Review of the project management practices from the contractors' perspective to respond to the identified critical challenges in the Canadian green construction industry

by

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Revue des pratiques de gestion de projet du point de vue des entrepreneurs pour répondre aux défis critiques identifiés dans l'industrie Canadienne de la construction verte

Zahra ALAGHEHMANDAN

RÉSUMÉ

La construction écologique a été adoptée par l'industrie canadienne de la construction en raison de la demande de techniques de construction durables. Cependant, les projets verts doivent surmonter divers défis pour réussir.

Cette étude identifie et analyse les défis rencontrés par les entrepreneurs en construction écologique au Canada, ainsi que les stratégies employées pour répondre à ces défis.

Dix entrepreneurs ont été interviewés en plus d'une revue de la littérature et de la méthode du processus de hiérarchie analytique floue (AHP). L'analyse documentaire a révélé qu'il existe 34 défis répartis en six catégories. L'analyse Fuzzy AHP a classé ces catégories comme suit : tendances du marché, défis liés au temps, contraintes financières, défis liés au processus de construction, au gouvernement et contraintes technologiques.

Les entrevues ont révélé que les entrepreneurs emploient diverses stratégies pour surmonter ces défis, comme suivre les tendances de l'industrie, accroître l'efficacité, mener des activités de recherche et de développement, mettre en œuvre une gestion de projet efficace, plaider en faveur d'incitatifs gouvernementaux et favoriser la collaboration entre les intervenants.

Ces constatations soulignent la nécessité de poursuivre la recherche et la promotion pour promouvoir les pratiques de construction écologiques et les incitatifs à la construction écologique au Canada.

Mots-clés : bâtiment écologique, enjeux et défis, directive de l'entrepreneur, Adoption de bâtiments verts

Review of the project management practices from the contractors' perspective to respond to the identified critical challenges in the Canadian green construction industry

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ABSTRACT

Green construction has been adopted by the Canadian construction industry as a result of the demand for sustainable building techniques. However, green projects must overcome various challenges in order to be successful.

This study identifies and analyzes the challenges encountered by green building contractors in Canada, as well as the strategies employed to respond to these challenges.

Ten contractors were interviewed in addition to a literature review and the Fuzzy analytic hierarchy process (AHP) method. The literature review revealed that there are 34 challenges that fall into six categories. The Fuzzy AHP analysis ranked these categories as follows: market trends, time-related, financial, construction process-related, government-related, and technology challenges.

The interviews revealed that contractors employ a variety of strategies to overcome such challenges, such as keeping up with industry trends, increasing efficiency, conducting research and development, implementing effective project management, advocating for government incentives, and fostering collaboration among stakeholders.

These findings highlight the need for continued research and advocacy to promote green building practices and green construction incentives in Canada.

Keywords: Green Building, Issues and Challenges, Contractor’s guideline, Adoption of Green Buildings

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LIST OF ABREVIATIONS

TFN	Triangular fuzzy numbers
AHP	Analytical hierarchy process
ROI	Return of investment
BIM	Building information modeling
CVR	Content validity ratio
CI	Consistency index the
CR	Consistency ratio

LIST OF SYMBOLS

N	Total number of specialists
n_E	The number of experts who chose the challenge as relevant
$\otimes$	The result of multiplying two fuzzy numbers
m	Values of the extent analysis for a specific matrix
(u_i, m_i, l_i)	Positive values for fuzzy numbers
n	The dimension of the matrix
λmax	The eigenvalue that corresponds to the most significant Eigenvector

INTRODUCTION

The increase in world population and need for resources have had a devastating effect on nature. These effects include global warming, air and water pollution, ozone depletion, threats to renewable and non-renewable resources, deforestation, soil degradation, increased waste and species extinction (Weber & Sciubba, 2019). Sustainability is the main goal of all industrial sectors by reducing resource waste and increasing process efficiency. According to the most all-encompassing definition of sustainable development, this means providing for the needs of the current generation without sacrificing the ability of future generations to fulfill their own needs. Sustainable construction is a term used in the construction industry to describe structures that are built without harming the environment and can be used in the long-term without negative effects on the surrounding ecosystem. Incorporating environmental, social, and economic factors is essential for sustainable construction (Tan, Shen, & Yao, 2011).

A green building generates enough clean energy to power its operations and uses less external energy. Depending on the context, the term "Green Building" may refer to a structure that is either energy-efficient or environmentally friendly. Green buildings are similar to trees in that they use the sun and air to generate energy and use it efficiently without harming the environment. A green building is one that minimizes its impact on the environment both during its construction and its use (MacNaughton et al., 2016; Zuo & Zhao, 2014). Construction and operational impacts are minimized as much as possible in a green building. The primary objective of green building design is to reduce the building's impact on the environment by reducing its need for nonrenewable resources, improving the efficiency with which these resources are used, and increasing the building's reliance on renewable ones (MacNaughton et al., 2016).

New strategies have emerged in the construction industry as a result of rising global awareness of environmental factors and the demand for sustainable buildings. It appears that objectives such as nature conservation, prevention of threatening effects, and simultaneously responding to human needs can be attained with the aid of the concept of sustainability in construction management (Bon-Gang Hwang & Tan, 2012). This calls for scientifically informed approaches to problem solving.

0.1 Background of the problem

Since the beginning of time, one of the fundamental human needs has been housing and shelter. The widespread and rising demand for construction in society has increased the demand for new building systems and materials (Allen & Iano, 2019). New construction systems are expanding with the purpose of accelerating construction, elongating the structure's lifespan, and protecting the environment (Buyle, Braet, & Audenaert, 2013). Engineers' attention has been drawn to sustainable development as a result of the growing awareness of the diminishing environmental capacity. The primary objective of sustainable construction is to reduce environmental impact by preserving resource efficiency (Kwatra, Kumar, & Sharma, 2020).

Green buildings are one strategy for achieving long-term sustainability. Priority is given to the use of recycled, reclaimed, and natural materials in the construction of green buildings. Due to the efficient and effective use of water, energy, and raw materials, the occupants of these structures enjoy increased productivity, comfort, and health (Kubba, 2010).

According to the American Society for Testing and Materials, green buildings satisfy all performance requirements while minimizing construction-related disruption and enhancing the service life and function of global, regional, and local ecosystems (Z. U. Arif, Khalid, Sheikh, Zolfagharian, & Bodaghi, 2022). As stated by Burnett (2007), using renewable energy and passive design, optimizing building hydrologic cycles, integrating with local ecosystems, fully implementing indoor environmental quality measures, and closed loop material systems are the five main features of green buildings (Burnett, 2007). This standard for sustainable design should be the ultimate objective for all project managers and property owners. Recently, sustainable construction has become a popular issue. Designing, constructing, managing, and maintaining the specialized green services and facilities will demand the expertise of individuals with a higher level of education as the number of green buildings continues to rise (Z. U. Arif et al., 2022).

0.2 Statement of the problem

Architecture, engineering, and construction is one of the industries in which the observance of sustainability principles is of utmost importance (Mottaeva, 2016). The construction industry consumes approximately half of all natural resources, 40 % of the total of all industrial energy, and half of all industrial waste (Khasreen, Banfill, & Menzies, 2009; Probert, Miller, Ip, Beckett, & Schofield, 2010). Since this is one of the most visible sectors, it is imperative that sustainable strategies put into practice there. The development of instructions for achieving sustainability through building operations or on-site processes. Quantitative evaluations of sustainability using various rating systems are also available (Berardi, 2012).

The environmental impact of building construction and operation in Canada remains significant (McDonald, 2005). In response to a growing global concern for the detrimental impacts of human activities on the environment, several sectors have switched in recent years towards sustainable development and green projects. In many regions of the world, building companies adopt the green idea to lessen their projects' environmental impact (Hawang & Tan, 2012). Canada has declared promoting sustainable development a high national priority due to its importance (Anand, Bisaillon, Webster, & Amor, 2015).

However, green building is overlooked because the construction industry becomes too profit driven. Green building is emerging as a strategy to counteract these effects, but there is a widespread myth in the building design and construction industry that green buildings are more expensive to build than traditional buildings. Due to this misunderstanding, the development community, clients, and designers frequently disregard more stringent environmental performance goals (Cole, Brown, & McKay, 2010). Project managers are increasingly being asked to take on responsibilities that were not previously their primary focus as a result of the dynamic nature of the business world (Edum-Fotwe & McCaffer, 2000).

Contractors play a vital role in the construction sector as the group responsible for constructing and delivering a sustainable built environment. Considering the crucial relevance of green construction, little is known about the many challenges that may arise in Canada. Using a questionnaire survey and an interview, this study investigates the current state of green building in Canada, with an emphasis on the challenges contractors, face and an evaluation of their strategies for overcoming a subset of the primary challenges.

0.3 Purpose of the study

This study aims to identify the challenges of green construction to strengthen sustainable management practices in sustainable development-based construction projects. By promoting the sustainable use of materials and methods to reduce waste and environmental impact, identifying challenges contributes to the protection of human health and thus the environment (Holden, Linnerud, & Banister, 2014).

Objectives:

- Identifying the challenges facing contractors to implement the green construction approach in construction projects in Canada
- Rating the importance of the challenges facing contractors to implement the green construction approach in construction projects in Canada
  to identify the practices of contractor to drive green construction projects in Canada

0.4 Rationale of the theoretical basis for the study

Construction projects that take a greener approach cause less harm to the environment and last longer as a result. There has been little to no advancement in the construction industry despite the fact that a green construction approach to projects results in substantial improvements in sustainable construction (Allen & Iano, 2019). Challenges associated with this method in individual projects is a key factor in advancing the use of green building practices. In other words, if the challenges of green construction are identified, it will be possible to plan for them in a manner that will minimize costs, time, and other resources while avoiding conflicts with the interests of shareholders, employers, consultants, and contractors (Hussin, Rahman, & Memon, 2013).

0.5 Hypothesis of the study

1. The degree of willingness to adopt the green construction approach depends on the extent to which one is aware of the benefits of this approach.
2. Economic challenges affect the willingness to adopt the green construction approach.
3. Technological challenges affect the willingness to adopt the green construction approach.
4. The implementation of the green construction approach is not in conflict with the interests of contractors.

0.6 Questions of the study

1. What challenges do construction project contractors face in implementing the green construction approach in Canada?
2. Which of green construction's challenges in construction projects is most important from a contractor's perspective in Canada?
3. What practices do construction project contractors utilize in face of the green construction challenges in Canada?

0.7 Significance of the study

To adopt any construction management strategy, it is vital to identify the challenges and issues that hinder its execution. The construction sector has grown substantially in recent years, resulting in an increase in demand and subsequently resource consumption. Nowadays, sustainable management of building projects is an essential practice in the construction sector. Contractors and project managers play a significant role in the implementation of sustainable and green building. Therefore, it is necessary to identify the barriers and challenges contractors and project managers face when adopting a green construction strategy. By highlighting potential roadblocks, stakeholders in green building can better pinpoint the causes of any challenges and take steps to address them in an ongoing manner. The first steps towards implementing the principles of sustainable development in construction projects can be taken in a way that is both agreeable to the contractors and mindful of the challenges presented by green construction if attention is paid to those factors (Gunduz & Almuajebh, 2020).

Previous studies on green construction in Canada has conducted (Ruparathna & Hewage, 2015a, 2015b; Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013; Zadeh, Peng, Puffer, & Garvey, 2022). However, the barriers and challenges associated with implementing this strategy in the construction industry remain unknown. By identifying these challenges as well as examining the significance of each factor from the perspective of construction project contractors, the present study can close the current research gap.

0.8 Definition of terms (operational definitions)

Green construction: The phrase "green construction" refers to a collection of concepts and practices that strive to reduce the negative effects of building on the natural environment. Sustainable or green building practices start with the design phase and continue through construction, assembly, and use with the goal of reducing negative impacts and amplifying good ones (Kubba, 2010).

Construction project: A construction project is the planned and coordinated effort to create, renovate, or restore a facility or piece of infrastructure (Kubba, 2010).

Stakeholders: Those who have a vested interest in a construction project are referred to as stakeholders. Stakeholders might include owners, project managers, team members, facility managers and designers (Jarkas, 2017).

Contractor: A building contractor is an individual or company that agrees to construct, renovate, repair, extend, or demolish a building in exchange for payment of the agreed-upon fee, price, percentage, or other kind of compensation. The general contractor, or prime contractor, is the person or company in charge of running the day-to-day operations of a construction site, overseeing the work of numerous subcontractors, and keeping everyone apprised of developments (Jarkas, 2017).

0.9 Thesis structure

This study aims to measure the challenges that general contractors have when running green building projects and assess the techniques they adopt to address these challenges. On the basis of this, a list of challenges is compiled and will be used to investigate further during the interview, which will be surveyed and discussed in the following chapters.

A literature review determines the concepts of green construction and its characteristics in the construction sector. The objective of the review was to improve theoretical and practical comprehension of the notion of green approach in sustainable construction. Hence, the challenges associated with adopting a green approach in the construction business are recognized. Using a questionnaire, the significance of each of the potential challenges in green construction projects is then determined. In the first chapter of this dissertation, as mentioned, the introduction, generalities and expression of research problem, importance and necessity, goals and hypotheses are discussed. Also, in the first chapter, an introductory statement is made about the theoretical foundations and research background, and based on this, some studies conducted in the field of green construction and the factors affecting the adoption of this approach are reviewed.

In the second chapter, the research design method is described and the findings of the literature review through a survey with a questionnaire and interview are examined.

In the third chapter, the information obtained from the data analysis is analyzed and the results are discussed. Finally, in the Conclusion and Recommendations of this dissertation, the research suggestions and conclusions are summarized and presented.

CHAPTER 1

LITERATURE REVIEW

The detrimental effects of the construction industry on the environment pose a serious challenge to sustainable development. Construction projects can have a significant negative effect on the surrounding ecosystem, and it is therefore important to find ways to mitigate these effects as much as possible. Due to this issue, the green construction industry is becoming more well-known (Kwatra et al., 2020). For a building to be considered "green," every step must be taken to ensure that it has the smallest possible impact on the environment and utilizes the fewest available resources, including throughout the phases of planning, design, construction, operation, maintenance, renovation, and deconstruction (Zuo & Zhao, 2014). This chapter surveys the available literature on green building and sustainable development to present an in-depth introduction to these topics. The purpose of the current study's literature review is to better understand green construction principles and to highlight the challenges associated with this method, therefore it is more than just a compilation of prior studies.

In addition, this chapter gives an introduction of the construction industry and the importance of sustainable development. The findings in this chapter meet the objectives of the study's first phase and serve as a foundation for achieving other study objectives.

1.1 The nature of the construction industry

Construction is mainly related to the coordination of specialized and distinctive work at the level of a construction site. Many studies argue that construction is inherently a workshop-based activity in a particular project (Barthorpe, 2010; Gardezi, Manarvi, & Gardezi, 2014; Murray & Dainty, 2013). However, construction, in addition to worksite-level activity, could be defined as all the processes involved in creating human habitation, including the construction business and the entire project cycle. This means that construction can include various aspects in addition to site activities (Olanrewaju, Abdul-Aziz, Olanrewaju, & Abdul-Aziz, 2015).

The construction sector employs millions of individuals in a variety of engineering and technical occupations. Construction is a high-risk business that encompasses a variety of operations linked to building, altering, and repairing structures. Contemporary construction procedures and technology include prefabricated components, on-site assembling, and different forms of supply chain management (Nadim, 2012). Proper project management requires timely control, precise forecasting of project delivery schedule, and consideration of risk considerations. In order to manage a construction project, tools such as building materials cycle, information systems and management practices are needed (Halpin & Smith, 2017). Several distinguishing characteristics of the construction sector separate it apart from other industries. These distinctive features include (Mokhtariani, Sebt, & Davoudpour, 2017):

• The product is physical in nature.

• The product is normally made at the customer's place.

• Many construction projects do not have any prototypes available.

• Industry planning is such that the design phase is usually separate from construction.

Other characteristics of the construction industry include increased participation, ownership integration, and the importance of reducing waste and costs through value management (Kamal, Yusof, & Iranmanesh, 2016).

