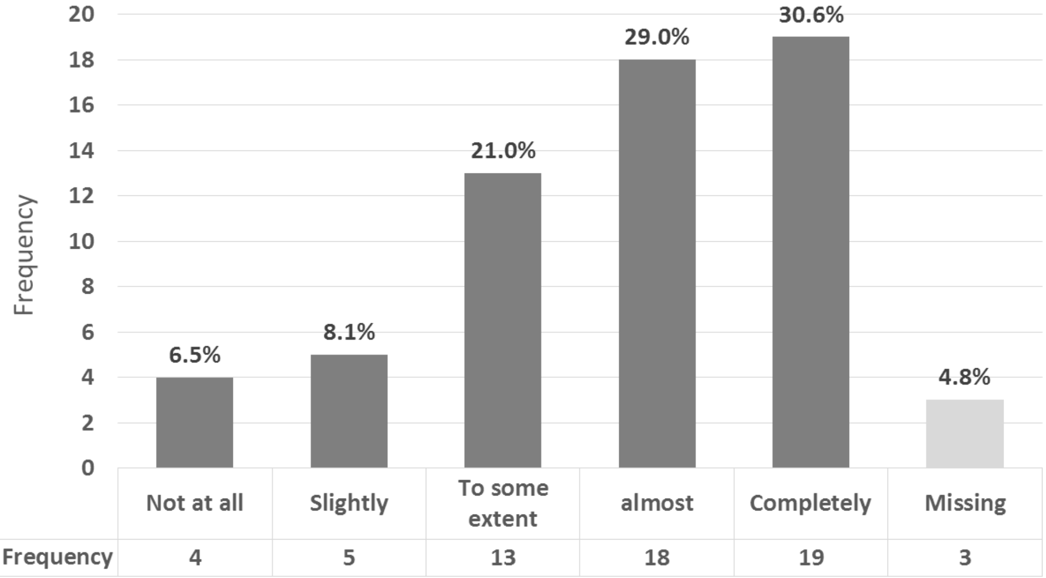
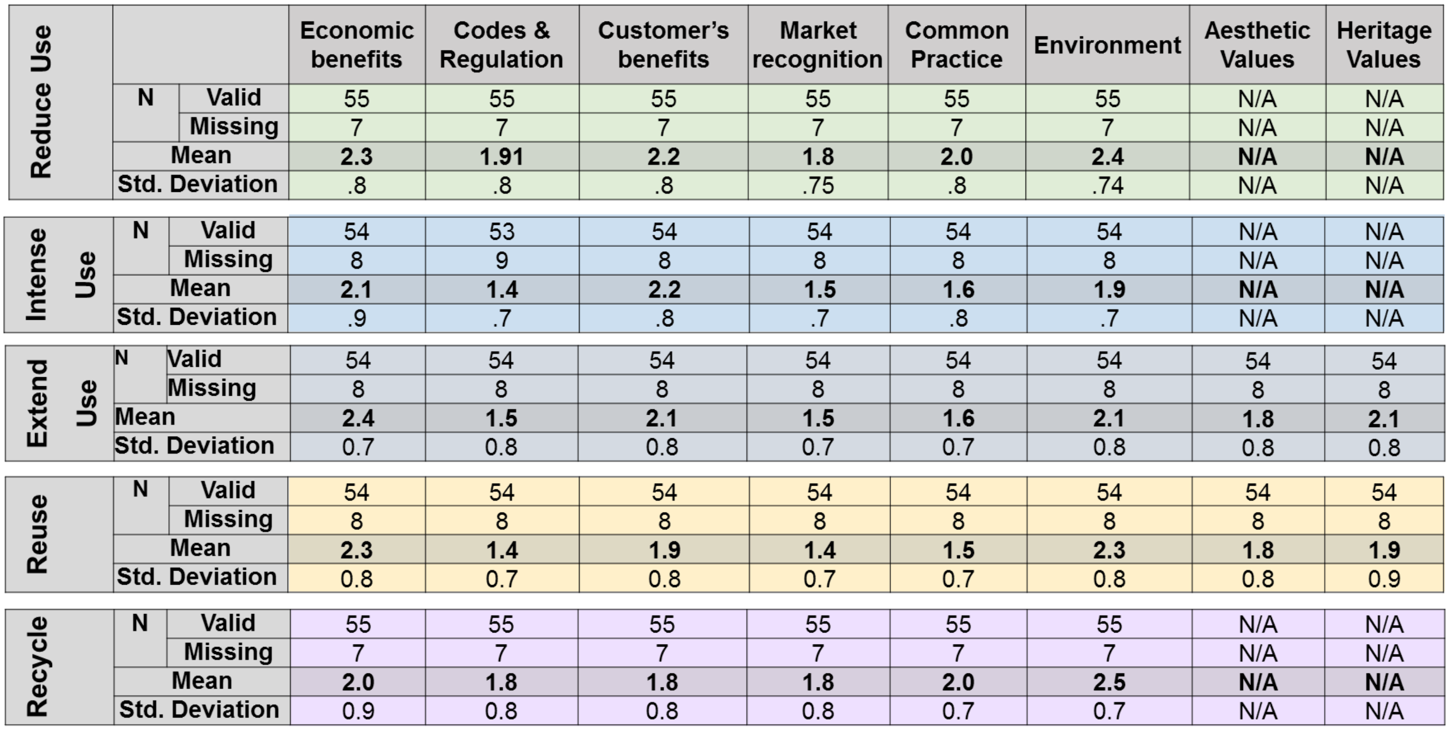


Figure 5.11 CME strategies practice in LEED vs. Non-LEED projects (question 12)

However, only a very small portion of all the construction projects built in North America are LEED certified (Wallbaum et al., 2010, p. 12). In 2010 to 2013, 109,947 residential building permits have been issued in British Columbia (BC Stats, 2014), while in the same period of time only 44 residential (3 low-rise, 18 mid-rise, 6 high-rose multi-unit residential buildings, and 17 single family homes), and in total 165 projects have been LEED certified. This indicates that despite the existence of current approaches and strategies for improving building environmental performance, there are some non-technical barriers that impede such improvement (Griffin et al., 2010). In a comparison of a sustainably certified project with four conventional mixed-use and residential buildings in England, Williams and Dair (2007) realized that a major problem for the progress of sustainability goals in traditional construction projects is simply that these projects do not investigate the feasibility of such goals.

Table 5.6 Descriptive statistics for question 13: motivations for implementing CME strategies (question 13)



			Economic benefits	Codes & Regulation	Customer's benefits	Market recognition	Common Practice	Environment	Aesthetic Values	Heritage Values
Reduce Use	N	Valid	55	55	55	55	55	55	N/A	N/A
		Missing	7	7	7	7	7	7	N/A	N/A
	Mean		**2.3**	**1.91**	**2.2**	**1.8**	**2.0**	**2.4**	**N/A**	**N/A**
	Std. Deviation		.8	.8	.8	.75	.8	.74	N/A	N/A
Intense Use	N	Valid	54	53	54	54	54	54	N/A	N/A
		Missing	8	9	8	8	8	8	N/A	N/A
	Mean		**2.1**	**1.4**	**2.2**	**1.5**	**1.6**	**1.9**	**N/A**	**N/A**
	Std. Deviation		.9	.7	.8	.7	.8	.7	N/A	N/A
Extend Use	N	Valid	54	54	54	54	54	54	54	54
		Missing	8	8	8	8	8	8	8	8
	Mean		**2.4**	**1.5**	**2.1**	**1.5**	**1.6**	**2.1**	**1.8**	**2.1**
	Std. Deviation		0.7	0.8	0.8	0.7	0.7	0.8	0.8	0.8
Reuse	N	Valid	54	54	54	54	54	54	54	54
		Missing	8	8	8	8	8	8	8	8
	Mean		**2.3**	**1.4**	**1.9**	**1.4**	**1.5**	**2.3**	**1.8**	**1.9**
	Std. Deviation		0.8	0.7	0.8	0.7	0.7	0.8	0.8	0.9
Recycle	N	Valid	55	55	55	55	55	55	N/A	N/A
		Missing	7	7	7	7	7	7	N/A	N/A
	Mean		**2.0**	**1.8**	**1.8**	**1.8**	**2.0**	**2.5**	**N/A**	**N/A**
	Std. Deviation		0.9	0.8	0.8	0.8	0.7	0.7	N/A	N/A

Scores are obtained from 3-poin Likert scale questions with the following choices:

Question # 13: 1 = Has minor influence, 2 = Has some influence, 3 = Has major influence

Moreover, LEED has been less successful in improving material consumption practices compared to the other performance categories. As discussed in section 6.5C.2, among all the strategies for CME, only recycled content material use, recycling materials in construction and demolition, and reuse in selection/construction are credited in LEED NC 1.0. Noticeably, very few of the certified projects have gained the reuse credit (see Table 2.2), which shows that LEED has not been successful in promoting all the CME strategies equally.

5.2.3 Motivations and barriers for CME

The responses to questions 13 and 14 (motivations and barriers for implementing CME strategies) are presented in Table 5.6 and Table 5.7. These results are illustrated in Figure 5.12 and Figure 5.13. The diagrams show that despite the variations in motivations and barriers for different CME strategies, the most influential motivations and barriers for the strategies are similar. According to Figure 5.12, environmental benefits, economic benefits and customer’s demand are considered to be the most influential motivations for CME. Barriers generally do not receive high scores, except for those related to time and budget limits and to a lesser extent customer’s disinterest (Figure 5.13).

It is not possible to easily identify the variety of different stakeholders’ opinions from the results presented up to this point. To gain a clearer understanding of the motivations for implementing

Table 5.7 Descriptive statistics for question 14: barriers for implementing CME strategies (question 14)

			Budget limits	Time limits	Technological facilities	Lack of knowledge	Customer’s disinterest	Codes and regulations	Functional requirement	Market Availability	Aesthetic requirement
Reduce Use	**N**	**Valid**	55	55	55	55	55	55	55	N/A	N/A
		Missing	7	7	7	7	7	7	7	N/A	N/A
	Mean		**2.2**	**2.1**	**1.4**	**1.6**	**2.0**	**1.5**	**1.8**	**N/A**	**N/A**
	Std. Deviation		0.8	0.8	0.5	0.7	0.9	0.8	0.7	N/A	N/A
Intense Use	**N**	**Valid**	N/A	N/A	53	53	53	53	53	N/A	N/A
		Missing	N/A	N/A	9	9	9	9	9	N/A	N/A
	Mean		**N/A**	**N/A**	**1.3**	**1.4**	**1.9**	**1.4**	**1.9**	**N/A**	**N/A**
	Std. Deviation		N/A	N/A	0.6	0.7	0.9	0.7	0.8	N/A	N/A
Extend Use	**N**	**Valid**	N/A	53	53	53	53	53	53	53	53
		Missing	N/A	9	9	9	9	9	9	9	9
	Mean		**N/A**	**2.0**	**1.4**	**1.5**	**2.0**	**1.6**	**1.9**	**1.6**	**1.6**
	Std. Deviation		N/A	0.8	0.6	0.8	0.9	0.7	0.8	0.8	0.7
Reuse	**N**	**Valid**	N/A	54	54	54	54	54	54	54	54
		Missing	N/A	8	8	8	8	8	8	8	8
	Mean		**N/A**	**1.9**	**1.3**	**1.4**	**2.0**	**1.5**	**1.8**	**1.4**	**1.6**
	Std. Deviation		N/A	0.8	0.6	0.6	0.9	0.7	0.8	0.7	0.7
Recycle	**N**	**Valid**	51	51	51	51	51	51	51	51	N/A
		Missing	11	11	11	11	11	11	11	11	N/A
	Mean		**2.0**	**1.6**	**1.2**	**1.3**	**1.8**	**1.4**	**1.5**	**1.3**	**N/A**
	Std. Deviation		0.9	0.8	0.4	0.6	0.8	0.6	0.7	0.6	N/A

Scores are obtained from 3-poin Likert scale questions with the following choices:

Question # 14: 1 = Has minor influence, 2 = Has some influence, 3 = Has major influence the strategies, it is necessary to differentiate the stakeholders based on their various individual interests and responsibilities rather than considering them as a whole. In practice, stakeholders are individuals and groups with diverging interests, responsibilities, and “areas of influence” (Cole, 2011; Lützkendorf, Fan, & Lorenz, 2011, p. 485). These individuals can be studied based on their personal preferences to gain a better understanding of their influence on CME. This thesis, however, is limited to comparison of the attitudes based on the stakeholders’ role. In doing so, the changes in the importance and practice rate of different strategies for CME throughout a building life cycle among the stakeholder groups who are involved in these phases

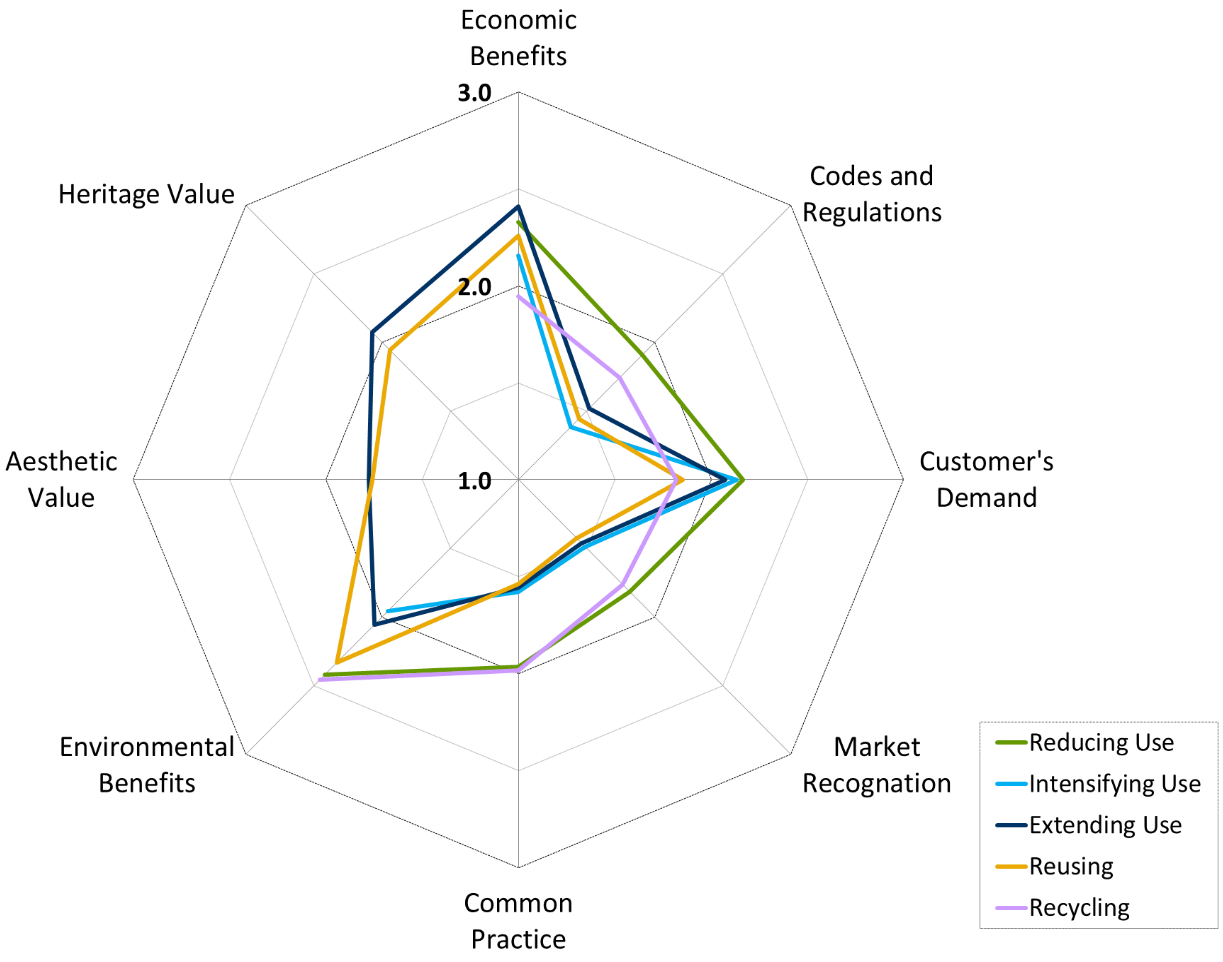


Figure 5.12 Average motivations for different CME strategies

will be compared in section 5.2.5. The influence of various motivating and limiting factors on the willingness of each group to implement these strategies will also be studied.

5.2.4 Respondents' opinion on the influence of various stakeholders

Figure 5.14 shows the responses to question 15, in which respondents have identified manufacturers, owners/developers, architects, and governments as the most influential stakeholders in implementing the CME strategies. Customers, building operators, and structural engineers are the least influential stakeholders in the respondents' point of view.

According to Figure 5.15, 68% of the respondents believe that their personal priorities and attitudes have a moderate or major influence on the implementation of CME strategies.

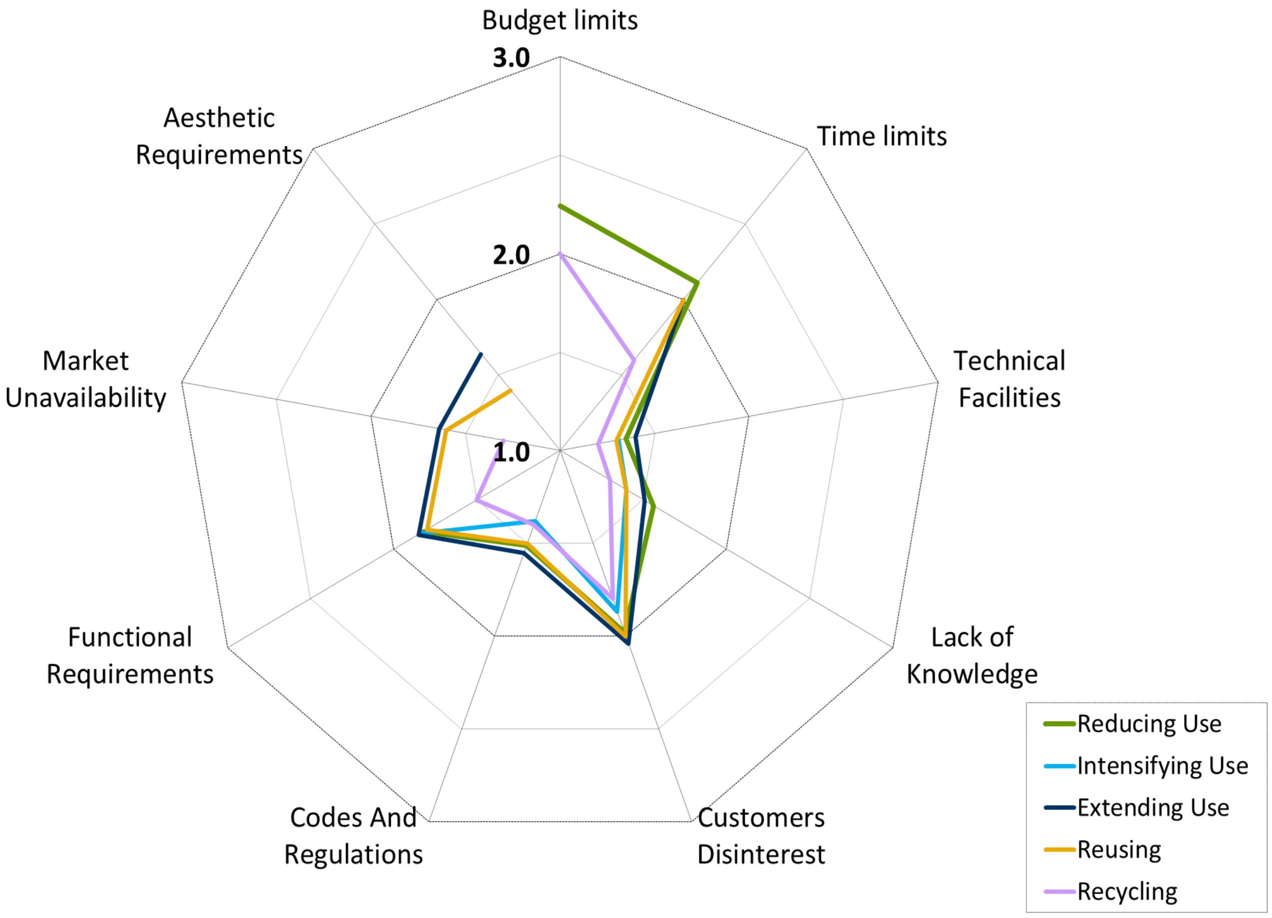


Figure 5.13 Average barriers for different CME strategies

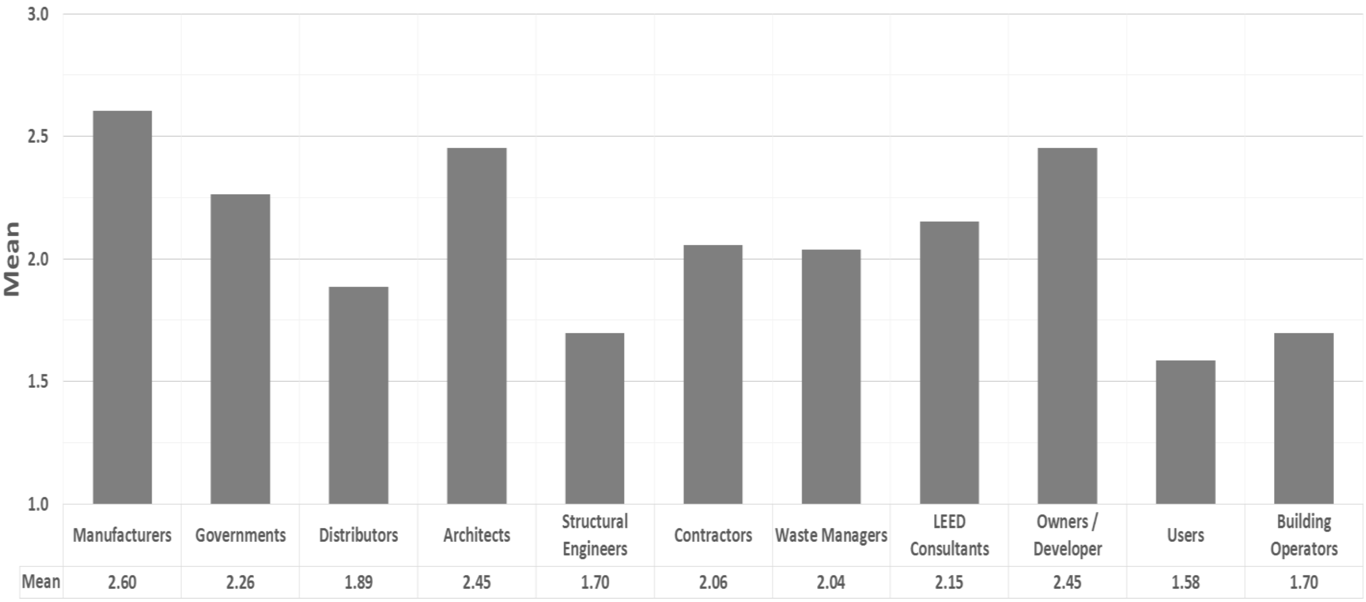


Figure 5.14 The influence of different stakeholder groups on improvising CME (question15)

5.2.5 Comparing different strategies among different stakeholders

Sustainable practices will be most widely implemented through the collective efforts of all the stakeholders throughout the whole materials life cycle, from the suppliers to the recycling companies (Dainty & Brooke, 2004; Osmani et al., 2006). Currently the stakeholders are not equally involved in the decisions leading to sustainable outcomes (du Plessis & Cole, 2011, p. 443). They are fragmented, and not well aware of the benefits of these decisions to themselves or to the larger community (Cole, 2011, p. 431). Thus, it is necessary to identify the various and sometime conflicting interests of various stakeholders in order to motivate them to improve the CME in their projects. To do so, this section will analyze:

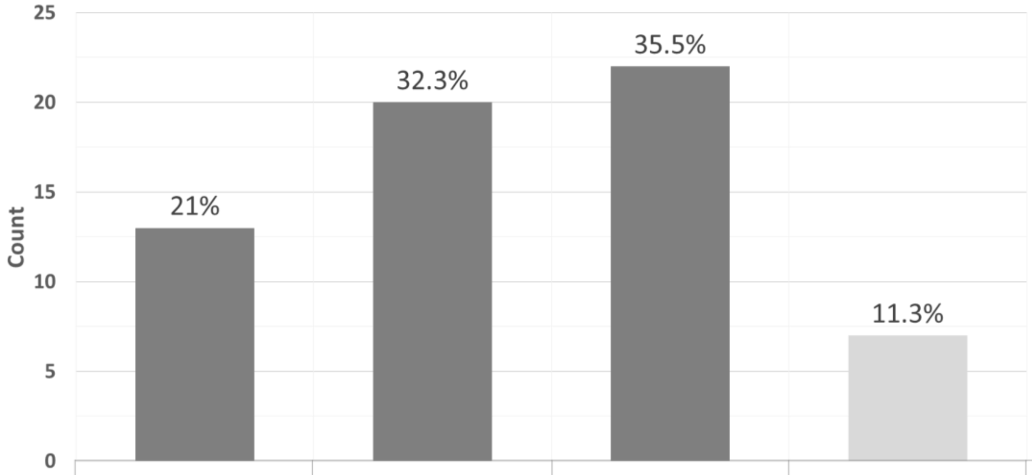
- The changes in the importance and practice rate of different strategies for CME throughout a building lifetime among different stakeholder groups who are involved in these phases

- The influence of various motivating and limiting factors on implementing the strategies among these groups.

