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Limits and opportunities of integrated design in sustainable buildings: The need for a more comprehensive project process

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RÉSUMÉ

La quête pour réduire les impacts environnementaux nationaux et mondiaux a eu un effet significatif sur l'industrie de la construction. Dans la plupart des pays développés, le secteur de la construction est responsable de 35% de la production des déchets, de 32% de la consommation en énergie et de 19% des émissions de gaz à effet de serre (GES). La théorie et la pratique montrent que le processus de travail traditionnel en silo encourage une organisation de la conception et de la construction linéaire et fragmentée. La division du travail en lots par spécialité constitue non seulement, un obstacle à l'innovation, mais également, une entrave à la mise en œuvre de meilleures pratiques visant à réduire l'empreinte écologique du cadre bâti.

Au Canada et à l'étranger, la conception intégrée (CI) suscite un intérêt croissant à titre de solution potentielle pour résoudre le manque de collaboration et d'innovation entourant la prise de décision dans les projets. Elle remet en cause l'approche séquentielle utilisée dans la pratique traditionnelle dans le but d'engager toutes les parties prenantes dans un processus de conception collaborative et multidisciplinaire qui couvre le cycle de vie complet du bâtiment, dès le début du projet. Bien que les principes généraux de la CI soient théoriquement fondés, il existe peu de preuves empiriques de son efficacité. L'objectif de cette thèse est d'examiner à partir des points de vue théorique et empirique, la portée, les forces, les limites et les conditions de réussite de la CI pour la conception de bâtiments durables.

La recherche est basée sur trois études de cas, soit des projets récents situés à Montréal qui ont été réalisés suivant un processus de conception intégrée. L'étude de plus de 350 documents comprenant des plans d'architecture, des revues de presse, des dossiers de construction et d'opération ainsi que d'analyse de cycle de vie et, la tenue de 28 entrevues approfondies, nous a permis de comprendre les processus impliqués, les résultats obtenus ainsi que l'intérêt et les attentes des parties prenantes en matière de CI.

Les résultats de la recherche révèlent que la CI favorise la collaboration et l'innovation, et, qu'elle contribue à réduire l'impact de l'empreinte écologique des bâtiments par rapport au processus traditionnel. Malgré ces avantages, la CI n'atteint pas son plein potentiel dans la façon dont elle est mise en œuvre aujourd'hui. Elle n’arrive pas à réduire complètement la fragmentation entre les parties prenantes et au cours des différentes phases du projet. Une barrière existe toujours entre les phases de conception, de construction et d’exploitation. Une attention insuffisante est accordée aux mesures de performance efficaces, au retour d’information rigoureux sur les projets ainsi qu’aux évaluations systématiques à l’occupation du bâtiment.

En identifiant les écarts entre les attentes et les pratiques efficaces, cette recherche présente les domaines dans lesquels des améliorations sont encore nécessaires dans le secteur de la construction. L'étude suggère, notamment, que les responsables de projet et l'équipe de conception peuvent (et devraient) assumer de nouveaux rôles ainsi que des nouvelles obligations et responsabilités pour optimiser les résultats d’un projet. Pour réduire efficacement les émissions de carbone, les parties prenantes devront, d’une part, développer une connaissance plus approfondie des outils d'évaluation du cycle de vie et de simulation énergétique, et, d’autre part, élaborer de nouveaux accords contractuels pour favoriser un engagement durable dans l’atteinte de résultats positifs tout au long d’un cycle de vie.

D'un point de vue théorique, les résultats de la recherche démontrent la pertinence et l'utilité de la CI, mais identifient également ses limites et les conditions permettant de créer de la valeur pour toutes les parties prenantes en vue d'améliorer les bâtiments. Les écarts entre la théorie et la pratique, constatés ici, révèlent un besoin urgent de modifier la réglementation du secteur de la construction (notamment la responsabilité professionnelle, les procédures de sélection basées sur la réglé du plus bas soumissionnaire, l’étiquetage et les codes du bâtiment, et les certifications) afin de réduire les impacts des bâtiments et de ralentir les changements climatiques. D'un point de vue pratique, les résultats mettent en évidence les moyens par lesquels les acteurs de l'industrie de la construction peuvent améliorer leur synergie et ainsi diminuer l’impact des bâtiments sur l'environnement. Tout cela peut aider et nous indique qu’il est temps d’entreprendre la construction de bâtiments plus appropriés pour nous-mêmes, nos collectivités et les générations futures.

Mots clés: Conception Intégrée; édifices durables; collaboration; innovation; performance environnementale; réduction de l'énergie et des GES; gestion de projet durable; rôle d'un gestionnaire de projet.

ABSTRACT

The quest to reduce national and global environmental impacts has had a significant impact on the construction industry. In most developed countries, the construction sector is responsible for 35% of waste generation, 32% of energy consumption, and 19% of greenhouse gas (GHG) emissions. Both theory and practice show that the traditional silo-type, linear, and fragmented design process is a significant barrier to innovation and the implementation of better practices in the built environment.

Integrated Design (ID) is increasingly seen in Canada and abroad as a potential solution to the lack of collaboration and innovation. Contrary to the traditional design process, ID allows all participants to work together from the beginning of the project, making decisions collectively and integrating otherwise fragmented products and processes. Although ID's potential is theoretically well-founded, there is little empirical evidence of its effectiveness. The objective of this dissertation is to examine – from both theoretical and empirical vantage points – the scope, strengths, limitations, and critical success factors of Integrated Design (ID) in creating sustainable buildings.

The research is based on three case studies of recent building projects in Montreal that implemented Integrated Design processes. The analysis of over 350 architectural plans, press releases and documents produced during construction and operation phases, life cycle analyses, and 28 in-depth interviews allowed us to understand the processes involved, the outcomes obtained, and the stakeholders' interest and expectations regarding ID.

Findings reveal that ID enhanced collaboration and innovation, and helped to reduce buildings' impacts when compared to the traditional processes. But ID failed to achieve its full potential. It did not completely reduce fragmentation between stakeholders and project phases. This research identified that a "wall" between design, construction and operation phases still exists in ID. As it is applied today, ID continues to underestimate the value of effective performance measurements, rigorous project feedback, and systematic post-occupation evaluations.

Identifying the gaps between expectations and effective practice, this dissertation reveals areas where improvements are still needed in the building industry. The study suggests, for instance, that project managers and the design team can (and should) assume new roles, liabilities and responsibilities for project outputs. Effective carbon reductions will require that stakeholders develop deeper knowledge of life-cycle assessment and energy simulation tools. New contractual arrangements between stakeholders will also be needed to favour sustained stakeholder commitment to achieve positive outcomes during the entire project life cycle.

From a theoretical point of view, the results demonstrate the relevance and usefulness of ID, but also identify its limits and the conditions that allow for the creation of value for all stakeholders and improvements in buildings. The gaps between theory and practice found here reveal the urgent need to change construction industry regulation (such as professional liability, traditional price-driven - lowest bidding - selection procedures, labeling building systems, building codes, standards, and certifications) in order to reduce buildings' impacts and slow climate change. From a practical point of view, the results highlight ways in which stakeholders in the construction industry can improve interactions among themselves to reduce buildings' impacts on the environment. All of this can help – and is needed to – create buildings that are more appropriate for today's society and future generations.

Keywords: Integrated design, Sustainable buildings, Collaboration, Innovation, Environmental performance, Energy and GHG reduction, Sustainable project management, Project manager's role.

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LIST OF ACRONYMS

AEC: Architecture, Engineering, and Construction Industry

BIM: Building Information Modeling

BOMA: Building Owners and Managers Association of Canada

BREEAM: Building Research Establishment Environmental Assessment Method

CaGBC: Canadian Green Building Council

CASBEE: Comprehensive Assessment System for Built Environment Efficiency

CD: Construction Documentation

CIB: The International Council for Building

DGNB: German Sustainable Building Certificate

FSC Forestry Stewardship Council

GB: Green Building

GBCs: Green Building Certifications

GBI Green Building Institute

GHG: Greenhouse Gas Emissions

HQE: Haute Qualité Environnementale

IDP: Integrated Design Process

IPCC: International Panel on Climate Change

IPD: Integrated Project Delivery

ISO: International Organisation for Standardisation

KPI: Key Performance Indicator

LEED: Leadership in Energy and Environmental Design

LCA: Life Cycle Assessment

LCC: Life Cycle Costing

MNEBC: Model National Energy Building Code

NGO: Non-Government Organizations

NRCan: Natural Resources Canada

O&M: Operations and Maintenance

PMBOOK: Project Management Body of Knowledge

PMI: Project Management Institute

SD: Sustainable Development

SME: Small and Medium Enterprises

TMO: Temporary Multi-Organization

UNEP: United Nations Environment Programme

USGBC: United State Green Building Council

VOCs: Volatile Organic Compounds

DEDICATION

À minha gatona
Flavia,
e aos meus pimpolhos amados
Ester, Nathan e Sarah.

Os meus queridos pais
Rui e Elda.

E aos meus avós (saudades) que já estão no céu com Deus
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PREFACE

My father was an inspiration for me. As an engineer, he always sought to improve construction processes. Instead of engineering, I chose to study Architecture and Urbanism. From the beginning of my studies, I have worked in construction and project management companies. After five years as an employee, I decided to open my own firm with two partners: a mechanical engineer, and a civil engineer. We were a multidisciplinary firm, but still working in the traditional way, in silos.

After 2 years I suggested to my partners that we work more closely. The meetings with clients were no longer just with me, the architect, but included the structural and mechanical engineers. Later, we included the contractor. My partners were initially resistant, but they soon saw the time-savings in the execution of the projects as well as project improvements. In the end, the results were more in line with client's wishes.

At the end of 2007, I decided undergo training in project management. In 2009, I began my studies for an MGPA in this faculty. To finish my master's program, I did an internship at the Center for sustainable development (CSD) in 2010. This building, intended to be a model for the city of Montreal, definitely influenced my career.

To my surprise, the same work methodology that I had developed in Brazil was applied in this project under the name of Integrated Design. After four months of internship, I wrote my master's thesis. It was published by this Faculty and is still available on the grif's website. At the end of my internship, Equiterre offered me a position that would allow me to continue my work. I was then able to follow the whole process of construction, and the subsequent operation of a CSD building.

But how did Integrated Design influence the final results? Is it possible to evaluate the improvements? What challenges did ID face during the process? And how could ID be improved? It was in order to answer these questions that I, an architectural professional, decide to accept the challenge of embarking on an academic career, starting a doctorate.

Many years have passed, many more than I originally imagined. I began this journey with one daughter. Now, my wife and I have three beautiful kids. I continued working at Equiterre during my doctoral studies, initially 4 days a week, and then, when I got the Mitacs, 2 days a week. On the one hand, I can say that it is very difficult to pursue a PhD and work at the same time. On the other hand, I can say that this is the reason why my research, even with theoretical results, also has important practical ones. I can even say that the results of my research are already being used by industry. Throughout my doctorate I participated in a number of conferences. I presented my partial results in the form of conference articles in Montreal, Canada (Toronto) and abroad (South Africa, Portugal and Hong Kong). The three articles were published in three journals focusing on three different knowledge fields: construction (Construction Management and Economics), sustainability (Building and Environment) and project management (Architectural, Engineering and Design Management). The partner companies and the professionals I interviewed are still in contact with me and could easily benefit from my research results. This is certainly the case for Equiterre and the City of Montreal.

What can I say today, after 20 years – 12 as an architect and 8 as a researcher – about Integrated Design? The long answer is in my thesis and you will have to read it. The short answer: It depends! It depends on the way ID is applied! And if you want to know more, you have no other choice, you will have to read the thesis. Enjoy.