Challenges of the construction industry usually include low productivity, excessive cost and waste, lack of skilled labor and poor safety (Menegaki & Damigos, 2018). Therefore, it is necessary to evaluate the various dimensions of this industry and think of ways to improve the current situation.

1.2 Sustainable development

Industrial development should not degrade the quality of the environment and not reduce productivity over a long period of time. Improper construction methods have caused damage to the environment and created an unhealthy biological system. However, to protect the environment from the effects of construction, materials used in buildings and proper construction methods play an important role. The combination of these factors has led to the foundation of sustainable development. Sustainable development ensures greater environmental health by reducing global energy consumption (Abrahams, 2017).

1.2.1 Definition

The term "sustainable development" has several meanings in the academic literature. From its inception, the notion of sustainable development has been embraced and interpreted in many different contexts. Numerous authors have dismissed this idea as impenetrable mystery (Thatcher, 2014). Sustainable development is the process of ensuring the well-being of future generations while also safeguarding Earth's natural ecosystems. One common definition, however, states that sustainable development is achieved when "current demands are met without jeopardizing the ability of future generations to meet their own requirements." This is the most common way in which sustainable development is defined (Tomislav, 2018).

According to most explanations, the purpose of sustainable development is to ensure that people everywhere have access to the resources they need to thrive, without sacrificing the chances of future generations to do the same. Sustainable development is explained in terms of the triple bottom line (economic, social, and environmental). The importance of sustainable development and social responsibility as strategic problems for businesses across all sectors is on the rise (Porfiryev & Bobylev, 2018). Efficient resource use, natural capacity, and ecological complexity are all things that need to be considered in any sustainable development plan. Natural capital consists of environmental and natural resources and is maintained as a part of sustainable development. To protect the Earth's natural systems for future generations and guarantee that all people are treated fairly, we must build cultural institutions and infrastructure and effectively manage risks, uncertainties, and knowledge gaps (Tan et al., 2011).

Sustainable development, in its broadest sense, refers to a set of beliefs and values that promote the continued improvement of a society's ecological, social, and economic conditions across time. Efficient resource allocation, reductions in energy use and energy intensity in construction materials, increased material durability, reuse, and recycling, and other methods for better near- and far-term resource utilization are all part of sustainable development implementation. Awareness on many fronts, including human communities and enterprises, is needed to implement sustainable development in a world that is constantly changing (Beckerman, 2017).

1.2.2 Principles

The three pillars of sustainable development include environmental, social, and economic considerations. Sustainable development is a multifaceted notion that entails numerous facets. The three economic, environmental, and social components of sustainability are entirely interdependent, and the majority of academics evaluate sustainability in terms of these three aspects (Anand et al., 2015; Beckerman, 2017). Figure 1-1 depicts the links between the sustainable development principles.

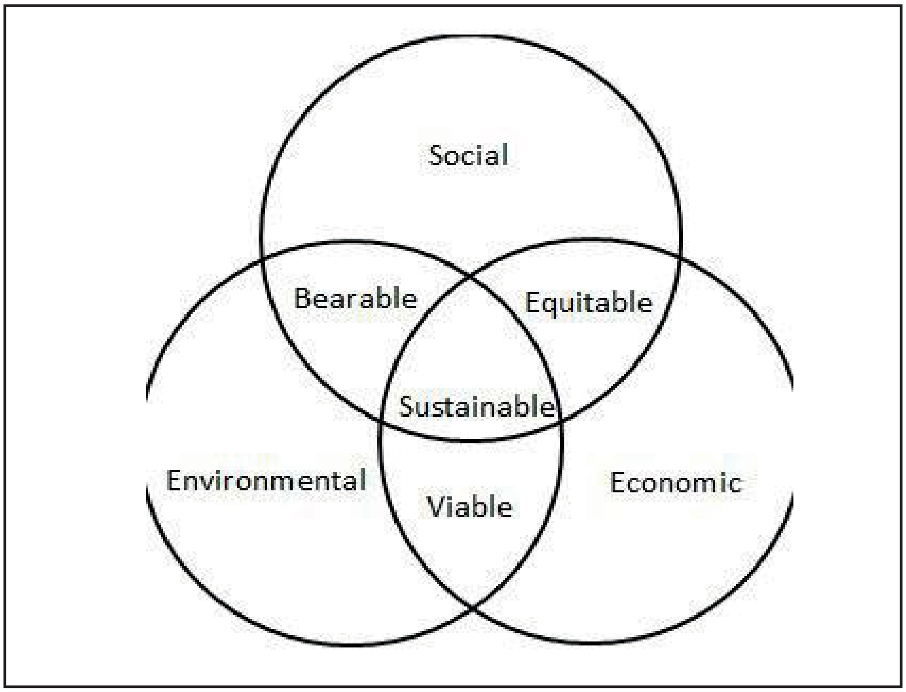

Figure 1.1 The main principles of sustainable development
Taken from Collins, O'Regan, & Cosgrove (2015)

In sustainable development, goals should be considered in three aspects as follows (Collins et al., 2015):

- Sustainable development must provide social growth in which the needs of all people are met.
- Sustainable development must provide effective protection of the environment and be careful in the consumption of natural resources.
- Sustainable development must lead to sustainable economic growth and economic prosperity.

Over the past two decades, there has been a significant rise in awareness of sustainability among governments, businesses, and consumers. While there are standards by which to judge progress toward sustainability, the standard technique exists for evaluating the economic, social, and environmental aspects of sustainable development in a unified whole are not still commonly used (Rafika, Rym, Souad, & Youcef, 2016).

1.3 Sustainable Construction

The construction sector has a substantial impact on the natural environment, economics, and society. In the construction sector, it is necessary to identify the criteria for selecting the most appropriate building materials and energy-efficient building systems for various purposes and climates (Gan, Zuo, Ye, Skitmore, & Xiong, 2015).

Experts in most nations throughout the world are focused on sustainable development and environmental preservation in construction activities. Establishing high standards of quality, safety, and comfort that protect human wellbeing is one of the primary objectives of sustainable construction.

Reasonable use of natural resources and proper construction management help preserve limited natural resources, reduce energy consumption, and improve environmental quality (Kibert, 2016).

1.3.1 Definition

Multiple definitions and approaches to sustainable construction are currently available. How the idea of sustainable construction is evolved in various countries results in vast variations in sustainable construction methods. Sustainable building is the construction industry's solution to the problem of long-term sustainability. Long-term sustainability pertains to the ability of a system, process, or activity to sustain its functions and viability over an extended duration. It guarantees the satisfaction of present needs while safeguarding the capacity of the future generations to provide for their own needs. It encompasses ecological, economic, and social dimensions, requiring a balance of environmental preservation, economic viability, and social equity.

The management of a sustainable building project needs to be aware of the many parties that will be impacted by the choices made in the name of sustainability (Gan et al., 2015).

Understanding the decision-making process and stakeholder interactions are crucial for implementing sustainable building practices (Kibert, 2016).

For any business to succeed in the long run, sustainable building practices are essential since they lead to significant cost savings, innovation, and increased competition (Gan et al, 2015). Not only do more people choose to buy homes that were built using sustainable practices, but there are also a number of other, less obvious benefits. Increased building quality, motivated and satisfied workers, delighted clients, and strengthened ties with key constituencies are just a few of the many upsides (Pitt, Tucker, Riley, & Longden, 2009). As per the findings of the World Green Building Council, it has been observed that green buildings have the potential to decrease operational expenses by approximately 8-9%, concurrently augmenting the value of the building by approximately 7.5% (WorldGBC, 2019a). There are environmental, economic, social, and health benefits that can be attained through sustainable building practices. Advantages to the environment include cleaner air and water, less use of energy, and less trash being thrown away. Financial gains boost profitability and save operating and maintenance expenses (Dobson, Sourani, Sertyesilisik, & Tunstall, 2013).

1.3.2 Framework

Many authors have done research on sustainable construction principles. This includes developing a framework for implementing sustainable construction practices. The frameworks of construction industry for environmental compatibility include (Du Plessis, 2007):

Systematic view: Construction cannot be viewed in isolation without regard to its surroundings. In fact, the supply chain for construction affects virtually the entire economy. For example, construction cannot be done without affecting energy, services, and the environment. Environmental analysis of construction involves the analysis of the consumed energy and is recognized as an effective part of the economy (Solaimani & Sedighi, 2020).

Project life perspective: Appropriate infrastructure should be viewed from a project life perspective. For example, design decisions at the beginning of a project will have long-term effects on operation and maintenance. Therefore, the environmental costs of project life should be managed with the right decisions (Hill & Bowen, 1997).

Prevention of environmental pollution: The importance of preventing environmental pollution cannot be overstated, particularly when taking into account the significant costs and efforts involved in environmental remediation. The term "environmental remodeling," as defined by Mitsch and Jørgensen (2003), encompasses the various processes and activities implemented to address and enhance environmental conditions following instances of degradation or pollution. This may entail activities such as the remediation of industrial sites, the rehabilitation of natural habitats, or the revitalization of urban areas. In general, the expenses related to restorative actions, including both direct and indirect costs, tend to be considerably higher compared to the proactive measures implemented to prevent pollution from occurring initially (Mitsch & Jørgensen, 2003). Architects, quantity surveyors, structural engineers, construction managers and contractors play an important role in determining the amount of environmental loading due to the construction of structures (Xing, Ye, Zuo, & Jiang, 2018).

Design of construction products: The use of higher quality products reduces construction damages and prolongs the life of the structure. It is important to know the depreciation rate of products predicted. The planning period for the economic analysis of construction products must be considered (Wahlström et al., 2013).

Construction materials: Using the right materials saves as much energy as possible. Construction materials must be analyzed before use and the most appropriate ones selected. For example, it must be investigated that what option has the lowest resource input and greenhouse gas emissions for the environment. The amount of waste during its useful life must be calculated. The recyclability of the materials needs to be considered (G. Xu & Shi, 2018).

Construction processes: In construction processes, energy and chemical particles are released. For example, concrete is a frequently employed material in the construction of high-rise buildings. The combination of cement, sand, and water in the production of concrete initiates a chemical reaction. The process of hydration, commonly referred to as a chemical reaction, results in the liberation of thermal energy. During the process of curing and hardening, the chemical particles included in the concrete mixture undergo transformations, resulting in the emission of energy. The liberation of energy not only facilitates the solidification and fortification of the concrete, but also plays a role in the broader energy dynamics of the construction site. Research is needed to quantify and rank these pollutants, as well as to determine their impact on the environment and construction workers (Horman et al., 2006).

Construction machinery: Although environmental officials control the amount of exhaust gases from private vehicles, the amount of pollutants emitted by construction machinery is still under investigation. Greenhouse gas emissions from construction machinery must be considered. Efforts must be done to reduce the amount of pollutants (Su et al., 2023).

Structural design: The relationship between environmental consequences and material selection must be investigated. Construction plans must be optimized with the three principles of sustainable development including engineering, economics, and environment (Pongiglione & Calderini, 2016).

Environmental damage: The Environmental damage is measured at the construction site. Research issues have a lot of variety and multiplicity according to the scale, which is very important to pay attention to them and their use helps to reduce the environmental impact of construction and create sustainable development (Ding, 2008).
Figure 1-2 compares the principles of sustainable construction with those of conventional construction.

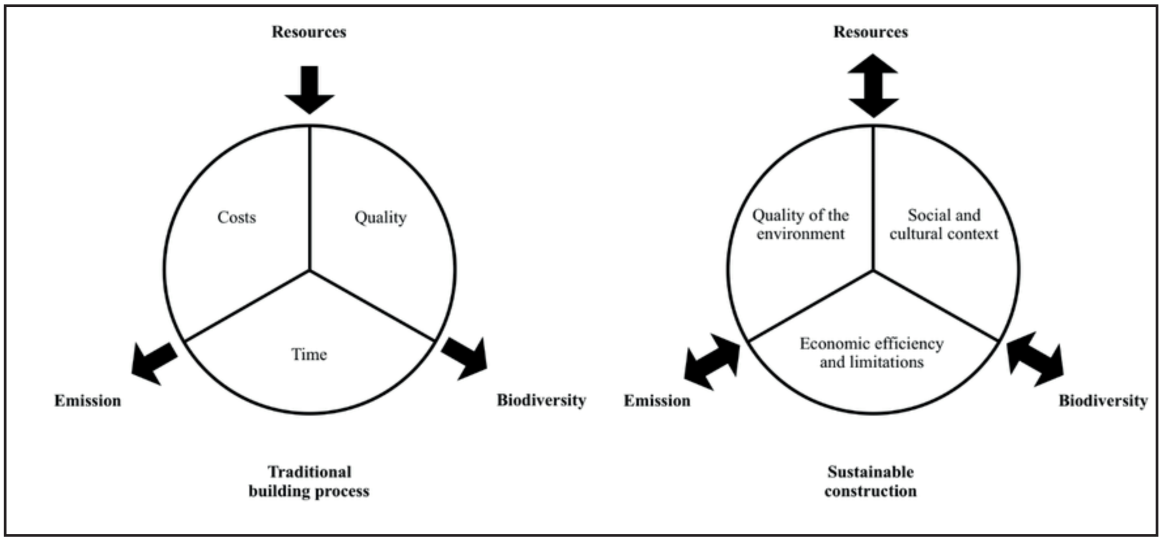

Figure 1.2 Sustainable construction principles compared to the conventional construction approach Taken from Bříza (2019)

A framework and set of goals are needed to achieve and measure progress in a sustainable construction project. A Sustainable construction framework based on the mentioned operational themes is necessary to observe the principles of sustainability in the project (Ofori, 1998).

1.3.3 Green construction

The concept of ecological building was first proposed in 1969, and at present, it is widely promoted as green construction. Recent demand for green construction facilities with lowest environmental impact has been driven due to the increasing energy costs and environmental issues. Green building construction can be an integral part of an organization's long-term strategy for achieving sustainable growth (Kibert, 2016; Kubba, 2010).

1.3.3.1 Concept

Green construction practices prioritize the safety and well-being of the building's inhabitants and its financial stability, all while minimizing the building's environmental impact over the course of its lifetime. Green construction, also known as green structures or sustainable buildings, was developed in response to the low-carbon agenda and the sustainable building movement. The term "green" is used interchangeably with "sustainable," "energy-efficient," and "low carbon" when referring to environmental friendliness in this study. The point is, of course, to generate products and services that are less harmful to the environment (Mosgaard, 2015).

Kibert (2016) argues that a sustainable building is one that prioritizes the health and well-being of its occupants while also being built in an environmentally conscious and resource-efficient manner. While designing and constructing a building, "green" practices are implemented to lessen the impact on the environment. Measures are done continuously throughout the product's lifecycle (from conception to retirement) to lessen its impact on both humans and the environment. All of the negative environmental impacts, such as greenhouse gas emissions, pollution, resource depletion, and waste, should decrease once the building is complete (Kibert, 2016).

Green buildings, as stated by Robichaud and Anantatmula (2011), are beneficial to the health, safety and productivity of their occupants as well as to the growth of the economy and the financial advantages to investors and communities. A sustainable structure is more than a collection of eco-friendly tools and materials. Various systems and equipment within the site and the building are applied as part of the design process, resulting in subsequent steps including reevaluation, integration, and optimizations of the impact and interdependence of these elements (Robichaud & Anantatmula, 2011).

From the earliest stages of site planning to the final stages of designing and detailing the envelope, the building as a whole is characterized by an emphasis on integrated and optimal design. Due to the lengthy time commitment involved, Wu and Low (2010) believe that green construction should be viewed as a process rather than a product, with ownership throughout the entire project life cycle. In order to be considered "green," every step of the building process, from planning to deconstruction, must be completed in a way that is friendly on the environment and economical with its resources. Throughout the entire process, all parties involved in a green building project, including the contractor, architect, engineer, and client, must work closely together (Wu & Low, 2010). Green construction is an approach to building that goes beyond the traditional construction priorities of cost-effectiveness, functionality, durability, and occupant satisfaction (Zuo & Zhao, 2014).