These analeses will be further discussed in Chapter 6.

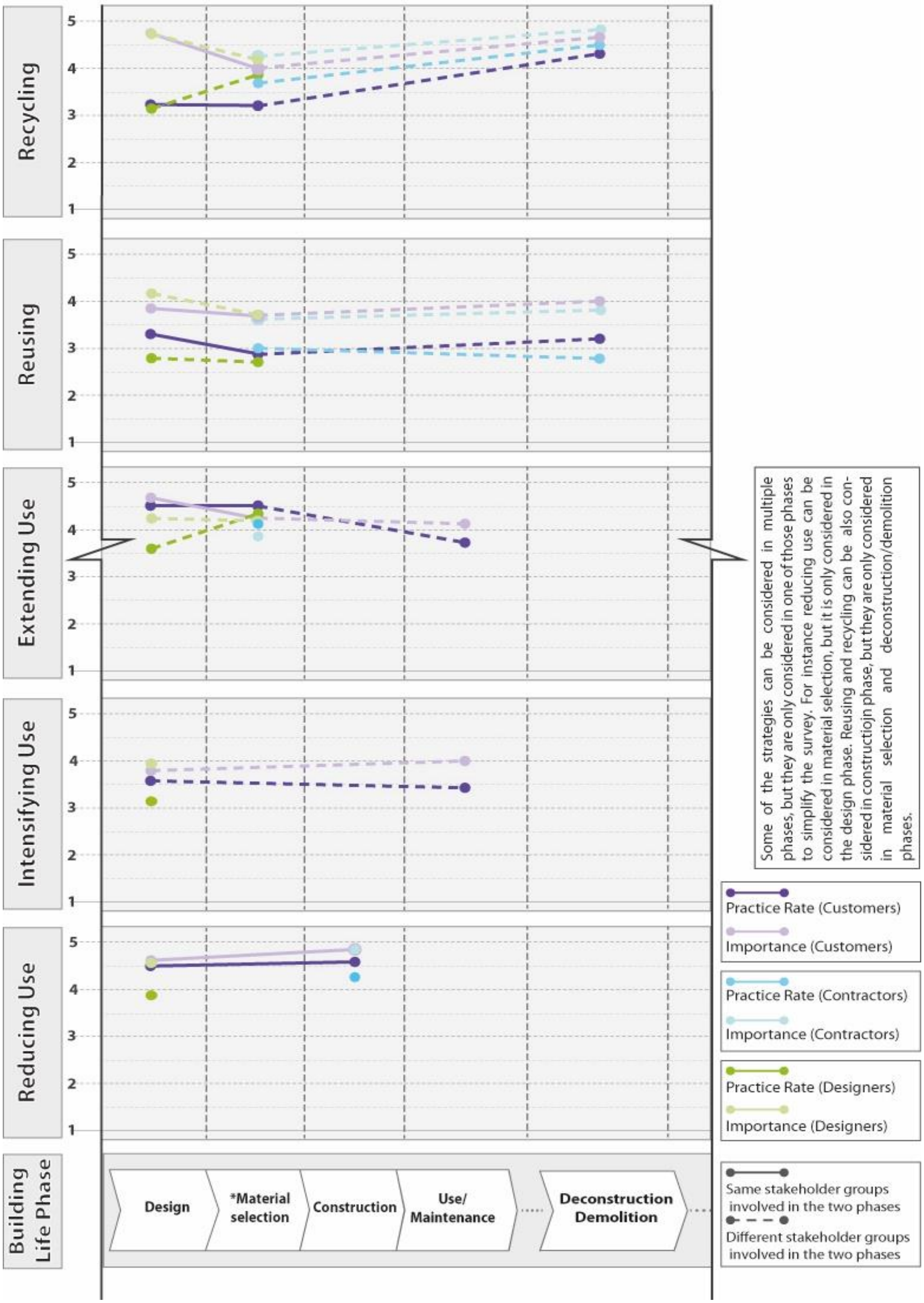
5.2.5.1 Reduce use strategy

According to Figure 5.17, a major portion of the respondents have high motivations for implementing reduce use, which is evidenced in the higher practice rate (Figure 5.16). Customers are motivated by environmental benefits, codes and regulation, and economic benefits which is evident in their higher demand for practicing this strategy (Rodriguez-Nikl et al., 2014). Contractors are motivated by economic benefits, customer's demand, and market recognition and to a lesser extent by environmental benefits. Overall, designers have the lowest level of motivation relative to other stakeholder groups but are motivated by economic and environmental benefits.



	Has minor influence	Has some influence	Has major influence	Missing	Total
Frequency	13	20	22	7	**136**
Percentage	21%	32.3%	35.5%	11.3%	**219.4%**

Figure 5.15 The influence of the respondents' personal priorities and attitudes on the implementation of CME strategies (question 16)



Some of the strategies can be considered in multiple phases, but they are only considered in one of those phases to simplify the survey. For instance reducing use can be considered in material selection, but it is only considered in the design phase. Reusing and recycling can be also considered in constructiojn phase, but they are only considered in material selection and deconstruction/demolition phases.

Figure 5.16 Practice rate and importance of CME strategies for different stakeholder groups during a building life cycle

5.2.5.2 Intense use strategy

The *intense use* strategy is practiced to a medium level by both customers and designers (see Figure 5.16). Customers stated a slightly higher practice rate compared to designers. According to Figure 5.18, customers are motivated by economic benefits and customer's demand and designers, while having a lower overall level of motivation, are motivated by customer's demand and also limited by their customer's disinterest.

5.2.5.3 Extend use strategy

Extending the use of materials is highly practiced by all the stakeholders in all the phases (Figure 5.16). Customers are highly motivated by economic benefits of reduced maintenance and replacement costs (Figure 5.19). Designers show less motivation for extending materials use than

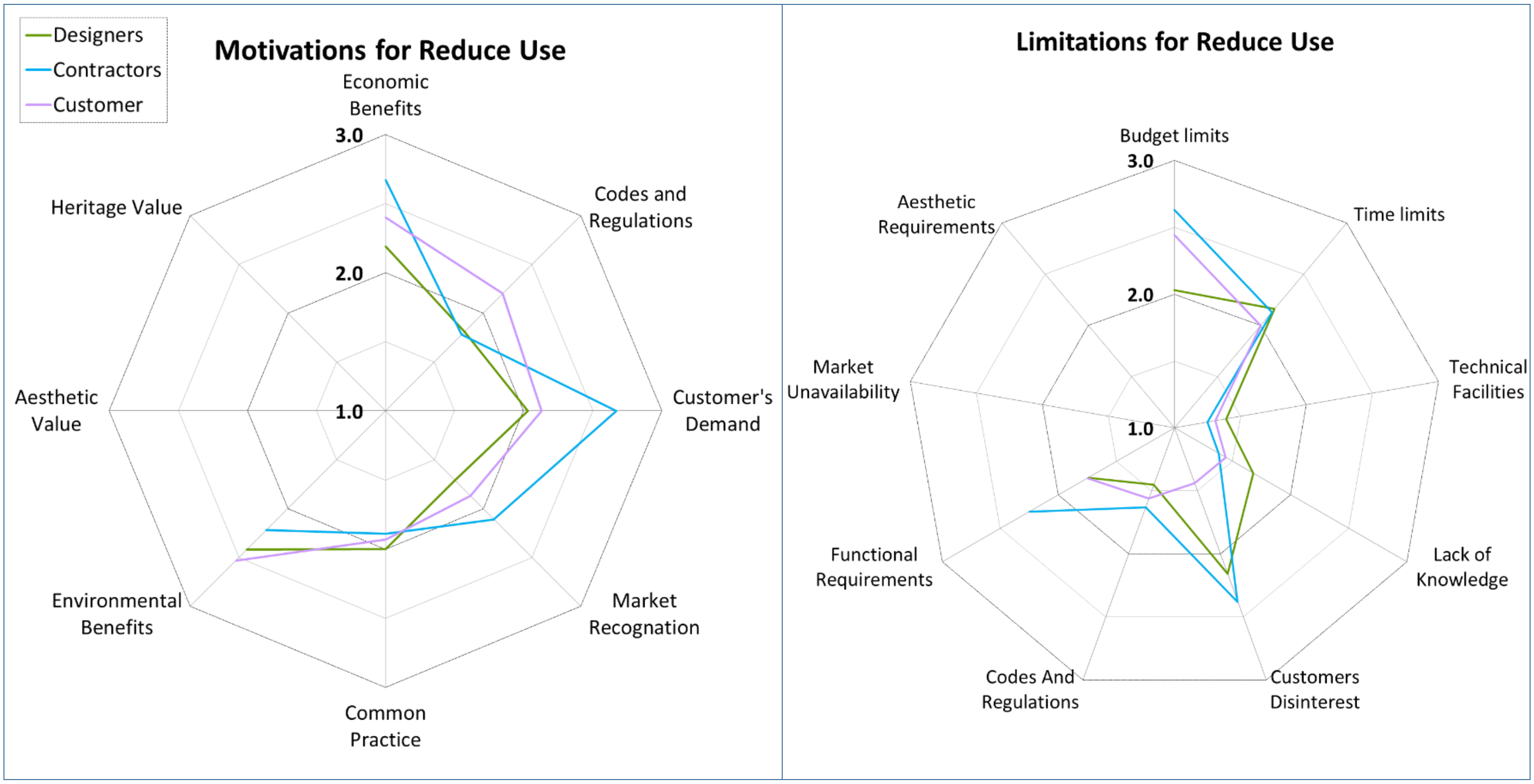


Figure 5.17 Motivations and barriers for reduce use strategy for different stakeholder groups

owners/developers and contractors. Designers and contractors consider customer's disinterest and time limits as the key barriers. Both contractors and designers are highly influenced by customer's demand to extend the use of materials. Although, the barriers presented in Figure 5.19 do not show any significant limitation from designers' perspective, extend materials use is less practiced by designers in the design phase (i.e., facilitating maintenance and repair in design) compared to the material selection phase (using durable materials).

5.2.5.4 Reuse strategy

Figure 5.16 indicates that all of the stakeholders are aware of the importance of the reuse strategy for improving material effectiveness. However, this awareness is not sufficient to translate into a high practice rate of this strategy. Reuse has the lowest practice rate among all the phases and for all the stakeholders. Interestingly, none of the barriers to reuse identified in the literature review

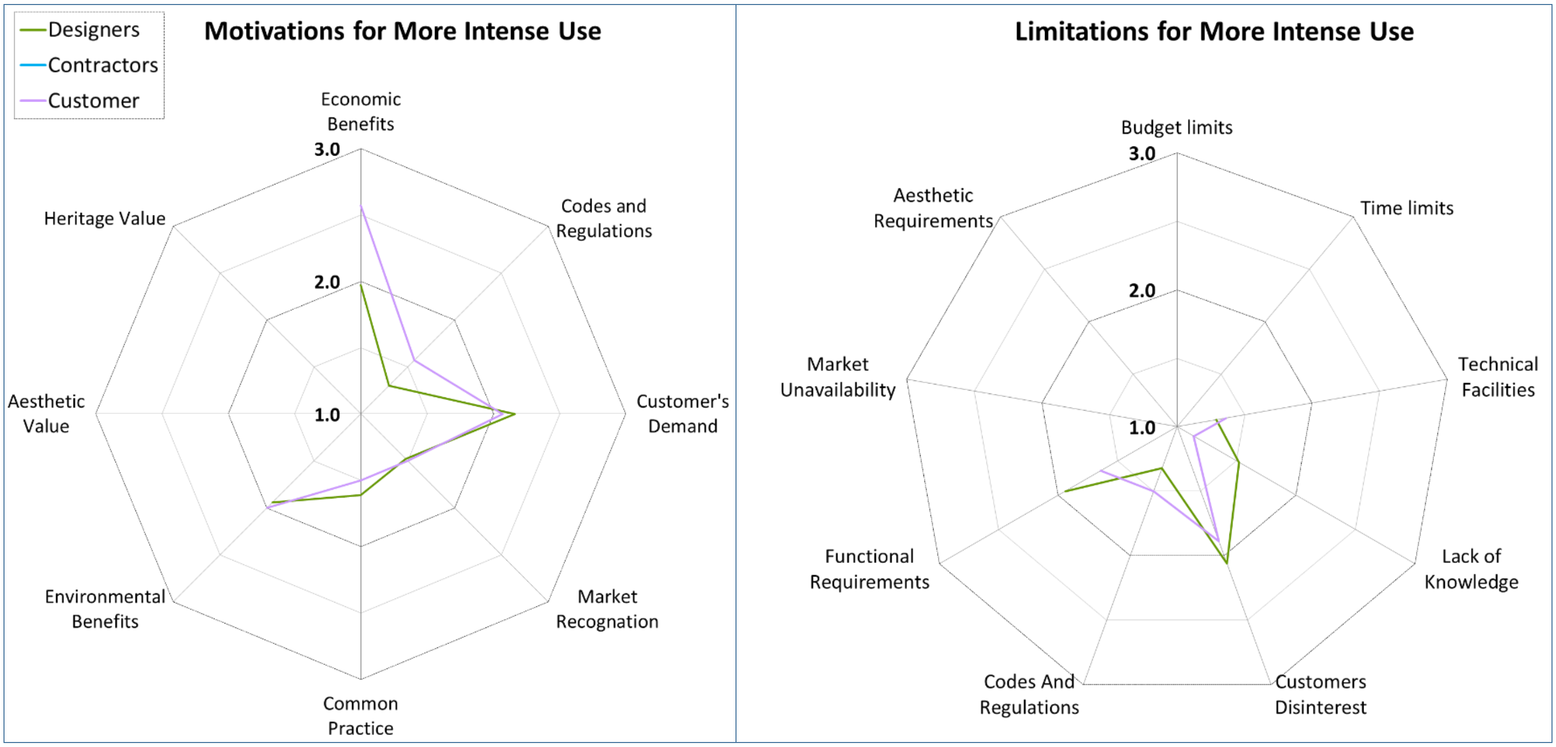


Figure 5.18 Motivations and barriers for intense use strategy for different stakeholder groups

(see section 2.1), are highly rated by any of the stakeholder groups within this research presented here. According to Figure 5.20, the customers stated that they are highly motivated by economic and environmental benefits. Contractors are mainly motivated by economic benefit and customer's demand. Generally, designers are not highly motivated to design for deconstruction and designing with salvaged materials. One of their highest motivating factors is economic benefit. It is also noticeable that service providers are considerably more interested in the heritage and aesthetic value of salvaged materials relative to that identified by customers.

5.2.5.5 Recycle strategy

Despite customer’s low demand for recycling, this strategy is a highly practiced in the material selection/construction and deconstruction/demolition phases (Figure 5.16). Contractors are highly motivated for implementing recycling strategies, mostly as a result of customer demand, market

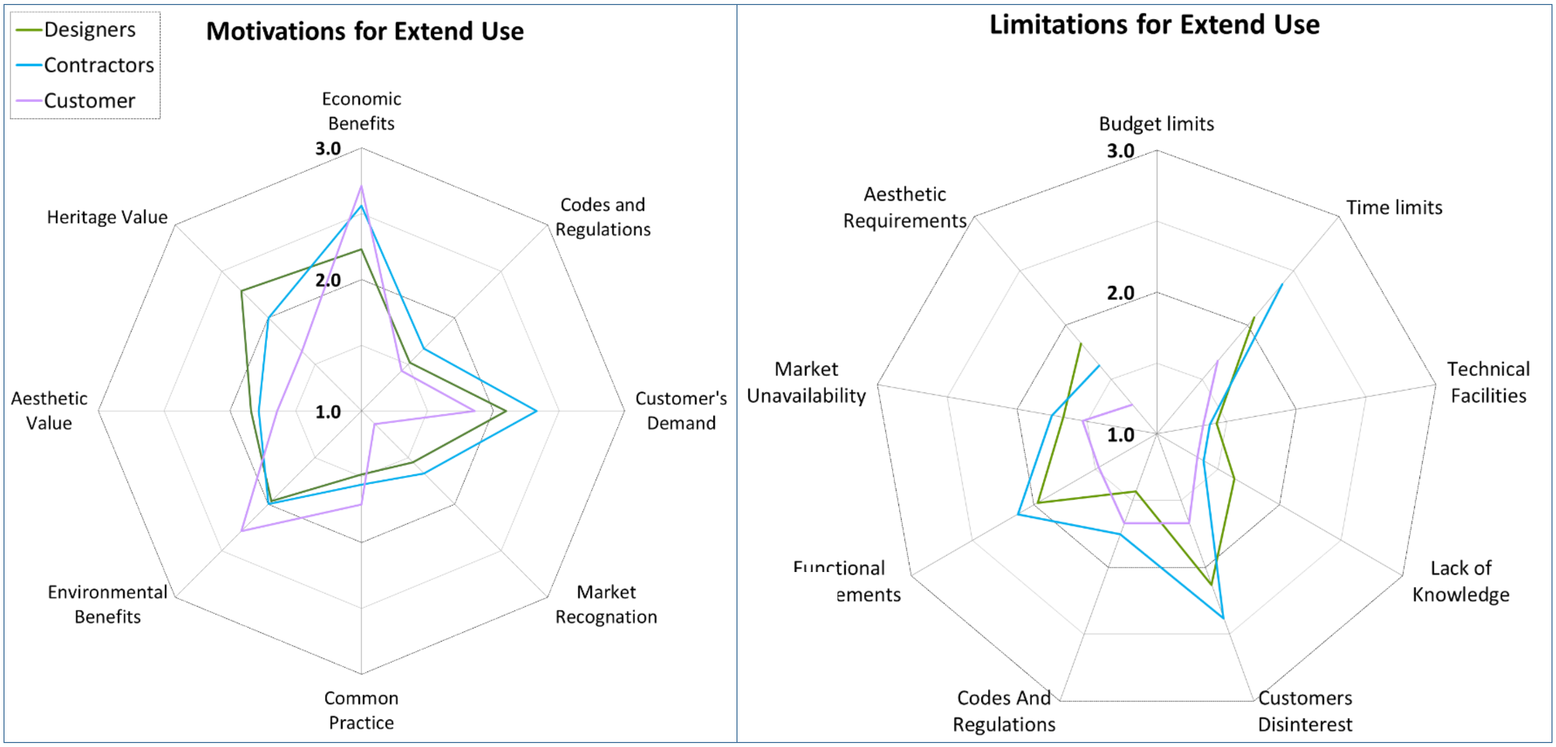


Figure 5.19 Motivations and barriers for extend use strategy for different stakeholder groups

recognition and, to some lesser extent, economic benefits and it being increasingly common practice. Designers, on the other hand, are less motivated as evidenced in the lower practice rate in the design phase (Figure 5.21).

5.2.6 Principal factor analysis

For question 13 and 14, the respondents were asked to rate different motivations and barriers according to their influence on their company's ability or interest in implementing different material effectiveness strategies. It should be noted that stakeholders’ expressed belief regarding the importance of a motivation does not necessarily translate into motivation to engage a specific strategy. They rather believe that if such motivations exist, they will be encouraged to implement a strategy. As for the barriers, it is not clear whether the existence of a barrier actually discourages them to implement a strategy. Therefore, it is necessary to examine the influence of

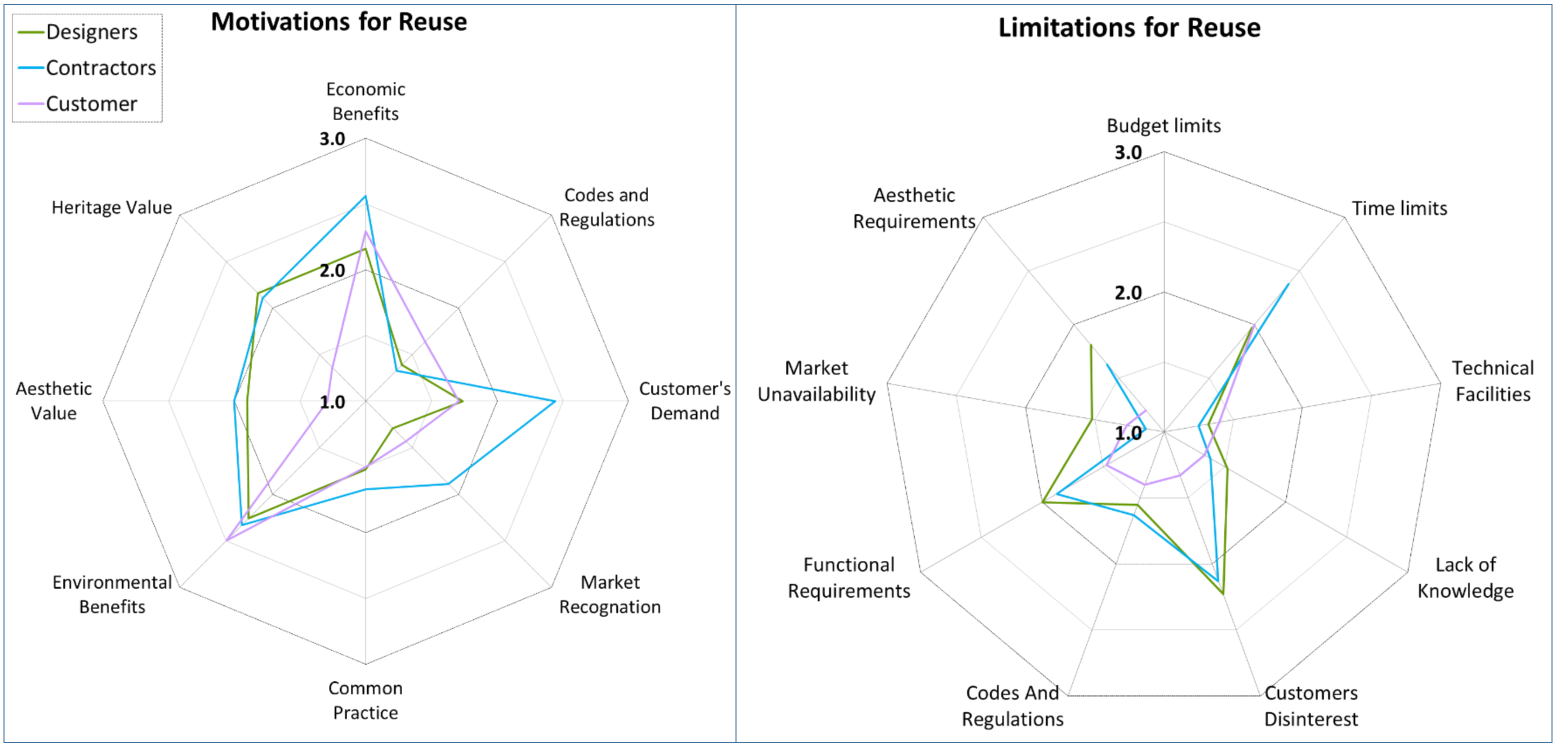


Figure 5.20 Motivations and barriers for reuse strategy for different stakeholder groups

different motivations and barriers on the practice rate of the strategies for each individual to ensure such motivations or barriers do indeed affect their decision-making process. To do so, first SPSS was used to conduct a factor analysis to group the motivations and barriers for different CME strategies into “smaller set of underlying [primary] factors” which “best describe” the motivations and barriers (Akadiri, Olomolaiye, & Chinyio, 2013). The correlation of the resulting factors and their influence on the practice rate of different strategies was then tested in section 5.2.7 and 5.2.8 respectively, using Pearson correlation coefficient test and linear regression analysis.