1. INTRODUCTION

The purpose of this article-based thesis is to examine the strengths, limitations, and opportunities of Integrated Design (ID) in sustainable buildings and by doing so, to bridge gaps in the literature, in practice, and in policy. I begin this section by presenting the background and the practical motivations of this research. I shall then present a summary of the pertinent literature and concepts used to understand collaborative and innovative methods in the construction industry. Subsequently I shall pursue by formulating a problem statement and pertinent research questions. To conclude, I provide an overview of the dissertation's structure, summarizing the key components and contributions of each chapter.

1.1. Background and research justification

> *"The time of waste is over, and we have to face this challenge. We must save energy and money and make green architecture, now everything must be green. " Frank Gehry in an interview to Miguel Mora (2009)*

Since the publication of the Brundtland (1987) Report entitled *Our Common Future*, many steps have been taken to translate the notion of sustainability into reality. In June of 1992, the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro consolidated the term "sustainable development" as a matrix that crystallizes three questions: (a) the ecological question, (b) the question of solidarity (between current and future generations and between North and South), and (c) the question of the modes of production, consumption and regulation (Valenduc *et al.*, 1996).

With the adoption of the Rio Agenda 21 and then the Millennium Development Goals (MDGs) by the United Nations, 179 countries have pledged to establish programs of actions and recommendations for the 21st century (Du Plessis, 2002). The Rio Earth Summit also marked international awareness of the risk of climate change.

The construction industry has been accused of contributing significantly to environmental degradation through both construction and the buildings themselves (Huovila, 2007; Kibert, 2007). Buildings account for 42% of total energy consumption worldwide and produce about 35% of all greenhouse emissions (Jayr *et al.*, 2011). In the United States, the emission of greenhouse gases has actually increased at a faster rate in the construction sector than in other sectors., The US consumed forty-five percent more energy in 2000 compared to 1970, and will achieve ninety-three percent more by 2020 (Addington, 2003).

In response to this pressure, the construction sector is progressively moving forward towards building sustainable policies and more collaborative practices with a focus on green building-certification (Berardi, 2012). In this context, professionals are applying certification systems (LEED, BOMMA, AQUA, etc.) as a reference guide for measuring social and environmental performance strategies in a project (McDonough & Braungart, 2010).

Research on green building design and the rational use of building materials is already underway to minimize environmental impact (Ding, 2008). The objective is to improve the comfort and health of the occupants by limiting the building's impacts on the environment. It seeks to integrate buildings as respectfully as possible into an environment and to use natural and local resources as much as possible. While different strategies are possible, such as the reduction of consumption, improving efficiency, or developing new and less harmful solutions, in all cases, innovations are necessary.

In this context, it is important to understand to what extent the actual strategies improve a building's quality and its relationship with the environment (see Figure 1). More specifically, assessing the limits and opportunities of the collaborative processes of Integrated design (ID) will uncover the ways in which stakeholders in the construction industry can improve interactions among themselves in order to design buildings that are better for society and nature.

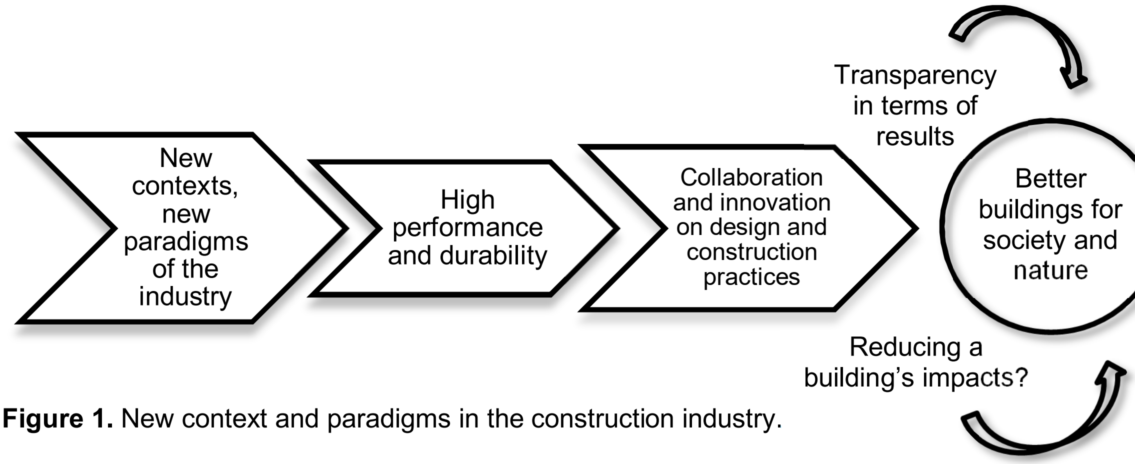

Figure 1. New context and paradigms in the construction industry.

1.2. Practical motivations

From a practical perspective, the desire to investigate this particular area comes from my professional experience. I worked as an architect for a project management organisation. Over the years, I was confronted with recurrent problems concerning lack of precision, errors, and consequently cost overruns. Most of the problems occurred because the professionals involved simply did not know how to truly collaborate in the early phases of the project. In 2006, I had the opportunity of starting my own company. From day one, I proposed my partners (engineer and electromechanics) to work collaboratively. All teams participated in all meetings with the client. In the beginning, my partners resisted. It is true to say that they were not easy to convince. After two years, resistance weakened but nonetheless persisted.

In 2008, I decided to do a Master's Degree at the University of Montreal. My master's thesis was published by the IF research group of the University of Montreal. In that dissertation, I sought to identify the limitations and specific aspects of an innovative project (the Center for Sustainable Development), carried out by a non-profit organisation in Montreal. The work analyzed three mutually influential aspects of this project: (a) sustainable supply management, (b) integrated design, and (c) the legal and financial structure of the project. In my master's thesis, I was again confronted with Integrated Design and resistance from stakeholders to truly embrace this process. After my master's, I maintained my interest in understanding the impact of ID in project management practices and project outputs. This research project is, consequently, a continuation of my master's degree as well as my 14 years of professional experience.

1.3. Theoretical framework

The study of Integrated Design (ID) in a sustainable building project benefits from contributions in social sciences, architectural, and project management. These disciplines have their own bodies of knowledge and research methodologies and are influenced by their ontological and epistemological position. Ontology is primarily concerned with the nature of social reality, whether they exist independently from social actors or whether they are constructed by the actions of these same actors (Bryman, 2016).

This research adopts a constructivist approach. Constructivism is an epistemology that opposes the perspective of a predetermined and ordered world. Instead, they believe that knowledge takes shape from a human process of continual construction and reconstruction (Le Moigne, 2007). In a constructivist approach the system is assumed open and dynamic (second generation systems approach). The problems that stakeholders faces during the project development are considered ill-defined, requires an interpretative approach to deal with them (Cucuzzella, 2010). “Since the knowledge is constructed through the interaction between the subject and the objects, a recursive process of change (assimilation of knowledge) occurs” (p.83).

A constructivist point of view assumes that people experience the same situation differently; they also create their own explanation and definitions of phenomena (Creswell, 2003). The approach provide access to “the meanings people attribute to their experiences and social world” (Fellows & Liu, 2008, p. 156). This means that to recognise that even if stakeholders have common training (Architects, Engineers, Designers), their experiences will endow them with different ways to solve the same problem. This is due to their specific interactions, individual thoughts, or constructed realities.

The research influences

The underlying philosophical assumption is that Integrated Design (ID) in a sustainable building project varies according to the environment (social, economic, and political influences). Constructivist researchers recognize that their own antecedents and personal experience influence the way they analyse data in order to understand (or interpret) the meanings of observed facts (Creswell, 2003).

Professional’s past experience also influences their actions. They ‘reflect in action’, in which manner Schön (1983) describes the professional as a “The reflective practitioner”. The author describes the design process as a conversation with a situation. Through this reflection, the professionals restructure the courses of action based on the newly found appreciation of the situation. In an Integrated Process many stakeholders are involved in the design and construction process, each participant (professionals, owner, users, and facility team) uses his or her own perceptions, descriptions, and appreciation to collaborate in the creation of the artefacts.

The intention of this thesis is neither to "discover" reality in a research laboratory nor to demonstrate the empirical application of a pre-established theory or hypothesis. On the contrary, it is to examine a reality that is constructed and revealed by many actors in the field, using an iterative process where contextual and temporal contingencies loom large and where not only the project but its context is considered. Instead of starting with a theory (as in post-positivism), this research aims to inductively generate or develop a pattern of meaning (Creswell, 2003).

The research approaches

This research is influenced by the ‘‘engaged scholarship research’’ collaborative method proposed by Ven and Johnson (2006). The authors identified a problem in the transfer of knowledge from theory to practice. Practitioners failed to adopt the research findings, and academic researchers paid little attention to transfer the knowledge they had produced (Beyer & Trice, 1982; Lawler *et al.*, 1999).

> *“To bridge the gap between theory and practice, we need a mode of inquiry that converts the information provided by both scholars and practitioners into actions that address problems of what to do in a given domain. Thus, our proposed method of engaged scholarship is a means of creating the*

> *kind of knowledge that is needed to bridge this gap. We define engaged scholarship as a collaborative form of inquiry in which academics and practitioners leverage their different perspectives and competencies to co-produce knowledge about a complex problem or phenomenon that exists under conditions of uncertainty found in the world.”* (Ven & Johnson, 2006, p. 803).

The research context

To understand the application of Integrated Design (ID) in a sustainable building project, we also need to understand its context in the built environment. In this research, we define the term “built environment” as “all buildings and living spaces that are created, or modified, by people (Sarkis *et al.*, 2012).

Additionally, there are categories drawn from construction industry firms: Architecture, Engineering, and Construction AEC (Gluch & Bosch-Sijtsema, 2016). Buildings, in turn, can be defined as “a complex, information-dependent, prototype production process where conception, design and production phases are compressed or concurrent and highly interdependent, in an environment where there exists an unusually large number of internal and external uncertainties” (Pryke, 2004, p. 790). Cherns and Bryant (1984) call the team comprised of the client, professionals, users, facility team and other stakeholders involved in project realisation the Temporary Multi Organization (TMO) project (see Figure 2).

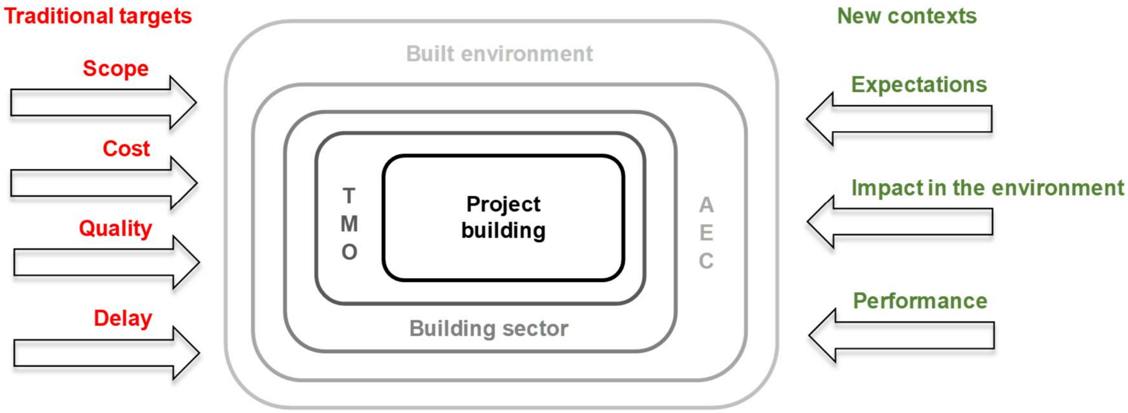

Figure 2. Building projects and their context

The research methodology

The research methodology is defined as a system describing how we go about doing something, in this case in research. The research methodology is located in the philosophy pertaining to how we come to know things, that is, epistemology. Morris *et al.* (2007) consider that an appropriate research methodology is only part of the way we construct knowledge. To understand the application of Integrated Design (ID) in a sustainable building project, we first need to identify the intellectual frameworks that "shape the way practitioners, professionals and academics perceived the discipline, and directly shape many of the tools and techniques, service offerings and certifications programs" (p.424).