To achieve the lowest possible cost of energy and comfort, a green building must be a climate-adaptive building, which means it must make extensive use of appropriate technology to cut down on energy consumption (Y. Li, Yang, He, & Zhao, 2014).

1.3.3.2 Characteristics

As outlined above, green construction is characterized by a variety of features, the majority of which are centered on reducing material and energy consumption (Kubba, 2010). The following sections will elaborate on energy conservation, environmental protection, and livability.

1.3.3.2.1 Energy efficiency

As indicated in Figure 1-3, green building is characterized by a reduction in resource consumption throughout the planning, design, construction, operation, and demolition. Green construction, on the one hand, aims to maximize resource efficiency throughout the project life cycle, from initial design to final cleanup. The building's design incorporates natural wind to cut down on the need for air conditioning; the interior lighting of green buildings should be enhanced, with an emphasis on using natural light; and the importance of thermal insulation in green building design should be emphasized to maximize the buildings' energy efficiency (Song et al., 2021).

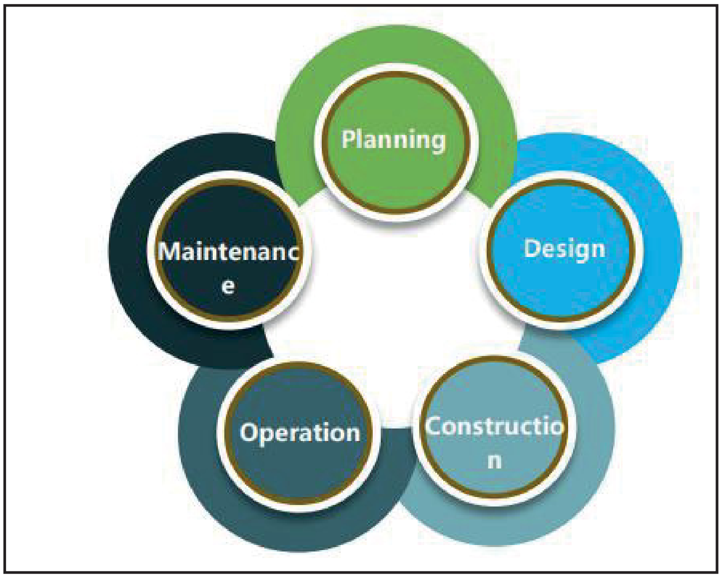

Figure 1.3 Life cycle of green construction
Taken from Song et al. (2021)

Conversely, a green building's energy consumption can be reduced by the employment of a number of energy-saving devices that either directly tap into natural energy sources or make indirect use of bioenergy during operation and use. For instance, solar and wind power are directly employed to transform their respective sources of natural energy into electricity that can be used in structures. Greening the building and using various forms of vegetation as a thermal insulation and indoor climate regulator can assist save water and heat in the winter and keep the building at a comfortable temperature all year round (Song et al., 2021). Here is an example of a green building in Canada that integrates natural wind and optimizes the utilization of natural light: The Canadian Green Tower, situated in Toronto, serves as a remarkable exemplification of green construction within Canada. The 20-story residential structure, which has been designed by the acclaimed architect Lisa Chen, exhibits a dual focus on minimizing its carbon footprint and enhancing the living conditions of its inhabitants through meticulous design principles. The architectural design of the building integrates the utilization of natural wind patterns, resulting in a notable reduction in the dependency on air conditioning systems. To accomplish this, the tower has a distinctive design element known as a 'wind funnel'. The present novel methodology capitalizes on the prevailing wind patterns in Toronto to effectively direct cold air into the atrium and circulation rooms of the building.

The presence of wind within the structure facilitates natural ventilation, hence diminishing the need for energy-intensive air conditioning equipment. Residents derive pleasure from the presence of fresh and cool air, hence obviating the necessity for excessive cooling measures. This phenomenon not only leads to energy conservation but also results in reduced utility expenses. Moreover, the lighting system employed within the Canadian Green Tower exemplifies a sustainable approach to illumination. The design by Lisa Chen places a high emphasis on incorporating natural light into both individual apartments and shared spaces. The incorporation of sizable, energy-efficient windows and strategically positioned skylights facilitates the ingress of natural sunshine into residential areas, thereby diminishing the need for artificial illumination during daylight hours. Furthermore, the implementation of an innovative lighting management system enables the adjustment of artificial lighting in response to the presence of natural light, thereby assuring optimal illumination within the structure while simultaneously reducing energy usage. The Canadian Green Tower exemplifies sustainable living in Canada, demonstrating the integration of architecture and nature to establish environmentally conscious and comfortable residential environments (Johnson, A., 2023).

1.3.3.2.2 Conservation of the Environment

For as long as there has been "green construction," its guiding principle has been the protection of the environment at every phase of the construction process. The first steps in the planning and site selection processes should be focused on coordinating with the surrounding environment, minimization environmental damage, and making use of clean, renewable energy and materials (Y. Li et al., 2014).

During the building process, reducing energy consumption and preventing environmental interference and contamination can be accomplished through the application of cutting-edge construction technology and scientific management practices. It will control the amount of pollution released into the atmosphere, especially carbon dioxide, from the building's heating, cooling, lighting, and plumbing systems. The stage of operation also accounts for environmental protection. Annual building energy consumption has dropped noticeably as a result of the growing use of renewable resources like solar, wind, and geothermal heat. Construction with renewable materials allows for their recycling even after demolition has begun. As a result of this, the process of redevelopment will call for a smaller amount of materials and will result in a smaller amount of waste from construction (Song et al., 2021).

1.3.3.2.3 Livability

Green construction is meant to serve the objective of providing living space for human beings, where they can work, live, and reside. The purpose of green building is to provide a healthier built and natural environment for occupants. The sustainable green building represents the symbiotic interaction between humans and nature through its organic combination of artificial and natural materials (Song et al., 2021). This is a broad definition of "livable" that encompasses both the building in which residents live and their natural environment. The caves in Shanxi, for instance, combine the local environment in a way that makes the structure comfortable year-round, fully reflective of energy saving and environmental protection, and adequate for its intended use. Shanxi is a paradigm of eco-friendly architecture in green construction (J. Xu, 2018).

1.3.3.3 Green buildings rating systems

Independent, voluntary, and market-driven, green building rating systems (GBRS) are a set of criteria that encourage the adoption of ecologically, socially, and economically sustainable practices in the design, construction, and management of buildings (Shan & Hwang, 2018).

A rating system is a way to evaluate something's worth by classifying it into one of several categories based on how well it meets a set of criteria that has some bearing on the quality of its performance. Regulatory thresholds or a resemblance reference model with other buildings can be used in conjunction with a variety of other factors to create a rating system that can be used to assess a building's sustainability (Reeder, 2010). A rating system is a mechanism for evaluating and rewarding building performance relative to predetermined environmental criteria and standards (Ismaeel, 2018; Shan & Hwang, 2018).

Green building rating systems are used to determine how well a building performs in comparison to established benchmarks for environmental friendliness (Ismaeel, 2018). As a result, rating tools, the adoption of which is usually voluntary, have become a way to publicly acknowledge and reward the efforts of businesses and individuals that construct and operate more sustainably (Reeder, 2010).

Numerous rating systems have been developed, and public and private organizations continue to create more. An estimated 600 green rating systems exist across the globe (Shan & Hwang, 2018). Many sources claim that BREEAM (Building Research Establishment Assessment Method) was the first grading instrument to assess a building's efficiency in reference to established criteria (Awadh, 2017). The United States' Leadership in Energy and Environmental Design (LEED), Canada's LEED Canada, France's HQE (High Environmental Quality), Germany's DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen), Australia's Green Star, Japan's CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), and Hong Kong's BEAM (Building Environmental Assessment) are just a few of the certification systems available (Ismaeel, 2018).

In comparison to non-certified buildings, BREEAM- and LEED-certified buildings can save between 30 and 60 % on their annual energy costs (Vimpari & Junnila, 2014) and 18 to 39 %, respectively (Scofield, 2013).

1.3.3.3.1 BREEAM

The Building Research Establishment (BRE) in the United Kingdom created and manages BREEAM, which is considered the world's first green building rating system (Awadh, 2017). Released to the public in 1990, it underwent its first round of revisions for use by tax authorities in 1993 (Freitas & Zhang, 2018). The majority of the major green grading systems, including as LEED, Green Star, and CASBEE, may trace their origins back to BREEAM. BREEAM flexibility has allowed it to be used in a variety of contexts. It not only assesses local norms, but also makes them usable in buildings all around the world (Doan et al., 2016; Freitas & Zhang, 2018). The New Construction, In-use, Refurbishment and Fit-Out, Communities, and Infrastructure guides published by BRE provide for a comprehensive evaluation of a building's performance from inception to decommissioning. Because of this, BREEAM has given over 560,000 certificates to far (Awadh, 2017). That number ought to keep climbing, given past tendencies. The total number of nations using BREEAM has increased gradually since 1990. BREEAM certifications for environmentally friendly buildings account for 80% of the European market (Freitas & Zhang, 2018). Although BREEAM is capable of assessing all areas of sustainability, it places particular emphasis on the eight environmental impacts of management, energy, transportation, water, materials, waste, and pollution (Shan & Hwang, 2018).

1.3.3.3.2 LEED

The United States Green Building Council (USGBC) established LEED as an optional benchmark (Poveda, 2017). It was first implemented in 1998 as a test program. In spite of LEED's later release than BREEAM, it has seen greater international adoption, with over 79,000 projects using the rating system in 135 countries as of 2012 (Altomonte & Schiavon, 2013), nearly 150 countries and territories as of 2014 (Poveda, 2017), and more than 160 countries and territories until the year 2016 (Doan et al., 2016). Since 2008, the overall square footage of LEED-certified buildings has climbed by more than a hundred percent, from 0.15 billion to more than 15 billion square feet 2016 (Freitas & Zhang, 2018). When contrasting LEED to BREEAM, it is easy to evaluate how much importance is placed on environmental considerations such Sustainable Sites, Resource Efficiency, Energy and Resources, and Indoor Environmental Protection (Awadh, 2017). The guides on building design and construction, interior design and construction, building operations and maintenance, and community development might all be used to evaluate the full building life cycle (Ismaeel, 2018; Reeder, 2010).

1.3.3.4 Green construction in Canada

Critical to Canada's economy, the construction industry accounts for 7,5% of GDP (Canadian Construction Association, 2022). The social, environmental, and economic aspects of sustainability are all significantly impacted by construction projects (Kibert, 2016). Resource-rich countries such as Canada and Australia have the highest rates of building expansion among the industrialized world (Perspectives & Economics, 2020). Between 2000 and 2010, the construction industry contributed 42.7% to Canada's GDP growth, compared to the overall 20.2% growth (Ruparathna & Hewage, 2015b). Canada's federal government has pledged to cut greenhouse gas emissions by 45 percent from 2005 levels by 2030 and to achieve net-zero emissions by 2050. Prioritizing decarbonization, or decreasing or eliminating emissions into the atmosphere, is essential to achieving these goals because the buildings sector is the third-largest producer of emissions in Canada. There are, however, considerable obstacles that must be overcome before 2050's goal of net-zero emissions from buildings can be realized (Perspectives & Economics, 2020).

In Canada, several incentives have been established at the federal, provincial, and municipal levels to promote the use of green building supplies and practices (Zadeh et al., 2022).

1.3.3.4.1 Canadian Green Building Standards and Rating Systems

It is administered by the Canada Green Building Council (CaGBC) that Canada has implemented multiple green building rating systems and standards to facilitate the adoption of sustainable and ecologically conscious construction techniques. The following are a few of the well-known green building rating systems and standards in Canada (CAGBC, 2023b):

1.3.3.4.1.1 LEED Canada

An acronym for Leadership in Energy and Environmental Design, LEED® is one of the most important indicators of sustainability and green building in Canada. By emphasizing sustainable practices, LEED's tried-and-true comprehensive approach helps almost all building types minimize carbon emissions, preserve resources, and cut operating costs. One of the top countries in the world for LEED certification is Canada (CAGBC, 2023b).

LEED's effectiveness lies in its recognition of the importance of sustainability throughout the design, construction, and operation of a building. By providing the best circumstances for health, comfort, and productivity, such greater air quality and natural light, LEED also enhances people's quality of life (CAGBC, 2023b).

In order to attain excellent performance in six areas of human and environmental health, a building project must be LEED certified, which is independent, third-party verification (CAGBC, 2023b). Figure 1-4 shows the LEED certification Scopes (CAGBC, 2023b).

Figure 1.4 LEED certification Scopes
Taken from CAGBC (2023b)

1.3.3.4.1.2 Zero Carbon Building Standards

The Zero Carbon Building™ (ZCB) standards from the CAGBC are Canadian frameworks that elevate carbon to the status of the new yardstick for building innovation. They acknowledge the significance of building emissions in fulfilling national climate goals and are among the first zero-carbon building standards in the world. The ZCB standards are a crucial instrument for the green building industry's initiatives to decarbonize Canadian structures. A zero-carbon structure uses less energy and produces fewer greenhouse gas emissions during construction and operation. High-quality carbon offsets can be used as a counterweight until all emissions can be stopped (CAGBC, 2023c).

1.3.3.4.1.3 Green Globes

As part of the Green Globes program, a procedure and grading system are available online for developing, operating, and managing green buildings. In addition to being interactive, flexible, and cost-effective, it facilitates third-party recognition of a building's environmental qualities (Green Globe, 2021).

Mostly utilized in Canada and the USA, Green Globes is an online tool for grading and certifying green buildings. Modules from the Green Globes are available in Canada, including (Green Globe, 2021).

- An award for a new building or major renovation under the Green Globe program;
- Interior projects or fit-outs for commercial or rental properties are eligible for Green Globes for Sustainable Interiors.

In addition to commercial, institutional, architectural, educational, treatment, and recreational applications, these modules are incredibly versatile (Green Globe, 2021).

CHAPTER 2

METHODOLOGY

2.1 Introduction

This chapter describes the research methods used to identify the most significant challenges in the green construction industry in Canada and to examine the project management practices adopted by contractors to respond to them.

This study's approach consists of three stages: literature review, fuzzy Analytical Hierarchy Process (AHP) analysis, and interviews with Canadian green construction contractors. The literature review aims to identify critical challenges in green construction industry in Canada. The discovered challenges are then ranked in order of priority using fuzzy AHP-based prioritization. Finally, interviews are performed with green building contractors to investigate their management practices for responding the highlighted challenges.

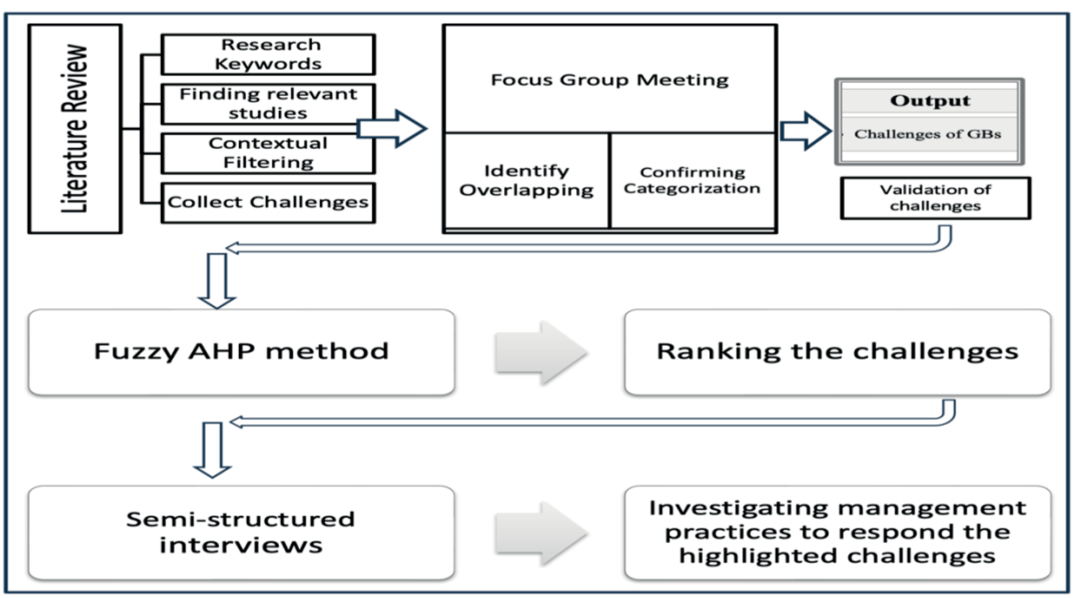

Figure 2.1 Research Methodology

2.2 Research Philosophy

The study is grounded in a research philosophy of positivism. Positivism, which is based on the principles of natural science, aims to investigate objective reality. The foundation of this philosophy is based on the assumption that there is an objective reality that can be examined using empirical observations and scientific methodologies. However, it is important to note that positivism is merely one of several research philosophies. Other options encompass interpretivism, which places emphasis on subjective interpretation and comprehension, and critical realism, which asserts the existence of an objective reality but acknowledges that our understanding of it is always influenced by human interpretation and societal factors, among other perspectives. Positivism is widely observed in numerous scientific disciplines owing to its focus on objective and empirical investigation. However, the extent of its influence varies depending on the specific characteristics of the study and the field of inquiry. In the field of social sciences, interpretive methodologies are frequently utilized, whereas positivist approaches are often favored in the natural sciences (Caldwell, 1980).