Factor analysis “… identif[ies] the not-directly-observable factors …” by revealing the measurable interrelationships between a set of variables. In the factor analysis the following steps should be taken (Norusis, 1993 cited in Lingard et al., 2000):

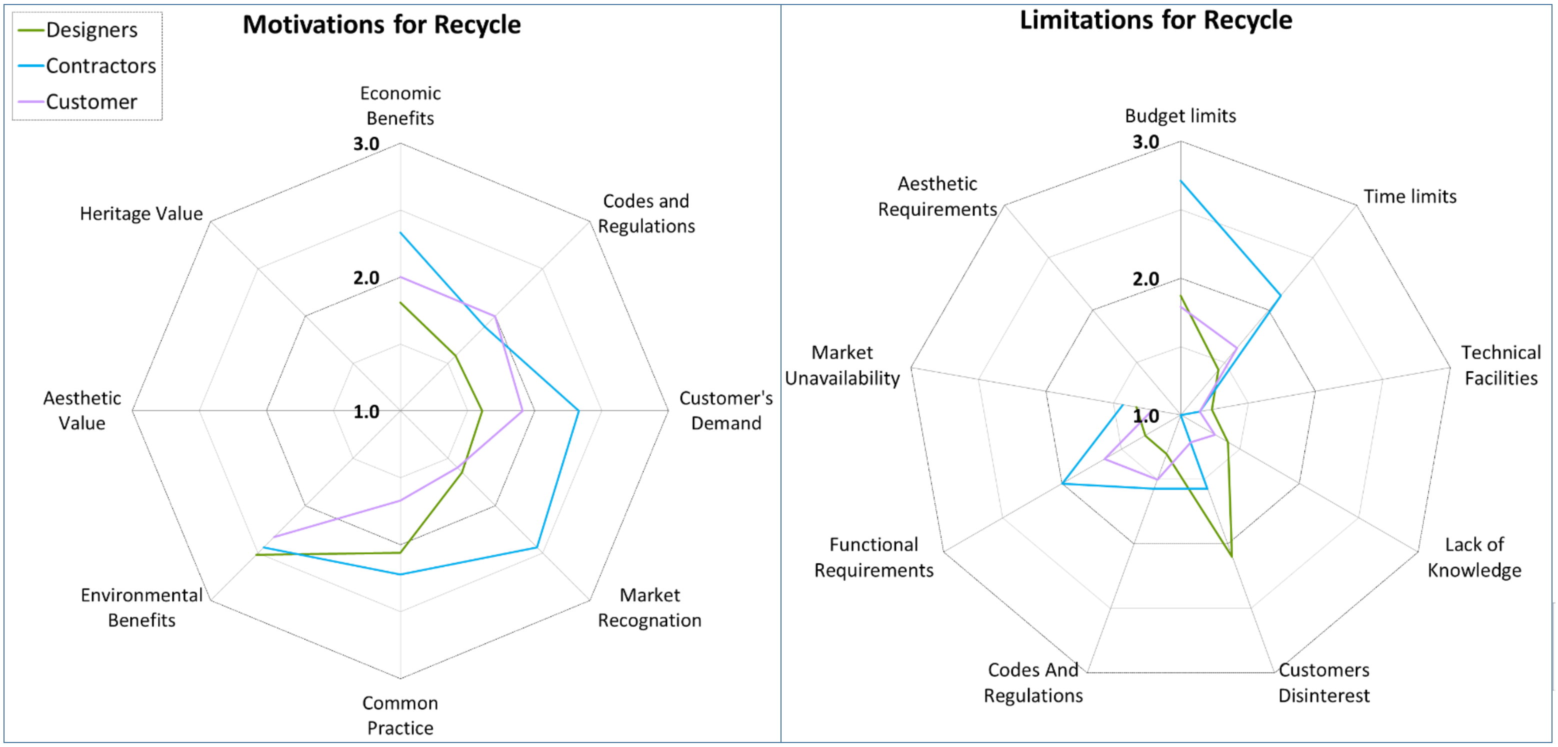


Figure 5.21 Motivations and barriers for recycle strategy for different stakeholder groups

- First a method is chosen to calculate the factors. Principal component analysis (PCA) method is used in this study for factor extraction. “The first principal component is that which accounts for the largest amount of variance in the sample, the second principal component is that which accounts for the next largest amount of variance and is uncorrelated with the first, and so on.” Loadings of the variables on the factors are calculated to show the influence of each variable on the identified factors. A high loading value indicates a large contribution of the variable on the factor (Akadiri et al., 2013, p. 118).

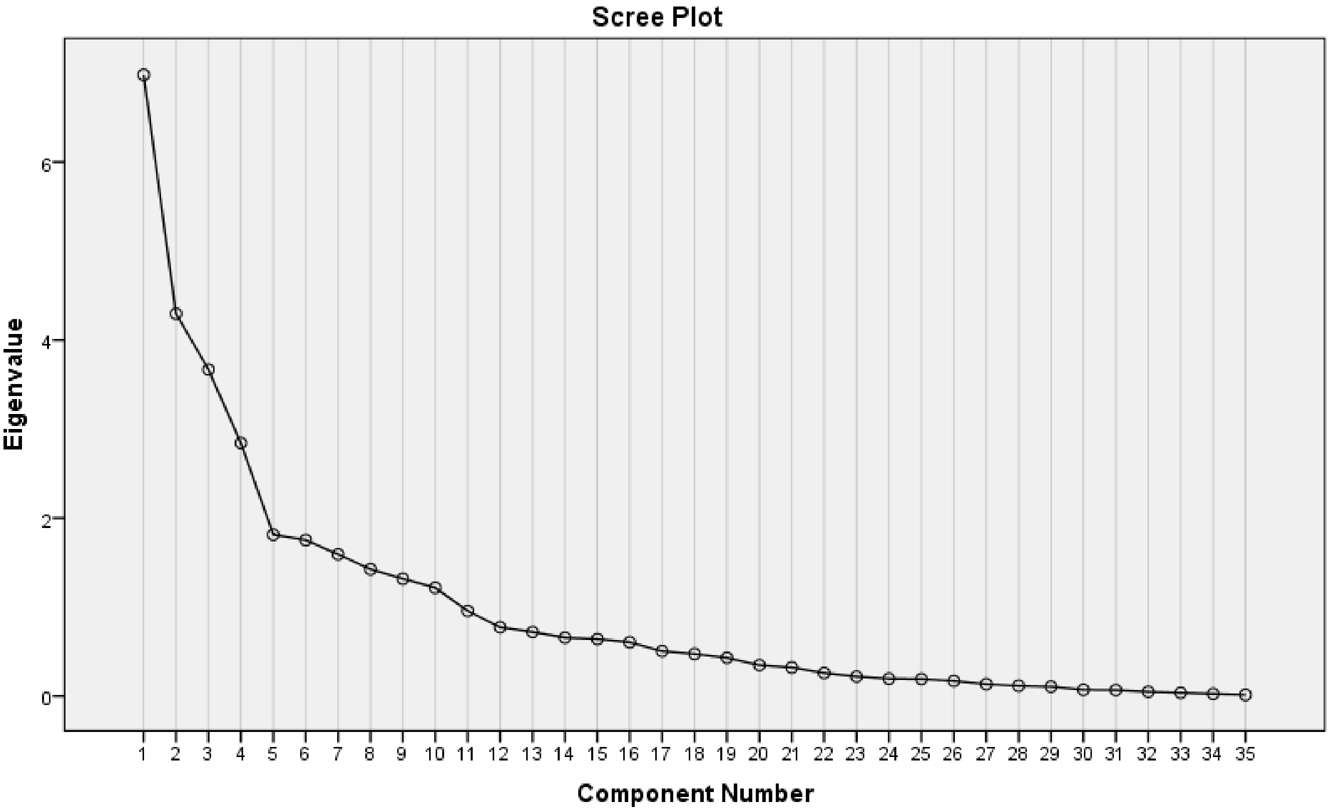


Figure 5.22 Scree plot of Eigenvalue for the barriers for EUCM

- To decide about the number of the factors to retain the scree test is used (see Figure 5.22 and Figure 5.23). In this test, the extracted factors are the ones above the break point in the scree plot of the eigenvalues (Costello & Osborne, 2005). An eigenvalue measures the contribution of standard variables to principal components (Dallas, 1998 cited in de Silva et al., 2004). In scree test the inflection point is usually excluded; however, component number 6 in motivating factors and component number 5 in limiting factors are retained in this study, as they result in the best fit of the factors to the data which resulted in the most meaningful interpretation of the factors (Costello & Osborne, 2005). The Eigenvalues for the retained factors are larger than 1.5. These 6 factors cumulatively explain 61.25% variance of the original variables.

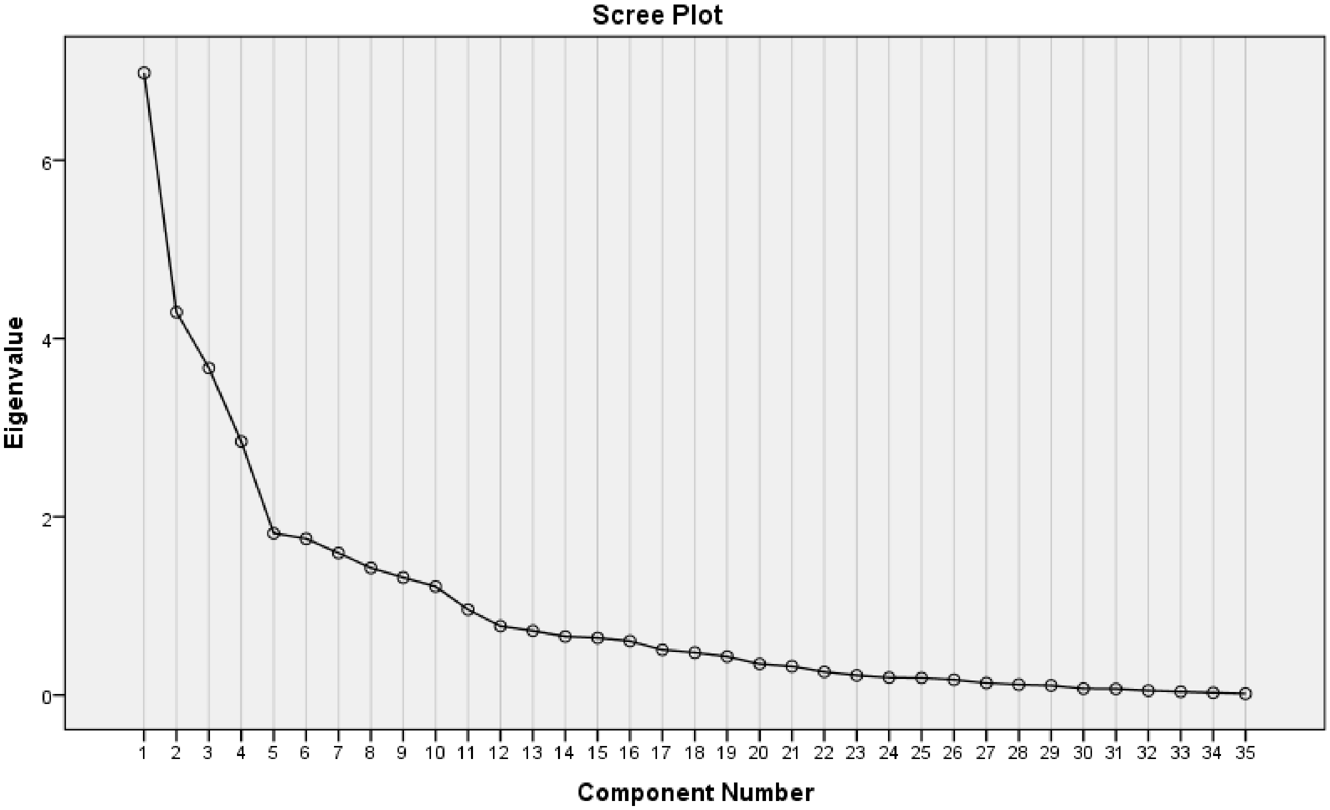


Figure 5.23 Scree plot of Eigenvalue for the barriers for EUCM

- It is difficult to interpret the factors from the original factor matrix because most of the factors are correlated. Therefore, the factor matrix is transformed into a component matrix in which variables have loading only on limited factors by a rotation (see Table 5.8 and Table 5.9). Although, varimax rotation might neglect some correlations between variable, it is the most common rotation method because it maximizes the distribution of variable loadings within factors and minimizes the number of variables that have high loadings on each factor (Field, 2013). This makes it easier to interpret and name the resulting factors.
- After rotation, a score can be assigned to each case for all the extracted factors. These scores are then used to test the influence of motivating factors on actual practice rates of the strategies, which can be an indicator of the existence of these motivations for different CME strategies in the current green building practices.

Table 5.8 show the extracted motivating factors, their eigenvalue, and the loadings of the variables on the factors. Small loadings, i.e., lower than 0.3, are not shown in order to simplify the table and the interpretation of the factors. After completing the PCA, resulting motivating factors are named as the following: economic benefits, codes and regulations, market recognition, environmental benefits, heritage or aesthetic values, and common practice. These motivating factors explain 61.2% of the variance of the contributing motivating variables. It can be noticed in Table 5.8 that customer’s demand is motivated by different factors for each strategy:

- Reducing materials use it is motivated by market recognition and, to a lesser extent, economic benefits.

- Extending materials use is motivated by market recognition.
- The *intense use* strategy is motivated by both economic benefit and aesthetic values. A possible explanation for the influence of aesthetic motivation is that designers may consider shared or multi-purpose spaces in their design due to their aesthetic features.
- The reusing materials strategy is motivated by economic benefits, market recognition, and aesthetic values respectively.
- For recycle strategy it is firstly motivated by economic benefits and then by common practice motivation.

Table 5.8 Rotated component matrix for principal component analysis of the motivations for CME

Factors	Variables	Component					
		1	2	3	4	5	6
	Eigenvalues	8.31	3.78	2.58	2.52	2.08	1.55
Economic Benefits	Motv.Reuse.Economic	.794					
	Motv.Extend.Economic	.786					
	Motv.Recycle.Economic	.658	.455				
	Motv.Intense.Economic	.643		-.309			
	Motv.Reuse.Customer	.569		.484		.344	
	Motv.Recycle.Customer	.538					.440
	Motv.Reduce.Economic	.517	.506				
	Motv.Intense.Customer	.472				.441	
Codes and Regulations	Motv.Extend.Codes		.789				
	Motv.Intense.Codes		.771				
	Motv.Reduce.Codes		.696				
	Motv.Recycle.Codes		.680				
	Motv.Reuse.Codes		.588			.468	
Market Recognition	Motv.Reuse.Recognition			.699			
	Motv.Recycle.Recognition			.661	.336		.371
	Motv.Extend.Recognition		.390	.595			
	Motv.Reduce.Recognition			.585			
	Motv.Extend.Customer			.549			
	Motv.Reduce.Customer	.308		.475			
	Motv.Intense.Recognition		.347	.365	.355		

Factors	Variables	Component					
		1	2	3	4	5	6
	Eigenvalues	**8.31**	**3.78**	**2.58**	**2.52**	**2.08**	**1.55**
Environmental Benefits	Motv.Reduce.Environmental				.792		
	Motv.Extend.Environmental		.326		.689		
	Motv.Reuse.Environmental				.656	.348	
	Motv.Recycle.Environmental			.321	.588		
	Motv.Intense.Environmental		.336		.587		
Heritage/Aesthetic Values	Motv.Reuse.Heritage					.774	
	Motv.Reuse.Aesthetic					.763	
	Motv.Extend.Aesthetic				.341	.666	
	Motv.Extend.Heritage				.403	.617	
Common Practice	Motv.Intense.CommonPractice						.861
	Motv.Extend.CommonPractice						.797
	Motv.Reuse.CommonPractice						.683
	Motv.Reduce.CommonPractice						.632
	Motv.Recycle.CommonPractice						.356

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 8 iterations.

Table 5.9 shows the extracted limiting factors with their eigenvalue, and the loadings of the limiting variables on the factors. The resulting limiting factors are classified as knowledge and technological requirements, codes & regulatory requirements, customer's disinterest, aesthetic and functional requirements, and market unavailability. These factors explain 56% of the variance of the original variables. The table shows that time and budget limit and functional barriers do not create separate factors, but rather contribute to other factors:

- The time limit for recycling and reusing is placed within the *code and regulatory limit* factor. One possible explanation is that project teams may need to spend extra time to check the compatibility of recovered materials with codes and regulations.
- The time limit for reducing and extending use is considered to affect customer's disinterest.
- Budget constraints for recycling and reducing material use is an influential variable in customer's disinterest factor. The budget limit has a weak negative relation with aesthetic and functional requirements.
- The functional limit for recycling is placed in the "code and regulatory limits" factor.
- The functional limit for extend use, reuse, and intense use is related to aesthetic requirement. This means that respondents consider functional limits more for visible materials.

Table 5.9 Rotated component matrix for principal component analysis of the barriers for CME

Factors	Variables	Component				
		1	2	3	4	5
	Eigenvalues	6.98	4.30	3.67	2.84	1.81
Knowledge & Technological requirements	Lmt.Reduce.Knowledge	.777				
	Lmt.Extend.Knowledge	.737				-.303
	Lmt.Reuse.Knowledge	.730				
	Lmt.Extend.TechnologicalFac	.714				
	Lmt.Reuse.TechnologicalFac	.681	.310			
	Lmt.Reduce.Technological.Fac	.666				
	Lmt.Recycle.Knowledge	.660				
	Lmt.Intense.Knowledge	.654				
	Lmt.Recycle.TechnologicalFacilities	.589	.339			.319
	Lmt.Intense.TechnologicalFac	.506	.336			
Codes & regulatory requirements	Lmt.Intense.Codes		.840			
	Lmt.Recycle.Codes		.796			
	Lmt.Reduce.Codes		.769			
	Lmt.Extend.Codes		.739			
	Lmt.Reuse.Codes		.636			
	Lmt.Recycle.Timelimits		.557	.319	-.374	
	Lmt.Reuse.Timelimits		.523			
	Lmt.Recycle.Function	-.341	.424			

Factors	**Variables**	**Component**				
		1	**2**	**3**	**4**	**5**
	Eigenvalues	**6.98**	**4.30**	**3.67**	**2.84**	**1.81**
Customer’s disinterest	Lmt.Extend.CustomersDisinterest			.820		
	Lmt.Intense.CustomersDisinterest			.814		
	Lmt.Recycle.CustomersDisinterest			.808		
	Lmt.Reuse.CustomersDisinterest			.792		
	Lmt.Reduce.CustomersDisinterest			.586		
	Lmt.Recycle.Budget			.535	-.309	
	Lmt.Reduce.Timelimits			.479		
	Lmt.Extend.Timelimits		.340	.378		
	Lmt.Reduce.Budget		.320	.375	-.344	
Aesthetic & Functional requirements	Lmt.Extend.Function				.773	
	Lmt.Extend.Aesthetic				.761	
	Lmt.Reuse.Aesthetic				.729	
	Lmt.Reuse.Function			.337	.517	
	Lmt.Intense.Function	-.312		.345	.411	
Market unavailability	Lmt.Recycle.MarketUnavailable					.789
	Lmt.Reuse.MarketUnavailable					.678
	Lmt.Extend.MarketUnavailable		.382	.337		.461

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 6 iterations.

5.2.7 Correlation between the practice rates of the CME strategies and motivating and limiting factors

The correlation between the motivating factors and the practice rate of different strategies was tested using Pearson correlation coefficient test. The test result is categorized based on the lifetime phases of a building given that a specific number of stakeholder groups are involved in each phase. The Pearson test for each phase only includes those stakeholders who are involved that phase, which are named in the “phase” section in Table 5.10. The Pearson correlation coefficient test for the motivating factors indicates the following results:

- A moderate relation exists between economic benefits and reduce use/design strategy ($r=.38$, $p < 0.05$). Except for the reduce/design strategy, there is not a high economic motivation for implementing the other CME strategies.
- A moderate relation exists between environmental benefits and reduce use/design ($r=.33$, $p < 0.05$), extend use/selection ($r=.31$, $p < 0.05$), and reuse/design ($r=.34$, $p < 0.05$). There is also a strong relation between environmental benefits and intense use/design ($r=.45$, $p < 0.01$), extend use/design ($r=.45$, $p < 0.01$), and recycle/design ($r=.5$, $p < 0.01$).
- There is a strong relation between market recognition and reduce use/construction ($r=.48$, $p < 0.05$) and recycle/deconstruction ($r=.49$, $p < 0.05$)
- A strong relation exist between heritage or aesthetic values and reuse/deconstruction ($r=.59$, $p < 0.05$).
- Current codes and regulations do not provide significant motivation for implementing CME strategies.
- The test does not support that any of the strategies are motivated because of being common practice.

Table 5.10 Pearson correlation between practice rate of the strategies for CME and the motivating factors

Phase	**Strategy**	**Motivating Factor**	Economic	Codes & Regulation	Recognition	Environmental	Heritage/ Aesthetic	Common Practice
		(Eigenvalue)	**(8.31)**	**(3.78)**	**(2.58)**	**(2.52)**	**(2.08)**	**(1.55)**
Design *Designer *Owner/ developer	Reduce	Pearson Correlation	**.379***	.000	.155	**.326***	-	-.018
		Sig. (2-tailed)	**.019**	.999	.352	**.046**	-	.914
		N	**38**	38	38	**38**	-	38
	Intense	Pearson Correlation	-.002	.017	-.066	**.451****	-	.080
		Sig. (2-tailed)	.991	.918	.690	**.004**	-	.627
		N	39	39	39	**39**	-	39
	Extend	Pearson Correlation	.058	-.144	.272	**.452****	-.059	.279
		Sig. (2-tailed)	.735	.395	.104	**.005**	.727	.095
		N	37	37	37	**37**	37	37
	Reuse	Pearson Correlation	.010	.040	-.034	**.343***	.054	.069
		Sig. (2-tailed)	.951	.808	.836	**.033**	.743	.677
		N	39	39	39	**39**	39	39
	Recycle	Pearson Correlation	.076	.017	-.032	**.509****	-	.097
		Sig. (2-tailed)	.644	.918	.848	**.001**	-	.557
		N	39	39	39	**39**	-	39

Phase	**Strategy**	**Motivating Factor**	Economic	Codes & Regulation	Recognition	Environ mental	Heritage/ Aesthetic	Common Practice
		(Eigenvalue)	**(8.31)**	**(3.78)**	**(2.58)**	**(2.52)**	**(2.08)**	**(1.55)**
Material selection *Designer *Contractor *Owner/ developer	Extend	Pearson Correlation	.178	.123	-.078	**.309***	.252	.176
		Sig. (2-tailed)	.226	.406	.598	**.033**	.085	.231
		N	48	48	48	**48**	48	48
	Reuse	Pearson Correlation	-.013	.123	.207	.122	.037	-.031
		Sig. (2-tailed)	.930	.406	.159	.410	.805	.833
		N	48	48	48	48	48	48
	Recycle	Pearson Correlation	-.192	-.031	.204	.247	-	-.171
		Sig. (2-tailed)	.191	.834	.163	.091	-	.244
		N	48	48	48	48	-	48
Construction *Contractor *Owner/ developer	Reduce	Pearson Correlation	.455	.200	**.483**	.203	-	.112
		Sig. (2-tailed)	.067	.442	**.050***	.434	-	.667
		N	17	17	**17**	17	-	17
Use & Maintenance *Owner/ developer *Building operator	Intense	Pearson Correlation	.249	.242	-.256	.387	-	.094
		Sig. (2-tailed)	.390	.405	.377	.172	-	.750
		N	14	14	14	14	-	14
	Extend	Pearson Correlation	.398	.288	-.277	.270	-.025	.216
		Sig. (2-tailed)	.159	.317	.337	.350	.932	.459
		N	14	14	14	14	14	14

Phase	**Strategy**	**Motivating Factor**	Economic	Codes & Regulation	Recognition	Environmental	Heritage/ Aesthetic	Common Practice
		(Eigenvalue)	**(8.31)**	**(3.78)**	**(2.58)**	**(2.52)**	**(2.08)**	**(1.55)**
Deconstruction	**Reuse**	Pearson Correlation	-.047	.193	.031	.358	**.586**	-.297
*Contractor		Sig. (2-tailed)	.852	.442	.903	.144	**.011***	.231
*Owner/ developer		N	18	18	18	18	**18**	18
	Recycle	Pearson Correlation	.410	.186	**.499**	.091	-	.174
		Sig. (2-tailed)	.102	.476	**.041***	.728	-	.503
		N	17	17	**17**	17	-	17

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

The Pearson correlation coefficient test between the limiting factors and the practice rate of different strategies shows correlation for only a few of the strategy/stages (Table 5.11). The table indicates that:

- A strong correlation exists between codes and regulations and intense use/design strategy ($r=.41$, $p < 0.05$). A moderate relation exists between codes and regulations and reuse/design ($r=.35$, $p < 0.05$)
- A strong correlation exists between knowledge and technology and reduce/construction strategy ($r=.55$, $p < 0.05$).