Smyth and Morris (2007) identified four paradigmatic approaches drawing on project context rather than on management (Table 1 and Figure 3). Each paradigm adds complementary understandings to the bodies of knowledge:

Table 1. Paradigm approaches to managing projects by Smyth and Morris (2007) .

Paradigm	Definition and authors	Characteristics
Traditional	Techniques and tools that tend to have a task-orientated, efficiency focus (Turner, 2009; Turner & Müller, 2003).	Tightly aligned scheduling tools, earned value, lean production, and supply chain management.
Information processing	Technocratic input-output model of managing projects (Winch, 2003).	Linear task-orientated thinking; human dimensions tend to be subsumed under technocratic and managerial considerations
Functional	Strategic, front-end 'management of projects' (Morris *et al.*, 2007). Programme and projects strategies and partnering (Egan, 1998).Task-driven agendas that dovetail with the traditional approach - lean production for example (Koskela, 1992).	More integrated paradigm, embracing structures, open-systems and processes in pursuit of functional outcomes
Relationship	Project performance and client satisfaction, achieved through an understanding of the relationship between stakeholders (Pryke & Smyth, 2012).	This paradigm argues that people add value individually and through relationships because relationships are behind all the other tools and techniques.

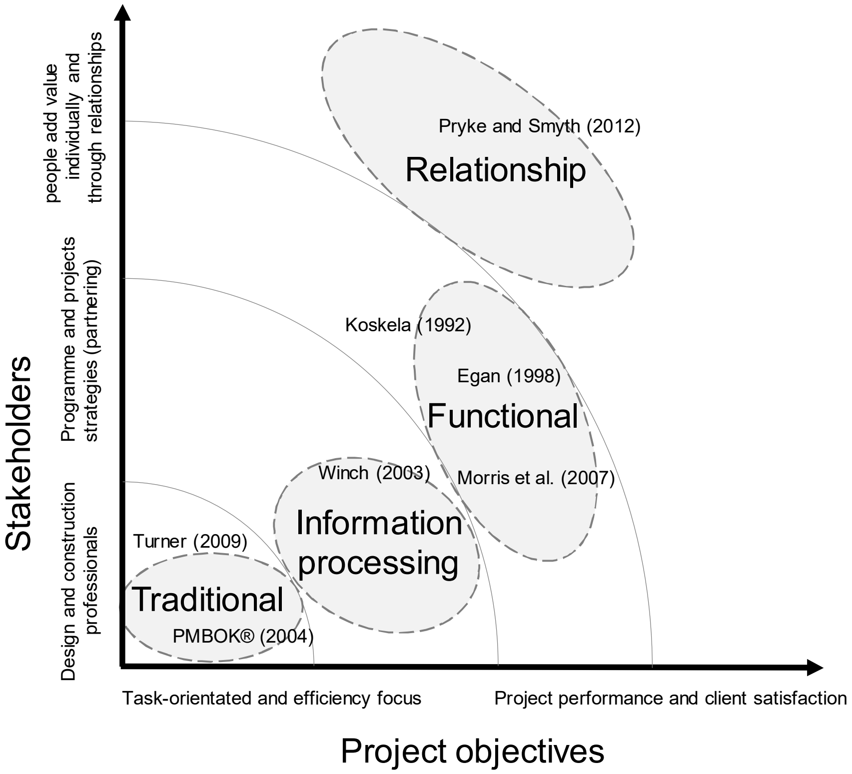

Figure 3. Managing approaches and their context

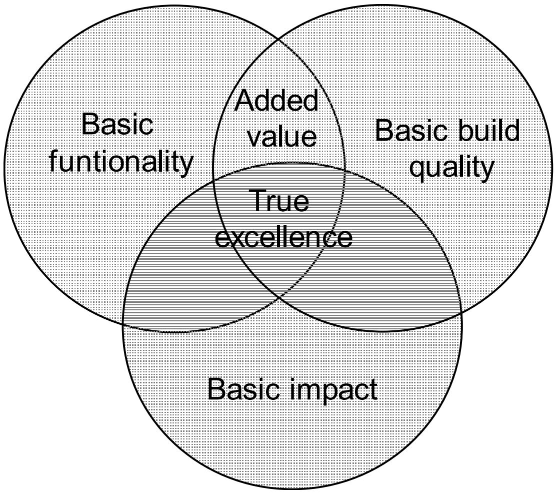

Figure 4. Truly excellent design quality (Smyth & Pryke, 2009, p. 185).

All approaches have embraced many of the key human dimensions for managing projects. However, only the “relationship approach” articulate the dynamics of the relationship from the inception of the project right up to its completion. “Relationship” is, therefore, the closest to Integrated Design approach. This approach states that “the final goal of collaboration in architecture is to construct a product that fulfils the wishes for the build quality articulated by the stakeholders” (Smyth & Pryke, 2009, p. 184). The excellent design quality in this approach is only achieved when the three-quality fields - functionality, build quality, and impacts - work together (see Figure 4).

The research design is based on the and Yin (2003) model that propose an inductively-oriented approach. This research, in construction and the built environment, consider projects, their management and their context. It is coupled with the emergent complexity theory, that points to more reality-oriented methods, like case studies (Fellows, 2010). The case-study research method provides the opportunity to study the events that provide insights into the nature of the phenomena. It considers the events that happen in an environment and that are helpful to understand: “what influenced ID performance? “and “how can ID be improved?” (Easton, 2010)

1.4. Project and its management context

Traditionally, project performance is evaluated according to three variables: time (project duration), quality (meeting performance requirements) and cost (budget adherence) (PMI, 2013; Saunders *et al.*, 2013). Nonetheless, other researchers have defended the integration of new performance indicators (KPIs). There is, for example, the achievement of the project objectives by maintaining "good relations" with the client (Kerzner, 2017), and by meeting the expectations of all the participants (Ramroth, 2006). This thesis considers that the "right project" must not only meet the immediate objectives of the project and the expectations of the actors implicated, but also the goals and expectations of future generations (Lizarralde & Djemel, 2010). Professionals act "ethically", it is argued, when the project "meets the needs of the present without compromising the ability of future generations to meet their own needs" (p. 5).

Integrated project and management process

> *"The inefficiencies inherent in the process of design and construction are necessitating a shift to greater multidisciplinary collaboration and information sharing among project team members" Andrew Pressman (2007).*

The problems in the construction industry have also been identified in the theoretical literature. The literature review (chapter 2) as well the first article (chapter 4.2) identified that the lack of innovation, the inefficiency, the silo-type, the linear and fragmentation acted as significant barriers to improve buildings performance. This thesis stated from a problem identified in practice (inefficiencies in the process of design and construction) and has sought to produce knowledge to bridge the gap between theory and practice.

Fragmented nature of the construction industry

The fragmentation of the construction process and the resulting adversarial relationships between the parties involved have been a constant topic of critical writings for decades. The traditional building design process still uses the "over-the-wall" approach (Evbuomwan & Anumba, 1998).

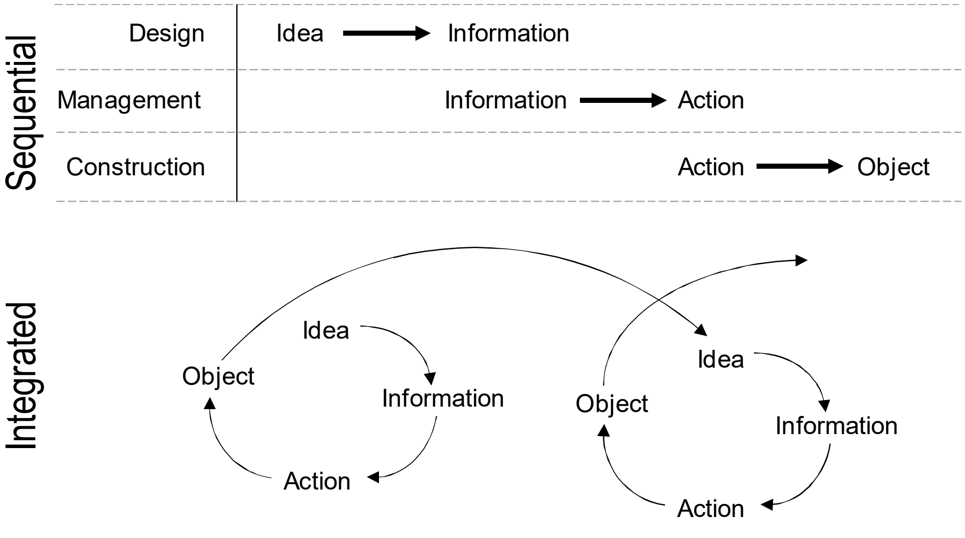

Figure 5. Feedback loops creates opportunities for project improvement (Elvin, 2007, p. 35).

Sequential communication among the participants is the norm: structural design does not begin until the completion of architectural drawings, with both needing to be completed before mechanical systems design begins, and subsequently for the others professionals to engage in the design (Kalay *et al.*, 1998).

In this context, meetings can take place but, in fact, they are only ever for coordinating purposes (Cole *et al.*, 2008). The design deliverables of each speciality are prepared separately by each professional or firm and assembled at an advanced stage of the process (see Figure 5). In addition, members of the project teams change from design phase to construction phase. Different types of fragmentation overlay the construction process: (i) construction industry fragmentation; (ii) traditional procurement fragmentation, (iii) design project fragmentation, and (iv) labor fragmentation at construction site (see Table 2).

Table 2. Forms of fragmentation in the construction sector.

Construction industry (CI) fragmentation	The fact that the industry is largely composed of a vast number of small and medium enterprises that work together for only short periods of time is seen as a barrier to the creation of sustained partnerships and alliances (Mossman *et al.*, 2010; Pries & Janszen, 1995). There is also a strong division of labour, poor coordination among project participants, and significant amounts of subcontracted work (Gottlieb & Haugbølle, 2013; Ofori, 2000; Thomassen, 2003; Van Nederveen *et al.*, 2010).
Traditional procurement fragmentation	It is believed that conventional procurement methods and contracts create adversarial relationships between parties reinforcing socio-cognitive barriers that hinder team efficiency and collective search for new ideas (Forgues & Koskela, 2008; Mossman *et al.*, 2010).
Design project fragmentation	The disjointed and sequential character of traditional design practice, as well as the increasing specialization of roles, lead to sub-optimal solutions, poor constructability, and operability. Rework in design and construction are typically identified as significant barriers to project efficiency (Huovila *et al.*, 1997; Nam & Tatum, 1997).
Labor fragmentation at the construction site	Canada adopted (1969) the need for accreditation for workers in construction (one employer's organization as an exclusive agent for contractors). This collective bargaining has fragmented the workforce by trade, sector, and geographic area. The increase of certified trades in the construction due to new performance-based codes and highly-specialized labour with growing numbers of trade workers focusing on sector-specific skills (152 different skills in total) delay the process and increase the price of construction (Globe-Advisors, 2013; Lizarralde & Davidson, 2008; Rose, 1977).