Positivism is relevant to this subject because it permits the acquisition of empirical evidence through a methodical and objective methodology. This philosophy contributes to the corpus of knowledge in the field of green construction by aiding in the identification of the most significant challenges of green construction and evaluating project management practices in respond to these challenges (Crossan, 2003).

In addition, the positivist philosophy encourages statistical analysis, which will be crucial when employing fuzzy AHP to prioritize the identified challenges. This attitude ensures the research findings' precision, dependability, and validity.

In conclusion, positivism provides a solid framework for the study by emphasizing objectivity, empirical observation, and scientific methodologies, which are crucial for identifying major challenges and evaluating project management practices in green construction.

2.3 Research Design

The research strategy for this investigation is a hybrid approach, combining qualitative and quantitative methods. This approach was favored because it opens up opportunities for a deeper understanding of the challenges involved in green building and allows for a more objective rating of options. Following are some questions that are addressed by the study's methodology:

- What are the most severe challenges in green construction?
- How might these challenges be prioritized in the context of Canada?
- What management practices can green building contractors employ to respond to these challenges?

2.4 Sampling strategy and participants

This study employed a purposive sample technique, which involves selecting individuals according to specific criteria pertinent to the research issues. In this case, for participating in questionnaire and semi-structured interview, ten contractors with experience working on green construction projects in Canada were chosen.

Initially, a comprehensive inquiry was conducted to ascertain the number of contractor firms operating within the field of green construction. Subsequently, a compilation of pertinent data pertaining to each company was meticulously compiled. Then, an inquiry was initiated to identify individuals inside these organizations who possess expertise in the realm of green construction, along with other specified qualifications. The selection criteria included contractors who had two of the following criteria: had executed or were involved in at least one LEED-certified project, had experience with green building materials and technology, and had at least five years of industry experience. In this stage, three contractors confirmed to participate in the research; therefore, the selection method was conducted using snowball sampling, in which the original participants were asked to recommend other potential participants who fit the selection criteria. As a result of this endeavor, a selection of contractors specializing in the considered field was successfully found. It is worth mentioning that communication was facilitated through several means, including personal introductions, and the utilization of professional networking platforms such as LinkedIn, e-mail, text messaging, and telephone conversations. Initially, the total number of individuals invited amounted to 101; however, the participation of 10 individuals was finally confirmed. In conclusion, a total of ten individuals were chosen to participate in the fuzzy Analytic Hierarchy Process (AHP) and semi-structured interviews. It should be noted, that when selecting the contractor, the estimated time for participation was mentioned to the invited experts as issues such as accessibility and connectivity were crucial to conducting the questionnaire and interviews.

2.5 Identification of Critical Challenges

2.5.1 Literature Review

In the first part of the research, the most significant challenges with green buildings are identified by a thorough literature analysis. The purpose of this investigation is to comprehend the current state of research more fully in the subject by identifying and categorizing the critical challenges highlighted in the available literature.

Many academic databases, including ETS University library database, ScienceDirect, and Google Scholar, as well as industry reports from the Canada Green Building Council (CaGBC), Canadian Construction Association (CCA), and the National Research Council (NRC), were used to search.

The selection criteria for relevant material include journal articles, conference papers, and industry reports published after the year 2005. This literature review's methodological structure was influenced by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach described by Moher et al. (2009) (Moher et al., 2009).

The use of search terms such as “green construction”, “green building”, “sustainable building”, “challenges”, “Barriers”, “Adoption of green building”, “Canadian green construction Industry”, "project management practices," and "contractors' perspective" was essential in obtaining relevant results. The goal of this literature analysis was to find and classify the most significant challenges that Canadian contractors experience when working on green construction projects. The goal of this sorting is to provide a more organized means of analyzing data and to make it simpler to find responses to pressing challenges.

2.5.1.1. Focus group

To enhance the validity and comprehensiveness of the findings obtained from the systematic literature review, the research methodology included the integration of a focus group. The objective of the focus group was to provide a forum for subject matter experts to contribute their insights, feedback, and practical experiences pertaining to the themes identified in the literature review.

The composition of the focus group comprised ten individuals who were chosen for their esteemed expertise and notable contributions within the pertinent field of study. The participants were invited with a background in one or more of these three field categories: including, researcher, LEED-certified, or individuals active in the industry in the same field. Looking for inviting participants started with having connections with people in the same field and having referrals from them, green buildings active groups, groups of LEED exam preparation courses, groups of certified experts in the related field, LinkedIn, and university communication groups including researchers that were created by admins and students. The invitation and communication with participants were conducted by referral, texts, calls, LinkedIn, Email, and communication applications. The invitations to participate in the focus group were distributed during the autumn season of 2019 and to receive ten positive answers, 32 people were invited to participate in this meeting. The meeting was held in two online sessions; the first session took about 1 hour and 15 minutes, and the second session took about 30 minutes. The participants were given a summary of the initial findings from the literature review beforehand, enabling them to adequately prepare for a well-organized discussion.

The focus group sessions were guided by a skilled moderator. The moderator's responsibility was to facilitate the discussion, ensuring that all essential themes from the literature review were covered, while also allowing room for fresh insights or perspectives to arise.

The data was analyzed using thematic analysis, in which emergent themes were identified, coded, and compared with the findings. By adopting this approach, the study was able to effectively incorporate expert opinions into the existing literature, thereby enhancing the comprehensiveness and validity of the research. By weighing in with comments and reactions, the final list of challenges mentioned in the literature review was confirmed. Since the final classification of challenges in the next step would reflect the opinions of industry experts, it can be deemed as an accurate and comprehensive analysis of the challenges facing the Canadian green construction industry.

The examination of existing literature provided a framework for determining which challenges are pressing for the Canadian green building sector. It also helped to shape the questionnaire interview used to elicit information from Canadian green construction contractors about the methods employed in project management to overcome the various kinds of challenges they face.

2.5.2 Validation of challenges

In order to validate and verify each of the significant challenges, a survey of industry experts was carried out. The experts were tasked with analyzing Canada's current challenges of green construction and suggesting any additional challenges to add to the list. A Likert scale from 1 to 5 was then used to have respondents rate the importance of each challenge. The lower the score, the less relevant the challenge is for Canada, and the higher the score, the more relevant the challenge is. The quantitative approach proposed by Lawshe (1975) was used to evaluate the challenges' validity (Almanasreh, Moles, & Chen, 2019; Lawshe, 1975). The following equation in (3.1) was used to calculate the content validity ratio (CVR), where N is the total number of experts and n_E is the number of experts who chose the challenge as relevant.

$$CVR = \frac{n_E - \frac{N}{2}}{\frac{N}{2}} \tag{3.1}$$

According to the total number of experts, challenges with a CVR of 0.37 or less were considered to be deleted.

2.6 Fuzzy AHP Analysis

Numerous factors must be considered when deciding how to approach complex, actual issues. In the 1970s, Thomas L. Satty developed the AHP to address unstructured problems involving multiple criteria in economics, social sciences, and management (Saaty, 2003, 2004).

The full scope of the problem under consideration is defined by the axioms of the popular decision-making tool AHP. Relative risk metrics are determined using an ordered set of matrices and their corresponding Eigenvectors (Liu, Eckert, & Earl, 2020). An AHP problem hierarchy consists of a problem statement, a set of decision criteria, and the sub-criteria and options derived from those criteria. In paired comparisons, groups of decision-makers evaluate the weight assigned to each criterion (Saaty, 2003, 2004).

Despite its widespread use and apparent ease of conception, the AHP approach is often criticized for failing to adequately deal with the inherent imprecision and uncertainty involved in trying to reduce the complexity of human thought to a set of numbers. There is always the possibility of subjectivity due to the involvement of humans; however, using AHP helps to reduce these types of errors. The AHP method is combined with Triangular Fuzzy Numbers (TFN) to address ambiguity when making subjective ratings-based decisions. The Fuzzy AHP method helps analyze the decision-making functionality of complex systems because it evaluates human judgment by assigning weights to various system variables (Liu et al., 2020). As a result, the Fuzzy Analytic Hierarchy Process method is utilized in this study to rank the most critical challenges in green construction in Canada.

AHP/Fuzzy AHP has the potential to produce better results than other decision analysis methods, such as fuzzy ANP/ANP, ELECTRE, and fuzzy TOPSIS/TOPSIS, which have their limitations in terms of acceptability and complexity (Torfi, Farahani, & Rezapour, 2010).

The fuzzy AHP analysis criteria and sub-criteria are identified based on the literature review and expert opinions. The criteria and sub-criteria are developed to capture the various aspects of Canada's green building challenges. The identified criteria and sub-criteria are hierarchically organized to form a decision tree.

In this research, each category of challenges and their relative importance are calculated using fuzzy AHP. The following are the steps of the Fuzzy AHP:

Step 1: Choosing a scale of judgment

In this step, a scale was employed to enable comparisons between challenges. Most research employs Saaty's 1–9 scale. This study uses TFNs to create a linguistic scale of relative importance, as shown in Table 2-1.

Table 2.1 The scale of judgment used to evaluate the responses (Liu et al., 2020)

Judgment linguistic definition	Saaty's scale defined values (x)	TFNs
Weakly important	1	(1, 1, 3)
Fairly important Medium	3	(1, 3, 5)
Highly important	5	(3, 5, 7)
Absolute dominance	7	(5, 7, 9)
Absolutely important	9	(7, 9, 11)

Step 2: Creating the matrix of pair-wise comparisons

An evaluation matrix is built on the basis of these comparisons. The sum of the responses can be used to build the pair-wise assessment matrix. Average, geometric, and range techniques are typically used to collect the responses. In this analysis, the experts' perspectives are averaged out.

Step 3: Calculating values for each challenge's weight

In order to rank the importance of the challenges, extent analysis technique established by Chang was used (Chang, 1996). In this method, TFNs are used at all levels of the hierarchical structure to depict matrices of pair-wise subjective judgements, as shown in the following phrase.

Assume that the object set $O = \{o_1, o_2, \dots, on\}$ and the goal set $U = \{g_1, g_2, \dots, g_m\}$ are two sets of data. Each object is evaluated independently under Chang's extent analysis, and then the analysis is performed for each object in terms of all possible goals gi. As a result, (3.2) is used to calculate the values of m for each extent analysis.

$$\widetilde{M}_{g_i}^1, \widetilde{M}_{g_i}^2, \dots, \widetilde{M}_{g_i}^m, i = 1, 2, \dots, n \quad (3.2)$$

In this context, all the numbers $\widetilde{M}_{g_i}^j (j = 1,2,3, \dots, m)$ are TFNs. $M_{(x)}$ stands for the TFN's membership function. Regarding the ith object, the value of fuzzy synthetic extent is represented as (3.3)

$$Si = \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}\right]^{-1} \tag{3.3}$$

Where $\otimes$ represents the result of multiplying two fuzzy numbers using the extended multiplication operator. Using (3.4), we add m values of the extent analysis for a specific matrix to obtain $\sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}$.

$$\sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j \,, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{3.4}$$

We then perform the fuzzy addition operation of $\widetilde{M}_{g_i}^{j}$ $(j = 1,2,\dots,m)$ values according to (3.5)

to obtain $[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}]^{-1}$.

$$\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} = \left(\sum_{i=1}^{n} l_i \,, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{3.5}$$

Afterward, using (3.6), we can find the inverse of the vector.

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i} \,, \frac{1}{\sum_{i=1}^{n} m_i,} \,, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{3.6}$$

In this case, u_i, m_i, and l_i are positive values $(u_i, m_i, l_i > 0)$.

Using (3.7), we can finally calculate Sj.

$$Sj = \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{g_i}^{j}\right]^{-1}$$

$$= \left(\sum_{j=1}^{m} l_j \otimes \sum_{i=1}^{n} l_i \,, \sum_{j=1}^{m} m_j \otimes \sum_{i=1}^{n} m_i \,, \sum_{j=1}^{m} u_j \otimes \sum_{i=1}^{n} u_i\right) \tag{3.7}$$

Step 4: Defuzzified Score Computation

Using (3.8), we can define the degree of possibility of $\widetilde{M}_2 = (l_2, l_2, l_2) \geq \widetilde{M}_1 = (l_1, m_1, u_1)$.

$$V\,(\widetilde{M}_2 \geq \widetilde{M}_1) = sup[\,min\,(\widetilde{M}_1(x)\,, \widetilde{M}_2\,(y))] \tag{3.8}$$

Alternatively, this can be written as (3.9)

$$V\ (\widetilde{M}_2 \geq \widetilde{M}_1\ ) = hgt\ (\widetilde{M}_1 \cap \widetilde{M}_2) = \widetilde{M}_2\ (d) = \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \tag{3.9}$$

For the abscissa value d and $m_1 < l_1 < u_2 < m_1$, Figure 2-1 shows the value of $V(\widetilde{M}_2 \geq \widetilde{M}_1)$ for the maximum crossover point D between $\widetilde{M}_1$ and $\widetilde{M}_2$.

$V(\widetilde{M}_1 \geq \widetilde{M}_2)$ and $V(\widetilde{M}_2 \geq \widetilde{M}_1)$ must both be known in order to make a valid comparison between $\widetilde{M}_1$ and $\widetilde{M}_2$.

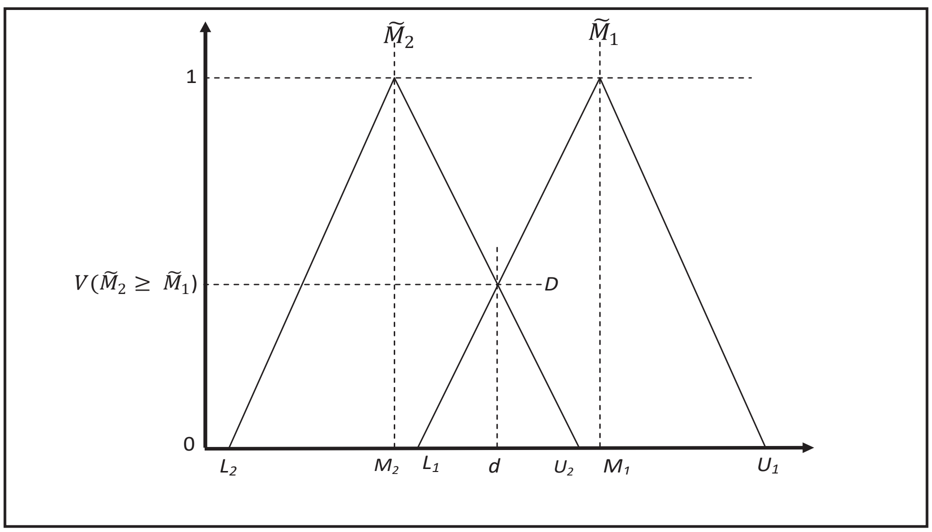

Figure 2.2 The degree of possibility related to $\widetilde{M}_1 \geq \widetilde{M}_2$

A convex fuzzy number has a higher probability of being larger than k other convex fuzzy numbers of $M_i(i = 1, 2 \ldots K)$, which is defined using (3.10).

$$V\left(\widetilde{M} \geq \widetilde{M}_1, \widetilde{M}_2, \ldots, \widetilde{M}_k\right) = \min V\left(\widetilde{M} \geq \widetilde{M}_i\right), \quad i = 1, 2, \ldots, k \tag{3.10}$$

In conclusion, the weight vector can be identified by using Equation (3.11).

$$W = [min\ V(S_1 \geq S_k), min\ V(S_2 \geq S_k), \ldots, min\ V(S_n \geq S_k)]$$

Where, $k = 1, \ldots, n$. (3.11)

2.6.1 The consistency test on the pair-wise comparison matrix

Due to the inherent fallibility of humans, fuzzy AHP tolerates a degree of judicious inconsistency. The consistency index and the ratio scales originate from the principal Eigenvalue and principal Eigenvector, respectively. The ratio is used to determine whether or not criterion values are consistent with one another.