Table 5.11 Pearson correlation between practice rate of the strategies for CME and the limiting factors

Phase	**Strategy**	**Limiting Factor**	Knowledge & Technology	Codes & Regulations	Customer's disinterest	Aesthetic & Function	Market unavailability
		(Eigenvalue)	**(6.98)**	**(4.30)**	**(3.67)**	**(2.84)**	**(1.81)**
Design *Designer *Owner/ developer	**Reduce**	Pearson Correlation	.165	.279	-.252	.082	.025
		Sig. (2-tailed)	.337	.100	.139	.634	.884
		N	36	36	36	36	36
	Intense	Pearson Correlation	.256	.413	-.221	-.188	.123
		Sig. (2-tailed)	.127	**.011***	.189	.266	.469
		N	37	37	37	37	37
	Extend	Pearson Correlation	.037	.084	-.144	-.099	-.201
		Sig. (2-tailed)	.832	.632	.409	.570	.248
		N	35	35	35	35	35
	Reuse	Pearson Correlation	.320	**.352**	-.172	-.253	.107
		Sig. (2-tailed)	.053	**.033***	.308	.130	.530
		N	37	**37**	37	37	37
	Recycle	Pearson Correlation	.257	.185	-.210	-.123	-.055
		Sig. (2-tailed)	.125	.272	.212	.470	.748
		N	37	37	37	37	37
Material selection *Designer *Owner/ developer *Contractor	**Extend**	Pearson Correlation	.186	.039	-.073	.194	-.192
		Sig. (2-tailed)	.226	.802	.638	.206	.212
		N	44	44	44	44	44
	Reuse	Pearson Correlation	.186	.039	-.073	.194	-.192
		Sig. (2-tailed)	.226	.802	.638	.206	.212
		N	44	44	44	44	44
	Recycle	Pearson Correlation	.249	.154	-.195	.083	.220
		Sig. (2-tailed)	.103	.318	.205	.593	.150
		N	44	44	44	44	44

Phase	Strategy	Limiting Factor	Knowledge & Technology	Codes & Regulations	Customer's disinterest	Aesthetic & Function	Market unavailability
		(Eigenvalue)	**(6.98)**	**(4.30)**	**(3.67)**	**(2.84)**	**(1.81)**
Construction *Contractor *Owner/ developer	**Reduce**	Pearson Correlation	**.548**	-.197	.120	.003	.089
		Sig. (2-tailed)	**.034***	.481	.670	.992	.751
		N	**15**	15	15	15	15
Use & Maintenance *Owner/ developer *Building operator	**Intense**	Pearson Correlation	.124	-.021	-.317	-.419	.195
		Sig. (2-tailed)	.687	.947	.292	.154	.524
		N	13	13	13	13	13
	Extend	Pearson Correlation	.171	.022	-.334	-.326	-.202
		Sig. (2-tailed)	.577	.944	.265	.278	.508
		N	13	13	13	13	13
Deconstruction *Contractor *Owner/ developer	**Reuse**	Pearson Correlation	.193	.126	.056	.475	.179
		Sig. (2-tailed)	.490	.655	.844	.074	.523
		N	15	15	15	15	15
	Recycle	Pearson Correlation	.446	-.186	.210	.173	.293
		Sig. (2-tailed)	.096	.507	.453	.537	.289
		N	15	15	15	15	15

*. Correlation is significant at the 0.05 level (2-tailed).

5.2.8 Regression analyses

In this section, the relationship between different motivating and limiting factors collected in the survey and the practice rate of different strategies for CME is quantified using stepwise simple linear regression analysis. The linear regression analyses is used to predict the practice rate of the CME strategies (dependent variables) based on motivating and limiting factors (independent variables) (Field, 2013). For instance, Table 5.12 shows a significant regression function for predicting the practice rate of the reduce use strategy/design, based on economic and environmental motivating factors (F(2,32) = 7.191, p<.003). The practice rate of the ‘reduce use strategy/design’ increases by 0.709 by every unit increase in economic and environmental motivating factors.

The R^2 indicate the percentage of the dependent variable that can be predicted by the independent variables. It is noticeable that only a small percentage of the practice rate of the CME strategies can be predicted by the factors studied in the research. For the reduce use/design strategy only 31% of the variable can be predicted by economic and environmental motivating factors.

The analyses results presented in Table 5.12 show that:

- Environmental benefits affect the practice rate of most of the strategies in the design and material selection phase (except for the reuse strategy).
- Reuse in the deconstruction phase can be predicted by the level of heritage or aesthetic motivation (adjusted R^2 = .37).
- Recycle/deconstruction and reuse/material selection have a significant relationship with market recognition motivation.
- Reuse/design practices are positively related to codes & regulation barriers, meaning that those who have a better understanding of the codes and regulatory limitations for designing for future reusability are likely to practice the strategy a greater extent.

- Reduce use/construction is related to knowledge or technology limitations. Similar to reuse/design, this relationship is positive, i.e. those who are more aware of the technical and knowledge limitations of reducing waste generation in the construction phase are likely practice the strategy more.

While the regression analysis shows the existence of the influence of the factors on the practice rate of the strategies, because this study is done using Likert scale questions which are not actually quantitative data, the result should not be treated as a quantitative finding. Moreover, since the number of respondents in the use/maintenance and construction phases are low, there is a need for further study with larger number of respondents to confirm the findings in this study.

The regression analysis also included some of the demographic and professional information collected in the survey, such as age, graduation year, building work experience, percentage of LEED certified projects. However, no significant regression was found in the analysis for these variables.

Table 5.12 Regression analyses of the practice rate of the CME strategies based on the motivating and limiting factors

Phase	Strategy	Variables/ Factors Entered	F	P <	R^2	B
Design *Designer *Owner/ developer	Reduce	Motivation Economic Benefit	F(2,32) = 7.191	.003	.310	.352
		Motivation Environmental Benefit				.357
	Intense	Motivation Environmental Benefit	F(1,34) = 9.208	.005	.213	.410
	Extend	Motivation Environmental Benefit	F(1,32) = 8.187	.007	.204	.510
	Reuse	Limitation Codes & Regulations	F(1,34) = 4.802	.035	.124	.444
	Recycle	Motivation Environmental Benefit	F(1,34) = 11.519	.002	.253	.501
Material selection *Designer *Owner/ developer *Contractor	Extend	Motivation Environmental Benefit	F(1,41) = 5.013	.031	.109	.225
	Reuse	Motivation Market Recognition	F(1,34) = 8.131	.007	.193	.407
	Recycle	Motivation Environmental Benefit	F(1,41) = 6.218	.017	.132	.313
Construction *Contractor *Owner/ developer	Reduce	Limitation Knowledge & Technology	F(1,13) = 5.592	.034	.301	.581
Use & Maintenance *Owner/ developer *Building operator	Intense	No variables were entered into the equation				
	Extend	No variables were entered into the equation				
Deconstruction *Contractor *Owner/ developer	Reuse	Motivation Heritage/ Aesthetic	F(1,13) = 9.158	.010	.413	.597
	Recycle	Motivation Market Recognition	F(1,13) = 6.898	.021	.347	.493

Chapter 6: Discussion and conclusion

The interpretations of the survey analyses presented in this section are based on the comparison of respondents' point of view and the literature. Studying the respondents' attitude regarding the strategies for CME is worthwhile since these stakeholders may directly or indirectly encourage/discourage the implementation of these strategies in the different life phases of a building.

6.1 Different strategies among different stakeholders

In this section the findings from sections 5.2.5 to 5.2.8 will be further discussed in greater detail to discover the reasons behind the differences between the practice rate, importance, motivations, and limitations of different CME strategies among different stakeholders and throughout the different phases of a building's life.

6.1.1 Reduce use strategy

As stated in section 5.2.5.1, customers are typically motivated by codes and regulations and economic benefits to reduce material use. However, currently there are no direct codes or regulations that require reduction of material use in design or reduction of waste generation in building construction. As such, customer respondents in the questionnaire might be referring to dumping fees in the transfer stations or landfills which can result in their higher demand for reducing waste in construction (Greater Vancouver Regional District, 2008)

As discussed in section 2.1, it is widely accepted that the design phase offers the greatest opportunity for reducing material use and waste (Osmani et al., 2006; Osmani et al., 2008).

However, the survey results show that contractors have higher motivations (economic benefits, customer demand, and market recognition) compared to the designers and, as such, this may be the reason for contractors' higher practice rate. It can be argued that, in contrast to contractors and customers, designers are not directly responsible for, or benefited from, savings of reduced material used (Rodriguez-Nikl et al., 2014). Contractors however, are responsible for the amount of waste they generate through contractual terms such as waste allowance (Public Works and Government Services Canada, 2000, pp. 8–7).

6.1.2 Intense use strategy

It is mentioned in section 5.2.5.2, customers have a higher motivation for the *intense use* strategy compared to designers. Customers generally gain economic benefit from *intense use* strategy (shared or multipurpose use), as a result of reduced materials use and construction costs. For designers however, if they are being paid on a construction cost percentage basis, reduced construction costs may result in reduction of the design service fees (Architectural Institute of British Columbia (AIBC), 2009).

Implementing the *intense use* strategy may be more difficult for the construction industry, compared to other strategies. Moreover, in a consumer-culture in which ownership is considered to be a major factor that contribute to comfort and prestige, there might be less interest among customers to share aspects of their buildings (De Vries, 2008 cited in Allwood et al., 2011; Prettenthaler and Steininger, 1999). On the other hand, as Allwood et al., (2011) emphasize, many buildings are empty more than half of each day and they have the potential to be designed for multi-purpose or shared use.

6.1.3 Extend use strategy

Maintainability and selecting durable materials reduce the costs of maintenance. However, it was shown in section 5.2.5.3 customers may be less interested in designing for repair and upgrade than selecting durable material/products. As such, there is probably less motivation for implementing this strategy in the design phase than in material selection process. The "high labour [sic] cost" relative to the lower cost of new material/products in developed economies can be a major disincentive to the lack of interest for repair and upgrade. New materials/products typically have a lower cost because most materials/products are produced in developing economies with low labor cost. The repair of those products, however, will most typically happen within the Metro Vancouver, BC, where labor costs are considerably higher (Allwood et al., 2011, p. 370).

Another reason may be customer's desire for new products, which is more important in the case of visible material/products such as finishing materials. This is supported in the motivations diagram in Figure 5.19 which indicates that, while heritage values of materials is the highest rated motivation for designers to extend use, it is not an important motivation for customers. It was argued in section 3.2 that people have a natural tendency to preserve those things that represent memories of times and places in order to preserve past cultures and ideologies (Chini & Bruening, 2003). However, the more recent mass-produced construction materials are not sufficiently unique to be memorable and/or valuable to preserve and customers might not see a specific aesthetic or heritage value in these materials/products. It was also discussed that the fear of hidden defects of old materials discourages people from repairing them, because they do not want to risk going through the hassle of replacing the old products in case of hidden flaws (Arkes

& Hutzel, 1997). In the construction industry, disinterest for repair can be even more because the repair services are less likely done by the original producer or material/product distributer, therefore there is less guarantee for the quality of repair.

Customer’s disinterest is considered to be a major barrier for the extend use strategy. This can be the result of their disinterest in paying the extra service fees that service providers may require for the time and effort spent on selecting maintainable and durable materials, products and systems. Service providers on the other hand are “reluctant to assume further responsibilities and liabilities”, if they are not being paid for such services (de Silva et al., 2004).

6.1.4 Reuse strategy

For owner/developers, the economic benefits are considered to be important motivation for the reuse strategy (see section 5.2.5.4). Therefore, the lower practice rate of this strategy in all the stages can be interpreted as a lack of economic benefits. Salvaged materials may be generally cheaper than new materials; however, since the ‘reuse’ strategy is not commonly practiced in the design, material selection, and construction phases (see Figure 5.20), there is lack of knowledge and certainty regarding implementation details of the strategy. Therefore, designing with salvaged materials requires designers and contractors to be more flexible and willing to deal with many unforeseen issues, such as availability, quantity, size, structural characteristics, and functional requirements of reclaimed materials. Understandably, the fee for such design and construction is higher (Allwood et al., 2011, p. 372; Gorgolewski, 2008, p. 184; Matsumoto, 2009). If this extra service fee is not taken into account by clients, service providers usually have less desire to engage in such practices (Gorgolewski, 2008, p. 184; Matsumoto, 2009). This higher service fee can offset the lower material cost borne by clients. Moreover, according to Architectural Institute of British Columbia (AIBC) (2009), even when salvaged materials are used, designers' percentage fee is calculated with the assumption that all materials have been new. As such, any reduced cost as a result of below market costs of materials, does not reduce designers' service fee.

Contractors are mainly motivated by economic benefit and customer's demand. Since there is currently little customer demand, if there is no economic benefit in reuse, contractors will not voluntary put much effort on implementing it. Heritage value of old building components is also identified as a considerable motivation for material reuse in the literature (City of Vancouver, 2011). However, the results suggest that customers have not shown much interest in heritage and aesthetic value of salvaged materials compared to service providers. Their lack of interest in heritage and aesthetic value can reduce designers' motivation in considering this aspect of using salvaged materials. Moreover, this is also limited to specific materials which attract the attention of a narrow group of customers. In many cases materials/products with higher heritage value can be even more expensive than new materials (da Rocha & Sattler, 2009).

Design for deconstruction can be far less attractive to both service providers and customers compared to building deconstruction and material reuse. Considering the reusability of materials in the design phase is an approach the benefits of which cannot be guaranteed and if they do occur will be far in the future when another group of stakeholders are replacing/renewing an old building. A life cycle cost analysis of design for deconstruction shows that the extra cost will potentially be offset when the savings are considered in terms of reduced deconstruction costs and recycling and reuse revenues (Catalli & Williams, 2001; Gorgolewski, 2008; Kibert, 2008). Whereas, the life cycle benefit is not a motivating factor for the stakeholders who are involved in different phases of materials life cycle (Rodriguez-Nikl et al., 2014). Guy, Shell, and Esherick (2006, p. 4) suggest that it may create a greater motivation for the customers and investors if design for deconstruction techniques are to be compatible with other resource efficiency strategies which yield in the operational phase (rather than end of life cycle). They provide the example of raised flooring which facilitates deconstruction and result in energy efficiency, easier maintenance, and adaptability.

6.1.5 Recycle strategy

As presented in section 5.2.5.5, in the material selection, construction, and deconstruction phases, the recycle strategy is practiced in a higher level than customer’s demand. It is important to note, however, that in this strategy customers may not be personally motivated but they do not impede service providers from implementing the strategy either. This is because they believe they are obligated to implement the strategy by regulations.

Designers are not generally motivated for design for recyclability since they neither gain direct benefits, nor they are demanded to design for future recyclability. Other than environmental benefits, designers are mostly driven by the common practice (Figure 5.21) and considering future recyclability is not commonly practiced in the industry. Design for future recyclability does not have a standard measure for assessment (Saghafi & Teshnizi, 2011; Thormark, 2001), nor do the local governments promote the strategy (Metro Vancouver, 2011).

In contrast to design for recyclability, several measures have been developed to encourage the use of recycled content and recycling rate of materials. Most green building assessment systems (such as LEED) credit the use of recycled content and recycling but not recyclability of materials. Regulatory incentives have been created in regional policies to increase waste diversion which were described in section 2.2.5. The existence of such measures results in a higher motivation for recycling and using recycled content materials in comparison to design for recyclability.

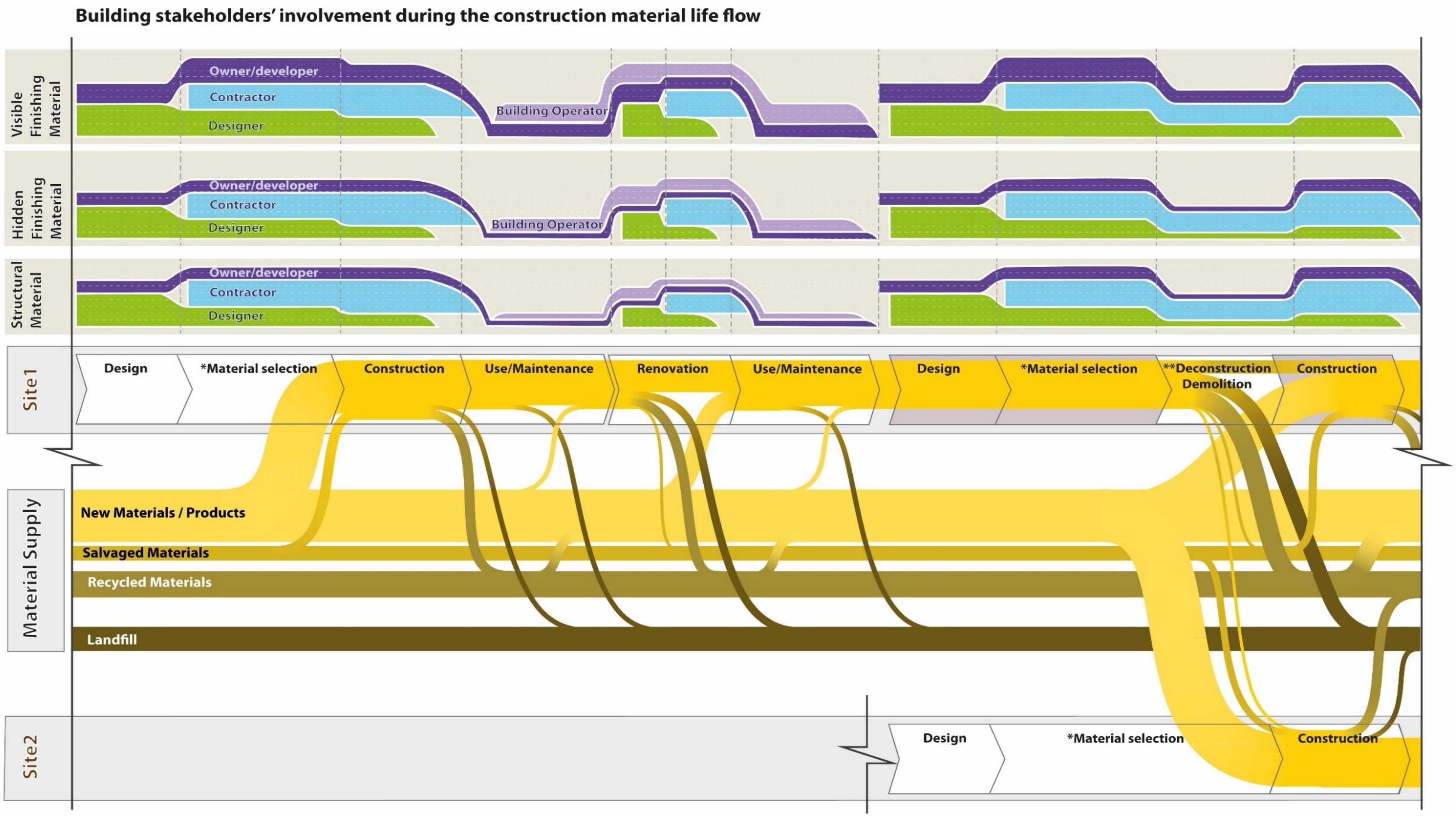
6.2 Conclusion

It was shown that most of the respondents admit the importance of CME strategies (Figure 5.10) and they consider the environmental benefits to be an influential motivation and for all the CME strategies (Figure 5.12). Environmental benefits have higher rates for reduce, reuse, and recycle strategies, for which there is a greater awareness and education compared to *extend use* and *intense use*. However, despite the stakeholders' awareness about environmental benefits of the CME strategies, the practice rate of different strategies vary for different stakeholder groups and different building lifetime phases. The considerable gap between the practice rate and importance of some of the strategies in Figure 5.10 (for example in recycle/design and reuse/all the phases) shows that these strategies are not currently practiced to the extent that their perceived level of importance would suggest.

The contrast between stakeholders' opinion and their practice indicates that, even in the best instances of green building projects, environmental decisions for CME do not solely depend on the awareness of the stakeholders about the importance and environmental benefits of such decisions. Other factors may compromise their ability or interest in practicing the strategies (Bamberg, 2003; Gibbons et al., 2004 , Ohtomo & Hirose, 2007 Kulatunga et al., 2006; Osmani, Glass, & Price, 2008; Teo & Loosemore, 2001). Moreover, as discussed in section 3.2, due to the "situational context" people may make unintentional decisions that are against their intended goal (Bamberg, 2003; Gibbons et al., 2004). Since a larger number of stakeholders are involved in a construction project and each stakeholder has a specific area of responsibility, control, and benefits, it is more probable that some of the decisions made in a project are contrary to some of the stakeholders' value or intention. Rodriguez-Nikl et al. (2014) suggest that environmental concerns have a more considerable influence on people's personal life than their professional decisions, which can be result of the fact that they have more control and sense of responsibility in their personal life than in their work environment. By contrast, it was indicated in section 5.2 that 68% of the respondents believe that they have a moderate or major influence on the implementation of CME strategies (Figure 5.15). This shows the importance of motivating individuals to change personal preferences toward prioritizing CME in their practices.

Comparing the practice rates and importance of the strategies in different building lifetime phases, (Figure 5.10) shows that the importance and practice rate of the strategies change throughout a building's lifetime. For instance, the respondents stated a relatively high practice rate in the material selection phases for strategies that extend materials use, but less so for the design and use phase. Such a varied commitment to the strategies during the materials lifetime highlights an incomplete chain of collaborative effort. Therefore it seems necessary to identify the current inconsistency in the stakeholders' involvement and the ways to improve their collaboration.

Figure 6.1 illustrates the changes in the level of different stakeholder groups' involvement in material related decisions during a hypothetical material flow in a building. The diagram shows that each stakeholder group is involved and concerned about only a limited number of phases. For instance, designers and contractors, who have a major role in selecting materials/products used in a building, are only involved in early design and construction phases. Therefore it is expected that they usually do not put much effort into strategies and techniques such as flexibility, maintainability, reparability, recyclability, and reusability of materials used in a building. It is because the benefits of these strategies are experiences in phases which these stakeholders are neither involved nor responsible. The figure also shows that the level of stakeholders' involvement varies for different types of materials. For example, owner/developers are more involved in selecting and dealing with visible materials compared to hidden structural or non-structural materials.