Integrated Practices in the construction industry

> *« Increasing attention to sustainability has led architects, contractors and other professionals to develop alternative design plans and methods" Forgues and Koskela (2009)*

The four levels of fragmentation identified in the construction industry leave no room for innovation or collaboration. This generates conflict between the expected and the actual project quality, which then results in buildings that operate below their optimum potential (Jayasena & Senevirathna, 2012; Koskela & Huovila, 2000). Figure 6 and next paragraphs describes collaborative forms of project delivery that have been and are being developed under various themes and titles:

Concurrent engineering is "a systematic approach" to the integrated, concurrent design of products and their related processes, including manufacturing and support. As opposed to the traditional processes, it advocates for cooperation, trust, and sharing in such a manner that decision-making would be made through consensus in order to generate more successful projects (Bidault *et al.*, 1998; Evbuomwan & Anumba, 1998; Prasad, 1996).

Fast-track building production should not be confused with concurrent design and construction. Fast-track is seldom planned well in advance by an interdisciplinary team. Rather, it is a default process necessitated by the need to accelerate the project schedule. The process puts designers in a reactive position relative to construction (Elvin, 2007).

Project Lean Delivery is based on an integrated project organization, defined as an effective and efficient collaborative team responsible for the design and construction of the project. The collaborative team includes the client, the architect, design consultants, the general contractor and client team (facility team and users). The overall goal is to optimize the project as a whole and not just parts of it (Huovila & Koskela, 1998; Nawi *et al.*, 2014).

Visioning is based on an intensive day-long meeting between the design-build team and owners' team (including facilities managers and users) that seeks to 'create a living, useful guides for actions intended to position the community for the future'. Participants in a visioning process are asked to contribute ideas at the beginning before experts and administrators narrow the range of options. A visioning session is an opportunity for prospective users to describe what they like and dislike about their current environment as well as their desires for their future (Sanoff, 2008; Thomas *et al.*, 1988).

Partnering is a cooperative management strategy in which the project stakeholders act as a team, seeking « win-win » outcomes based on shared goals and recognition of each other's interests. » It promotes a more successful project environment where all parties work together, and claims are avoided or readily resolved. This is accomplished by establishing trust and open communication, discussing methods of handling conflict, and establishing a cooperative and collaborative management effort that enables the parties to complete the project as effectively and cost-efficiently as possible (Clay *et al.*, 2004; Harmon, 2003; Moore & Dainty, 1999).

Project alliancing is a method of delivering major capital assets where the owner and nonowner participants work together as an integrated, collaborative team in good faith, acting with integrity and making unanimous, best-for-project decisions, managing all risks of project delivery jointly, and sharing the outcome of the project. (Lahdenperä, 2012; Yeung *et al.*, 2007).

Integrated project delivery (IPD) is a project delivery method distinguished by a contractual agreement between a minimum of the owner, design professional and builder, where risk and reward are shared and stakeholder success is dependent on project success (Cohen, 2010).

Integrated Design (ID) is an approach that challenges the very foundation of traditional design practices. It requires abandoning the practice of coordinating work between each discipline to engaging in a collaborative and multidisciplinary design process. The design process is no longer linear. It uses iterative loops focused on problem analysis and optimization of design solutions. Thus, the integrated design is based on four principles: 1) ongoing collaboration between stakeholders (consultants and other stakeholders), 2) upstream iterations, 3) innovation and 4) decision-making driven by performance objectives (Busby, 2001; Larsson, 2002; Reed, 2009).

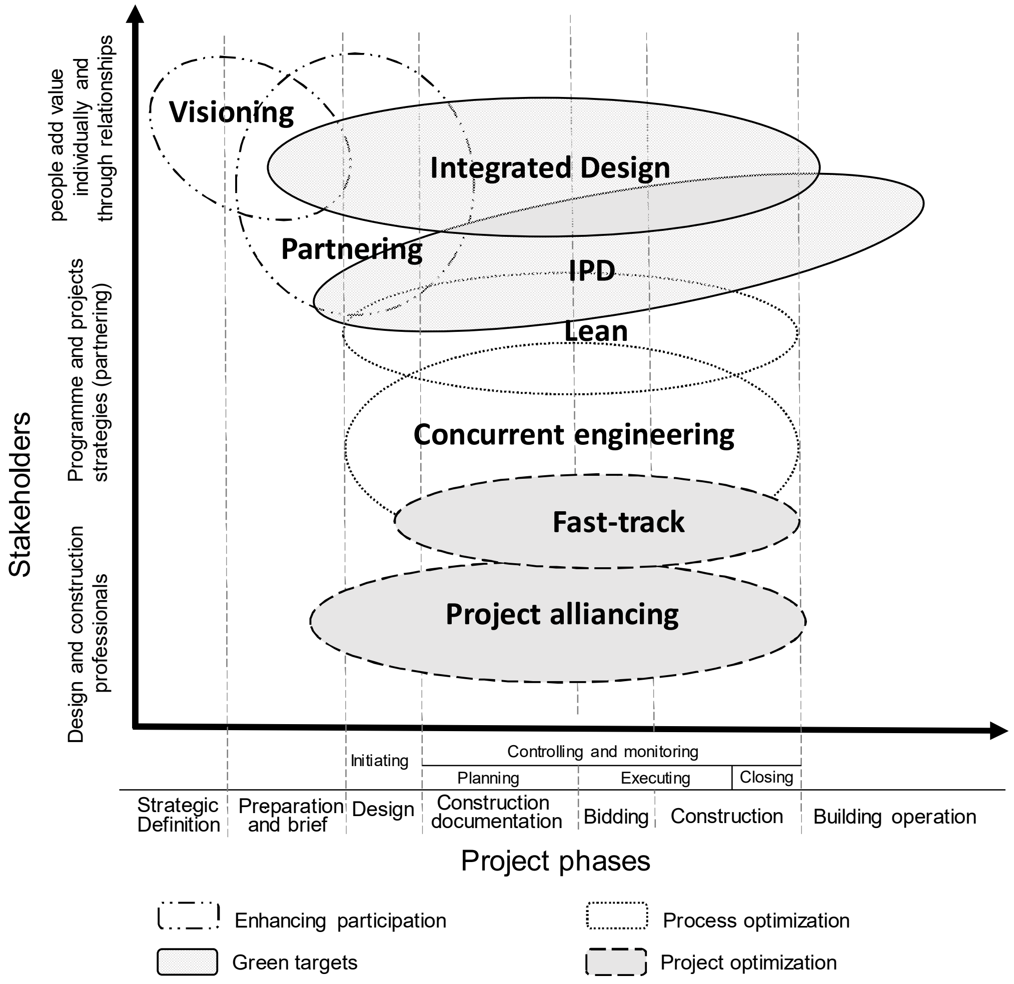

Figure 6. Integrated Practices in the construction industry.

1.5. Delivering sustainable buildings

The ID concept was introduced in the early 1990s by Natural Resources Canada's C-2000 program to support the design of energy-efficient commercial buildings. However, the impact of the program was unfortunately very limited, with less than 20 projects.

The procedure has, however, been used by the International Initiative for a Sustainable Built (iiSBE) and integrated into the SBTools. Nonetheless, it was only when the Green Building Council (GBC) integrated the process into the list of its LEED standard certification criteria that ID became widely known (Forgues & Dionne, 2015). Unlike traditional design processes, ID increase the team effort in a front-end loaded design to reduce costly changes in subsequence phases of the project (Sødal, 2014). Pressman (2007) describes ID as front-end effort to reduce cost (see Figure 7)

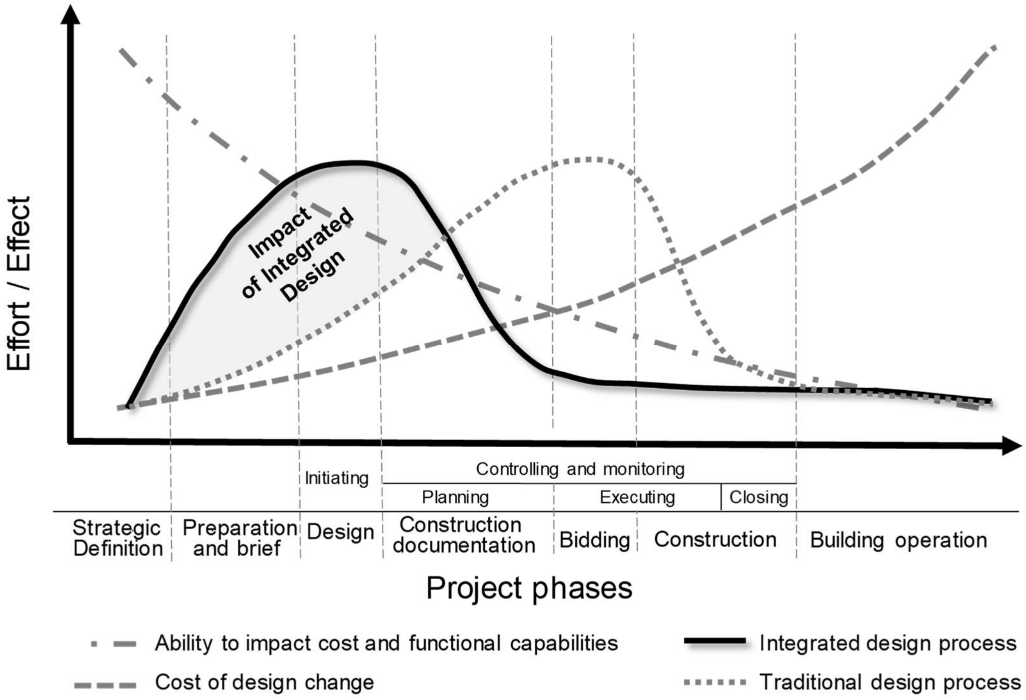

Figure 7. Integrated design process versus the traditional design process (Pressman, 2007)

Among the list of integrated practices in the construction industry, ID remains the most widely used for the realization of ecological buildings (Dionne, 2015). Traditional practices do not emphasize collaboration and multidisciplinary design teams, which is essential in a sustainable project context (Zimmerman, 2004). A thorough analysis of the literature of key concepts and approaches helped us to understand the scope and strengths of Integrated Design. Table 3 shows how Integrated Design responds to the weakness of the traditional design delivery process. Their relationship with the categories of analyses will be further discussed in the first article (chapter 4.2) and in the discussion section (chapter 5) of this thesis.

Table 3. A Comparison between the traditional approach and ID.

Traditional approach	Basis of analysis	**Integrated Design**
Fragmented, involves team members only when essential.	Teams	Inclusive from the outset, assembled early in the process, open, collaborative.
Linear process, knowledge gathered “just-as-needed"; silos of knowledge and expertise.	Process	Iterative process; information openly shared.
Functional specialization; fragmented, silo-based and strongly hierarchical.	Organization design	An open, collaborative, and integrated team of key players.
Gathered “just - as - needed”, hoarded in silos.	Knowledge and expertise	Shared openly and early in the process.
Limited to constrained optimization.	Optimization	Allows for full optimization.
Emphasis on up-front costs.	Costs	Life-cycle costing.
Individually managed, transferred to the greatest extent possible.	Risk	Collectively managed, appropriately shared.
Encourages unilateral effort; allocates and transfers risk; no sharing.	Agreements	Encourages, fosters, and supports multi-lateral open sharing and collaboration.
Budget output, activity, standards, productivity.	Measures	Related to purpose, capability, and variation.
Minimum effort for maximum return; (usually) first-cost based.	Compensation / Reward	Team success tied to project success; value-based.
Exploiting loopholes, individual reward, risk aversion.	Culture	Learning, continual improvement, engaging with reality.
Systems often considered in isolation, unilateral effort; optimizes parts.	Thinking	Whole-systems thinking; encourages multilateral open sharing and collaboration.
Contractual.	Attitude to client	Understanding users' human and technical concerns.
Typically finished when construction is completed	Life cycle	The process continues through post-occupancy.
Paper-based, 2-, 3- dimensional; analogue.	Communications / Technology	Digitally based, virtual; BIM (3-, 4- and 5-dimensional).
Top-down: managing the contract, the program, budgets, and people.	Management ethos	Outside-in: acting on the system to improve it for customers.
More decisions made by fewer people, separated from work.	Decisions	Decisions influenced by a broad team; based on data.
Diminished opportunity for synergies, no collaboration in the early stages.	Synergies	Seeks synergies, time and energy invested early.