It is attainable to determine both the consistency index (CI) and the consistency ratio (CR) with the use of (3.12) and (3.13) (Pant, Kumar, Ram, Klochkov, & Sharma, 2022).

$$CI = \frac{(\lambda max - n)}{n-1} \tag{3.12}$$

$$CR = \frac{CI}{IR} \tag{3.13}$$

Where, n is the dimension of the matrix and λmax reveals the eigenvalue that corresponds to the most significant Eigenvector or relative weights of the comparison matrix. The consistency matrix is considered reliable as long as the CR is under 10%. This limit can be adjusted depending on the issue's specific circumstances and the level of tolerance of those in charge of decision-making.

2.6.2 Sensitivity analysis

A sensitivity analysis is performed in order to assess how reliable the results are. Chang has developed an extended analysis of fuzzy AHP that includes a sensitivity analysis of the weights of the criteria and sub-criteria. When conducting a sensitivity analysis, it is common practice to make small adjustments to the values used in the pair-wise comparison matrix and then see how that affects the overall rankings. For this purpose, the weights are changed within a certain range while focusing at the way the priority of the challenges changes (Chang, 1996). The purpose of the sensitivity analysis is to ascertain the consistency of the ranking and to identify any potential biases or inconsistencies in the weights assigned to the criteria and the sub-criteria. Applying the results of the sensitivity analysis to the process of fine-tuning the weights can improve the overall ranking's accuracy.

2.7 Semi-structured interviews

The purpose of the semi-structured interviews was to discover about the practices employed to respond to the major challenges in green building projects and to provide answers to the research questions. The semi-structured interviews with green building contractors focus on their management practices for responding the critical challenges identified in the previous sections.

The considered time for semi-structured interviews were calculated to be 30 minutes; however, depending on the respondents' pace of talking and points of views, each interview took from 20 minutes to 35 minutes. It should be noted that some respondents were interested to know more about the research topic and asked some questions about it that were not counted in the interview's duration or transcript.

This methodology can provide valuable insight into the management practices used to respond to the most critical challenges in Canada. The open-ended interview questions encouraged participants to share their experiences and perspectives. Questions centered on the following topics derived from the questionnaire (ANNEX I) results:

1. Management practices used to respond to the critical challenges identified in the literature review and fuzzy AHP analysis
2. Challenges and enablers to the implementation of these management practices
3. The effectiveness of these management practices in addressing the critical challenges in green construction projects

Each interview question was put through a series of pre-tests to guarantee that it was easy to understand and would yield valuable data. Two green building contractors who were not included in the sample group participated in the preliminary testing.

All the interviews were recorded and later typed up word for word. The data were analyzed using a thematic analysis strategy. Learning the data, coding it, finding commonalities, and concluding were all parts of the analysis process. First, the transcribed data was coded into meaningful segments, and then, themes were identified using the research questions and the study's goals. The researcher reviewed the identified themes to ensure they were still applicable and in line with the research objectives.

Furthermore, inconsistencies or discrepancies between the interviews and the fuzzy AHP analysis were identified by comparing the two data sets. Participants' identities were kept confidential, and their data was used exclusively for scientific analysis. The researcher was the only one accessing the audio recordings and transcripts.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Introduction

This section presents the results of the study's analysis and interpretation, addressing the research questions and objectives stated in the introductory section. This chapter summarizes the literature review results, the fuzzy AHP analysis, and the semi-structured interviews with green building contractors. This research should highlight the most critical challenges and practices for advancing green building initiatives in the building sector.

3.2 Identified challenges in green construction industry

The initial search resulted in 556 articles vetted for relevance to the research topic. From the publications examined, 76 studies were chosen based on their relevance to the topic of the study. Within the initial list of 232 challenges to green construction, a number of duplicates and contextually similar challenges were found. To address this issue and streamline the list, a focus group meeting was held to identify overlapping challenges, in accordance with the statements made by Morgan and Krueger (1998) (Morgan & Krueger, 1998). The results of the systematic literature review were presented with validation from a focus group discussion.

The focus group procedure is depicted in Figure 3-1. After a brief presentation by the author showing the results of the initial systematic review, participants in the focus groups were asked to provide feedback on a topic. It was also asked of the focus group if they agreed with the categorization of green construction challenges as market trend, financial, technology-related risks, time-related, government-related, and construction process-related challenges.

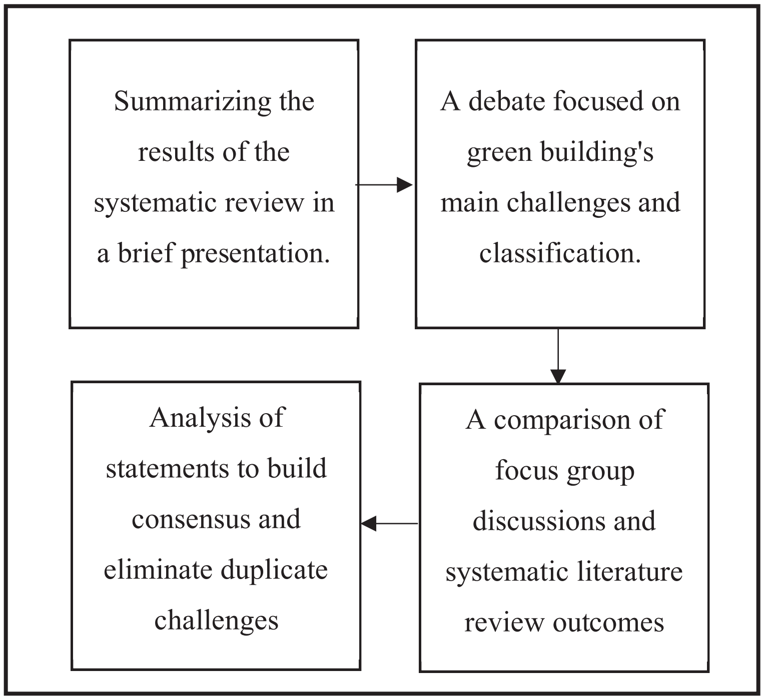

Figure 3-1 Focus group procedure

In the result of all the mentioned steps, 34 green construction challenges were revealed from initial list of 232 challenges. These challenges are the result of combining and refining the initial list of challenges taking into account their similarities and redundancies. It is important to note that the specific nature of these challenges and their potential responses will depend on the context of the construction project and the particular objectives of green construction.

The thirty-four challenges were divided into six main groups. Table-A II-1 shows the challenges of green construction in Canada.

The discovered challenges were divided into six groups based on the literature's familiar themes: market trend challenges, financial challenges, technology-related challenges, time-related challenges, government-related challenges, and construction process-related challenges.

Market trend challenges included a lack of interest and market demand for green buildings, benefit conflicts with competitors, and reluctance to migrate from conventional to green approaches. Financial challenges included complex building expenses and legislation to evaluate cost-benefits, higher costs than anticipated, and the need for more funding schemes. Technical challenges included insufficient knowledge of green building practices among project staff, a lack of appropriate green building materials and tools, and the absence of established green technology standards. Extended pre-construction time requirements, meeting deadlines, and delays caused by green construction all posed scheduling challenges. Among the government-related issues are the need for more government incentives, a lack of green building standards and regulations, grading systems, and labelling. Planning multiple construction sequences, finding reliable subcontractors to provide green construction services, and keeping up with expanding responsibilities during the maintenance phase were most challenges that needed to be overcome during construction. Overall, the literature review provided a framework for identifying the key challenges confronting Canada's green construction industry.

3.3 Finalization and validation of the identified challenges

The survey results with experts and a review of the current literature yield a total of thirty-four challenges classified into six distinct categories. According to Lawshe (1975, considering the opinions of 10 experts, a CVR of 0.37 or higher is necessary for content validity) (Almanasreh, Moles, & Chen, 2019; Lawshe, 1975). The fuzzy AHP phase only includes challenges with a CVR of 0.37 or higher; those with a crisp score of less than 0.37 were removed. Table 3-1 reveals the findings from the literature review phase of the study.

Table 3.1 CVR values of challenges

Criteria	Sub-criteria	CVR values
Market trend challenges	MA1	0.76
	MA2	0.92
	MA3	0.84
	MA4	0.68
	MA5	0.76
	MA6	0.76
	MA7	0.92
	MA8	0.68
	MA9	0.76
	MA10	0.52
	MA11	0.76
	MA12	0.60
Financial challenges	FI1	0.68
	FI2	0.76
	FI3	0.52
	FI4	0.76
	FI5	0.92
	FI6	0.60
Technological risks	TE1	0.68
	TE2	0.52
	TE3	0.76
	TE4	0.68
	TE5	0.60
	TE6	0.84
	TE7	0.60
Time-related challenges	TI1	0.52
	TI2	0.76
	TI3	0.76

Criteria	Sub-criteria	CVR values
Government-related challenges	GO1	0.68
	GO2	0.76
Construction process-related challenges	CO1	0.76
	CO2	0.60
	CO3	0.68
	CO4	0.76

According to Table 3-1, no challenge has had a CVR lower than 0.37, and thus no challenge was removed from consideration. Although the experts were allowed to suggest changes to the list, they generally agreed on the validity of the 34 challenges identified in the previous review of the relevant literature. All 34 challenges were thus confirmed and selected for further investigation.

3.4 Respondents' profile

Ten individuals working for general contractor companies in Alberta, British Columbia, Ontario, and Quebec provinces, who had at least five years of industry experience in green construction practices accepted to participate in this survey which has been explained in the methodology (chapter 2). This sample size is enough for the objectives of the present case study (Mavi, 2015; Oluleye, Ogunleye, & Oyetunji, 2021; Sirisawat & Kiatcharoenpol, 2018; S. Xu & Sun, 2021). Respondents' demographics are listed in Table 3-2. Respondents were conveniently sampled based on their level of interest in taking part, and their information was obtained from an official database.

Table 3.2 Respondents’ demographics

Category	Position/Value	No. (%)
Degree of education	Bachelor	8
	Master	2
Organization	Public sector	7
	Private sector	3
Work experience (year)	5-10	3
	10-20	4
	>20	3

3.5 Fuzzy AHP results

As a result of consultation with field experts, a hierarchical framework for this study has been developed. The developed decision hierarchy has three levels: first, prioritizing the challenges to green construction; second, categorizing those challenges into six groups; and third, identifying the importance ranking of thirty-four specific green construction challenges. A hierarchy of the objectives of the presented study is presented in Figure 3-2.

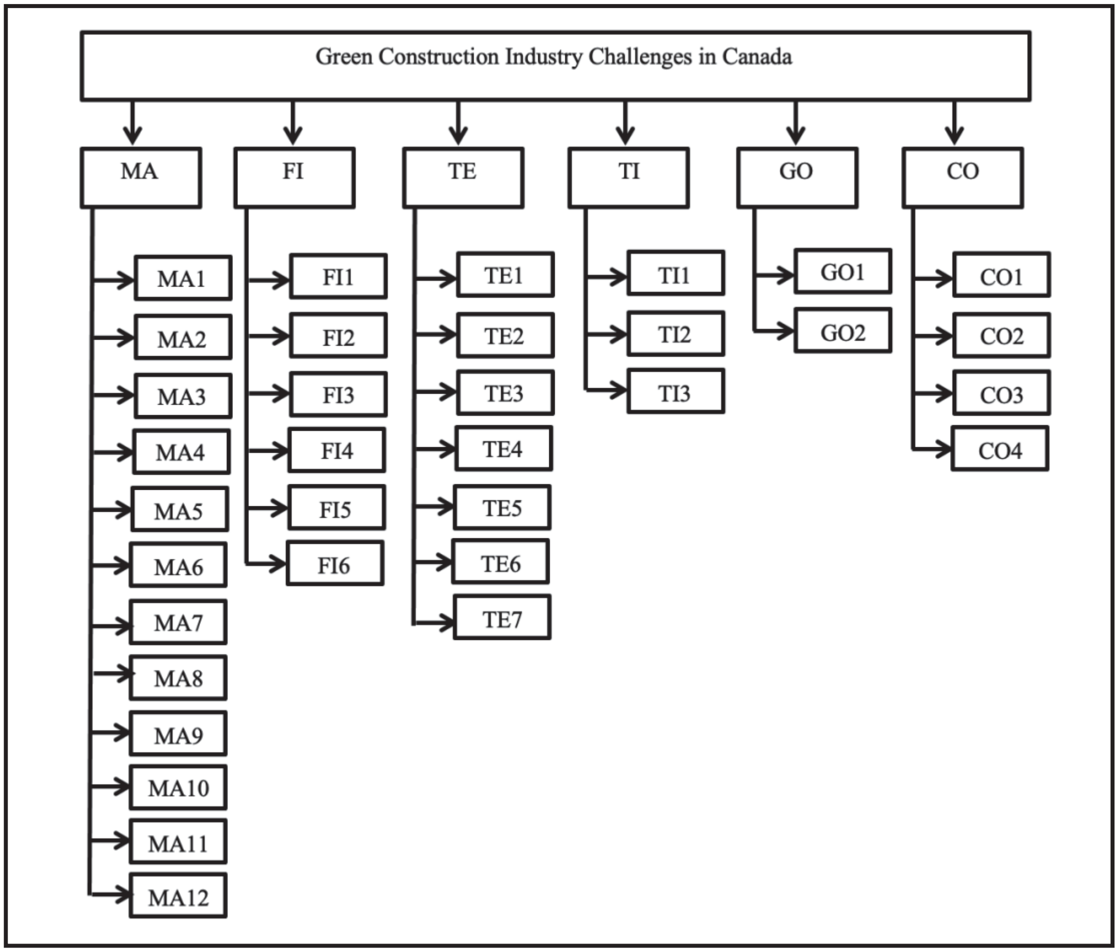

Figure 3.2 The decision-making hierarchy for prioritizing green construction industry challenges in Canada

3.5.1 The Construction of the Fuzzy Pair-wise Evaluation Matrix

After the hierarchy model was complete, pair-wise assessment matrices were also formulated. A panel consisting of ten contractors that were introduced in part 3.4 and table 3-2, agreed to finalize the variables and provided their opinion. The values of the linguistic variable were used to form expert-input pair-wise assessments of the challenges. Linguistic variables provide decision-makers with a means to articulate their preferences using qualitative terms, which can then be converted into fuzzy numbers. These variables have the ability to represent a range of judgments. Table 3-3 displays the final fuzzy pair-wise comparison matrix applied to the Eqns. 2-6 to compute the weight assigned to each category of challenges.