* In reality material selection is not a seperate phase from design and construction. However, since in the common practice material selection will happen late in the design phase and early in construction phase, it is treated as a separate phase.

** In some cases, deconstruction/demolition happens before the design of the new building. However, since in the common practice deconstruction/demolition of the existing building is the responsibility of the new owner/developer's, this phase is located after the design of the new building.

Figure 6.1 The current level of involvement of different stakeholders during the construction materials life flow *(The diagram is schematic)*

This research revealed that barriers generally do not have high average scores (Figure 5.13). This indicates that lack of motivation may be a more significant reason for not prioritizing the efforts to improve the effectiveness of construction material use than the existence of barriers. This stands in contrast to most of the existing literature, where the focus is on identifying and overcoming the stakeholders' barriers (Cole, 2011, p. 432). Griffin et al. (2010, p. 3) state that the research on the barriers for construction of green buildings is less based on interviews, and therefore the researchers identify the barriers that *may* exist during the process rather than identifying the barriers that stakeholders have actually experienced them. It can be argued that there is a need to shift the focus from overcoming the barriers to creating motivation for each stakeholder group, because when the stakeholders are not motivated they may use the barriers as an excuse for not taking any action to improve CME rather than actually facing the barriers and trying to resolve and overcome them.

This study has shown that personal benefits (economic benefits) and responsibilities (customer's demand) are stronger motivations for CME strategies than altruistic motivations (e.g. environmental benefits) (Feige et al., 2011, p. 511; Lützkendorf et al., 2011, p. 17). The importance of economic benefits supports previous research findings that economic benefits are the most direct measures to increase the voluntary involvement in sustainable movements (Feige et al., 2011, p. 511; Lützkendorf et al., 2011, p. 17). Therefore, financial incentives and educating about possible financial benefits at an individual or corporate level can significantly motivate stakeholders.

The importance of customer's demand and market recognition confirms that economic benefits are not the only measures to motivate stakeholders (Nicol, 2011, p. 467; Whyte & Sexton, 2011, p. 478). It is becoming more apparent that simply taking an economic view is a too narrow and limited perspective to promote environmental decisions. Figure 5.12 indicate that for recycling strategy, which has a relatively high practice rate (even higher level than customer's demand (Figure 5.10), economic benefits have their lowest average motivating influence compared to other strategies. Rather recycling is currently motivated by responsibilities that are defined through codes and regulations and also by market recognition, which is a more indirect personal benefit that results from being acknowledged by green building certifications (e.g., LEED) or by compliance to the regulations (Figure 5.21). Through time, these motivations are turning this strategy into a common practice.

One of the highest rated barriers for service providers is customer's disinterest. A substantial difference is evident between service providers' perception of customer's lack of interest and owner/developers' high demand for many of the CME strategies. This could be the result of the sample group in this study is limited to the best practices in green building and is not a representative of typical construction projects, or that service providers interpret customer's unwillingness to spend extra cost for CME strategies as lack of interest in the strategies. The relatively high rates that designers and contractors have assigned to time limit and budget limit for most of the CME strategies (which means they are considered to be important barriers) support this statement. While sustainable materials/products and systems may cost more in some cases, the stakeholders tend to generalize this idea to all the strategies. This uninformed presumption eliminates the chance of a real cost analysis for CME strategies (Griffin et al., 2010). Service providers typically increase the fees, cost estimations, and bids when they are required to implement a CME strategy that is not commonly practiced and they do not personally benefit from it (e.g. reuse/reusability, recyclability, reparability), to address their uncertainties about the implementation of the strategy (Allwood et al., 2011; Gorgolewski, 2008).

Despite the importance of customer's interest in implementing CME strategies, the result showed that wherever service providers are personally motivated by factors such as market recognition or economic benefits, they are more likely to implement the strategies regardless of customer's demand. This supports Feige et al's (2011) suggestion that instead of following the *circle of blame* (Cadman, 2007) among the stakeholders, research should invest on developing a *stakeholder motivation circle*, in which major motivations and concerns of the stakeholders are identified and policies are developed accordingly.

The practice rate of the strategies are generally lower in the design phase, due to the less personal or obligational motivations of the stakeholders and especially designers. However, one interesting finding in section 5.2.7 is that environmental benefits are correlated with all the strategies in the design phase. It can be concluded that due to the lack of personal benefits or obligations, stakeholders who stated a higher practice rate for the strategies in this phase, are typically those who have higher personal belief in and commitment to the environmental benefits of the CME strategies.

The regression analyses showed that a few of the motivating factors and even lesser of the limiting factors actually affect the practice rate of the strategies (see section 5.2.8). It indicates that limitations are not the main reason for not improving the construction material effectiveness. It is rather the lack of motivations that place material effectiveness as a lower priority for stakeholders. The low level of contribution of the motivating and limiting factors in the regression analyses (low R^2 level) indicates a need for further studies on other motivating and limiting factors which were not identified in this study.

Different stakeholders' interests can be conflicting, which makes it more difficult to look for a single solution for all stakeholders (Whyte & Sexton, 2011), and thereby suggesting the need to identify various interests of different stakeholders more specifically. With such deeper understanding, measures can be explored to address multiple motivating factors for as many stakeholder groups as possible. As shown in this study, the lack of interest in one stakeholder groups could hold back or discourage others. The motivating factors can help CME strategies to become a common practice in the industry through time.

6.3 Suggestions

The following subsections provide possible measures that can help motivate stakeholders to consider CME strategies in their projects:

6.3.1 Improving and promoting multi-stakeholder decision making processes

This study has shown that future recoverability and maintainability of materials is not a priority for the design and construction teams, because they are not much concerned and/or informed about the challenges and opportunities that may exist in subsequent phases. Moreover, adding only green building specialists, such as LEED consultants, to the project team does not appear to be effective enough to achieve CME throughout the complete lifetime of a building. This is possibly because green building specialists also lack the experience of dealing with projects during their operation and maintenance phases. In addtion, they may not have enough control and responsibility to influence the key stakeholders' decisions.

To overcome this problem, stakeholders who are responsible for the later phases could be invited to participate in design and construction phases. Through communication and information sharing, the team could then see the project as a whole, rather than only from the narrow lens of their own area of responsibility. This gives the stakeholders the opportunity to find more opportunities to improve CME and also offset the extra costs of CME strategies by integrating them with other efficiency goals (Griffin et al., 2010). For instance, if building operators are involved in the design and construction phases, they may add more interest and information about intense use and extend use strategies. However, an apparent challenge for some of the projects (especially smaller private projects) is that stakeholders of later phases are not always known during the earlier phases.

One possible solution is that third-party professionals represent the future stakeholders' interest and experiences in the design and construction phases. Having commissioning agents is necessary for construction projects to ensure the performance, quality, and durability of different building systems including electricity, water, and HVAC systems. LEED certification requires fundamental commissioning and assigned credits for enhanced commissioning (U.S. Green Building Council, 2015). Commissioning processes, particularly inspecting maintainability and future recoverability, could also consider the efficient use of construction material resources. For commissioning processes to be successful it is important that they consider the overall expected performance of a system rather than only focusing on the performance of each element and component of the larger system (Fedoruk, 2013).

An example of third-party representative is presented in Halme et al.'s (2007) paper. They use the business model for energy service companies (ESCo) to suggest the creation of independent material service companies (MaSCo). Considering the substantial amount of initial time and budget required for improving material effectiveness, their suggestion can be an effective model for such services. These unconventional businesses are specialized in material effectiveness services and gain revenue from the cost savings and environmental improvements rather than for the service or product they provide. The MaSCo business model has been suggested generally for the manufacturing sector. Extending this idea to a construction projects can be challenging due to the considerably longer and insecure payback period[8]. However, the idea can be more practical for the building layers with shorter lifetime such as ‘services’, ‘space plan’, and ‘stuff’ layers (see **Error! Reference source not found.**).

MaSCo companies can be stand-alone, part of an ESCo company, part of a service or equipment provider (e.g. waste management or contractor company), or part of a material distributer company. MaSCo service needs a considerable early investment, which can come from the company’s own fund, the customer, or a third party. In the two latter financing methods, the MaSCo company has to provide a material saving guarantee. In the third case either the customer

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[8] The payback period for manufacturing industry is assumed to be an average of 3 years (Halme et al., 2007)

or the MaSCo company get the loan from a financing organization. The organization either have the right to the savings or “take security interest”.

6.3.2 Educating about personal benefits of CME

This study has shown that it is more effective to motivate stakeholders by providing information about potential economic, social, or environmental benefits of CME rather than merely educating about negative environmental impacts of construction materials. This education should be more specific about personal and corporate benefits of CME rather than overall life cycle benefits. For the strategies which do not have any personal benefit for the stakeholders (e.g. future recoverability), some contractual, regulatory or economic incentives should be developed in order to motivate the stakeholders.

6.3.3 Educating about lifecycle environmental benefits of CME

The results of this study indicate that respondents have a high level of environmental motivation, but even in the design of the studied green buildings there is little attention to the future recoverability and maintainability of materials/products. The survey results indicated that among all the CME strategies environmental benefits are associated more with reduce, reuse, and recycle strategies (3Rs). This indicates the effectiveness of extensive education about the waste management strategies (Allwood et al., 2011; Peng, Scorpio, & Kibert, 1997; Yuan & Shen, 2011).

Further efforts are required to educate the industry about the life cycle impacts of their material choices on the environment rather than focusing only on a few strategies. It is important that project teams differentiate the various CME solutions based on their environmental benefits. For instance, they should differentiate between reuse and recycling or down-cycling and a closed loop recycling. To support life cycle environmental impact consideration of materials/products LEED v4 has assigned up to 2 point for projects that use products with publically available Environmental Product Declarations (EPDs) (See Appendix 6.5C.2).

It is crucial that project teams note the differences in the environmental benefits of CME strategies for different material types and also for different projects and regions. Therefore, generic prioritization of the strategies such as 3Rs in waste management hierarchy might be misleading. There is rather a need for material and region specific life cycle assessment of CME strategies in order to decide on the most appropriate solution. Moreover, to allow producers and project teams to explore innovative solutions for CME, it is important that assessment systems and tools do not specify the preferred strategies, but rather specify the expected environmental benefits of the applied strategies and techniques.

Material assessment tools can help develop product databases that provide information on the environmental performance of materials currently available in the market. These databases can address the stakeholders' lack of time for considering CME, which was identified in the survey results. Considering that CME is not generally a personal or obligatory priority for most of the stakeholders, it is therefore important to simplify the material selection process by providing simple, accessible, and comparable information about materials. Examples of such databases include:

- Cradle-to-cradle Certified Product Registry[9] (See Appendix 6.5B.4) which has been credited in LEED v4 (U.S. Green Building Council, 2013b);
- Declare[10], a database provided by Living Future Institute and provides the full ingredients of products to indicate whether these products are free from hazardous materials (see section 6.5C.3);
- EcoSpex[11], developed by *Blue Wilderness Group* (an Ontario base corporation) and the UK Building Research Establishment (BRE), is an online database of "third party verified and certified green building products" in North America;

6.3.4 Sharing the benefits and responsibilities of CME

This study has shown that unequal distribution of benefits and responsibilities among different stakeholder groups throughout the material life cycle is a major reason for the lack of interest in some of CME strategies. de Silva et al. (2004) suggest that extending defects liability beyond its typical 1 year will increase the design and construction teams' involvement in the use/maintenance phase. However, the challenge is that service providers are not willing to assume further responsibilities without any increase on their payment (Cole, 2011; de Silva et al., 2004). It is important to develop policies to enable the benefits to be shared among all the influential stakeholders throughout the materials life cycle.

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[9] http://www.c2ccertified.org/products/registry
[10] http://declareproducts.com/
[11] http://www.ecospex.com/

Public-Private Partnership (PPP) procurement methods for urban infrastructure projects can be an examples of extending service providers' responsibilities alongside their benefits. PPP models solve the problem of dealing with a fragmented stakeholder network by giving the lifetime responsibility (typically 20 to 30 years) of a project to one private partner who is responsible for financing, risk for delivery, and performance of the project. In PPP models:

- The operation and maintenance teams work with design and construction teams to make sure that the choices of materials, products, and systems allow standard performance of the project over its lifetime (Canadian Council for Public-Private Partnerships & PPP Canada, 2011).
- The public sector (owner/developer) defines project requirements in measurable criteria and allow the private sector to employ innovative solutions to achieve these requirements (Canadian Council for Public-Private Partnerships & PPP Canada, 2011). By including environmental performances such as CME in the project requirement, owners/developers can ensure that environmental performance of their project will be improved. However, since the performance requirements of the project have to be measurable to be included in the contract, it can be challenging to include non-measurable environmental performances such as *intense use* strategy. Moreover, since PPP models do not cover the end of life phase of the projects, it may not motivate service providers to plan for future recoverability.
- Benefits are given to the private partner, because these procurement methods give a long-term business opportunity and a stable *revenue stream* to the private partner. In these models, the first payment will be after the completion of a major part of the project, and a considerable portion of payment will be made during the lifetime of the project only if

> performance criteria have been met. This performance-based payment method provides financial motivation for service providers to deliver a project with high quality lifetime performance.

A key challenge for CME, compared to energy and water efficiency, is that the extra initial cost for some CME strategies (e.g., ‘extend use’, ‘reuse’, and recoverability solutions) will not produce an economic payoff (or be balanced out) within a building lifetime. Thus, it is less likely that any of the stakeholders will be willing to pay this extra cost, in exchange for uncertain benefits that might occur at the end of a building lifetime. Consequently, these strategies are only considered if the goal is to construct a green building. To consider these strategies in common practice construction projects, the voice of silent or absent stakeholders, such as the community, future residents, future generations, and nature can be included in the decision making process through policies and regulations (Griffin et al., 2010).

The responses to the survey indicate that current codes and regulations do not provide any significant motivation for improving CME. However, wherever authorities define clear requirements and/or incentives for actions, change has happened. For instance the Technical Guideline of the University of British Columbia requires all new construction and major renovation projects to achieve a minimum waste diversion rate of 75% (for residential projects which should attain Residential Environmental Assessment Program (REAP) [12]

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[12] “The UBC Residential Environmental Assessment Program (REAP) is a framework for mandating and measuring sustainable building practices for market-based and staff/faculty/student residential developments located in Neighbourhood [sic] Housing Areas at UBC’s Vancouver campus” (University of British Columbia, 2014).

certification) or 85% (for LEED certified projects) (University of British Columbia, 2013, 2014). This has resulted in an average diversion rate of 84% between 2011 to 2013 fiscal years (UBC Campus and community planning, 2014). Another example for such top-down initiatives is the Green Demolition Bylaw of the City of Vancouver, which promotes extending use of buildings, reusing building materials/components, and recycling material. This bylaw requires heritage houses to divert a minimum of 75% of their deconstruction waste. It also allows non-heritage houses to start the deconstruction of the existing building before receiving their building permit if they deconstruct rather than demolish and commit to a minimum 75% waste divertion. However, a shortcoming of this initiative is that it does not differentiate between reuse and recycling or between different qualities of recycling, which may result in a tendency toward down-cycling as it is the most common and therefore preferred choice.

Although regulatory incentives like the Green Demolition Bylaw can improve waste management practices, imposing waste charges and responsibilities only to contractors who are responsible for demolition/deconstruction of a building “is neither fair nor effective” (Lu & Yuan, 2011, p. 1258). This is because contractors do not have any control on the upstream stages of the material life cycle. Therefore, ideally the incentives and responsibilities for CME should address all the stakeholders, including those involved in the upstream stages.

An example of a more inclusive initiation for CDR waste management is the demolition protocol developed by the Institution of Civil Engineers (ICE) in the UK. This protocol motivates both demand and supply of recovered materials by defining an index for recovering materials in demolition projects along with an index for recovered material use in new construction projects (EnviroCentre Ltd., 2010).

Although the ICE demolition protocol includes the stakeholders from design, constructions and demolition/deconstruction phases, it does not yet include the supply chain stakeholders. One solution to include manufacturers is to use products as service rather than as a commodity to be purchased (Addis, 2008). In this case, manufacturers are the owners of materials/products and will be responsible for them at the end of buildings lifetime. If the expected rise in the cost of raw materials is considered, owning the products can be valuable for manufacturers. However, the experience of employing this solution in Park 20|20 - a mixed-use office-led development project in Amsterdam - showed that this procurement method is not feasible for fixed materials in buildings with current legal definitions of ownership wherein the fixed parts of a building are the owner/developer's possessions (Scott, 2014).

A solution for motivating producers in current legal systems is that customers still pay the full price of the products but the manufacturers be responsible for dealing with materials/products at the end of the buildings lifetime. According to the Canada-wide Action Plan for Extended Producer Responsibility, British Columbia as a member jurisdictions of Canadian Council of Ministers of the Environment (CCME) is committed to work toward adopting extended producer responsibility (EPR) for construction, demolition, and furniture materials by 2017 (Canadian Council of Ministers of the Environment, 2009). LEED v4 has assigned one point credit for using products that their manufacturer is personally responsible for or participates in an EPR program (U.S. Green Building Council, 2015)[13].

Despite the positive influence of EPR on improving CME, it may be yet far from supporting a closed loop system. Depending on recycling and/or landfill fees compared to raw material fees, producers may still prefer to use new materials and sell old materials to other industries to be used in a degraded quality, or safely discard them. For a positive approach to material use in construction, there is a need to shift the focus from considering waste management as a start point to resource consumption as a start point and integrating waste and resource management policies and regulations (Lilja, 2009a, 2009b).

One major impediment to extending stakeholders' responsibilities is the industry's resistant to take additional responsibilities. The lobbies of "those most likely to be economically influenced by change" (Allwood et al., 2011) can prevent passing environmental policies and regulations to support EPR. In order for the industry to accept environmental policies and regulations, there should be a "soft bridging phase" (Lilja, 2009b). In a study of material efficiency policies in Finland, Lilja (2009b) suggests that sector specific Negotiated Environmental Agreements (NEA) between governments and business organizations can be used to motivate *early adopters*. Despite its voluntary nature, *a sense of inevitability*, measurable *quantitative goals*, and *credible monitoring* are necessary for the success and effectiveness of NEA. However, the enforcement and monitoring in NEA should focus on the final goals rather than *specific technical actions or*

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[13] "Products meeting extended producer responsibility criteria are valued at 50% of their cost for the purposes of credit achievement calculation".

limits. This would allow early adopters to use their expertise to find innovative solutions for achieving the goals (Lilja, 2009b).

Greyson (2007) suggests *pre-cycling insurance* as a financial tool to share the benefits and responsibilities of CME and promote waste prevention rather than waste diversion (Birkeland, 2008, p. 66). *Pre-cycling insurance* is a concept developed from *recycling insurance* model. Recycling insurance is a financial guarantee that a producer provide for managing waste caused from their product. In this model, producers do not have to recycle their product but can "buy [an] insurance, which guarantees payment of all future recycling costs. The price of the insurance depends upon the recyclability of the product" (Greyson, 2007). This price will internalize the recycling cost of a product as it become part of product cost. *Pre-cycling insurance* takes one step further as it "would set premiums according to the risk of a product ending up as waste rather than as a new resource for people or nature." Such financial tool will motivate investment on solutions such as remanufacturing, local repair/reuse, and using biodegrade (Greyson, 2007).

6.4 Research limitations

The findings of this study cannot be generalized to a larger context of building industry, because the sample group was limited to the best practices of green buildings (LEED Platinum and Gold certified projects) in the Metro Vancouver, BC. However, the study findings are still valuable for all the building industry, especially in North America, for it presents the opinions and attitudes of a particular group of green building professionals about implementation of CME strategies in their projects.

At this stage of the research, the implications of the study should be considered tentative because of the relatively small sample size and even smaller size of the stakeholder subcategories. However, the suggested research method which is to study and juxtapose the attitudes and motivations of different stakeholder groups throughout a building lifetime is valuable for future studies. This approach suggests that looking at the overall life cycle benefits of environmental strategies do not necessarily motivate all the evolved stakeholders, because they may not benefit from these overall advantages.

The author is aware that the survey questionnaire used in this study was long and time consuming, which may have resulted in a lower response rate and in some cases incomplete responses. If it was not for the time constraints of the research, this survey would have ideally been designed in 2-3 separate questionnaires. However, the value of this study lies highly in comparing and contrasting different CME strategies, different stakeholder groups, and different building lifetime phases, so that the improvement potentials can be identified.

To simplify the research, the scope of this study was limited to five stakeholder groups and one building lifetime rather than considering all the stakeholder groups who are involved throughout the whole life cycle of construction materials. However, in future works it is crucial to consider the full life cycle of materials in order to find the critical points in which stakeholders' priorities and the interrelations influence the implementation of the strategies for CME.

This study was limited to the strategies which are more familiar to the stakeholders, in order to make the survey questionnaire understandable for the respondents. While these strategies may not necessarily be the best solutions for CME, it should be noted that the goal of this study was not to find the best measures for achieving CME. This study was rather intended to investigate various stakeholders' attitudes about CME.

6.5 Future research

Suggestions for possible future steps of this research include:

- Similar research should be conducted on a larger sample sizes to validate the findings of this study.
- Interview with different stakeholder groups will help to attain a more comprehensive and in-depth understanding of first the reasons why some of the strategies are applied and some others are not; second the factors which shape different stakeholders' interests; and thirdly the influence of different stakeholders' on each other's interest and ability to improve CME.
- The study can be expanded to a more inclusive life cycle of construction materials and more stakeholder groups, especially the stakeholders in the upstream and downstream phases (i.e., extraction, production, demolition/deconstruction, hauling, recycling, and reuse market). Such study will provide a more comprehensive understanding of how to motivate different stakeholders and how different stakeholders' priorities influence each other.
- In reality, the stakeholder groups consist of individuals with diverging interests, responsibilities, and area of control. These individuals can be studied to find out the influence of their personal interests and priorities. The analyses in this thesis did not

show a significant influence of the respondents on the implementation of CME strategies; however, a different data collection method or a different sample might show otherwise.

- Studying the influence projects characteristics, including different types of clients (public and private), different types of contracts (design-build, design-bid-build, integrated design process, etc.), and different size of projects.
- Conducting comparative studies on the motivations for and practice rates of CME strategies in different regions, especially for North American and European regions.