1.6. Problem statement

The construction industry plays a vital role in the development of national economies. In Canada, construction accounts for 6.0% of Canada's gross domestic product (GDP), contributing $76.5 billion (StatCan, 2013) to the economy. The industry employed more than 1.3 million men and women in 2011 and accounted for 7.3% of all industrial employment. Despite its importance, the construction industry is considered to be a conservative, low-technology sector when compared to other sectors. It has great difficulty in adopting innovations from other areas such as aerospace, technology and automobile manufacture (Harty, 2008).

Yet, innovation is an important contributor to the well-being of contemporary societies and has become vital to national prosperity. It holds the key to the continuity and growth of companies (Harkema & Golriz, 2012; Van de Ven *et al.*, 1999). The fragmented nature of architectural design, construction and a building's operation has been identified as a significant barrier to innovation and collaboration. The pressure for cost reduction imposes significant time and resource constraints on project development (Reed, 2007).

In such circumstances, stakeholders meetings occur only for coordination purposes (Cole *et al.*, 2008). The isolation of the design disciplines from other members of the construction project leaves little room for optimization and generally leads to costly changes (Larsson, 2002; Magent, 2005). This creates not only a gap between the expected and actual performance of the construction project, but also significant impacts on the environment (Jayasena & Senevirathna, 2012; Larsson, 2002). The construction sector is responsible for 35% of waste generation, 32% of energy consumption, and 19% of greenhouse gas (GHG) emissions globally (Solís-Guzmán *et al.*, 2009; Zhang *et al.*, 2017).

The construction industry is consequently a key player when it comes to creating a more sustainable environment (Harkema & Golriz, 2012). To change this scenario, however, construction needs to shift its current focus on cost, schedule, and quality, to sustainable objectives, like low energy-consumption, users' health, waste and pollution reduction, and environmental protection (Bonham, 2013; Vanegas *et al.*, 1995).

Within this context, Integrated Design (ID) has emerged as an alternative to designing buildings that seek to achieve high performance on a wide variety of well-defined environmental and social goals while simultaneously staying within budgetary and scheduling constraints (Busby Perkins+Will & Stantec Consulting, 2007). ID involves a holistic approach that relies upon every member of the project team sharing a vision of sustainability and working collaboratively to implement sustainability goals.

Promising to enhance both, innovation and collaboration, ID propose a participatory process that brings together interdisciplinary experts and stakeholders (professionals, builders, experts, users, and owners) through intensive work sessions (dubbed design “charrettes”) during the project design phase (Ghassemi & Becerik-Gerber, 2011; Jayasena & Senevirathna, 2012). Decisions are made collectively in order to integrate otherwise fragmented products and processes (Forgues & Koskela, 2009) with the aim of designing better performing and more appropriate buildings for our society (Zerjav *et al.*, 2011).

Under these circumstances, it is expected that ID will enhance collaboration, and subsequently innovation, to achieve more sustainable buildings (Forgues & Koskela, 2009; Larsson, 2002). Although ID’s premises are theoretically well-founded, a close empirical look at its practices shows that numerous challenges compromise its results and efficiency. Nonetheless, ID's success as an innovative and collaborative process is seen as fundamental to reducing the impacts of climate change and to reversing the negative impacts of the built environment on nature and the health of users (Reed, 2007).

In this research, I am interested in understanding to what extent ID is able to improve the quality of buildings and their relationship with the environment. Assessing the limits and opportunities of ID will uncover the ways in which stakeholders in the construction industry can improve interactions among themselves in order to design buildings that are better for society and nature.

1.7. Research objective and questions

Scholars have long advocated the development of academic research connected to practical problems. They note that a central mission of scholars is to conduct research that advances both a scientific discipline and the practice of the related professional domains (Simon, 1967; Van de Ven, 2007). This is not always the case insofar as a number of scholars have pointed out that research needs to become more useful in solving practical problems (Beer, 1997; Gibbons *et al.*, 1994). Van de Ven and Johnson (2006) suggest that researchers can significantly increase the likelihood of advancing both theoretical and practical knowledge when they interact with practitioners through four interrelated activities during the research process:

1) Ground the research question or problem in contemporary, observable phenomena in order to situate its multiple dimensions and manifestations.
2) Develop concepts and models that take into account the main aspects of the observed phenomena and that thereby provide a basis for new theories to address the central research issue.
3) Use appropriate methods to design the research and gather empirical evidence for the examination the phenomenon.
4) Disseminate the research findings and their application to both academics and practitioners.

The construction industry is socially and economically crucial to Canada; however, it is also responsible for a number of negative impacts on the environment. In this context, Integrated Design (ID) is a method that aims at making the industry more efficient (Bonham, 2013). Despite its advantages over other methods and the massive support of professionals, researchers, and governments (AIA, 2007; Natural Resources Canada, 2015; USGB-Council, 2014), its results and effective use have been challenged (Chiocchio *et al.*, 2011; Kent & Becerik-Gerber, 2010; Owen *et al.*, 2010) thus suggesting that its limits and potential in the realm of architectural projects deserve to be studied.

The main objective of this dissertation is to examine, from a theoretical and empirical point of view, the scope, strengths, limitations, and critical success factors of Integrated Design (ID) in sustainable buildings in the construction industry.

Comparing ID theory and its practices, I was able to identify a gap between the often-high expectations of stakeholders and effective project performance. This objective leads me to formulate several questions such as: What is the extent of this gap? What influences the results of ID? What are the consequences of this gap for project performance? What opportunities does ID generate in the construction industry? How can ID be enhanced in order to improve the project management process?

This research focuses, however, on the following research questions: (RQ) To what extent does ID effectively improve buildings' performance in sustainable projects? The purpose is to provide new theoretical and empirical insight into building sector organizations and project processes through the study of the implementation of ID and its influence on project management.

In order to do so, several bodies of knowledge in innovation and collaboration, buildings' environmental impacts, and project management performance are examined in chapter 2 and allow me to define four additional research questions: (RQ-1) How can ID improve collaboration between stakeholders in a project?; (RQ-2) How can ID enhance innovation in a sustainable project?; (RQ-3) How does ID reduce the environmental impacts of buildings?; and (RQ-4) To what extent does ID influence project management practices in sustainable projects?

1.8. Research contributions and structure

This study examines the scope, strengths, limitations, and critical success factors of Integrated Design (ID) in sustainable buildings in the construction industry. The findings of this dissertation are that ID enhanced collaboration and innovation, and helped to reduce a building's impacts when compared to the traditional processes. ID failed, however, to achieve its full potential. It did not completely reduce fragmentation between stakeholders and subsequent phases. Identifying the gaps between the ID theory and its practice, this dissertation reveals areas where improvements are still necessary. The study suggests that project managers and design team can (and should) assume new roles and take on more responsibility in order to generate better project outputs. To do so, new contractual and informal arrangements between stakeholders are needed.

This dissertation has five chapters. This first chapter introduces the research problem and presents the objectives and research questions. The research process benefited from the author's experience and academic background in the fields of architecture, management, and sustainability. After many years of practice, several theoretical questions emerged to connect these disciplines. The four research questions are all interconnected in the sense that their content, investigation, and resolution build upon each other. To answer the questions, an extensive study was conducted, and findings reported in three conference articles and three publications.

The questions that emerged at the beginning of the doctoral dissertation were tested in a pilot case and presented to and discussed by other academics and professionals at different international conferences. The initial results were then validated and extended in three case studies, resulting in the publication of three articles in peer review journals. The publications were part of an iterative process during which individual publications provided new knowledge, perspectives, and ideas with which to understand the impact of ID in the building sector. Each article structured around two research questions and one body of knowledge. The overall result is a coherent thesis (see Figure 8).

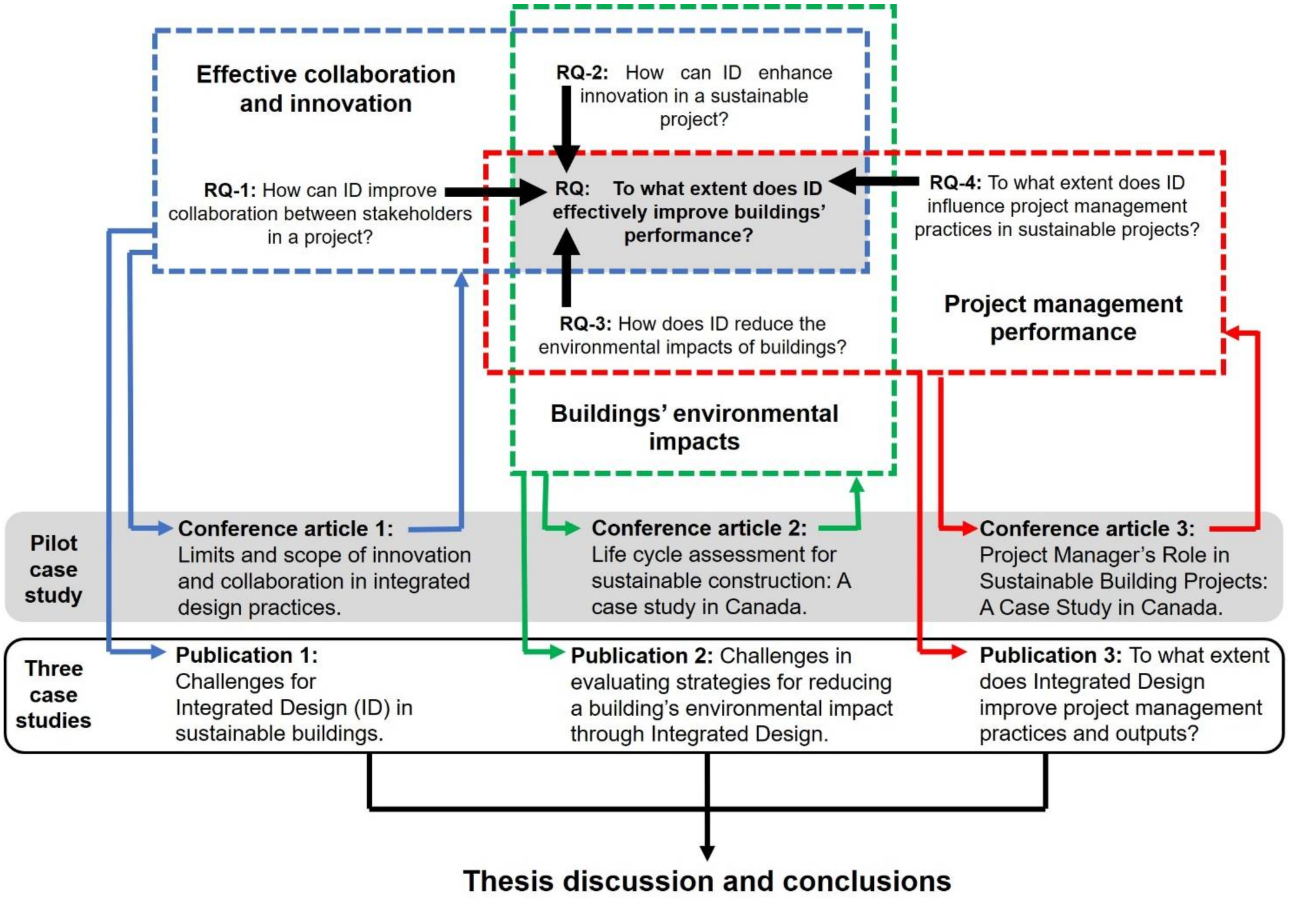

Figure 8. Individuals publications and their relationship with the specific research questions

The publication of scientific articles allowed me to disseminate the results of this thesis more widely and more rapidly to the international community than a traditional thesis. To establish the links between the publications and the essential components of a traditional thesis, two sections were added. In the second chapter, I develop a part of the analytical framework that was not treated systemically in the publications. A section at the end of this document draws together the results from the three publications and elaborates a unique discussion and synthesis.