Table 3.3 The formation of the fuzzy pair-wise comparison matrix

	MA			FI			TE			TI			GO			CO		
MA	1.00	1.00	1.00	0.60	0.85	1.43	1.47	1.85	2.14	1.07	1.51	2.22	1.83	2.68	3.96	1.09	1.54	2.10
FI	0.7	1.2	1.67	1.00	1.00	1.00	0.58	0.84	1.33	0.64	1.05	1.73	1.43	2.08	2.61	1.01	1.71	2.5
TE	0.47	0.54	0.68	0.75	1.19	1.72	1.00	1.00	1.00	0.30	0.50	0.70	0.35	0.50	0.78	0.25	0.34	0.50
TI	0.45	0.66	0.93	0.58	0.95	1.56	1.43	2.00	3.33	1.00	1.00	1.00	1.49	2.23	3.57	0.72	0.99	1.35
GO	0.25	0.37	0.55	0.38	0.48	0.70	1.28	2.00	2.86	0.28	0.43	0.67	1.00	1.00	1.00	0.51	0.79	0.36
CO	0.48	0.65	0.92	0.40	0.58	0.99	1.89	2.94	4.00	0.74	1.01	1.38	2.8	1.27	1.98	1.00	1.00	1.00

Using Eqns. 12 and 13, the consistency of all the relative matrices found in this analysis was verified. It is determined that the consistency ratio is below 0.1, which is considered an acceptable value for consistency. Consistency checks are conducted in order to assure the coherence of these Fuzzy assessments and to prevent the occurrence of contradictory outcomes.

3.5.2 Preference weight values for challenges and their relative significance

Using Chang's Extent Analysis technique, preference weights were assigned to each category and the associated specific challenges. Using (2.7), the normalized row sum for each significant category of the challenge was calculated.

Table 3-4 provides an overview of the normalized row-sum values. Eqns. 10 and 11 are then used to calculate the relative weights.

Table 3.4 Normalized sums of rows for the categories of six critical challenges

	l	m	u
S_1	0.1234	0.2260	0.3988
S_2	0.0937	0.1888	0.3364
S_3	0.0545	0.0975	0.1670
S_4	0.0991	0.1876	0.3644
S_5	0.0647	0.1215	0.1906
S_6	0.1278	0.1785	0.3187

As listed in Table 3-5, the weight vectors for the various categories of challenges have been calculated, as well as identifying their relative importance and the global weights and rankings.

Table 3.5 Calculated relative weight and global ranking for the various categories of challenges

Fuzzy weight	Criteria	Ranking	Global weights	Global ranking
0.2402	MA1	7	0.0353	15
	MA2	9	0.0243	21
	MA3	2	0.0584	2
	MA4	6	0.0378	11
	MA5	12	0.0047	31
	MA6	8	0.0316	16
	MA7	11	0.0131	27
	MA8	5	0.0408	10
	MA9	4	0.0508	6
	M10	3	0.0567	3
	MA11	10	0.0204	23
	MA12	1	0.0622	1
0.2045	FI1	3	0.0429	9
	FI2	2	0.0452	8
	FI3	1	0.0530	5
	FI4	5	0.0376	13
	FI5	4	0.0378	12
	FI6	6	0.0272	18

Fuzzy weight	Criteria	Ranking	Global weights	Global ranking
0.0609	TE1	2	0.0144	25
	TE2	5	0.0072	30
	TE3	1	0.0158	24
	TE4	3	0.0132	26
	TE5	7	0.0032	33
	TE6	4	0.0117	28
	TE7	6	0.0044	32
0.2072	TI1	2	0.0271	19
	TI2	3	0.0006	34
	TI3	1	0.0537	4
0.094	GO1	2	0.0096	29
	GO2	1	0.0243	20
0.1932	CO1	2	0.0354	14
	CO2	3	0.0276	17
	CO3	1	0.0500	7
	CO4	4	0.0218	22

The market trend challenge is the most critical category of challenges in green construction industry, with a relative weight of 0.2402 (out of a possible 1.00). The analysis revealed that time-related challenges were the second most significant (0.2072), followed by financial (0.2045), construction process-related (0.1932), government-related (0.094), and technological challenges (0.0609).

3.6 Market Trend Challenges

The market trend toward green practices is selected as of the main categorized challenge against the adoption of green buildings. ‘Market trend’ refers to the challenges raised by the attitude that existed amongst the construction industry against practicing green construction. For the market trend challenges, the AHP analysis results are displayed in Table 3-6. According to the results of a Fuzzy AHP analysis, the most critical challenge in this category is the "risks and uncertainties associated with the adoption of new technologies" (MA12), with an importance weight of 0.143. This confirms prior studies' findings that new technology risks

and uncertainties were a severe challenge to the widespread application of various green construction practices (Aliagha et al., 2013). Williams and Dair (2007) reported that one of the most commonly cited challenges to achieving sustainability is the lack of consideration given to sustainability measures by stakeholders (Williams & Dair, 2007). This is often due to stakeholders perceiving risks and uncertainties associated with green construction projects (B.-g. Hwang, Shan, & Supa'at, 2017; Rafindadi, Mikić, Kovačić, & Cekić, 2014).
With a weight of 0.134, "conflicts in benefits with competitors" (MA3) is another crucial sub-criterion. Contractors may feel compelled to use conventional methods and less green materials when they observe their competitors doing the same in order to remain competitive. This is often due to the perception that such methods are less costly. This emphasizes the significance of competitive pressure in the construction industry, which may discourage the use of green construction practices due to concerns that they will raise project costs or lower profit margins, as shown in previous studies (MS Hasan & Zhang, 2016; Shi et al., 2013).

Among the criteria, "lack of awareness about the benefits" (MA10) has the third highest weight, at 0.130. Bilec et al. (2007) emphasized that civil engineers play a critical role in increasing awareness among owners and contractors regarding the benefits of adopting green practices. This is particularly important because the stakeholders may be unfamiliar with the financial and environmental advantages associated with green buildings (Bilec, Ries, & Matthews, 2007).

Limited experience with the use of unconventional procurement methods (MA9) is another significant challenge to the adoption of green construction, with a weight of 0.116. This challenge may cause more difficulty during the procurement stage when an especial specification is issued by the owner and the contractors are not willing to bid due to lack of knowledge.

In addition, misunderstanding green technologies (MA8) and resistance to change from conventional to green practices (MA4) both received relatively high importance weights of 0.094 and 0.087, respectively. Adopting green practices in the construction industry may be hampered by stakeholders' lack of knowledge and experience with green construction practices, such as procurement methods and technologies. In addition, lack of demonstration projects, technical procedures, and frameworks (MA11) is another challenge with a relative weight of 0.047 (Shi et al., 2013). A construction enterprise may reject the proposed green material by the contractor in the procurement stage when they are unfamiliar with a certain product (B.-G. Hwang & Ng, 2013; RezaHoseini, Noori, & Ghannadpour, 2021).

On the other hand, "lack of communication among the stakeholders" (MA5) received the lowest importance weight of 0.011, making it the least critical challenge in this category. Nonetheless, it is a crucial challenge that must be solved to guarantee efficient cooperation and coordination among key stakeholders. Contractors and suppliers, according to Shen et al. (2017), should be brought in on construction projects early on, so that they can apply their expertise in resolving environmental concerns related to construction activities and materials (Shen, Zhang, & Long, 2017). According to Yin et al. (2018), open lines of communication and active participation from all parties involved are crucial for a sustainable project's ultimate success (Yin, Laing, Leon, & Mabon, 2018).

Table 3.6 Results of fuzzy AHP analysis for market trend challenges

Criteria	Fuzzy Weight	Normalized Weight	Ranking
MA1	0.568	0.081	7
MA2	0.390	0.056	9
MA3	0.939	0.134	2
MA4	0.608	0.087	6
MA5	0.076	0.011	12
MA6	0.508	0.072	8
MA7	0.211	0.030	11
MA8	0.656	0.094	5
MA9	0.817	0.116	4
MA10	0.912	0.130	3
MA11	0.328	0.047	10
MA12	1.000	0.143	1

Overall, the findings suggest that developing green construction practices in Canada requires responding to risks and uncertainties associated with adopting new technologies and the stakeholders' knowledge, awareness, and experience with green construction practices and technologies.

3.7 Financial Challenges

The financial challenges associated with green construction in Canada can significantly influence the decision-making process of project investors and project owners. In the construction industry, cost efficiency is a major factor in decision-making (Meryman & Silman, 2004). The results of the fuzzy AHP analysis are presented in Table 3-7, which includes the criteria, sub-criteria, fuzzy weights, and ranks for each sub-criterion.

With a weight of 0.217, the criterion with the highest weight is the additional cost required due to lengthy construction time (FI3). This indicates that the time required to construct green buildings can affect the financial aspect of a project. A longer construction duration can result in increased labor and material costs, which can significantly influence the overall project budget. According to Hwang (2018), this time difference is the result of the critical parties' lack of familiarity with green concepts, which in turn leads to change orders in the project, which in turn means a delay in the project (B. Hwang, 2018). While only 17.39% of conventional projects experienced a delay, 33.33% of green projects did, according to research by Hwang and Leong (2013) (Bon Gang Hwang & Leong, 2013).

Higher cost than budget/higher cost of materials (FI2), with a weight of 0.185, is the sub criteria with the second-highest weight. This sub criteria highlights the difficulties associated with estimating and controlling green construction costs. The use of sustainable materials and technologies can increase the initial construction cost, which can be problematic for project owners with budgetary constraints. Another factor contributing to the higher cost of green practices is a lack of required expertise in green practices, which leads to an unnecessary increase in project costs because key members of the team are unable to use green practices efficiently (Malin 2000). In addition, the cost of construction is likely to rise as a result of reworks and change orders necessitated by a lack of familiarity with green standards (B. Hwang, 2018).

Complex building costs and regulations to evaluate cost benefits (FI1) weights 0.176, indicating that it is also a significant factor in the financial difficulties of green construction. Green construction necessitates a thorough evaluation of the cost benefits, which can be difficult due to the complexity of green construction costs and regulations. One of the primary reasons for the cost premiums between green and conventional construction projects is that owners face this challenge, making it difficult for them to adopt green building practices. When the design and construction of the project become more complicated due to the objective of the project, this cost can affect both the cost and productivity of the project (Ofori & Kien, 2004).

The availability of financial support mechanisms is an essential consideration for the success of green construction projects, and the absence of such schemes (e.g., bank loans) (FI4) weights 0.154. As the initial challenge to adopting innovative ideas such as green initiatives, the availability of more financial schemes including loans can assist decision-makers to overcome this challenge. This is supported by prior research from two distinct countries (Lam, Chan, Poon, Chau, & Chun, 2010; Ofori & Kien, 2004).

Higher investment cost/long duration of ROI (FI5) weights 0.155, indicating that this criterion can be a significant challenge for project owners and investors in green construction due to the extended time required to generate a return on investment. Green construction can require a more significant initial investment than conventional construction, and it can take longer to recoup that investment, resulting in more significant financial risks (Qi, Shen, Zeng, & Jorge, 2010).

Finally, the weight of 0.112 assigned to the challenge Separation of capital and operational costs (FI6), suggests that this can be another significant challenge to overcome in green construction projects. Initial capital expenditures for green construction are higher, but lower operational expenditures can offset these costs over time. However, the separation of capital and operating costs can make it challenging for project owners and investors to assess the long-term benefits of green construction.

Table 3.7 Results of fuzzy AHP analysis for financial challenges

Sub-Criteria	Fuzzy Weights	Normalized Weights	Rank
FI1	0.810	0.176	3
FI2	0.853	0.185	2
FI3	1.000	0.217	1
FI4	0.710	0.154	5
FI5	0.714	0.155	4
FI6	0.513	0.112	6

The financial challenges associated with it in Canada can significantly influence green construction projects' success. Project owners and investors can better evaluate the economic viability of green construction projects and the associated challenges by considering these criteria during the decision-making process.

3.8 Technological Challenges

Defeating the category of technological challenges is essential for the success of green building projects in Canada. To perform the sub-criteria analysis, we used the AHP fuzzy weighting approach. Table 3-8 displays the outcomes of the fuzzy AHP analysis.

The lack of mature green technology specifications (lack of comprehension) (TE1), the absence of local institutes for research and development (TE4), and the availability of green material and equipment and suppliers (TE3) are the three criteria with the highest combined weight of 0.226. Materials and equipment that are environmentally friendly are absolutely necessary in order to achieve green construction (Shi et al., 2013). One factor that may contribute to the difficulty of implementing green building practices is the lack of supply of certified materials for use in green construction. Access to green building materials, equipment, and suppliers can have a major impact on the outcome of green construction projects (TE3). Obtaining green materials and equipment may be challenging, which may cause delays, increased costs, and a lower quality product. Therefore, it is crucial to locate reliable suppliers and guarantee the availability of materials and equipment.

The second most important factor is the lack of mature green technology specifications (lack of comprehension) (TE1). Related to this criterion is (TE5), the lack of green building technological training for project staff, which has the lowest weight of all the criteria at 0.046. In light of these standards, it is clear that green construction projects must invest heavily in training and education for all involved parties.

When evaluating the advantages and disadvantages of investing in research and development to catalyze the development of new green technologies and materials, the absence of local institutes for research and development (TE4) is the third most important factor to consider. This criterion highlights the role that government policies and funding play in accelerating the development of green technologies and the widespread adoption of green construction practices.

There is less emphasis placed on the need for more green building technology (TE7), the lack of databases and information (TE6), and the uncertainty in the performance of green materials and machinery (TE2). However, these criteria's sub-criteria also need consideration and focus on green building projects.

Table 3.8 Results of fuzzy AHP analysis for technological challenges

Sub-criteria	Fuzzy weight	Normalized weight	Ranking
TE1	0.913	0.206	2
TE2	0.456	0.103	5
TE3	1.000	0.226	1
TE4	0.836	0.189	3
TE5	0.203	0.046	7
TE6	0.741	0.167	4
TE7	0.282	0.064	6

The results suggest that technological challenges are a significant barrier to Canada's widespread use of green building methods. The findings point to increased funding for research and development, educational and training initiatives, and the development of trustworthy supply chains for greener products. These measures can aid in overcoming the challenges identified in this criterion and facilitate the successful implementation of green construction projects.

3.9 Time-related Challenges

It is crucial to consider time-related issues in green construction since they can significantly influence project outcomes. The identified criteria for this category include more extended pre-construction time requirements (TI2), total time brought on by green construction due to approvals (TI1) and meeting the schedule/cause delay (TI3). In Table 3-9, the results of the fuzzy AHP analysis for time-related challenges are presented.

According to Chan and Kumaraswamy (2002), the construction project schedule is a significant performance indicator (Chan & Kumaraswamy, 2002). Completing and delivering the project on time is a primary concern for builders, owners, and contractors in nearly every nation (Ofori & Kien, 2004). One of the most common reasons for construction time and expense overruns is unexpected delays (Arditi & Pattanakitchamroon, 2006). Meeting the schedule/cause delay (TI3) is the main challenge, with a weight of 0.66, according to the fuzzy weights. This finding suggests that keeping to the project schedule is a major challenge for green construction projects. Any delays can have significant cost implications, leading to increased project risks, which may hinder the project's success (Marandi Alamdari et al., 2023).

A weight of 0.333 indicates that the additional time required for green construction due to approvals (TI1), is a challenge of moderate importance. This difficulty refers to the time required to obtain approvals and permits for the green construction project, which may delay completion. It is important to note that obtaining permits and approvals for green construction projects can be more challenging due to their unique requirements, which may result in additional time.

The increased time needed for the construction's pre-construction phase (TI2) carries the least weight at 0.007. This challenge is related to the time required to plan and prepare for the green construction project before beginning the construction process. Even though it poses the least significant risk, pre-construction delays can have a negative impact on the project's budget and schedule (Shi et al., 2013).

Table 3.9 Results of the fuzzy AHP analysis for time-related challenges

Sub-criteria	Fuzzy Weight	Normalized weight	Ranking
TI1	0.505	0.333	2
TI2	0.011	0.007	3
TI3	1.000	0.660	1

In conclusion, it is essential to consider time-related challenges in green construction during project planning and implementation. The fuzzy weights indicate that meeting the project's timeframe poses a significant challenge, followed by the additional time caused by green construction due to approvals. Timely completion of the project requires careful planning and management on the part of project managers and stakeholders, as well as the implementation of measures to mitigate the delay caused by approvals.

3.10 Government-related Challenges

Government-related challenges to green construction include inadequate incentives and a need for more policies, regulations, rating systems, and labeling. The success and timeliness of green construction projects can be affected by these factors. The results of a fuzzy AHP analysis of government-related issues are presented in Table 3-10.