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Appendices

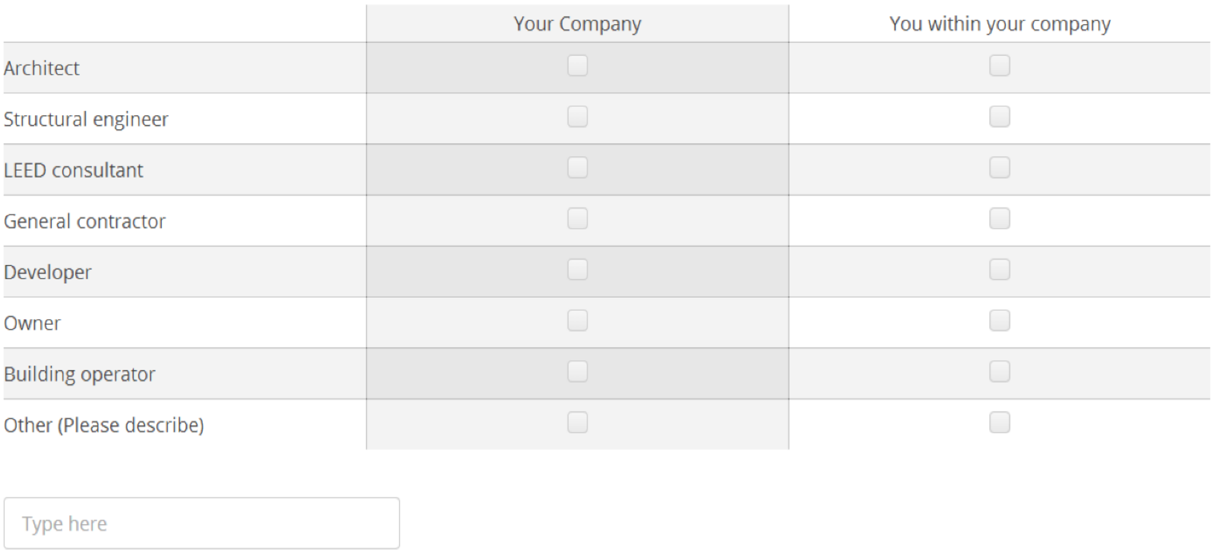
Appendix A : Online survey

A.1 General background

1. What is your age?
2. What is your primary area of education?
    - ☐ Architecture
    - ☐ Environmental sciences
    - ☐ Engineering or building sciences
    - ☐ Management or business
    - ☐ Economics
    - ☐ Social sciences
    - ☐ Other: ___________________
3. What is your highest level of education in Architecture?
    - ☐ Some college credit, no degree
    - ☐ Trade, technical, or vocational training
    - ☐ Bachelor degree
    - ☐ Post graduate degree
    - ☐ Other: ___________________
4. What year did you get your highest degree in Architecture? (YYYY)

A.2 Professional background

5. Specify your own and your company's typical role in projects. (You can choose more than one option.)



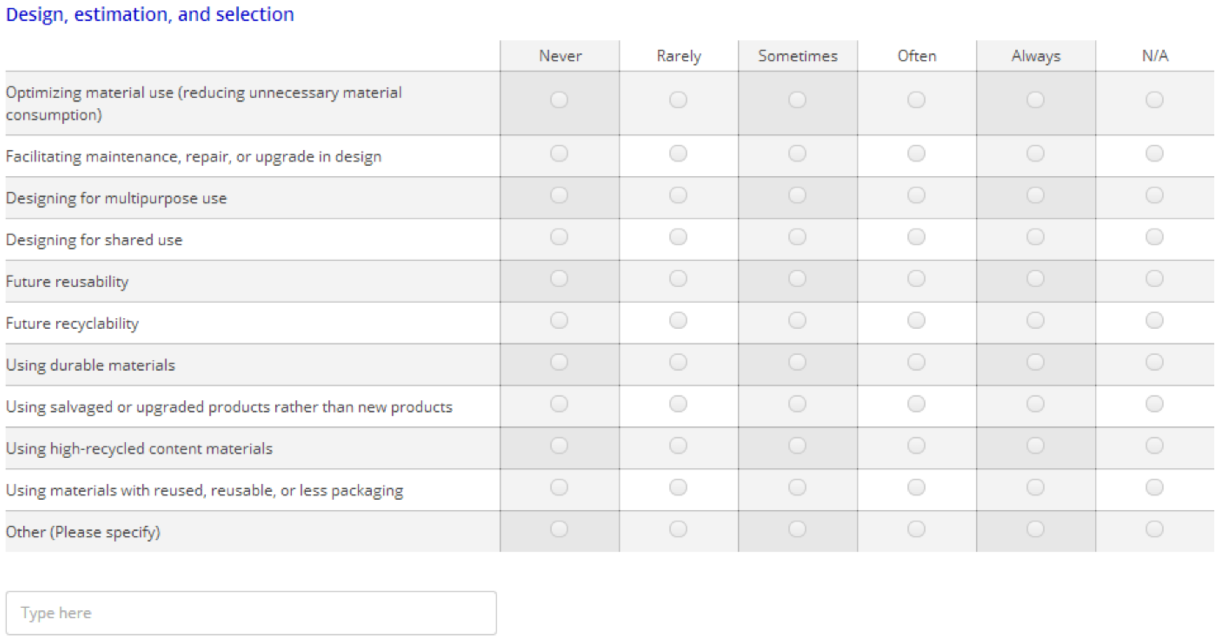
	Your Company	You within your company
Architect	☐	☐
Structural engineer	☐	☐
LEED consultant	☐	☐
General contractor	☐	☐
Developer	☐	☐
Owner	☐	☐
Building operator	☐	☐
Other (Please describe)	☐	☐

6. How many years have you been working in the building industry? (If you are not working in the building industry, please type 0 for the answer.)
7. What is the typical cost of the projects your company undertake? (You can choose more than one option.)
    - ☐ Up to $5 million
    - ☐ Between $5 and $15 million
    - ☐ Between $15 and $50 million
    - ☐ More than $50 million
    - ☐ N/A
8. What type of projects is your company typically involved in? (You can choose more than one option.)
    - ☐ Institutional
    - ☐ Commercial
    - ☐ Residential
    - ☐ Educational
    - ☐ Governmental
    - ☐ Industrial
    - ☐ N/A
    - ☐ Other: ____________________

9. What portion of the projects that your company undertake achieve any level of LEED certification?

A.3 Material effectiveness strategies

10. How often does **your company** apply or require other stakeholders to apply the following strategies in the projects?



Design, estimation, and selection

	Never	Rarely	Sometimes	Often	Always	N/A
Optimizing material use (reducing unnecessary material consumption)	○	○	○	○	○	○
Facilitating maintenance, repair, or upgrade in design	○	○	○	○	○	○
Designing for multipurpose use	○	○	○	○	○	○
Designing for shared use	○	○	○	○	○	○
Future reusability	○	○	○	○	○	○
Future recyclability	○	○	○	○	○	○
Using durable materials	○	○	○	○	○	○
Using salvaged or upgraded products rather than new products	○	○	○	○	○	○
Using high-recycled content materials	○	○	○	○	○	○
Using materials with reused, reusable, or less packaging	○	○	○	○	○	○
Other (Please specify)	○	○	○	○	○	○

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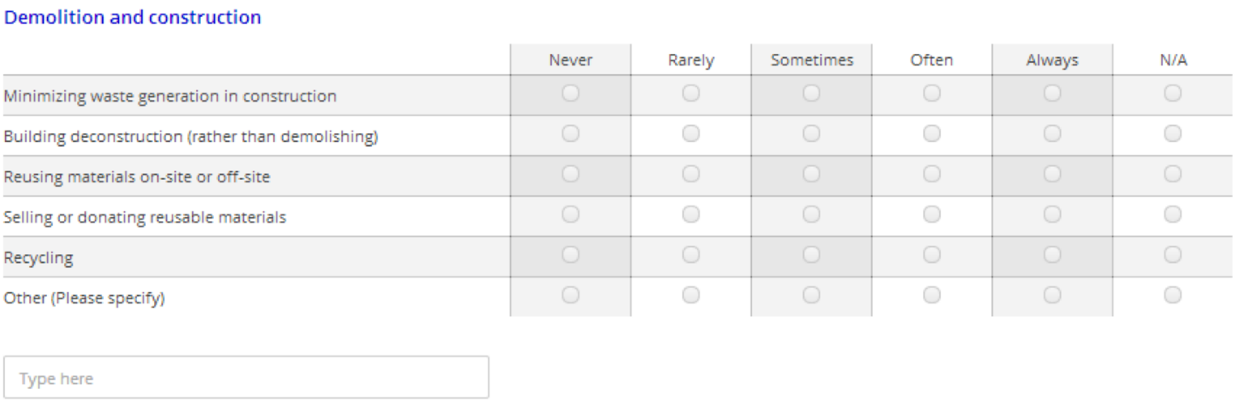

Demolition and construction

	Never	Rarely	Sometimes	Often	Always	N/A
Minimizing waste generation in construction	○	○	○	○	○	○
Building deconstruction (rather than demolishing)	○	○	○	○	○	○
Reusing materials on-site or off-site	○	○	○	○	○	○
Selling or donating reusable materials	○	○	○	○	○	○
Recycling	○	○	○	○	○	○
Other (Please specify)	○	○	○	○	○	○

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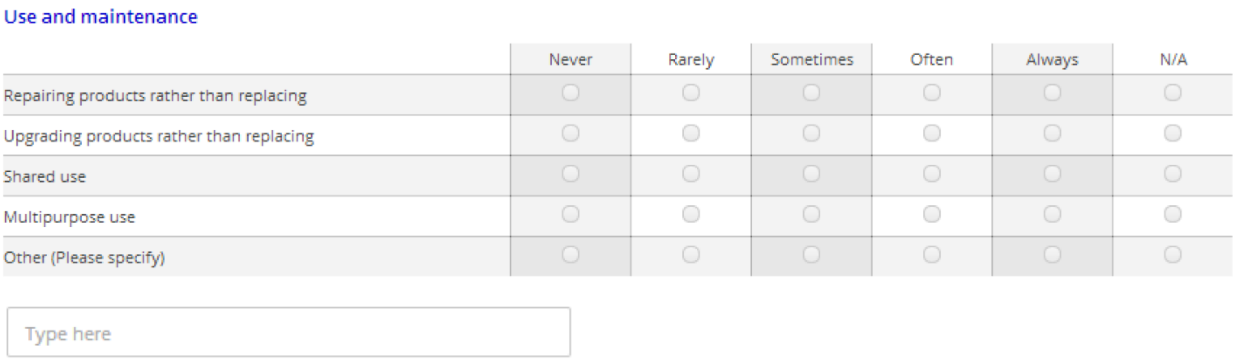

Use and maintenance

	Never	Rarely	Sometimes	Often	Always	N/A
Repairing products rather than replacing	○	○	○	○	○	○
Upgrading products rather than replacing	○	○	○	○	○	○
Shared use	○	○	○	○	○	○
Multipurpose use	○	○	○	○	○	○
Other (Please specify)	○	○	○	○	○	○

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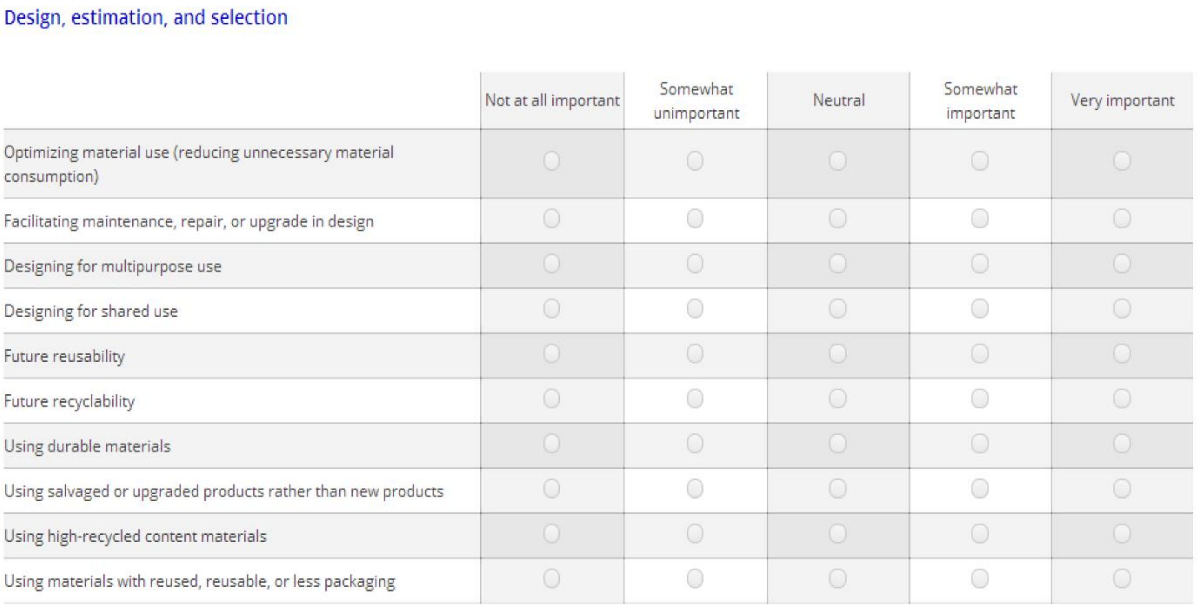
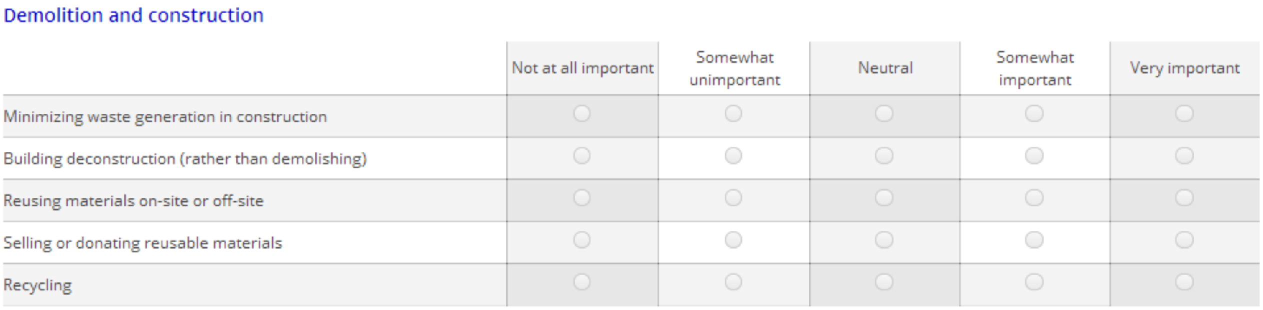
11. Regardless of the strategies that you currently practice, how important do you believe the following strategies are in improving material effectiveness?



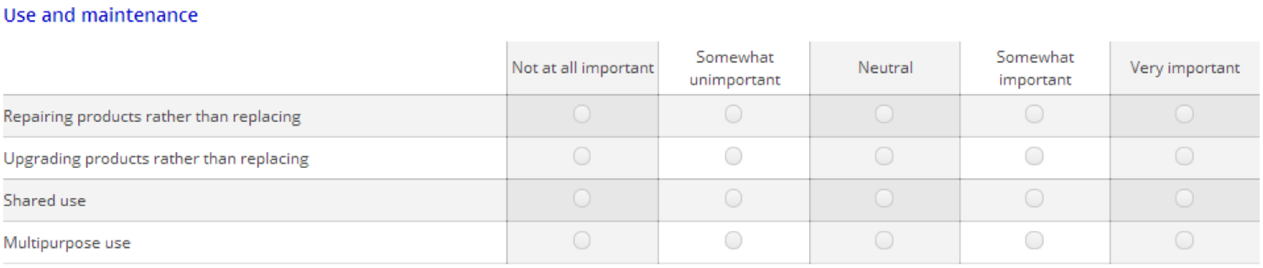
Design, estimation, and selection

	Not at all important	Somewhat unimportant	Neutral	Somewhat important	Very important
Optimizing material use (reducing unnecessary material consumption)	○	○	○	○	○
Facilitating maintenance, repair, or upgrade in design	○	○	○	○	○
Designing for multipurpose use	○	○	○	○	○
Designing for shared use	○	○	○	○	○
Future reusability	○	○	○	○	○
Future recyclability	○	○	○	○	○
Using durable materials	○	○	○	○	○
Using salvaged or upgraded products rather than new products	○	○	○	○	○
Using high-recycled content materials	○	○	○	○	○
Using materials with reused, reusable, or less packaging	○	○	○	○	○



Demolition and construction

	Not at all important	Somewhat unimportant	Neutral	Somewhat important	Very important
Minimizing waste generation in construction	○	○	○	○	○
Building deconstruction (rather than demolishing)	○	○	○	○	○
Reusing materials on-site or off-site	○	○	○	○	○
Selling or donating reusable materials	○	○	○	○	○
Recycling	○	○	○	○	○



Use and maintenance

	Not at all important	Somewhat unimportant	Neutral	Somewhat important	Very important
Repairing products rather than replacing	○	○	○	○	○
Upgrading products rather than replacing	○	○	○	○	○
Shared use	○	○	○	○	○
Multipurpose use	○	○	○	○	○

12. Does your company pay the same amount of attention to the implementation and success of material effectiveness strategies in LEED versus non-LEED projects?

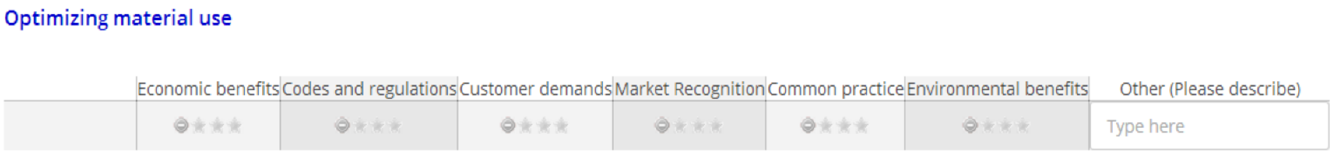
○ Not at all ○ Slightly ○ To some extent ○ Almost ○ Completely ○ N/A

13. Please rate the motivating factors listed below according to their relative influence on your company's ability or interest in implementing each of the following material effectiveness strategies.

3 stars = Has major influence

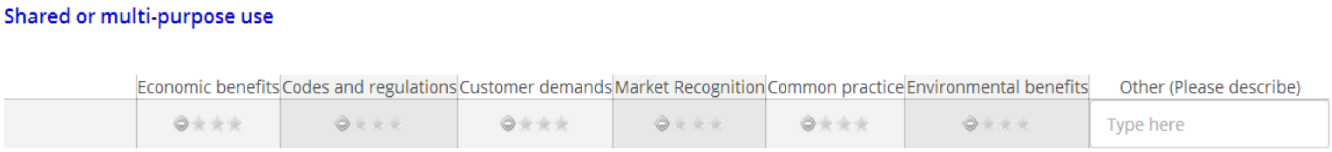
1 star = Has minor influence

2 stars = Has some influence



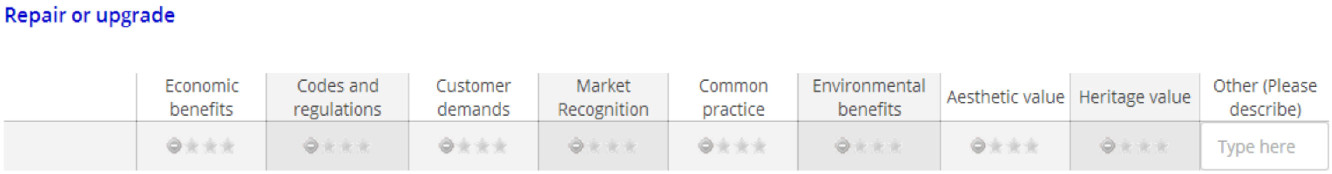
Optimizing material use

	Economic benefits	Codes and regulations	Customer demands	Market Recognition	Common practice	Environmental benefits	Other (Please describe)
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type here



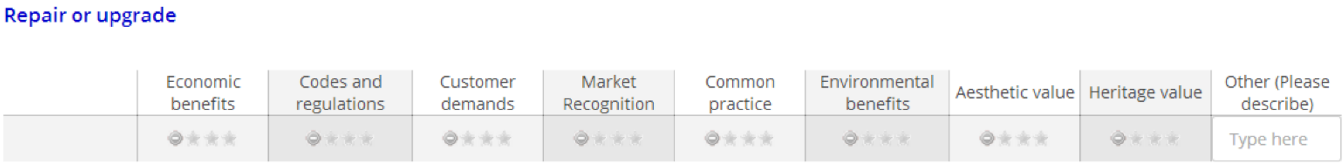
Shared or multi-purpose use

	Economic benefits	Codes and regulations	Customer demands	Market Recognition	Common practice	Environmental benefits	Other (Please describe)
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type here



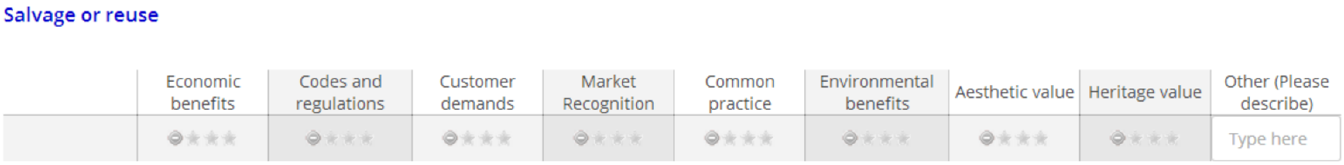
Repair or upgrade

	Economic benefits	Codes and regulations	Customer demands	Market Recognition	Common practice	Environmental benefits	Aesthetic value	Heritage value	Other (Please describe)
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type here



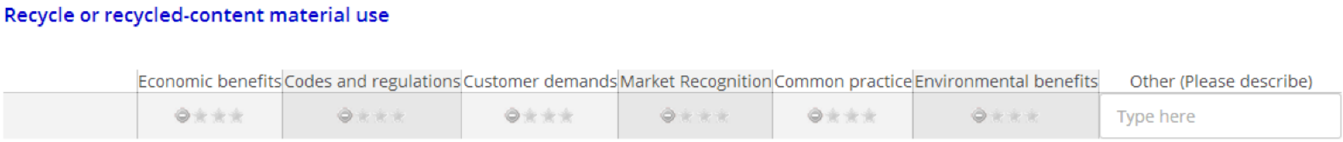
Repair or upgrade

	Economic benefits	Codes and regulations	Customer demands	Market Recognition	Common practice	Environmental benefits	Aesthetic value	Heritage value	Other (Please describe)
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type here



Salvage or reuse

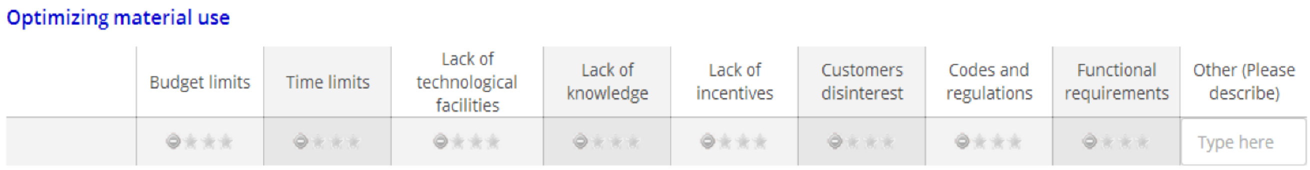
	Economic benefits	Codes and regulations	Customer demands	Market Recognition	Common practice	Environmental benefits	Aesthetic value	Heritage value	Other (Please describe)
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type here



Recycle or recycled-content material use

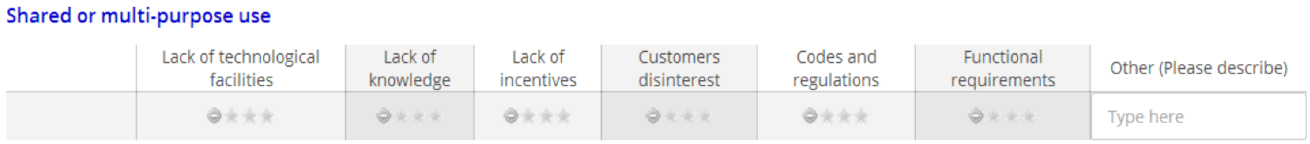
	Economic benefits	Codes and regulations	Customer demands	Market Recognition	Common practice	Environmental benefits	Other (Please describe)
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type here

14. Please rate the barriers listed below according to their relative influence on your company's ability or interest in implementing the following material effectiveness strategies.