I was the leader in the preparation of all the publications included this thesis. This preparation included: 1) literature research (including identification, analysis and synthesis of articles and books); 2) empirical research, 3) data analysis (including mapping activities, production of tables, diagrams, summary documents, testimonial identification, etc.), 4) writing, 5) planning and organization of research (including project visits, interviews, document collection, photo taking, analysis of plans, etc.), 6) follow-up on the publication submissions, answering reviewers questioning during the publication processes. The co-author, my thesis director, discussed the analytical framework, proposed readings, suggested strategies and methods, revised the text and proposed alternatives for data analysis. These are the traditional tasks of a thesis director.

The **second chapter** of this thesis presents a literature review of the global construction industry and current challenges to the enhancement of project performance. It presents the primary integrated approaches and the theories used to understand ID approaches. I analyse the current state of Integrated design research and identify the gaps in the literature.

This thorough analysis of the literature enabled me to identify three bodies of knowledge to better understand ID performance: (1) effective innovation and collaboration in the built environment; (2) a building's environmental impact; and (3) project management performance. The review of the literature in each domain was necessary to better understand the general impact of the domain in the construction industry before being examined in the field of Integrated Design. A more specific literature review is presented in each conference article and publication.

The **third chapter** presents the research method used to answer the research question. This research project proposes the exploratory case study as its primary methodology. The chapter explains the iterative and cyclical process of this research: I first applied the analytical framework, developed in chapter 2, to a pilot case study. I then went back into the field and refined the questions that served for further investigations in three case studies. This methodology was applied to each of the bodies of knowledge identified in the literature review. The chapter then goes on to present the methods and tools, the analytical approach, unit of analysis, and the sampling strategy and data collection. The chapter ends with the ethical considerations that I have considered.

The **fourth chapter** presents the findings of the six articles that is to say, the three conference articles and three publications. One major difference between a traditional thesis and a thesis by articles is that there is some repetition of the information contained in the publications. For example, the theoretical discussions, methodology, and case study identification must be explained in every publication. Figure 1 illustrates how the six articles articulate the research questions and the three bodies of knowledge in order to create a coherent thesis.

- **Effective collaboration and innovation:** Conference article 1 (Chapter 4.1.1) examined, both theoretically and empirically, the contingencies that limit Interactive Design's capacity to achieve innovation and collaboration goals. The results of the pilot case study helped to refine RQ-1 and RQ-2, questions that were further developed in Publication 1 (Chapter 4.2).
- **Buildings' environmental impacts:** Conference article 2 (Chapter 4.1.2) measured the environmental impacts of the innovations implemented in the pilot case study applying Life Cycle Assessment (LCA). The results of the pilot case study helped to refined RQ-2 and RQ-3, questions that were further developed in Publication 2 (Chapter 4.3).
- **Project management performance:** Conference article 3 (Chapter 4.1.3) assess empirically the extent to which ID improves project management practices (reducing fragmentation between project phases) and outputs (reducing a building's environmental impact). The results from the pilot case study helped to refined RQ-3 and RQ-4, questions that were further developed in Publication 3 (Chapter 4.4).

The fifth chapter summarizes the conclusions. The results from each publication are first used to answer to each research question individually. They are then used to develop a unique discussion and synthesis to answer the main research question (RQ). The chapter also discusses the validity, reliability and limits of the empirical research and raises questions for future research.

2. LITERATURE REVIEW

In this chapter I present the relevant academic literature to understand integrated project-delivery process challenges in the construction industry in general. In doing so, I identified three bodies of knowledge that will be used as a "lens" to help to answer the research questions. I present here an initial review of the literature of each lens. The lenses and their literature will be further developed in the publications. The purpose of this chapter is not to reiterate the literature review of each publication, but to emphasize the concepts and tools that connect the publications and fill the knowledge gaps that were not covered. The objective is to analyze the process and the values created by the ID process throughout a building's entire life cycle (see Figure 9).

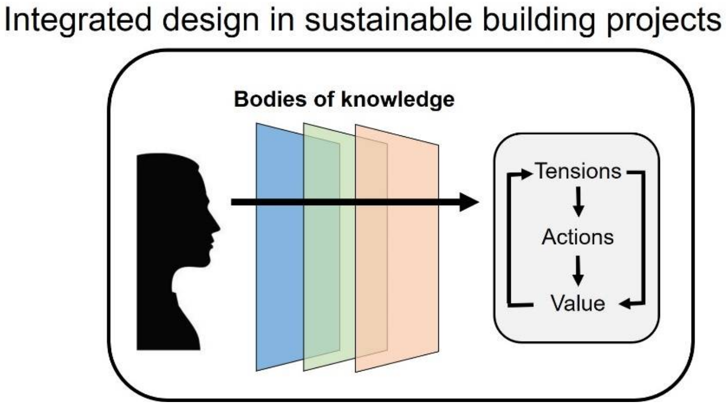

Figure 9. Representation of the procedure of our analytical framework based on Lizarralde *et al.* (2013).

2.1. Challenges to project performance in the building sector

The fragmented nature of the industry, the unwillingness of stakeholders to take risks, the lack of the stakeholders' commitment to the project, and the customary constraints (time and resources) have been identified as significant barriers to innovation and collaboration (Huovila *et al.*, 1997; Kulatunga *et al.*, 2011; Lu *et al.*, 2000; Smyth & Pryke, 2009). In fact, buildings are typically designed on a project-by-project basis by temporary coalitions of stakeholders brought together for a limited and finite purpose (Cherns & Bryant, 1984). Stakeholders in the traditional construction industry work in silos in a linear and fragmented way and are often characterized in the literature as being poorly coordinated (Magent, 2005).

The various disciplines work in isolation during the design and construction processes (Kashyap, et al., 2003), leaving little room for optimization (Owen *et al.*, 2009). This in turn leads to costly changes, duplicated design efforts, and redundancies in the final design (Koskela, 2007) as well as inefficiency, problems of quality, and buildings that operate below their optimum potential (Ofori, 2000). In addition, members of the project teams will change from the design phase to the construction phase, which often creates a gap between the expected and the actual project quality (Jayasena & Senevirathna, 2012).

Increasing attention towards the principles of sustainability, however has prompted professionals, clients, and all members of the design and construction industry to seek new modes of operation and cooperation (Bonham, 2013). All industry participants are being increasingly challenged to innovate in order to satisfy society's aspirations and the need for an expanded definition of ethical practice (Latham, 1994). Integrated Design is one alternative method that aims at reducing this fragmentation in order to make the industry more efficient (Zerjav *et al.*, 2011).

Ever since the 1990's, scholars have argued that integrating the key participants involved in a project (i.e. clients, architects, structural engineers, quantity surveyors, mechanical/electrical service engineers, contractors, and material suppliers) as opposed to the traditionally fragmented approach, generally leads to more successful projects (Evbuomwan & Anumba, 1998; Koskela & Huovila, 2000). To better understand Integrated Design in the construction industry, it is important to first review Concurrent Engineering (CE).

2.2. Concurrent engineering

As opposed to the traditional processes in the industry in general, in the 1980s a number of scholars advocated for cooperation, trust, and sharing in such a manner that decision-making would be made through consensus in order to generate more successful projects (Evbuomwan & Anumba, 1998; Prasad, 1996). Ettlie and Reza (1992) defined Concurrent Engineering (CE) as "the coordinated development effort in timing and substance of the various disciplines and organizational functions that span the life-cycle of new products and services."

The term CE first appeared in 1986 at the Institute for Defense Analyses and was then defined as "a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support (Bidault *et al.*, 1998). This approach was intended to force developers to consider all elements of the product life cycle, from conception to disposal, including quality, cost, schedule, and user requirements from the very outset (Carter & Baker, 1992). Even in the absence of any great concern for the environment r sustainability, CE proposed that the firms could benefit (time and profits) from the early involvement of various disciplines in new product development (Owen *et al.*, 2009; Prasad, 1996). In this regard, CE created the basis for Integrated Design in the construction industry (Forgues & Koskela, 2009).

2.3. Integrated Design

CE principles were introduced into the construction industry in the 1990's as a promising method for radical process improvement in construction projects. The design method proposed by the Canadian C2000 program (later called Integrated Design Process – IDP) was launched in 1993 as a more holistic approach to designing high-performance and lower-impact buildings (Forgues & Koskela, 2009; Larsson, 2004). ID entails a simultaneous participatory process that brings together all stakeholders involved in projects in the construction industry (professionals, manufacturers, interdisciplinary experts, users, and managers of the building) through intensive collaborative design workshops (called "charrettes") where the client takes a more active role than usual (Chiocchio & Forgues, 2008; Forgues & Lejeune, 2011).

Unlike traditional design processes, ID allows all stakeholders to work together from the beginning of the project throughout the entire project life-cycle, from pre-design through occupancy and into operations (Guenther & Vittori, 2008). Reed and Gordon (2000) explain that Integrated Design emphasizes the three "E's": Early participation by Everybody involved in the project design to discuss Everything having to do with the design. Decisions are taken collectively, reducing fragmentation in the design process and enhancing project and industry efficiency to deliver sustainable projects (Ghassemi & Becerik-Gerber, 2011; Jayasena & Senevirathna, 2012; Zerjav *et al.*, 2011). ID is aligns the incentives and goals of the project team through shared risk, early involvement of all parties, and a multiparty agreement making the construction industry more efficient (Kent & Becerik-Gerber, 2010; Zerjav *et al.*, 2011).

The process aims at enhancing both collaboration and innovation in order to fulfill new expectations and the needs of a broader group of stakeholders (Ghassemi & Becerik-Gerber, 2011; Jayasena & Senevirathna, 2012; Latham, 1994). As described by Larsson (2002) in a workshop for practitioners held in Toronto in October 2001 :

> "*Integrated Design is a method for realizing high-performance buildings that contribute to sustainable communities. It is a collaborative process that focuses on the design, construction, operation, and occupancy of a building over its complete lifecycle. The integrated design process is designed to allow the client and other stakeholders to develop and realize clearly defined and challenging functional, environmental, and economic goals and objectives. It requires a multi-disciplinary design team that includes or acquires the skills required to address all design issues flowing from the objectives" [as quoted by Forgues and Koskela (2009, p. 3)].*

In ID, design is not only about problem-solving, but also about problem-finding. Dillon (1982) explains that finding (discovering, formulating, posing) a problem represents a distinct and creative act that is even more valuable than finding a solution. Einstein and Infeld (1961) noted: "The formulation of a problem is often more important than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle requires imagination and marks a real advance in science".

The teams, in ID, for example, are increasingly called upon to consider the whole life cycle of the building, not just the initial capital investment in construction (Rekola *et al.*, 2012). By developing and sharing new knowledge, all stakeholders generate added value in the process and to the final product (Ghassemi & Becerik-Gerber, 2011; Jayasena & Senevirathna, 2012). ID can be differently defined and named with each variation bearing its own particularities (see Table 4) but all of which adhere to the main ideas discussed above.