Insufficient government incentives (GO1) were assigned a weight of 0.282, indicating that it is a moderately significant obstacle. Due to the perception of high costs and a lack of financial returns, this factor may discourage private sector investment in green building projects. Government incentives, such as tax credits and rebates, can assist in offsetting these costs and encouraging investment in green building practices. The absence of incentives may be due to a lack of political will or budgetary restrictions.

The lack of green building policies and regulations/rating systems and labeling (GO2) is given a weight of 0.718, indicating that it poses a substantial challenge. The establishment of green building standards and guidelines is dependent on government policies and regulations. Uncertainty about return on investment for green building projects may be reduced if developers and builders are given clear standards to adhere to. In addition, consumers can benefit greatly from rating systems and labels, which can inform them of important information and aid them in making environmentally sound purchases. The growth of the green construction industry could be stunted if these systems led to a reduction in interest in and demand for green construction.

Table 3.10 Fuzzy AHP analysis results for government-related challenges

Sub-criteria	Weighted Score	Normalized weight	Ranking
GO1	0.393	0.282	2
GO2	1.000	0.718	1

In conclusion, the absence of government support in the form of incentives, policies, regulations, and rating systems is a considerable challenge that can significantly influence the success of green construction projects. Providing incentives, establishing regulations, and promoting green building practices are all critical roles the government plays in creating a favorable situation for green buildings.

3.11 Construction Process-related Challenges

Construction process-related challenges are those that arise during the building of a green constructions. Two crucial aspects of green building are post-construction liability protection and construction insurance. Costs associated with maintenance are high because the energy used in maintenance accounts for about 12% of total construction (Thormark, 2002). The outcomes of the fuzzy AHP analysis for the construction process sub-challenges are shown in Table 3-11.

Based on the weights assigned to the individual criteria, the most significant challenge in this area is handling design changes and variations during the construction process (CO3), weighted at 0.371. As a result, it appears that making modifications to the design is not only a hassle, but also adds unnecessary expenses to the overall project budget. With a weight of 0.262, sequential construction planning issues (CO1) represent the next most significant challenge. This challenge may arise due to new and innovative green technologies, which demand a particular construction sequence for optimal results. With a weight of 0.205, selecting subcontractors (CO2), is also a significant challenge when providing green construction services. This suggests that locating a subcontractor with the required expertise and experience in green construction is difficult, which can result in project delays and cost increases.

The subcriteria with the lowest weight is the additional responsibilities for the maintenance stage (CO4), which weights 0.162. This challenge may result from the use of green technologies, which may require more maintenance and upkeep than conventional technologies.

Table 3.11 Results of the fuzzy AHP analysis for
the construction process-related challenges

Sub-criteria	Fuzzy weight	Normalized weight	Ranking
CO1	0.707	0.262	2
CO2	0.552	0.205	3
CO3	1.000	0.371	1
CO4	0.436	0.162	4

Overall, the construction process-related challenges can substantially affect the budget and schedule of a green building project. In order to finish the project on time and under budget, it is essential that careful planning and management of the construction process be implemented.

Analyzing the construction process's issues provides insightful information regarding the obstacles contractors face when implementing green building projects. To implement green building practices better, contractors can formulate strategies to counteract the significant challenges.

3.12 Interviews

This section presents the findings from ten semi-structured interviews with green building contractors which has been explained in the methodology (chapter 2). The interviews were conducted to supplement the fuzzy AHP's quantitative analysis with a qualitative view of the challenges and responses encountered by green building contractors. The purpose of these interviews was to collect data for this study and discover common themes and patterns in the contractors' responses to better understand the elements that contribute to the success or failure of green building projects.

The interviews highlighted the necessity of stakeholder engagement and communication, a holistic project management strategy, the challenges of balancing costs and environmental sustainability, government incentives and restrictions, and contractor and client education and training.

These interviews provide essential information for future green building projects and can inform policies and practices that support green building.

3.12.1 Practices to address market trend challenges

Contractors in the green construction industry were interviewed to gain insight into the specific strategies they employ to meet the sub-criteria of the market trend challenges revealed by the fuzzy AHP analysis. The contractors' comments were reviewed to determine the responses and practices employed to deal with the challenges.

Contractors cited client education and promotion of sustainable design as solutions to the need for more interest and market demand requirements. "It is attempted to inform clients about the advantages associated with green buildings, such as energy savings, health benefits, and greater marketability," said one contractor. Another option discussed was providing clients that choose to develop green with financial incentives or refunds. These incentives may be offered by governmental entities, local municipalities, or utility companies in order to promote and incentivize the adoption of sustainable building practices. For instance, a local government may offer tax incentives or rebates to developers who comply with green building standards, while utility companies may provide reduced rates to buildings that have lower energy consumption.

Contractors stressed the importance of open lines of communication between project teams and management in response to the absence of management support and inadequate time management as a sub-criteria. As one contractor expressed, having open lines of communication between the project team and management is crucial for everyone to be on the same page. Contractors also underlined the significance of being adaptable and having reasonable deadlines.

Contractors have pointed out the necessity to set themselves apart from rivals by emphasizing the benefits of green building in response to the conflicts in benefits with competitors' sub-criteria. According to one contractor, "We promote the benefits of green building to differentiate ourselves from competitors that utilize less environmentally friendly products." Contractors also noted the significance of establishing relationships with suppliers providing eco-friendly products to maintain a competitive advantage.

Regarding the sub-criteria of "resistance to change from conventional to green techniques," contractors stressed the significance of educating workers and stakeholders on the advantages of green building. One contractor claimed, "We train our staff to ensure they understand the significance of the green building and the benefits it can bring to the community." Including workers and stakeholders in the decision-making process could also help increase their enthusiasm for green construction methods.

Contractors stressed the importance of holding consistent meetings and keeping lines of communication open to address the issue of poor communication between stakeholders. When asked how they keep everyone apprised of the project's status, one contractor responded, "We hold regular meetings to ensure all stakeholders are informed and up to date." Also, contractors stressed the significance of outlining roles and responsibilities to prevent misunderstandings.

Contractors underlined the need for education and training programs for both workers and clients in light of the need for more understanding of green construction sub-criteria. When asked about their efforts to educate their employees and customers on green building practices, one contractor said, "We offer training programs to guarantee personnel and clients understand the fundamentals of green construction." It was also suggested that giving clients case studies and examples of successful green building projects would help to boost their knowledge and understanding.

Contractors, as a collective, have placed significant emphasis on the significance of education, communication, and collaboration with various stakeholders, including architects, engineers, suppliers, regulatory bodies, and clients. This approach is crucial in effectively addressing the challenges presented by prevailing market trends in the realm of green building. This collaborative effort across multiple disciplines ensures a comprehensive approach, utilizing expertise from diverse sectors to effectively promote sustainable construction practices. Contractors' efforts to set themselves apart from the competition and gain critical stakeholders' support often emphasized the advantages of green building.

3.12.2 Practices to address financial challenges

The fuzzy AHP analysis revealed that contractors implementing green building projects face several financial obstacles. Through the interviews, contractors revealed their approaches to addressing these challenges. According to contractors, they conduct comprehensive cost-benefit analyses to determine the financial viability of green building projects. In addition, they stated that they work closely with clients to comprehend their budget constraints and identify areas where cost reductions can be made without compromising sustainability. One consultant stated: "To help our clients comprehend the financial implications of green building, we employ a comprehensive cost-benefit analysis. We collaborate closely with them to determine the most cost-effective strategies and technologies for achieving their sustainability objectives within budget constraints."

Frequently, contractors use value engineering to identify cost-saving measures while maintaining the project's viability in response to higher-than-anticipated costs. They also mentioned that they negotiate better prices for eco-friendly materials with their suppliers.

According to one contractor, "When costs exceed expectations, we use value engineering to identify cost-cutting measures that do not jeopardize sustainability. We also negotiate better prices for green materials with our suppliers."

According to contractors, extending the duration of a construction project increases expenses, such as labor costs and equipment rentals. Contractors reported collaborating closely with their clients to identify strategies for accelerating the construction process in order to mitigate these costs. According to one contractor, "Construction delays can add extra expenses, such as labor and rental tools. To reduce these costs, we collaborate closely with our clients to identify strategies for expediting the construction process, such as modular construction and prefabrication."

Contractors reported that they frequently assist their clients in identifying financing options for green building projects, such as energy-efficient mortgages and tax credits for green buildings, in addressing the challenge of more financial schemes. Additionally, they mentioned that they collaborate closely with financial institutions to develop financing options that are tailored to green building projects. One contractor said, "We advise our clients on the best ways to secure funding for their green construction projects, including energy-efficient mortgages and tax credits. In addition, we encourage our clients to collaborate and form partnership with financial institutions to develop green building-specific financing options."

According to contractors, they collaborate closely with clients to develop long-term ROI projections and identify strategies for accelerating ROI. Additionally, they mentioned that they educate clients on the non-financial benefits of green building, such as improved indoor air quality and occupant health, which can result in long-term cost savings. One consultant stated: "We collaborate closely with our clients to develop long-term ROI projections and to identify ROI-accelerating strategies, such as energy performance contracting and green leases. Additionally, we educate our clients on the non-financial advantages of green building, which can result in long-term cost savings."

To address the challenge of separating capital and operational costs, contractors reported that they collaborate closely with clients to develop a comprehensive cost-benefit analysis that considers both capital and operational costs. According to one of the contractors, "We collaborate closely with our customers to develop an all-encompassing cost-benefit analysis that considers the costs of both capital investments and ongoing operations. Additionally, we educate our clients on the long-term cost savings associated with green building, allowing them to shift their attention from initial capital costs to long-term operational savings."

They mentioned that they educate clients on the long-term cost savings associated with green building, which can assist in shifting their focus from initial capital costs to long-term operational savings.

3.12.3 Practices to address technological challenges

Interview questions focused on the contractors' approaches to solving challenging issues. These inquiries were grounded in the sub-criteria uncovered during the fuzzy AHP analysis. Most contractors relied on trade groups, technical manuals, and training programs to stay abreast of developing green technology standards. Working with suppliers and manufacturers versed in green technologies was also emphasized. A contractor said, "We work with suppliers specializing in green building materials and rely on their expertise to ensure we use the most up-to-date and effective technologies."

Contractors have reported conducting extensive research and testing before implementing new technologies to address the unpredictability of green materials and equipment performance. In addition, they emphasized the significance of collaborating with suppliers who can prove their products' performance. The words of one contractor: "Before implementing a new technology into a project, during the pre-construction stages, we conduct extensive rigorous testing. Suppliers who have put their products through rigorous testing and can report on their results are also crucial to us."

In some instances, contractors have reported difficulty sourcing green materials and equipment, particularly for more specialized applications. They stressed the significance of establishing connections with suppliers and manufacturers to ensure a steady supply. For example, one contractor has said, "We have established relationships with several reputable suppliers and manufacturers specializing in green building materials, and we work closely with them to ensure we have access to reliable technology and products we need for our projects."

Contractors noted that they rely on national and international research institutions for information on new technologies to compensate for the dearth of local research and development institutes. As for academic partnerships, some builders have said they do research and development on eco-friendly building materials with universities. An expert builder was quoted as saying, "Research and development on cutting-edge technologies are conducted in collaboration with regional academic institutions. This enables us to keep abreast of new information and contribute to developing environmentally friendly construction methods."

Contractors have said they train their employees extensively on green building practices and technologies to compensate for the need for more training among project staff in this area. To ensure their employees have access to the best training possible, some contractors have said they partner with industry groups and training institutes. According to one contractor, " We emphasize educating our workforce on sustainable building methods and materials. We also work with trade groups to provide our employees with the most current resources for professional development."

To address the need for more databases and information, contractors stated that they rely on various sources for information on green building practices and technologies, including industry associations, research institutions, and manufacturers. Several other contractors stated that they invest in developing their own databases and information systems to ensure that they have access to the most current and relevant data. One contractor reported that "We have put time and money into compiling our own database of eco-friendly construction resources and methods; therefore, we can quickly access data on the products we employ in our projects and monitor developments in our industry."

Green building technology is currently unavailable. Contractors have said they collaborate with manufacturers and suppliers to create innovative green building technologies. In addition, they stated that they invest in research and development to create new technologies internally. One contractor said, "When necessary, we collaborate with our vendors and manufacturers to create innovative green construction technologies. We also invest in research and development to make our new technologies. Thanks to this, we can provide cutting-edge services to our clients while remaining at the forefront of environmentally responsible building practices."

Contractors have a variety of approaches to technological challenges, including working with industry associations, training personnel, establishing relationships with suppliers and manufacturers, conducting extensive research, and testing, and investing in research and development.

3.12.4 Practices to address time-related challenges

Interviews with green building contractors revealed various methods for dealing with the time constraints highlighted by the fuzzy AHP analysis.

When asked about the time it takes to get approvals for green building projects, some contractors said they proactively communicate with the appropriate authorities to ensure all permits and approvals are timely. To avoid unnecessary setbacks, one contractor explained, "We work closely with the pertinent authorities and relevant stakeholders in order to minimize delays to obtain the necessary approvals and permits promptly."

Regarding the lengthier duration of the pre-construction phase, some contractors emphasized the significance of planning and coordination. One builder, for instance, claimed that they sped up the pre-construction phase by using Building Information Modelling (BIM) software to plan and coordinate the project's numerous components. When asked how they prevent problems from escalating, they stated, "We use BIM software to plan and coordinate the various aspects of the project, which helps us to identify potential issues early on and address them before they become major problems."

Several contractors have mentioned using Lean Construction principles to increase project efficiency and decrease delay risk in order to meet the schedule. To quote one builder: "Lean Construction principles help us finish projects on time and under budget by highlighting and removing unnecessary steps and activities. We also stress the importance of open lines of communication and teamwork between all parties involved in a project to guarantee that everyone is pulling in the same direction."

Overall, the contractors demonstrated a commitment to planning, coordination, and effective communication in order to address the time-related challenges of green construction.

3.12.5 Practices to address government-related challenges

Contractors were questioned about their approaches to overcoming issues with governments on green building projects. Inadequate government incentives and a need for green building policies, regulations, rating systems, and labeling were identified as sub-criteria in the fuzzy AHP analysis.

Some contractors have pointed out the need to inform policymakers and decision-makers about the advantages of green building and lobby for policy changes supporting green building practices to counteract the problem of inadequate government incentives. As one contractor put it, "The only way to see more incentives coming is if we have more educational resources and obligations on the governmental level for policy makers."

The long-term benefits of green building, as well as the potential cost savings resulting from reduced energy and water usage, have been highlighted as a primary focus by other contractors. With government incentives, this may make green buildings more appealing to clients by reducing the financial burden of implementing green building practices.

Contractors have expressed concern over the lack of green building policies, regulations, rating systems, and labeling and have called for establishing clear guidelines and standards to ensure consistency and accountability in green building practices. Some construction companies have been reported as using international green building standards such as LEED, which lay out specific requirements for creating environmentally friendly structures. For example, one contractor said, "We need to have more government regulations on green building, and it should be mandatory for developers and contractors to follow these standards, whether LEED or any other standard that the government may provide."

Although contractors generally agreed that government funding for green building initiatives was crucial, they also recognized the need for private sector leadership and advocacy.

3.12.6 Practices to address construction process-related challenges

The contractors interviewed provided a wide range of practices for challenges caused during the construction process. The need for in-depth preparation and clear lines of communication among team members was a recurrent theme.

A contractor said, "We develop a detailed schedule that shows the construction sequence, so everyone knows what to expect." As another contractor pointed out, having a well-developed plan in place and ensuring everyone on the team understands their role in executing the plan is crucial.

Contractors noted the importance of selecting experienced and knowledgeable subcontractors when providing green construction services but noted the difficulty. For example, "We have a strict vetting process for subcontractors to make sure they have experience with green building practices," said one contractor. Another contractor emphasized the significance of open lines of communication with subcontractors: "We make sure subcontractors understand the green building requirements and the importance of meeting those requirements."