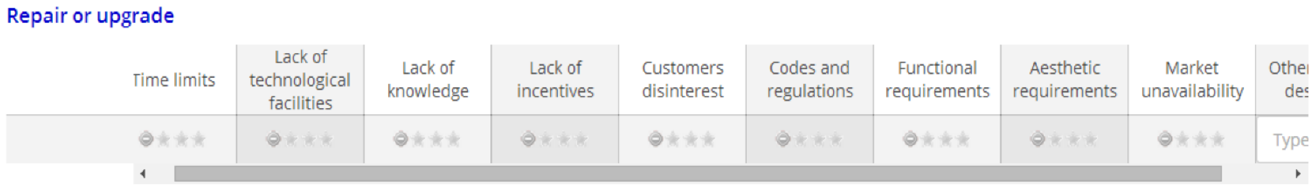
Optimizing material use

	Budget limits	Time limits	Lack of technological facilities	Lack of knowledge	Lack of incentives	Customers disinterest	Codes and regulations	Functional requirements	Other (Please describe)
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type here



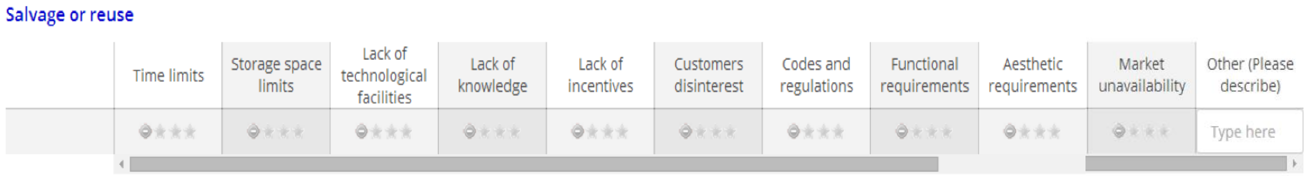
Shared or multi-purpose use

	Lack of technological facilities	Lack of knowledge	Lack of incentives	Customers disinterest	Codes and regulations	Functional requirements	Other (Please describe)
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type here



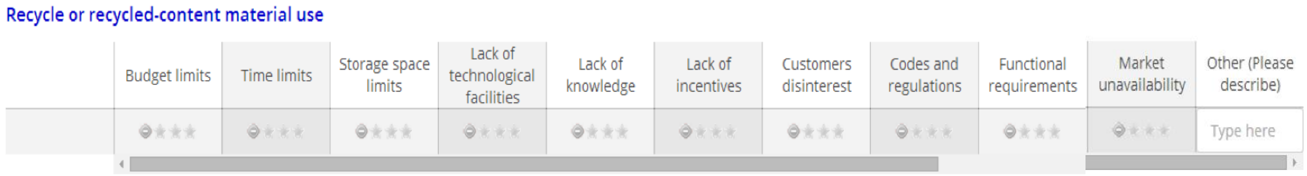
Repair or upgrade

	Time limits	Lack of technological facilities	Lack of knowledge	Lack of incentives	Customers disinterest	Codes and regulations	Functional requirements	Aesthetic requirements	Market unavailability	Othe des
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type



Salvage or reuse

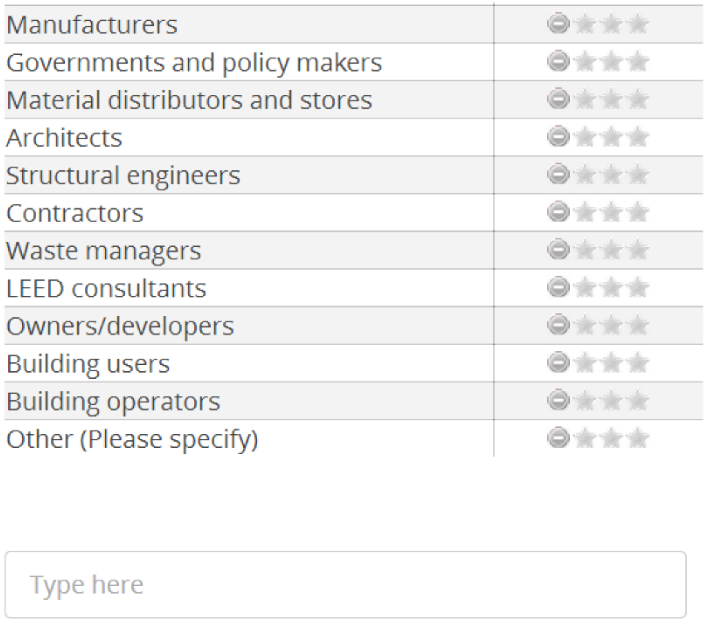
	Time limits	Storage space limits	Lack of technological facilities	Lack of knowledge	Lack of incentives	Customers disinterest	Codes and regulations	Functional requirements	Aesthetic requirements	Market unavailability	Other (Please describe)
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type here



Recycle or recycled-content material use

	Budget limits	Time limits	Storage space limits	Lack of technological facilities	Lack of knowledge	Lack of incentives	Customers disinterest	Codes and regulations	Functional requirements	Market unavailability	Other (Please describe)
	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	⊖★★★	Type here

15. Please rate the following stakeholders according to their influence on improving material effectiveness in the construction industry.



Manufacturers	⊖★★★
Governments and policy makers	⊖★★★
Material distributors and stores	⊖★★★
Architects	⊖★★★
Structural engineers	⊖★★★
Contractors	⊖★★★
Waste managers	⊖★★★
LEED consultants	⊖★★★
Owners/developers	⊖★★★
Building users	⊖★★★
Building operators	⊖★★★
Other (Please specify)	⊖★★★

Type here

16. How influential do you think your personal priorities and attitudes are in shaping the ways and extent which your company implements material effectiveness strategies?

- ○ Has major influence
- ○ Has some influence
- ○ Has minor influence

If you have any additional comments, please feel free to write them here:

Appendix B Different environmental material use solutions

This appendix reviews environmental material use solutions presented in the literature, which are arranged based on their different scopes and levels of environmental aspirations (see section 2.1).

B.1 Material efficiency

Material efficiency is a recently developed research field which aims to “reduc[e] the amount of (primary) material needed to fulfill a specific function or service” (Worrell et al., 1997). Allwood et al. (2011) have studied material efficiency opportunities for engineering materials[14]. In their study, they have defined material efficiency as “providing material services with less material production and processing”.

Researchers argue that material efficiency is a more inclusive plan than waste reduction programs, because it solves the problem from the source rather than treating waste as an end-of-pipe solution (Lilja, 2009b). Before the industrial revolution, material efficiency was *normal practice*, because the value of materials was considerably higher than the labor cost (Allwood et al., 2011; Worrell et al., 1997). However, the labor cost has continuously increased in developed economies, whereas material resource cost has been fluctuated and do not have a *trend* (Meyer et al., 2007).

In Allwood et al.'s (2011) definition of material efficiency, only strategies which result in reducing material production is considered as material efficiency measures. Using materials that

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[14] “Materials used to create buildings, infrastructure and good, and excludes the use of hydrocarbons for fuel” (Allwood et al., 2011).

help reduce energy consumption is considered to be an energy efficiency measure. For instance, Allwood et al. (2011) consider recycling as an energy efficiency strategy, while Ernst Worrell et al. (1997) state that closing material loop is one way of reducing material use. Moreover, Allwood et al. (2011) distinguish their definition of material efficiency from resource efficiency. The latter measures all the resources with the same weight measure regardless of their scarcity or their consumption rate. Material efficiency in their definition is also different from LCA studies, in which the significance of environmental improvement in the life cycle of a specific product is not clear. Material efficiency in their definition aims to reduce the consumption of some key materials which their reduction have global influence.

Some of the previous studies limit material efficiency to specific phases of a materials/products life. For instance, when material efficiency is limited to the production phase, it compares the resources used in the production stage with the value of the output product (Fischer, 2013; Rashid et al., 2008). However, it is suggested that material efficiency is most effective if it includes all the material life cycle phases and all the environmental impacts rather than only material consumption quantity (Rashid et al., 2008).

B.2 Resource efficiency

Resource efficiency is a similar concept to material efficiency. It, however, considers a different *system boundary* (Fischer, 2013). Resource efficiency looks at resources as a whole as opposed to limiting them to one stage of their life. It considers a wider range of environmental impacts, including reduction of waste, reduction of resource use, and reduction of negative impacts during extraction and production (Rashid et al., 2008). European Commission (2011) defines resource efficiency as reducing the Earth's resources use while minimizing impacts on the environment. Resource efficiency aims to "create more with less … [and deliver] greater value with less input".

A method that roughly calculates resource efficiency in a national scale is to compare the consumed resource with the added (economic) value. Some researchers believe that considering resource efficiency for *single businesses and manufacturers* is a challenging and complex task, because of the difficulty in tracking the resources used in their products or services. Also manufacturers and businesses do not have control over the full life cycle of their product. Others have identified the concept relevant and applicable to individual industrial units (Rashid et al., 2008).

Weizsäcker, Weizsäcker, Lovins, and Lovins (1998) and Schmidt-Bleek (1996) have suggested that there is potential to increase resource efficiency up to ten times. They state that, on the one hand, this improvement can be achieved through reducing resource use, increasing productivity, and closing the cycle. On the other hand resources should be equally distributed around the world. Although these quantitative goals might be technologically possible, there is a need for further investigation of economic and political actions required to incentivize the stakeholders (Rashid et al., 2008). It is crucial to understand how each stakeholder group who is involved throughout the resource flows is influenced by the changes in the material consumption practices.

Although resource efficiency aims to have a more holistic approach compared to material efficiency, there are inconsistencies in the literature regarding the life cycle phases and environmental impacts that are included in resource efficiency assessment methods. Some suggested quantification methods, which mostly aim individual businesses, only consider economic value added to the extracted resources (Dahlström & Ekins, 2005 cited in Rashid et al., 2008). Even in more inclusive measurement methods of resource efficiency, which are mainly developed for national level assessments, the environmental impacts of extraction and landfilling are usually excluded (Commission of the European Communities, 2003 cited in Rashid et al., 2008; West, Schandl, Heyenga, & Chen, 2013). However, recent governmental approaches to resource efficiency strive to have a more comprehensive approach and include all the environmental impacts of the complete life cycle of resources (European Commission, 2011).

B.3 Eco-efficiency

Eco-efficiency has a broader scope compared to resource efficiency, in terms of environmental impacts and included life cycle phases. World Business Council for Sustainable Development (WBCSD, 2000) states that Eco-efficiency can be achieved by:

> *"… delivery of competitively priced goods and services that satisfy human needs and bring quality to life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity".*

In other words, eco-efficiency aims to maximize the economic and social values generated while minimizing the negative life cycle ecological impacts of resources consumption. To quantify eco-efficiency the added value is compared to the imposed environmental impacts. In larger scales, such as national scales, eco-efficiency includes environmental impacts – other than resource consumption and waste generation (such as pollution emissions) – and social values in addition to economic values. However, when the concept is used in smaller scales, such as individual businesses, it is usually difficult to include all the environmental impacts and social added values (Rashid et al., 2008).

Eco-efficiency considers the Earth's carrying capacity as a bottom-line for environmental impacts reduction. However, this bottom-line is not factored in the assessment methods for Eco-efficiency. In other words, ecological impacts can still exceed the Earth's carrying capacity, despite the improved ratio of added (economic and social) values to environmental impact. Moreover, overgeneralizing the environmental impacts and neglecting the impact of each type of material resource can make it difficult to prioritize environmental actions in terms of their ecological benefits (Rashid et al., 2008).

B.4 Eco-effectiveness

Some researchers argue that eco-efficiency is not an ultimate solution for our environmental concerns, because it only moves towards less negative consequences and thus decreases the damage pace. These researchers believe that we can and should set our goals beyond eco-efficiency and zero impacts and move from "doing the wrong things better" to "doing the right things" (Birkeland, 2008; Cole, 2012; McDonough & Braungart, 2013).

These emerging concepts see *waste* and pollution as a design problem, i.e., placing materials in a wrong place, rather than a natural consequence of development (Birkeland, 2008; McDonough & Braungart, 2013). To eliminate the concept of *waste*, they suggest that we should not consider materials that can have a *purpose* waste, but rather *resource* (Birkeland, 2008; McDonough & Braungart, 2013; Pacheco-Torgal, 2014; Pongrácz & Pohjola, 2004). It is suggested to revise the current design methods, so that the resources can be kept within a cycle without losing their purity or quality, rather than merely trying to implement waste reduction strategies (reduce, reuse, and recycle) (Birkeland, 2008, p. 65; McDonough & Braungart, 2013).

McDonough and Braungart (2013, p. 30) question current *negating goal of zero emissions* and argue that by putting *human* against *nature* we have found the solution for the environmental concerns in reducing our growth and development. They suggest the concept of eco-effectiveness, which is inspired by living systems. Eco-effectiveness uses strategies for "creating healthy cradle-to-cradle material flow metabolisms". They argue that eco-efficiency and eco-effectiveness can be *complementary* as long as the goal is closing material loop. The authors claim that when eco-effectiveness goal has achieved, efficiency is no longer necessary, because material flows in the built environment will also nourish and "… regenerate ecological systems" (Braungart, McDonough, & Bollinger, 2007).

The necessity of moving from a linear resource consumption to a circular economy has been identified earlier by Robert (1991) in order to put an end to the environmental issues and degradation of global economy and public health. In a closed material loop, materials are used in a way that they can be infinitely recovered through industrial or natural cycles in a time frame that the industry is able to plan for its use; without significant loss of material quality and mass; and without uncontrolled or significant pollution emissions (Sassi, 2004).

Cradle-to-cradle, which is a central component of eco-effectiveness concept, take one step further from a closed material loop. Cradle-to-cradle is as an alternative design and production concept which, focuses on maintaining or even enhancing the quality and productivity of materials through endless subsequent technical (metabolizing inorganic materials) and biological (metabolizing biodegradable materials) cycles (Braungart et al., 2007). Cradle-to-cradle design has a "… positive agenda for the conception and production of goods and services that incorporate social, economic, and environmental benefit, enabling triple top line growth" (Braungart et al., 2007; McDonough & Braungart, 2010).

In typical conventional construction practices, the value of buildings gradually decreases over time and the remaining materials at the end of building lifetime are handled through "liabilities and demolition costs" (Addis, 2008, p. 12). On the contrary, cradle-to-cradle design suggests that construction materials can be reused in multiple cascading cycles, in which the materials are kept pure so that they will be recycled naturally or industrially (with the same quality) when they are not reusable anymore (McDonough & Braungart, 2013, p. 45). The ultimate goal of cradle-to-cradle design is to design buildings which "… have positive value at the end of their current use cycle …" and are conceived as *material banks* (McDonough & Zachariasse, 2014).

Although cradle-to-cradle design provides a solution for seeing value in what is conventionally referred to as waste, this concept puts a great deal of pressure on designers. This change can be beneficial for designers in terms of being recognized in green product and green building market. However, there is a need to investigate whether life cycle benefits of a cradle-to-cradle design can be a sufficiently strong motivation for designers and their customers.

B.5 Eco-productivity

Similar to McDonough and Braungart (2010), Birkeland (2008) criticizes the current building practices by an analogy that although no one accept a 'structurally unsound' building, we still allow the construction of 'ecologically unsound' buildings. She argues that resources efficiency, merely slows down the flow of resources from the built environment to landfills. Current resource efficiency strategies, despite their importance, are focused on limited number of phases of the resource flow and tend to neglect the upstream potentials and impacts. Moreover, eco-efficiency only considers "resource consumption per unit of material, but not the total consumption". Therefore, eco-efficiency does not lead to elimination of unnecessary product manufacturing, which are advertised for market and profit purposes of manufacturers.

Birkeland (2008) suggest that we need to go beyond eco-efficiency by shifting our design mindset from offsetting the negative impact to generating positive ecological impacts. We need to develop built environments in which the ecology is healthier than before development (Birkeland, 2008, p. xv). The construction industry is able to reverse the previous negative impacts and "generate natural function without capital and resource intensive industrial systems". The eco-productivity concept suggests that the built environment can and must be designed for "eco-services" by generating excess resources and contribute to the ecosystem, rather than live within the limits of ecosystem (i.e., net zero). In other words a built environments which “serve as bioconversion facilities, produce materials, and increase ecosystems and habitats”.

Birkeland (2008) asserts that in order to eliminate designed waste, it is necessary to “make [embodied] waste visible” from the design stage. However, currently waste is considered as an inevitable by-product of development that needs to be dealt with when it is generated, i.e., at the end of the flow. Moreover, zero waste in its current definition only includes post-consumer waste which according to Birkeland (2008, p. 65) is a very small portion of materials used in extraction and production.

In contrast to eco-effectiveness, eco-productive concept does not support the idea that there is no necessity for limiting our resource consumption, if this consumption have positive impacts on the environment. In assessing the impacts of resource use and waste generation, Birkeland (2008, p. 74) takes one step further by suggesting the concept of *ecological waste* which not only takes into account resource consumption and pollutant outputs, but also considers “space, time, and cost needed to restore the ecology and replace the loss of ecosystems”. A major challenge about implementing *ecological waste* analysis is its broad perspective which makes it difficult to be used for assessing different products and design developments. Moreover, although considering ecological loss in assessing a product or service will help reviving damaged ecosystem, it will put extra economic burden on the society at least in its initial implementation steps. The industry may not be self-motivated to move toward this change, unless they see a reasonable payback in their investment.

Birkeland (2008, p. 240) defines a hierarchy of ecological solutions based on their potential positive impact on the ecological systems (Table **6.1**). The categories in this hierarchy overlaps and higher level solutions usually encompasses the lower level. Nonetheless this hierarchy gives us a general idea about different levels of environmental benefits of the solutions. This table shows that even a closed-loop can have different levels of environmental benefits, i.e. down-cycling, up-cycling, or eco-cycling.

Birkeland's (2008) eco-productive concept may seem reasonable and may be achievable with no extra – or even less life cycle – capital and resource cost. However, she does not explain how this concept may affect individual stakeholders who are involved in limited phases of the resource flow. Would they personally benefit from it? If there is no significant benefit for individual stakeholders, what would motivate them to seek innovative solution for creating eco-productive cycles? Can environmental motivation be a driving incentive for all the stakeholders, especially in the early stages of shifting the common practice? This question becomes even more significant for construction materials, for which a payback period for environmental investment is not secured and may be very long.

B.6 Regeneration

Regenerative design and development is based on the fact that "… as individuals and societies, we are all embedded in (and ultimately dependent) on the cyclical process of nature." (Capra, 1996, p. 6; Cole et al., 2012). Therefore, it is important to understand that buildings can contribute to sustainability as a part of a lager system, but they cannot be sustainable on their own. (Cole, 2012).

Table 6.1 Hierarchy of ecological solutions (source: Birkeland, 2008)

Level	Description
1. Cleaner production **(Less negative)**	• New designs, products or production systems that increase resource flow overall but at less impact than the norm • Only reduce the relative impact of future actions • The least favored in terms of ecological innovations
2. Recycling **(Down-cycling)**	• Reduces impacts of waste from ongoing processes or activities through reuse or recycling • Usually includes some waste and reduced quality
3. Closing the loop **(Up-cycling)**	• Reduces impact of past development, add economic value, or use what would otherwise be wasted • Could involve increase in consumption and resource flows • Usually do not result in zero waste
4. Zero-Waste **(No-loop system)**	• Waste is entirely 'designed out' of an existing, ongoing or future system by using materials which are naturally or industrially recycled with the same quality • Could still create unnecessary product or rebound effect, where resource savings are spent on harmful activities.
5. Eco-cycling	• Up-cycling that contributes to human and ecological health
6. Net-positive	• Innovations that improve whole systems health • Eco-cycling that generates public good (beyond building level) or products with human and ecological health benefits • Increases both the ecological base and public state beyond pre-development site conditions.

Regenerative design does not reject the significance of technological improvements in green buildings. However, similar to eco-effectiveness and eco-productivity concepts, it argues that "reducing the degenerative consequences of human activity on the health and integrity of ecological systems" is insufficient. Regenerative design finds it crucial to re-conceptualize the design process with an emphasize on rethinking the role of buildings within their larger context to close the loops, create synergies, and have positive social, economic, and social influences (Cole, 2012).

Similar to eco-productivity, regenerative concept asserts that in current green building assessment systems there is more emphasis on the use phase compared to upstream and downstream phases. Moreover, these assessment systems mainly assess the quantity of resource consumption rather than its quality. As a consequence, resources are being used in a linear flow, in which the quality of resources is degraded. On the contrary, the premise of regenerative design is to use resources for multiple benefits of both human and natural systems, maintain or increase their quality throughout the flow, and make sure that resources *replenish* when they return to nature (Cole et al., 2012).

Appendix C : CME strategies in the North American environmental assessment systems

This appendix provides a short review of requirements for CME in some of the building and material assessment systems, which are developed and used in North America. The purpose of this review is to identify the strategies and the extent to which these strategies are being encouraged by these assessment systems.

C.1 Cradle-to-Cradle certified product standard (v3)

McDonough Braungart Design Chemistry (2012), have developed Cradle-to-cradle Certified Product Standard which is a *multi-attribute methodology* for evaluating products. This certification assess materials in five categories, which are material health and safety for humans and the environment; material reutilization by nature or industry; renewable and non-polluting energy and carbon management; protect and enrich water supplies; and social and environmental fairness. Products are certification at five levels (McDonough Braungart Design Chemistry, 2012):

- Basic: In this level product is assessed based on its generic materials, appropriate natural or industrial cycle for product is identified, product does not contain banned materials according to manufacturer self-declaration.
- Bronze: In this level minimum 75% (by weight) of materials in a product are assessed and a phase-out or optimization strategy has been developed for problematic materials.
- Silver: In the Silver level, minimum 75% (by weight) of materials are assessed and product contains no material with human health risk.
- Gold: In this level, 100% of materials are assessed and product meets all the cradle-to-cradle criteria including *Water Stewardship*

- Platinum: Product meets all the cradle-to-cradle criteria including *Social Fairness*.

Cradle-to-cradle system expect applicants to optimize each aspect of their product over time. The ultimate goal is to encourage innovation to design products that effectively and positively impact people and the environment. This certification is recognized in the latest version of Leadership in Energy and Environmental Design (LEED v4) as a material assessment tool (see 'LEED v4' section). However, Bronze level is the minimum required level of cradle-to-cradle certification in LEED v4, in which there is a greater focus on human health impacts rather than recoverability of materials (Cradle to Cradle Products Innovation Institute, 2013, p. 18).

C.2 Leadership in Energy and Environmental Design (LEED)

LEED is a green building certification program developed primarily in the US, but has been adopted in many countries around the world, including Canada. This sub-section presents some of the credits which promote CME in different versions of LEED:

- **LEED v3 (2009) (BuildingGreen Inc., 2013)**

LEED 2009 for New Construction and Major Renovations (LEED NC 2009)

MRp1: Storage and collection of recyclables (Required)

Projects are required to plan for providing accessible designated areas for collecting and storing recyclable materials in buildings. This includes at least: paper, corrugated cardboard, glass, plastics and metals

MRc1.1: Building Reuse (Structural Elements)

1-3 points for 55%, 75%, and 95%[15] (by area) maintain and reuse of roof, floor, and envelope walls

MRc1.2: Building Reuse (Non-Structural Elements)

1 point for 50% (of completed building area, including additions) reuse of nonstructural elements (e.g., interior walls, doors, floor coverings and ceiling systems). Projects are only eligible for this credit if the gross built area of the final building is less than two times the existing built area.

MRc2: Construction Waste Management

1-3 points for developing and implementing a construction waste management (CWM) plan in which 50, 75, or 95% (EP credit) of nonhazardous construction and demolition debris is recycled and/or salvaged (by weight or volume, but must be consistent). Excavated soil and land-clearing debris do not contribute to this credit.

MRc3: Material Reuse

1-3 points for 5, 10, or 15% (EP credit) use of salvaged, refurbished or reused materials permanently installed in the project (by cost). Mechanical, electrical and plumbing components and specialty items such as elevators and equipment cannot be included. Furniture may be included if it is included consistently in MRc 3 to 7 credits. If materials are salvaged onsite they should be used in another location or purpose than when originally installed.

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[15] 95% reuse gives the project an additional exemplary performance (EP) credit (total of 3 points)

MRc4: Recycled Content

1-3 points for 10, 20, or 30% (EP credit) use of materials with recycled content[16], which is the sum of post-consumer[17] recycled content plus 1/2 of the pre-consumer[18] content (by cost).

RPc1: Regional Priority (only in LEED Canada NC 2009)

1 point for "develop[ing] and implement[ing] a Building Durability Plan, in accordance with the principles in CSA S478-95 (R2007) (Guideline on Durability in Buildings). The guideline intends to "design and construct the building to ensure the service life equals or exceeds the design service life (DSL)" (CaGBC, 2010).

LEED 2009 for Existing Building Operations and Maintenance (LEED EBOM 2009)

MRc2: Sustainable Purchasing - Durable Goods

1 or 3 points for 40 or 80% (EP credit) (by cost) sustainable purchasing of durable goods[19], i.e. electric-powered equipment (MR2.1) and/or furniture (MR2.2), that are regularly used and replaced through the course of business. Sustainable purchases are those that meet one or more of the requirements regarding recycled content, salvaged materials, rapidly renewable materials,

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[16] Recycled content is defined in accordance with the International Organization of Standards document, ISO 14021 – Environmental labels and declarations – Self-declared environmental claims (Type II environmental labeling) (U.S. Green Building Council, 2013b).