Table 4. Different Integrated Design Schools

Name	**Organisation**	**Definition**
Integrated Project Delivery (IPD)	AIA - The American Institute of Architects	Formulated by the American Institute of Architects (USA) for AIA members and the public. Is a method of project-delivery distinguished by a contractual arrangement among a group consisting of the owner, the constructor and a design professional that aligns business interests of all parties. (AIA, 2007)
Integrated Design Process (IDP)	C-2000 Program - Natural Resources Canada (NRCan)	Supported by International Initiative for a Sustainable Built Environment (iiSBE), IDP is a method of intervention in early stages of the design process that supports the development and design team to avoid sub-optimal design solutions. (Larsson, 2002, 2009)
Roadmap for the Integrated Design Process (IDP)	Busby Perkins+Will and Stantec - BC Green Buildings Roundtable	Developed for the British Columbia Green Building Roundtable, IDP relies upon a multi-disciplinary and collaborative team to make decisions together based on a shared vision and a holistic understanding of the project. It follows the design through the entire project life, from pre-design through occupancy and into operation. (Busby Perkins+Will & Stantec Consulting, 2007)
Whole System Integration Process (WSIP)	ANSI – The Institute for Market Transformation to Sustainability	Supported by the Institute for Market Transformation to Sustainability (MTS). A discovery process optimizing the elements of all living systems and their interrelationships (the Whole) in the service of sustaining the health of living systems (human, biotic, and earth systems) (ANSI, 2007)
Integrated Design and Delivery Solutions (IDDS)	CIB and Robert Owen - University of Salford, UK	Promoted and encouraged by organizations such as CIB. Framework for an integrated and coordinated merger of people, process and technology issues to enact a radical and sustained transformation of the construction industries. (Owen *et al.*, 2009)
Integrative Process (IP)	ANSI – The Institute for Market Transformation to Sustainability	Developed by the American National Standards Institute (ANSI). Provides a common reference for all industry practitioners in support of process changes needed to effectively realize cost savings, a deeper understanding of human and environmental interrelationships, and an improved environment for all living systems. (ANSI, 2010)
Integrative Design Process (IDP)	7group and Bill Reed	Developed by 7Group and Bill Reed. Cross-disciplinary teamwork early in the design process to achieve the successful integration of community systems in a design "to form an integral whole and to function, operate, or move in unison. (Reed, 2009)

The Charrette in Integrated Design

The term “charrette” has its origin in the 19th century at the Paris School of Fine Arts. Proctors circulated a “charrette” to collect the final drawings while the students were finishing their work. Currently, the term charrette has a different meaning. Today, in ID context, it refers to a series of meetings that brings together all project stakeholders involved in a building project (Gibson & Whittington, 2009). Project teams benefit from immediate feedback as well as from the impact analysis of their proposals (cost, environmental impacts and viability). “The process works very well if you have both a facilitation process that enables people to understand it from the [experts’] point of view, and you have a facilitation process that really does not presume anything about the [community’s] input … because these people are very well-informed” (Sutton & Kemp, 2002, p. 125). Ideally, meetings should include the owner, the project team, the builder, facility managers, experts, users, and community members (Todd & Hayter, 2003). Although the charrettes are not mandatory for LEED certification (only points), it has been widely used in projects aimed at USGBC certification in green-building delivery (Forgues & Dionne, 2015).

2.4. Integrated Design research

Although several professional organizations (AIA, 2007; Busby, 2001; USGB-Council, 2014), professionals (Pearl, 2004; Reed, 2009), researchers (Forgues & Koskela, 2009; Owen *et al.*, 2010), and governments and governmental organizations (Hobbs & Royal Architectural Institute of Canada, 2009; Natural Resources Canada, 2015) support the advancement of ID, the number of projects using ID remains relatively small (Kent & Becerik-Gerber, 2010). Existing research initiatives and studies can be divided into two groups: a) professional organization manuals or guides describing the best practices in ID, or b) studies extolling the advantages of and barriers to ID implementation. The first group can be helpful in understanding the “modus operandi” of Integrated Design and in highlighting important differences among more traditional methods (see Table 5).

Table 5. Manuals or guides describing the best practices in ID.

ID approaches	Integrated project delivery: a relational contracting	(Matthews & Howell, 2005)
	UBC Sustainable Initiative	(UBC Sustainable Initiative, 2011)
	The integrative design guide to green building	(Reed, 2009)
	The Integrated Design Process (IDP)	(Larsson, 2004)
	Integrated Design and Delivery Solutions	(Prins & Owen, 2010)
	William McDonough + Partners	(McDonough & Partners, 2015)
ID guides	The integrated design process	(Natural Resources Canada, 2015)
	Integrated Project Delivery: A Guide	(AIA, 2007)
	Sustainable Design Fundamentals for Buildings	(Busby, 2001)
	Understanding the Integrative Process in LEED v4.	(Boecker, 2014)
	Integrated design process guide	(Zimmerman, 2004)
	Roadmap for the Integrated Design Process	(Busby Perkins+Will & Stantec Consulting, 2007)

The second group can also be divided into two sub-groups, one that emphasizes the advantages of ID and that concentrates primarily on the design phase. In the second sub-group there are studies that identify barriers to ID implementation. Table 6 summarizes these two sub-groups of Integrated Design studies.

Table 6. Reports and case studies about Integrated Design

Benefits for ID	Manitoba Hydro Place: Integrated Design Process Exemplar	(Kuwabara *et al.*, 2009)
	Centre for Interactive Research on Sustainability (CIRS)	(CIRS, 2011)
	The Practice of Integrated Design: The Case Study of Khoo Teck Puat Hospital, Singapore	(Yen, 2012)
	Integrated design for high performance green buildings	(Mcnamara Jr., 2010)
	Design Process Integration for Sustainable, High Performance Buildings	(Nofera & Korkmaz, 2010)
Challenges for ID	The Integrated Design Process on Paper and In Practice: A Case Study	(Rossi *et al.*, 2009)
	Teamwork in Integrated Design Projects: Understanding the Effects of Trust, Conflict, and Collaboration on Performance	(Chiocchio *et al.*, 2011)
	Challenges for Integrated Design and Delivery Solutions	(Owen *et al.*, 2010)
	Design charrette: A vehicle for consultation or collaboration	(Smith, 2012)
	Transitioning to Integrated Project Delivery: Potential barriers and lessons learned	(Ghassemi & Becerik-Gerber, 2011)
	Integrated design and building process: what research and methodologies are needed?	(Reed & Gordon, 2000)

To better understand ID practices in the development of green buildings, Reed and Gordon (2000) suggest that more well-documented case studies are required to examine the process and benefits of sustainable design and to monitor the design, construction, and operation of the projects. Even though ID proposes to influence the design, construction, operation, and occupancy of a building over its complete life-cycle, few studies analyze the construction phase and even fewer the operational phase of the building. Table 7 outlines some of the research on collaboration, innovation, and the integrated design field that support the approaches used in our research.

Table 7. Research studies in collaboration, innovation, or the integrated design field.

Manuscript	Methodology		
Design Process Integration for Sustainable, High Performance Buildings (Nofera & Korkmaz, 2010)	Case study / surveys and interviews	Quantify benefits of delivery attributes to high performance buildings	Quantitative
Can procurement affect design performance? (Forgues & Koskela, 2008)	Activity theory and grounded research / case studies	The influence of procurement on the performance of integrated design teams	Exploratory / Qualitative
The influence of green building certifications in collaboration and innovation processes (Herazo & Lizarralde, 2015)	Case study / interviews / document	Understand how GBCs have influenced building processes	Exploratory / Qualitative
Managing for Increased Design and Construction Innovation (Tatum, 1989)	Analyzes successful innovations in construction firms	Innovation to improve productivity and to increase competitiveness in construction	Qualitative
The Integrated Design Process on Paper and In Practice: A Case Study (Rossi *et al.*, 2009)	Case study / interviews / document	compares the integrated design process	Qualitative
Client's championing characteristics that promote construction innovation (Kulatunga *et al.*, 2011)	Multiple holistic case studies / interviews / cognitive mapping	Evaluates the characteristics of the construction client that promote innovation	Qualitative
A process and competency-based approach to high performance building design (Magent, 2005)	Case study / surveys and interviews	Identifies critical decisions that the design team encounters during the design of high-performance buildings	Exploratory / Qualitative
Challenges for Integrated Design and Delivery Solutions (Owen *et al.*, 2010)	Analyzes information from IDDS projects	Describes four key topics to improve IDDS based on the current situation and the potential future	Qualitative

2.5. Identifying key concepts - analytical framework

Reviewing integrated project-delivery charters helped us to identify a common theme linking Concurrent Engineering (CE), Integrated project delivery (IPD), integrated design processes (IDP) and Lean Design and Construction. These processes are meant to be a more ***efficient project management*** method that enhances ***innovation*** and creates an improved project with a ***reduced impact on the environment.*** They are all ***collaborative processes*** that aim to involve the multi-disciplinary design team ***throughout the project's design, construction and operation*** over its **complete lifecycle**.

These key concepts that structure integrated project delivery approaches will be used in this doctoral thesis as a categories of analysis (constructs). The constructs will serve as a "lens" to help reveal and understand the inherent tensions (conflicts, controversies, dilemmas, etc.) that arise from the ID practices in the construction industry. The following section will first review the literature on collaboration, innovation, buildings' environmental impacts, and project management performance in the construction industry in general. It will then be applied to ID projects specifically to help to answer the research questions (see Figure 10).

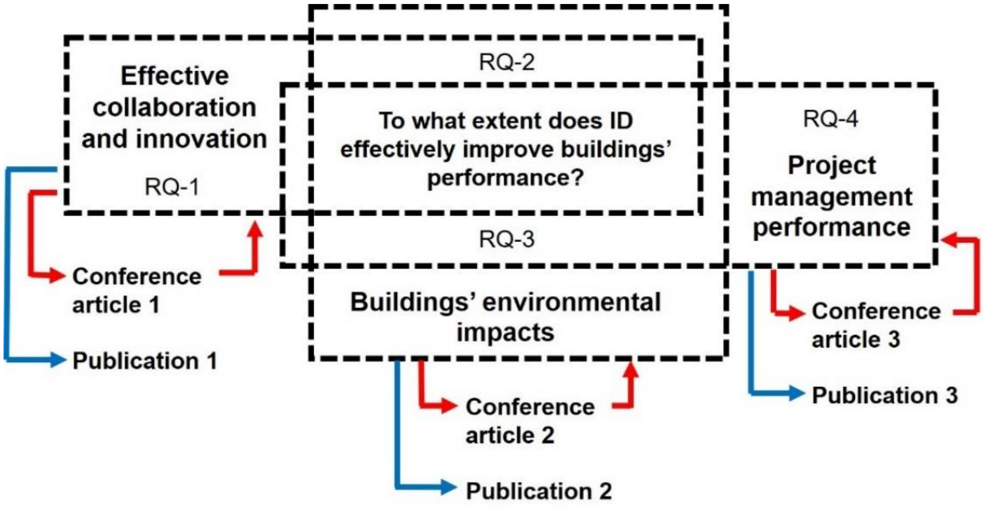

Figure 10. Relevant constructs to understand the inherent questions that arise in integrated project delivery approaches in the construction industry.

2.5.1. Effective collaboration and innovation

Innovation plays a significant role in enhancing and sustaining the economic growth of companies, in building industrial competitiveness, in improving the standard of living, and in creating a better quality of life (Gopalakrishnan & Damanpour, 1997; Van de Ven *et al.*, 1999). Collaboration between stakeholders has been identified as crucial to successful innovation in the construction industry (Von Stamm, 2004).

Even if collaboration is a critical factor in delivering successful projects, contradictory relationships between stakeholders are rarely well managed (Smyth & Pryke, 2009). The industry's ability to innovate is also crucial to national prosperity (Porter, 1991), and its absence may impoverish society (Serpell & Alvarez, 2014). The construction sector is considered, however, a conservative and low-technology domain that lags behind others sectors (aerospace, technology, and automobile) with regards to innovation (Kulatunga *et al.*, 2011) and collaboration (Huovila *et al.*, 1997).