Concerning the increased modification and variation of the design during construction, contractors emphasized the need for a flexible and adaptable team. " We have a team that can quickly adapt to changes and comes up with solutions," said one contractor. Another contractor emphasized the importance of clear communication with the design team, stating, "We work closely with the design team to ensure that any changes are quickly communicated and addressed."

Contractors stressed the significance of thorough documentation and training for building owners as additional responsibilities during the maintenance phase. To ensure that building owners can perform routine maintenance, one contractor stated, "We provide detailed maintenance plans and training for building owners." In addition, another contractor emphasized the significance of maintaining open lines of communication with building owners: "We may check in with building owners regularly to make sure they are maintaining their building properly and address any concerns they may have."

Contractors, in general, have stressed the value of careful preparation, open lines of communication, and collaborative problem-solving in the face of construction process challenges. In addition, they emphasized the significance of employing skilled and knowledgeable subcontractors, maintaining open lines of communication with design teams, and providing continuous communication and training to building owners.

CONCLUSION AND RECOMMANDATIONS

Numerous companies in the Canadian construction industry have adopted green building practices in response to the growing demand for green building methods. Various challenges must be overcome to ensure the success of green construction projects. Identifying and prioritizing these challenges is crucial for achieving the sustainability goals of green construction projects.

4.1 Key findings

A literature review, the fuzzy AHP method, and interviews with ten green building contractors were employed to identify and analyze the challenges faced by green building contractors in Canada and their practices. The Fuzzy AHP analysis ranked the groups of challenges as follows: market trends, time-related, financial, construction process-related, government-related, technology-related challenges.

The analysis revealed that market trend posed the most significant challenges, followed by time-related, financial, construction process-related, government-related, and technological challenges.

Additional cost required due to a long time of construction posed the most significant financial challenge, followed by higher cost than budget, higher cost of materials, and complex building costs and regulations to evaluate the cost benefits. However, the three most significant market trend challenges were the risks and uncertainties associated with the adoption of new technologies, conflicts in benefits with those of competitors leading to less expensive, less green supplies, and the lack of awareness about the benefits.

The availability of green materials and equipment and suppliers, followed by the immaturity of specifications for green technologies, and finally the need for local institutes for research and development, are the three biggest challenges to technological advancement. Meeting the schedule/causing delay was identified as the most critical time constraint, while total time caused by green construction due to approvals was identified as the second most critical. Lack of green building policies and regulations/rating systems and labelling, as well as the need for government incentives, are two of the biggest challenges facing this sector. Finally, additional changes and variations to the design posed the significant challenge during construction.

The interviews' findings highlighted the practices green building contractors adopted to overcome these challenges. The interviews showed that contractors use a wide variety of strategies and practices to deal with these issues. For example, in response to market trend challenges, contractors concentrate on keeping abreast of industry trends and leveraging their experience and expertise to offer clients innovative solutions. Contractors seek to increase their efficiency and decrease expenses in response to financial difficulties by implementing green construction practices and investing in training and development. Contractors engage in ongoing research and development to keep updated on novel technologies and materials, and they collaborate closely with suppliers to ensure the availability of green materials and equipment. Responding to time-related challenges, contractors prioritize effective project management and planning and collaborate with other stakeholders to ensure timely approvals and schedule adherence. Contractors seek government incentives and back the creation of policies and regulations that promote green building methods to address issues posed by governments. Contractors also prioritize open lines of communication and collaboration among all project stakeholders to reduce the number of design changes made during construction.

Both the fuzzy AHP analysis and the interviews uncovered several parallels between the problems that green building contractors face and those that traditional construction companies face, such as the importance of effective project management and planning, the importance of government incentives, and the importance of continuous research and development. The interviews also shed light on the contractors' strategies and practices for overcoming these challenges.

4.2 Implications of the study

Insightful conclusions are drawn about the challenges faced by green building contractors in Canada and the practices they use to overcome those challenges.
The study's results can help project managers and other stakeholders in Canada determine where to focus their attention and resources in order to have the greatest impact on the major challenges related to green building. These challenges must be overcome if green construction projects are to achieve their sustainability objectives and contribute to the larger goal of sustainable development. The findings highlight the need for additional research and advocacy for adopting green building practices in Canada, as well as the development of relevant policies and regulations. In order to provide more in-depth and specific insights, future research could focus on identifying and resolving the obstacles associated with implementing particular green construction technologies or practices.

4.3 Limitations of the study

When interpreting the findings of this study, there are several limitations that need to be taken into consideration. Due to the fact that only ten green building contractors in Canada were invited to participate in the interviews, it is possible that the findings are only representative of a subset of the industries. Furthermore, it is possible for bias to be introduced in the results due to the subjective nature of the literature review approach and the self-reported nature of the interviews. Lastly, the study did not take into account the views of other stakeholders like customers and government officials who may have different perspectives on the challenges and strategies for promoting green construction practices.

4.4 Recommendations for Future Research and Practice

The results of this research have far-reaching implications for the development of green building practices and knowledge. First, there is a need for more research to be conducted in order to determine the effectiveness of particular strategies and practices that are employed by green building contractors in order to deal with the challenges that have been identified. Second, to further promote green construction practices, future research could investigate the possibility of collaboration and knowledge sharing among green building contractors. Finally, this study's results stress the significance of persistent industry- and government-level advocacy and support for green construction practices.

ANNEX I

QUESTIONNAIRE: Review of the Project Management Practices from the contractors' perspective to Respond to the Identified Critical challenges in the Canadian Green Construction Industry

The purpose of our study is to address the challenges to green construction in Canada. There will be three parts to this survey. Section 1 provides an overview of the respondents, including their professional background and other relevant demographic information. The validity of challenges to green construction is investigated in Section 2, which also helps selecting the relevant ones. Section 3, aids in evaluating the selected challenges in order of priority.

1. Section 1

Degree of education:

Bachelor ☐

Master ☐

PhD ☐

Organization sector:

Please confirm whether the majority of green projects your company undertook were public or private.

Public sector ☐

Private sector ☐

Work experience (year):

5-10 ☐

10-20 ☐

>20 ☐

Work sector:

Please confirm whether the majority of all of the projects your company undertook were for any of the following sectors.

Private Sector ☐

Public Sector ☐

International company ☐

2. Section 2

Challenges to green construction are listed below. The author would conduct an analysis of the most pressing of these challenges to green construction in Canada, based on their relative importance.

Please use a 5-point scale (1 = not important, 2 = somewhat important, 3 = important, 4 = very important, and 5 = extremely significant) to rate the relevance of each of the following challenges in the Canadian green construction industry context. Moreover, please add the challenges applicable to the green construction industry (if any) that you find important and are not mentioned in the below table.

Table-A I-1 Challenges to the green construction in Canada

Criteria	Sub-criteria	Responses				
		1	2	3	4	5
Market trend challenges	Lack of market demand and interest (MA1)					
	Lack of management support and time management (MA2)					
	Conflicts in benefits with those of competitors leading to less expensive, less green supplies (MA3)					
	Resistance to change from conventional to green practices (MA4)					
	Lack of communication among the stakeholders (MA5)					
	Lack of knowledge on green construction (MA6)					
	The objectives of the building project (MA7)					
	Misunderstanding of green technologies (MA8)					
	lack of experience with using unconventional procurement techniques, in addition to challenges with the necessary specifications and performances (MA9)					
	Lack of awareness about the benefits (M10)					
	Lack of demonstration projects/ lack of technical procedures/ frameworks (MA11)					
	Risks and uncertainties associated with the adoption of new technologies (MA12)					

Criteria	Sub-criteria	Responses				
		1	2	3	4	5
Financial challenges	Complex building costs and regulations to evaluate the cost benefits (FI1)					
	Higher cost than budget/ higher cost of materials (FI2)					
	Additional cost required due to a long time of construction (FI3)					
	Lack of financial schemes (e.g., bank loans) (FI4)					
	Higher investment cost/ long duration of return on investment (ROI) (FI5)					
	Separation of capital and operational costs (FI6)					
Technological risks	Immature green technology specifications (lack of comprehending) (TE1)					
	Uncertainty regarding the performance of green materials, products and machinery (TE2)					
	Unavailability of green material, equipment and suppliers (TE3)					
	Lack of local institutes for research and development (TE4)					
	Lack of green building technological training for project staff (TE5)					
	Lack of database and information (TE6)					
	Unavailablity of technology for green buildings (TE7)					
Time-related challenges	Incremental time caused by green construction due to approvals (TI1)					
	Increased time needs to be allotted for pre- and post-construction work (TI2)					
	Meeting the schedule/ cause delay (TI3)					
Government-related challenges	Insufficient incentives from the government (GO1)					
	Lack of green building policies and regulations/rating systems and labelling (GO2)					
Construction process-related challenges	Sequential construction planning issues (CO1)					
	Challenges in finding reliable green construction subcontractors (CO2)					
	More desgin modification and variation during the construction process (CO3)					
	Additional responsibilities for the maintenance stage (CO4)					

3. Section 3

Building a pair-wise evaluation matrix between the identified main challenges and the specific challenges is necessary for ranking them. Since this is the case, please indicate your choice in the appropriate pairwise evaluation matrix for either the broad categories of challenges or the specific challenges themselves. As you enter your answers, please keep in mind the fuzzy linguistic scale provided.

Table-A I-2 A fuzzy linguistic scale for building a comparison matrix between two challenges

Judgment linguistic definition	Fuzzy score
Weakly important	(1, 1, 3)
Fairly important Medium	(1, 3, 5)
Highly important	(3, 5, 7)
Absolute dominance	(5, 7, 9)
Important	(7, 9, 11)

Table-A I-3 Pairwise evaluation matrix for main challenges

	MA	FI	TE	TI	GO	CO
MA	(1,1,1)					
FI		(1,1,1)				
TE			(1,1,1)			
TI				(1,1,1)		
GO					(1,1,1)	
CO						(1,1,1)

Table-A I-4 Pairwise evaluation matrix for market trend challenges

	MA1	MA2	MA3	MA4	MA5	MA6	MA7	MA8	MA9	MA10	MA11	MA12
MA1	(1,1,1)											
MA2		(1,1,1)										
MA3			(1,1,1)									
MA4				(1,1,1)								
MA5					(1,1,1)							
MA6						(1,1,1)						
MA7							(1,1,1)					
MA8								(1,1,1)				
MA9									(1,1,1)			
MA10										(1,1,1)		
MA11											(1,1,1)	
MA12												(1,1,1)

Table-A I-5 Pairwise evaluation matrix for financial challenges

	FI1	FI2	FI3	FI4	FI5	FI6
FI1	(1,1,1)					
FI2		(1,1,1)				
FI3			(1,1,1)			
FI4				(1,1,1)		
FI5					(1,1,1)	
FI6						(1,1,1)

Table-A I-6 Pairwise evaluation matrix for technological risk challenges

	TE1	TE2	TE3	TE4	TE5	TE6	TE7
TE1	(1,1,1)						
TE2		(1,1,1)					
TE3			(1,1,1)				
TE4				(1,1,1)			
TE5					(1,1,1)		
TE6						(1,1,1)	
TE7							(1,1,1)

Table-A I-7 Pairwise evaluation matrix for time-related challenges

	TI1	TI2	TI3
TI1	(1,1,1)		
TI2		(1,1,1)	
TI3			(1,1,1)

Table-A I-8 Pairwise evaluation matrix for government-related challenges

	GO1	GO2
GO1	(1,1,1)	
GO2		(1,1,1)

Table-A I-9 Pairwise evaluation matrix for construction-process challenges

	CO1	CO2	CO3	CO4
CO1	(1,1,1)			
CO2		(1,1,1)		
CO3			(1,1,1)	
CO4				(1,1,1)

ANNEX II

CHALLENGES OF GREEN CONSTRUCTION

Table-A II-1 Challenges of green construction

Criteria	Sub-criteria	References
Market trend challenges	Lack of market demand and interest (MA1)	(Bon-Gang Hwang & Tan, 2012)
	Lack of management support and time management (MA2)	(B.-G. Hwang & Ng, 2013)
	Conflicts in benefits with those of competitors leading to less expensive, less green supplies (MA3)	(MS Hasan & Zhang, 2016; Shi, Zuo, Huang, Huang, & Pullen, 2013)
	Resistance to change from conventional to green practices (MA4)	(Nejati, Rabiei, & Jabbour, 2017; Wimala, Akmalah, & Sururi, 2016)
	Lack of communication among the stakeholders (MA5)	(Richardson & Lynes, 2007)
	Lack of knowledge of green construction (MA6)	(Issa, Rankin, & Christian, 2010; Zuo & Zhao, 2014)
	The objectives of the building project (MA7)	(Horman et al., 2006; Vatalis, Manoliadis, Charalampides, Platias, & Savvidis, 2013)
	Misunderstanding of green technologies (MA8)	(Saleh & Alalouch, 2015; Shi et al., 2013)
	lack of experience with using unconventional procurement techniques, in addition to challenges with the necessary specifications and performances (MA9)	(MSMS Hasan, 2017; Khan et al., 2018)
	Lack of awareness about the benefits (M10)	(Azeem, Naeem, Waheed, & Thaheem, 2017)
	Lack of demonstration projects/ lack of technical procedures/ frameworks (MA11)	(Femenías, 2004; Serpell, Kort, & Vera, 2013)
	Risks and uncertainties associated with the adoption of new technologies (MA12)	(Aliagha, Hashim, Sanni, & Ali, 2013)

Criteria	Sub-criteria	References
Financial challenges	Complex building costs and regulations to evaluate the cost benefits (FI1)	(Debrah, Chan, & Darko, 2022; Khoshbakht, Gou, & Dupre, 2017)
	Higher cost than budget/ higher cost of materials (FI2)	(MS Hasan & Zhang, 2016; Shi et al., 2013)
	Additional cost required due to a long time of construction (FI3)	(M. Arif, Egbu, Haleem, Kulonda, & Khalfan, 2009; MS Hasan & Zhang, 2016; B.-G. Hwang, Zhu, Wang, & Cheong, 2017)
	Lack of financial schemes (e.g., bank loans) (FI4)	(B.-G. Hwang, Zhu, et al., 2017; Shi et al., 2013)
	Higher investment cost/ long duration of return on investment (ROI) (FI5)	(Lemoine, Woodard, & Richardson, 2015; Meyerson, 2005)
	Separation of capital and operational costs (FI6)	(Debrah et al., 2022; S. Li, Lu, Kua, & Chang, 2020)
Technological risks	Immature green technology specifications (lack of comprehension) (TE1)	(Omar et al., 2016)
	Uncertainty regarding the performance of green materials, products, and machinery (TE2)	(Shi et al., 2013)
	Unavailability of green material, equipment and suppliers (TE3)	(Marandi Alamdari, Jabarzadeh, Samson, & Sanoubar, 2023)
	Lack of local institutes for research and development (TE4)	(Darko et al., 2018; Kamar & Hamid, 2012)
	Lack of green building technological training for project staff (TE5)	(Wang, Chong, & Liu, 2021)
	Lack of database and information (TE6)	(Luo, Sandanayake, Hou, Tan, & Zhang, 2022)
	Unavailability of technology for green buildings (TE7)	(Wang et al., 2021)

Criteria	Sub-criteria	References
Time-related challenges	Incremental time caused by green construction due to approvals (TI1)	(B.-G. Hwang & Ng, 2013)
	Increased time needs to be allotted for pre- and post-construction work (TI2)	(Omar et al., 2016)
	Meeting the schedule/ cause delay (TI3)	(B.-G. Hwang & Ng, 2013; Shi et al., 2013)
Government-related challenges	Insufficient incentives from the government (GO1)	(Omar et al., 2016)
	Lack of green building policies and regulations/rating systems and labeling (GO2)	(Majid & Khan, 2021)
Construction process-related challenges	Sequential construction planning issues (CO1)	(Bon Gang Hwang & Leong, 2013)
	Challenges in finding reliable green construction subcontractors (CO2)	(B.-G. Hwang & Ng, 2013)
	More design modification and variation during the construction process (CO3)	(B.-G. Hwang & Ng, 2013)
	Additional responsibilities for the maintenance stage (CO4)	(Liao, Tan, & Li, 2012; Mohammad, Zainol, Abdullah, Woon, & Ramli, 2014)

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