[17] Postconsumer material is defined as waste material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product, which can no longer be used for its intended purpose (U.S. Green Building Council, 2013b).

[18] Pre-consumer material is defined as material diverted from the waste stream during the manufacturing process. Reutilization of materials (i.e., rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it) is excluded (U.S. Green Building Council, 2013b).

[19] Durable goods have a useful life of 2 years or more and are replaced infrequently or may require capital program outlays (U.S. Green Building Council, 2013a).

regional materials, forest Stewardship Council (FSC) certified paper products, or healthy materials.

MRc3: Sustainable Purchasing - Facility Alterations and Additions

1-2 points for 50 or 95% (EP credit) sustainable purchasing of materials for facility renovations, demolitions, refits and new construction additions. This applies only to base building elements[20] permanently or semi-permanently attached to the building itself. Materials considered furniture, fixtures and equipment are excluded from this credit.

MRc8: Solid Waste Management - Durable Goods

1-2 points for diverting 75 or 95% (EP point) durable goods waste from the landfill (by weight, volume or replacement value).

MRc9: Solid Waste Management - Facility Alterations and Additions

1-2 points for 70 or 95% (EP point) waste diversion from disposal and incineration in facility renovations, demolitions, refits, and new construction additions (by volume).

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[20] Base building elements include, at a minimum, building components and structures (wall studs, insulation, doors, windows), panels, attached finishing (drywall, trim, ceiling panels), carpet and other flooring material, adhesives, sealants, paints and coatings (U.S. Green Building Council, 2013a).

- **LEED v4**

The latest version of LEED (LEED v4) which is launched in November 2013, has major revisions in Materials and Resources (MR) credits. The changes in MR credits (related to CME) in LEED v4 for *new construction* and *operation & maintenance* will be presented below.

LEED v4 Building Design + Construction (USGBC, 2013a)

LEED v4 Building Design + Construction includes new construction and major renovation of core and shell, schools, retail, healthcare, data centers, hospitality, warehouses, and distribution centers.

Storage and collection of recyclables (Required):

This requirement is the same as MRp1 in LEED NC 2009. There is an additional requirement about planning for safe disposal of batteries, mercury-containing lamps, and electronic waste.

Construction and demolition waste management planning (Required):

This is a new requirement that demands development and implementation of construction and demolition waste management plan. The plan should described measures to divert minimum five material streams (including both structural and nonstructural). The plan should mention waste streams expected diversion rate, whether materials will be source separated or commingled, diversion facilities that will be used, and processing and diversion methods that the facilities use. Projects are also required to provide a detailed report describing waste generated and diverted in actual practice. The requirement to provide waste tracking report, can motivate project teams to achieve *Construction and Demolition Waste Management* credit that will be described below.

Building life-cycle impact reduction

LEED v4 supports early stage planning for environmental impact reduction of material use. This credit supports waste management hierarchy by giving the highest points to building and material reuse. Projects can achieve the credit through implementation of one of the following options:

Option 1. Historic building reuse (5 points)

This option value "historic building or contributing building in historic district" by requiring project teams to keep all "the existing building structure, envelope, and interior nonstructural elements" of these buildings, "unless it is deemed structurally unsound or hazardous".

Option 2. Renovation of abandoned or blighted building (5 points)

This option aims to add value to abandoned or blight building, by requiring project teams to keep minimum "50%, by surface area, of the existing building structure, enclosure, and interior structural elements" of these buildings. Project teams are allowed to exclude "[u]p to 25% of the building surface area", if it is deteriorated or damaged.

Option 3. Building and material reuse (2–4 points)

This option combines MRc1 and MRc3 in LEED 2009 by emphasizing on keeping the value or adding value to *off site or on site* "structural elements (e.g., floors, roof decking), enclosure materials (e.g., skin, framing), and permanently installed interior elements (e.g., walls, doors, floor coverings, ceiling systems)" by reusing them. Reused materials should be 25, 50, or 75% of completed project surface area for 2, 3 , or 4 points respectively. “[W]indow assemblies and any hazardous materials” should be excluded.

Option 4. Whole-building life-cycle assessment (3 points)

This newly added option promotes life cycle environmental impact consideration of buildings by requiring “life-cycle assessment of the project’s structure and enclosure” for the newly constructed buildings or portion of buildings. In addition to global warming potential, this assessment should show a minimum 10% impact reduction, compared with a baseline building with least 60 years service life, of at least two other impact categories specified below:

- depletion of the stratospheric ozone layer
- acidification of land and water sources
- eutrophication
- formation of tropospheric ozone
- depletion of nonrenewable energy resources

None of the categories assessed in the analysis should show more than 5% impact increase compared to the basline building.

Building product disclosure and optimization - environmental product declarations

This newly added credit aims to promote using products with transparent and reduced life cycle environmental impacts. Projects can comply with one or both of the following options:

Option 1. Environmental product declaration (EPD) (1 point)

This options aims to motivate producers to declare the life cycle environmental impacts of their product by requiring projects to “[u]se at least 20 different permanently installed products sourced from at least five different manufacturers …” that have publicly available critically reviewed or third party certified life cycle environmental assessment which conforms to related international standards and has a minimum cradle-to-gate scope. Products with product-specific critically reviewed EPD are valued as 1/4 for the purpose of credit achievement, those with industry-wide critically reviewed EPD are valued as1/2, and those with product specific third party certified EPD are valued as 1.

Option 2. Multi-attribute optimization (1 point)

This option supports products with reduced life cycle environmental impact by requiring projects to use third party certified products which have below industry average impact in three of the following areas. These product should comprise “50%, by cost, of the total value of permanently installed products in the project”.

- global warming potential
- depletion of the stratospheric ozone layer
- acidification of land and water sources
- eutrophication
- formation of tropospheric ozone
- depletion of nonrenewable energy resources

This credit supports local manufacturers by valuing products sourced (extracted, manufactured, purchased) within 100 miles (160 km) of the project site at 200% of their base contributing cost for credit achievement calculation purpose.

Building product disclosure and optimization - material ingredients

This credit aims to incentivize transparency in material ingredients and selection of products with minimized harmful ingredients. Projects can achieve up to two points by implementing up to two of the options below:

Option 1. Material ingredient reporting (1 point)

"Use at least 20 different permanently installed products from at least five different manufacturers that … demonstrate the chemical inventory of the product to at least 0.1% (1000 ppm)". This credit can be achieved through

- *Manufacturer Inventory:* Publicly available *complete content inventory* published by the manufacturer using the name and Chemical Abstract Service Registration Number (CASRN)[21] of the ingredients or the amount and GreenScreen[22] benchmark for "[m]aterials defined as trade secret or intellectual property"

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[21] A unique number identifier assigned to a specific chemical by the American Chemical Society and indexed in Chemical Abstracts. CAS number is a link to chemical and safety information about a specific material (Chemical Abstracts Service, 2015).

[22] GreenScreen for Safer Chemicals is a publicly available and transparent comparative Chemical Hazard Assessment (CHA) method developed by non-profit Clean Production Action that can be used for identifying chemicals of high concern and safer alternatives. The method includes criteria such as human and natural health hazards and environmental fate hazards to define a four level benchmark from the most hazardous (benchmark 1) to most benign chemicals (benchmark 4) (Clean Production Action, 2014).

- *Health Product Declaration*[23]: Published, complete Health Product Declaration in which all known hazards are stated.
- *Cradle-to-cradle:* Product certified at the Cradle-to-cradle v2 Basic level or Cradle-to-cradle v3 Bronze level.
- *Other USGBC approved material ingredient reporting program*.

Option 2. Material ingredient optimization (1 point)

Use products that document their material ingredient optimization using the paths below for at least 25%, by cost, of the total value of permanently installed products in the project.

- *GreenScreen v1.2 Benchmark*: Products that have no Benchmark 1 hazards.
- *Cradle-to-Cradle Certified:* Gold (v2) and Silver (v3) Cradle-to-Cradle certified products will be valued 100% of cost and Platinum (v2) and Gold (v3) are valued 150% of cost (see section C.1)
- *International Alternative Compliance Paths – REACH*[24] *Optimization: "*End use products and materials that do not contain substances that meet REACH criteria for substances of very high concern".
- *Other USGBC approved building product optimization programs*

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[23] Health Product Declaration provides a standardized way of self-reporting the material contents of building products, and the health effects associated with these materials. The HPD is developed according to the directions set forth by the Health Product Declaration Collaborative, and is considered to be complementary to life cycle documentation and Environmental Product Declaration (Health Product Declaration Collaborative, 2012).

[24] "REACH is a regulation of the European Union, adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals" (European Chemicals Agency, 2015).

Option 3. Product Manufacturer Supply Chain Optimization (1 point)

Use building products for at least 25%, by cost, of the total value of permanently installed products in the project that their manufacturer:

- Use “validated and robust safety, health, hazard, and risk programs which at a minimum document 99% (by weight) of the ingredients”, and
- Use “independent third party verification of their supply chain” that verifies at least processes and measures employed to:
    - “transparently prioritize chemical ingredients along the supply chain according to available hazard …”, “manage the health, safety and environmental hazard and risk of chemical ingredients”, and “optimize health, safety and environmental impacts when designing and improving chemical ingredients”
    - “identify, document, and communicate information on health, safety and environmental characteristics of chemical ingredients”, “communicate, receive and evaluate chemical ingredient safety and stewardship information along the supply chain”, make “safety and stewardship information about the chemical ingredients … publicly available from all points along the supply chain”

Products meeting the above option are valued at 100% of their cost. “[P]roducts sourced (extracted, manufactured, purchased) within 100 miles (160 km) of the project site” to have 200% value of “their base contributing cost”.

Construction and demolition waste management

This credit is similar to MRc2 (Construction Waste Management) in LEED 2009. The credit; however, requires that 50% waste diversion should include minimum 3 material streams and

75% waste diversion include 4 material stream, in order to achieve 1 or 2 points respectively. In addition the credit has added a waste reduction option. This option gives 2 point to projects that generate maximum “2.5 pounds of construction waste per square foot (12.2 kilograms of waste per square meter) of the building's floor area”.

Verified Construction & Demolition Recycling Rates (Pilot credit)

This pilot credit supports waste diversion quality improvement by giving one point to projects that – in addition to achieving *Construction and Demolition Waste Management* credit – use recycling facilities that achieve third part verification of their average diversion rate.

LEED v4 Operation + Maintenance (USGBC, 2013b)

Facility maintenance and renovation policy (required)

This newly added prerequisite requires projects to have a policy for purchases, waste management, and indoor air quality for building maintenances and renovations. Materials included in this prerequisite are “permanently or semi- permanently attached elements to the building, … furniture and furnishings as well as components and parts needed to maintain them”. This excludes fixtures, and equipment, which are not considered base building elements, mechanical, electrical and plumbing components and specialty items such as elevators.

Purchasing - facility maintenance and renovation

This credit combines *MRc2 (Sustainable Purchasing - Durable Goods)* and *MRc3 (Sustainable Purchasing - Facility Alterations and Additions)* credits in LEED 2009, but also add more lifecycle requirements and incentives for extending use and extended responsibilities. The credit gives up to 2 points to projects that implement one or two of the following options:

Option 1. Products and materials (1 point)

"Purchase at least 50%, by cost, of the total maintenance and renovation materials that meet at least one of the following criteria. … There is no minimum scope of renovation or new construction work required for eligibility of this credit." The credit give points to *each purchase* if each of the following criteria met.

- *Recycled content* which "is the sum of postconsumer recycled content plus one-half the pre-consumer recycled content".
- *Wood products* "must be certified by the Forest Stewardship Council or USGBC-approved equivalent".
- *Bio-based materials* must meet the sustainable agriculture standards and be legally harvested.
- *Materials reuse* "includes salvaged, refurbished, or reused products".
- *Extended producer responsibility* "Products purchased from a manufacturer (producer) that participates in an extended producer responsibility program or is directly responsible for extended producer responsibility. Products valued at 50% of their cost."
- *GreenScreen Benchmark* "Products that have fully inventoried chemical ingredients to 100 ppm that have no Benchmark 1 hazards".
- *Cradle to Cradle Certified.*

- *International Alternative Compliance Path – REACH*[25] *Optimization*
- *Product Manufacturer Supply Chain Optimization*
- *Low emissions of volatile organic compounds*.
- *VOC content requirements for wet-applied products*: “ [O]n-site wet-applied products must not contain excessive levels of VOCs”.
- *Low emissions of formaldehyde:* “Built-in … millwork containing composite woods must be constructed from materials documented to have low formaldehyde emissions … or no-added formaldehyde based resins. Salvaged and reused architectural millwork more than one year old at the time of occupancy is considered compliant ….”
- *Other USGBC approved program*.

Materials “within 100 miles (160 km) of the project site are valued at 200% of their base contributing cost”.

Option 2. Furniture (1 point)

“Purchase at least 75%, by cost, of total furniture and furnishings that meet one or more of the … criteria” described in *Option 1*.

Option 3. No alterations or furniture purchasing (1 point)

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[25] “REACH is a regulation of the European Union, adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals” (European Chemicals Agency, 2015).

The credit support extending use of existing products by giving one point to projects that “do not purchase any furniture”.

Solid waste management - facility maintenance and renovation

This credit gives 2 points for diverting minimum “70% of the waste (by weight or volume) generated by facility maintenance and renovation activities … Exclude furniture and furnishings that pose human health concerns (e.g., mold) as well as components not considered base building elements…”.

Verified Construction & Demolition Recycling Rates (Pilot credit)

Described in “LEED v4 Building Design + Construction” sub-section

C.3 Living Building Challenge 3.0

Living Building Challenge (LBC) is a building assessment program that aims to use “the most advanced measures of sustainability possible today in the built environment” and remove the *gap* between current reductionist green building goals and positive *regenerative design* of the built environments (International Living Future Institute, 2014).

LBC has seven *performance categories* (*petals*), which are: Place, Water, Energy, Health & Happiness, Materials, Equity and Beauty. Petals are comprised of twenty *Imperatives in total,* which are all mandatory. Material petal aims to create a *truly responsible economy* “that is non-toxic, ecologically regenerative, transparent and socially equitable” during the whole lifecycle of materials. However, LBC acknowledges that there are significant barriers for achieving a regenerative construction material cycle. Therefore it not only aims to mitigate the negative impacts, but also transform the industry. One of the most important deficiencies of the construction industry that LBC aims to transform is the lack of reliable data and transparency, which is due to the competitiveness of the industry. The five Imperatives in Material petal are described below:

- **Red List:** Materials that have known hazards to human and ecology and are banned from being used in buildings.
- **Embodied Carbon Footprint:** Buildings are required to offset all their embodied carbon through an approved carbon offset provider.
- **Responsible Industry:** This Imperative aims to develop a reliable third-party certification for products. Projects "must, [at least], send Declare[26] program information to at least 10 manufacturers not currently using Declare" and use "one Declare product for every 500 square meters of gross building area". Moreover, all wood products "must be certified to Forest Stewardship Council (FSC) 100% labeling standards". This includes salvaged materials and timber harvested onsite for land-clearing purposes.
- **Living Economy Sourcing:** Projects must support their regional sustainable economy by incorporating the following requirements:

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[26] "Declare supports the Living Building Challenge by providing a transparent materials database that project teams can select from to meet [Red List] Imperative". It also help project teams to identify local environmental products to support regional economies and meet *Living Economy Sourcing* Imperative (International Living Future Institute, 2011). Declare label also provide information about life expectance and end of life scenarios of products (International Living Future Institute, 2014).

- “20% or more of materials construction budget[27] must come from within 500 km of construction site.
- An additional 30% of materials construction budget must come from within 1000 km of the construction site.
- An additional 25% of materials construction budget must come from within 5000 km of the construction site.
- 25% of materials may be sourced from any location”.

- **Net Positive Waste:** This Imperative has the most direct relation with CME. It encourages projects to “reduce or eliminate the production of waste during design, construction, operation, and end of life in order to conserve natural resources and to find ways to integrate waste back into either an industrial loop or natural nutrient loop”. The Imperative requires product durability consideration in design phase, product optimization and waste diversion in construction phase, consumables and durables waste collection plan in operation phase, and *adaptable reuse and* d*econstruction* in the end of life phase.

  To develop the reuse market, the Imperative requires all projects with existing building in sites to conduct pre-building audit to identify reusable materials for their own project or for donation. Projects are also required to use salvaged materials or reuse an existing structure for every 500 square meters of project gross area. Projects should have a

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[27] “Materials construction budget is defined as all material costs and excludes labor, soft costs and land. Declare products and salvaged materials may be counted at twice their value” (International Living Future Institute, 2014).

“Material Conservation Management Plan that explains how the project optimizes materials in each [building phase]”.

Appendix D : Social-psychological factors affecting responsible material use

The following subsections, looks into the literature on responsible resource consumption and waste management. The literature presented in this section is used to identify motivating and limiting factors for different stakeholders to implement CME strategies in their projects (see section 5.2.3).

D.1 Waste aversion

Arkes and Hutzel (1997) claim that people are “waste-phobic” to the extent that they might give up their best interest in order to avoid being wasteful. Bolton and Alba (2012) also reference the universality of common-sense rules, moral tales, and religious moral instructions for preserving the resources to show that waste aversion has always been advocated in order to prevent *future deprivation*. Arkes and Hutzel (1997, p. 157) emphasize that the definition of wastefulness in people’s mind might be different from what is expressed by economists or environmentalists. “Wastefulness happens when a person spends more than it is necessary on an item”, or “when a person does not fully utilize the item that has been purchased”.

People generally tend not to waste money and natural resources, as they are concerned about the limits of these two resources more than any other *commodities*. Arkes and Hutzel (1997), have conducted surveys in which responders were asked to choose between renovating an old building or constructing a completely new one. In the first group of questionnaires they only mentioned that the building is in a very bad state and can either be renovated or be abandoned and a totally new building be built at the same location. The second group had an identical questionnaire except that the materials used to construct the old building were named, which were pine floor, oak walls, and clay brick. Arkes and Hutzel (1997) argue that in the second group, in which people were led to think of the impact of their choice on natural resource consumption, they preferred to preserve rather than demolish.

Arkes and Hutzel's (1997), study indicates that people have the desire to save the natural resources, but still may be wasteful if they cannot see the connection between their daily life choices and natural resource consumption. Bolton and Alba (2012) argue that in order for people to actively engage in waste prevention, future limitations and their behavior wastefulness needs to be visible to them. Nonetheless, many environmental consequences of human behaviors are gradual and happen out of human’s sight (Gladwin, Newburry, & Reiskin, 1997). Such disconnection of consumers and industries results in consumers’ lack of awareness or concern about negative environmental impacts of material consumption (Sheppard, 2012). As Calkins (2008) says:

> “Construction materials can be manufactured hundreds, even thousands, of miles from a project site, affecting ecosystems at the extraction and manufacturing locations, but unseen from the project location. Likewise, extraction of raw materials for these products can occur far from the point of manufacture, affecting that local environment. Disposal of manufacturing waste and used construction materials will affect still another environment. These impacts are invisible because they are likely remote from the site under construction and the people’s locale”.

D.2 Fear from hidden defects

Despite the fact that people dislike wasting, a strong factor inhibiting old materials reuse is the risk of hidden defects that may become apparent only after the purchase. This potential regret reduces the attractiveness of the reused materials. This dislike of used items is even higher for infrequent and costly purchases such as building materials. Arkes and Hutzel's (1997) study shows that even a full warranty for the used product won't replace the confidence people have with new items, because a warranty might replace financial loss, but not the *hassle* of replacing the used products in case of having hidden flaws. Often, people prefer inferior new materials over higher quality used ones, because whether an item is a lemon or not, the seller will represent it as good one. Thus, both high-quality and potentially faulty used products have to be sold at the same relatively low price to compensate for this uncertainty (Arkes & Hutzel, 1997).

D.3 Difficulty of the process

For the operational waste, studies indicate that an important reason for not recycling/reusing is the time and space it takes to prepare, store, and transport materials. Even believing in favorable environmental impacts of recycling or monetary incentives may not outweigh the trouble of preparing, saving, and transporting recyclables (Vining & Ebreo, 1990). Such difficulties may convince many people to choose an easier alternative and blame others such as governments and industries for the wasteful practice (Gladwin et al., 1997). Surveys about major reasons for not recycling indicate many responders mention inconvenience/lack of time, distance to recycling centers and storage difficulties as their major problems. However, some studies show that non-recyclers do not necessarily have less recycling capabilities than recyclers, but it is rather the perception of the difficulty of the process that results in their behavior (Belton, Crowe, Matthews, & Scott, 1994).

D.4 Demographic characteristics

Vining and Ebreo (1990), assert that it is important to analyze and understand demographic data – such as age, social class, and income – as an indicating factor for people's environmental concerns. This information can assist targeting the groups, who put less effort in preserving the environment. Some studies indicate that well-educated people and those with high incomes are more likely to engage in conservation behavior, including recycling. Belton et al. (1994), assert that it is possible that better access of higher socio-economic strata to information about recycling increases their willingness to recycle. They found that non-recyclers tended to be younger people in lower socio-economic groups.

However, Vining and Ebreo's (1990), study indicate that in the same demographic conditions recyclers and non-recyclers might be equally informed, yet the behavior of the non-recyclers might be incongruent with the incoming information and even with their own beliefs. Thus, non-recyclers may decide to ignore the information. Dunlap, Grieneeks, and Rokeach (1983), hypothesis that as long as protecting the environment is viewed as a luxury and not a necessity, actions that benefit the environment will be taken only by those who have strong environmental values.

Other group of researchers contradict Belton et al.'s (1994) statement and emphasize on the fact that lower-income strata may consume less resource and recycle more, due to the economic motivations. Chung and Poon (1999, 2001) indicate that in China lower class recycle mostly because they are able to benefit financially from selling the recyclables. Da Rocha and Sattler (2009) also claim that the low cost of reused material can be an attraction, specifically for low-income clients, to reuse building components.

D.5 Heritage values

Several psychological studies demonstrate a relation between long-term memories and preferences. Chini and Bruening (2003) emphasize that people have a natural interest in preserving those things that represent memories of times and places in order to preserve past cultures and ideologies. The preference of a group of people to renovate, restore and refurbish old houses into their homes is a result of their interest to secure a "*slice of history*".

As da Rocha and Sattler (2009) state specific reused components or demolition products (such as hardwood beams, ceramic bricks, old doors and windows and old metal window security frames) usually are sold to high-income clients at higher prices than the equivalent new products, due to their historical value. The uniqueness of components makes them memorable and valuable to preserve. However, it is obvious that a unique design would affect the primary cost of building products. Therefore, this higher value is not the case for many of the modern mass-produced construction materials (Allwood et al., 2011), and also for materials/products that are not visible and are hidden under the finishing.

D.6 Cultural ties

Culture is a major characteristic of the context which considerably affects people's perceptions and preferences (Bowles, 1998). Wildavsky (1987), claims that each individual will compare their interests with the interests of other individuals, separate the opposing interests, and ultimately opt for their own interests. People will act in a way that their actions are supported by their culture. Since our interests are produced in the context of social relations, our preferences are a result of these relations that is "how we wish to live with other people and how we wish others to live with us" (Wildavsky, 1987).

Concentration of the modern economy on market efficiency rather than social wellbeing has resulted in promoting consumption in order to benefit the market. Advertisements in the media invigorate consumerism culture especially among the northern elites (e.g. Europe, North America, and Japan). Moreover, mass media advertisements might create the illusion of abundance of resources in consumers, which results in potential carelessness about how they use resources (Allwood et al., 2011; Gladwin et al., 1997). This tendency stands against the fear of future deprivation, which was explained in section D.1. As a result, people may replace items that still function perfectly to obtain the newest and latest versions even if it was not really needed. In consumerism culture having the most modern item can indicate a high social or economic status. Industries invigorate this behavior by creating new technologies without caring about compatibility with older products or in some cases they purposely make new products incompatible with the older ones (Allwood et al., 2011; Arkes & Hutzel, 1997).