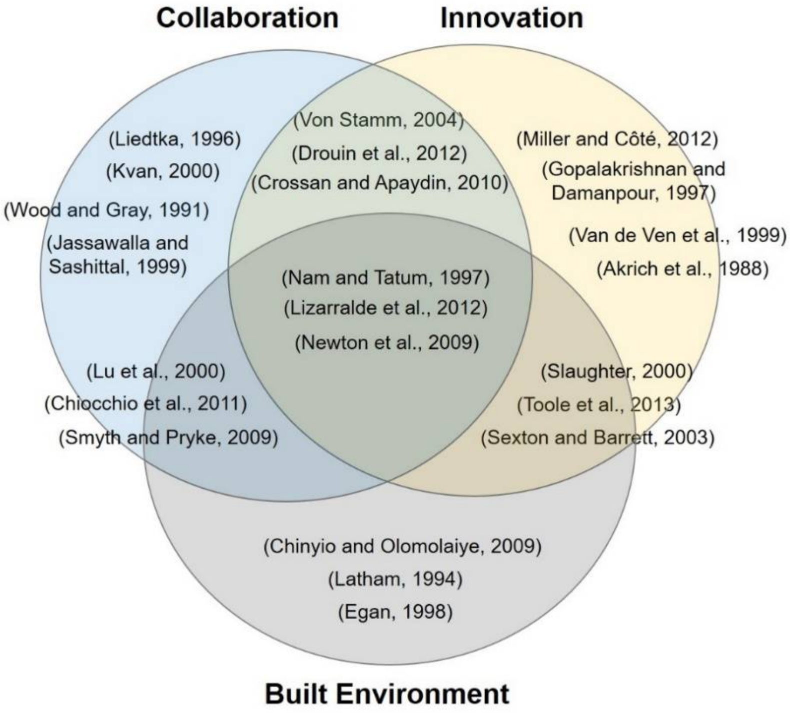

Figure 11. Relevant articles referenced to understand the relationship between innovation and collaboration and their links with the built environment.

This literature review (Figure 11) identified innovation as key in the creation of value and sustaining competitive advantage (Baregheh *et al.*, 2009; Toole *et al.*, 2013) Lizarralde *et al.* (2014) argue that an approach to innovation in the built environment must consider those who perceive the innovations as valuable. In this research, innovation in the built environment will be seen as a nontrivial improvement in terms of the value it creates for stakeholders (Lizarralde *et al.*, 2015) and collaboration as a mechanism to facilitate the sharing of information, resources and knowledge for the common benefit of stakeholders (Crossan & Apaydin, 2010; Von Stamm, 2004).

Collaboration

It is very difficult to talk about innovation in the construction industry without referring to collaboration as a mechanism for facilitating the sharing of information, resources, and knowledge (Crossan & Apaydin, 2010; Lizarralde *et al.*, 2014; Von Stamm, 2004). Liedtka (1996, p. 21) defines collaboration as a "process of decision-making among interdependent parties; it involves joint ownership of decisions and collective responsibility for outcomes". Wood and Gray (1991, p. 146) contend that collaboration occurs "when a group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain". Collaboration allows organizations to work and learn across silos and to facilitate the sharing of information, resources, and knowledge (Crossan & Apaydin, 2010; Von Stamm, 2004). Collaboration is successful when something is accomplished within a group instead of in an individual manner (Kvan, 2000).

Jassawalla and Sashittal (1999) noted that the term collaboration is often used interchangeably with cooperation. Despite this synonymy, the authors note relevant differences between them. As for Lizarralde *et al.* (2012), cooperation is often characterized by informal relationships (i.e. those that exist without a commonly defined mission, structure, or effort), while collaboration refers to higher levels of integration that frequently connote a durable relationship between "stakeholders that share similar responsibility and authority (notably among professionals or between professionals and contractors" (p.6).

Users' participation in a design process is defined by Sanoff (2000) as a series of meetings or information exchange sessions that aim to reduce the feeling of anonymity and communicate to the users a greater degree of concern on the part of others stakeholders. Mattessich and Monsey (1992) emphasize the point that collaboration requires a greater commitment to a common goal than cooperation. The authors add a third concept, coordination, which is more informal in terms of structure and formality, where each organization retains its authority and independence and avoids risk-taking. Table 8 summarizes the characteristics and *modus operandi* of each of them.

Table 8. Differences between cooperation, coordination, and collaboration.

		Characteristics	Modus Operandi	
	Participation	Information exchange, resolving conflicts, and supplementing design and planning direct public involvement in decision-making.	They can be invited to participate (meetings, for example) and also share their opinions, but they have no power of decision.	
Risk ↓	**Cooperation**	Informal relationships exist without a commonly-defined mission, structure, or effort.	Each cooperating organization remains independent, takes no risk, and retains complete authority.	**Commitment** ↓
	Coordination	Formal relationships and understanding of compatible missions exist. Some planning and division of roles are required, and communication channels are established.	Authority is retained by the individual organization, but there is some increased risk to all participants. Resources are available to participants and rewards are mutually acknowledged.	
	Collaboration	Implies a more durable and pervasive relationship and full commitment to a common mission.	Authority is determined by the collaborative structure. Risk is much greater.	

Success of collaboration in design depends on the capabilities and commitment of the stakeholders involved and not only on the orders issued from directors (Liedtka, 1996). For example, in the 1970's, European companies successfully implemented a new innovative strategy, engaging their workers (user-participation) in the development of new systems for the workplace in order to increase the value of industrial production. Initially called participatory design (Sanders & Stappers, 2008), the activity is now better known as co-creation and co-design.

Many articles treat the terms co-creation and co-design synonymously. Sanders (2002), however, highlights differences between them. This author uses the concept of co-creation in a broader way to refer to any act of collective creativity involving two or more people and the concept of co-design to refer to the creativity of designers and people not trained in design working together across the entire design process. Co-production is another term related to participatory design. In this kind of activity, users are not just adding value to the design process; they are “an operant resource” for the firm, “a collaborative partner who co-creates value with the firm” (Lusch *et al.*, 2007, p. 6). Co-production is related to the emerging concept of customer experience where consumers who participate in the production are also consumers (Humphreys & Grayson, 2008). The main characteristics and differences between them can be seen in Table 9.

Table 9. Different approaches to participation in the design phase.

		Characteristics	**Modus Operandi**	
	Participatory design	The challenge of engaging stakeholders as designers in the design process.	People express themselves and participate directly and proactively in the design development process.	
Risk ↓	**Co-creation**	A special case of collaboration where two or more people intend to create something that is not known in advance.	The customer or/and designers are genuinely co-developing the solution to the problem/situation that needs to be solved.	**Commitment** ↓
	Co-design	A collective creativity (designers and users) applied across the whole span of a design process.	Designers, end-users untrained in design, and perhaps other stakeholders work together	
	Co-production	The practice of engaging consumers in the production process (modification and development) of future products and services.	Experienced consumers serve as co-producers interacting with designers to improve the effectiveness and efficiency of product/service design (creating exchange value).	

Innovation

Several definitions of innovation exist in the literature. For Dulaimi *et al.* (2005), innovation is the generation, development, and implementation of new processes, products, or management approaches that are new to an organization and that increase efficiency and have practical benefits. Innovation is defined in the Oslo Manual (OECD/Eurostat, 2005, p. 46) as “the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace or external relations”.

Miller and Côté (2012) claim that the ideas need not necessarily be new, but should be followed by effective implementation in order to improve overall organizational performance. Innovation begins by asking questions about the whole system and sometimes assembling old things in new ways (Einstein & Infeld, 1961). Baregheh *et al.* (2009) identified six key attributes of innovation across various disciplines:

- **Stages of innovation**: Refer to all steps taken during an innovation process, which usually starts from idea generation and ends with commercialization.
- **Social context:** Refers to any social entity, system, or group of people involved in the innovation process or environmental factors affecting it.
- **Means of innovation:** Refers to the necessary resources (e.g. technical, creative, financial) that need to be in place for innovation.
- **Nature of innovation:** Refers to the form of innovation as in something new or improved.
- **Type of innovation:** Refers to the kind of innovation as in the type of output or the result of innovation, e.g. product or service.
- **Aim of innovation:** Is the overall result that the organization wants to achieve through innovation

Stakeholders can arguably improve innovation strategies by explicitly announcing the type of innovation being considered in the early phases of the project (Slaughter, 2000). Gopalakrishnan and Damanpour (1997) have conducted an extensive study in order to examine the ways researchers conceptualize innovation and found that the concepts have usually been commonly categorized into three sets of contrasting types: product vs process; radical vs incremental; and technical vs administrative (see Table 10).

These contrasting types are useful in understanding the construction industry and some of the challenges that Integrated Design attempts to overcome. Van de Ven (1986) claims that to understand the process of innovation, is important first to identify the factors that facilitate and inhibit the development of innovations. The factors (ideas, people, transactions, and evolution) and the central problems related are summarized in Table 11.

Table 10. Descriptive framework to categorize types of innovation adapted from Gopalakrishnan and Damanpour (1997)

Innovation Type		Description	References
Product vs process	**Products**	Include outputs or services that are introduced for the benefit of customers or clients.	Utterback and Abernathy (1975)
	The distinction between product and process relates to the areas and activities that an innovation affects.		Gopalakrishnan and Damanpour (1997)
	Process	Defined as tools, devices, and knowledge in throughput technology that mediate between inputs and outputs and are new to an industry, organization, or subunit	Capon *et al.* (1992); Capon *et al.* (1992); Ettlie and Reza (1992)
Radical vs incremental	**Radical**	Produce fundamental changes in the activities of an organization or an industry and represent clear departures from existing practices.	Tushman and Anderson (1986)
	Researchers identify an innovation as either radical or incremental by determining the degree of change associated with it.		Ettlie *et al.* (1984); Normann (1971)
	Incremental	Call for marginal departure from existing practices and mainly reinforce the existing capabilities of organizations.	Dewar and Dutton (1986); Henderson and Clark (1990)
Technical vs administrative	**Technical**	Include products, processes, and technologies used to produce products or render services directly related to the basic work activity of an organization.	Damanpour and Evan (1984); Daft (1978); Damanpour and Evan (1984)
	Technical and administrative innovations are, respectively, related to the technical and administrative cores of the organization.		Daft (1978)
	Administrative	Are indirectly related to the basic work activity of the organization and are more directly related to its management.	Damanpour and Evan (1984)

Table 11. Four central problems in the management of innovation according to Van de Ven (1986).

Central problems		Definitions
Ideas	The challenge of turning ideas into good currency	People and their organizations are designed to focus on, harvest, and protect existing practices rather than pay attention to developing new ideas.
People	The human problem of managing attention.	Invention is an individual activity, but innovation is a collective achievement of pushing and riding those ideas into fruition (implementation and institutionalization).
Transactions	The structural problem of managing part-whole relationships.	Multiple functions, resources, and disciplines are needed to transform an innovative idea into a concrete reality, but individuals involved in individual transactions can lose sight of the overall innovation effort.
Context over time	The strategic problem of institutional leadership	Innovations transform the structure and practices of these environmental settings over time. The strategic problem is one of creating an infrastructure that is conducive to innovation.

2.5.2. Champions’ Roles in Innovation and Collaboration

The champions’ role and leadership are important to stimulate innovation (Dean, 1987). According to Slaughter (2000), the decision to innovate often relies on the actions of a particular leader who is willing to shepherd the innovation throughout the design process. Champions typically inspire and enthuse others, showing a sustained commitment to stakeholders and the project (Maidique, 1980). Table 12 demonstrates the champion’s role in supporting and promoting innovation despite strong opposition.

Table 12. Champions’ Roles in Innovation and Collaboration (Nam & Tatum, 1997; Roberts & Fusfeld, 1982)

Champions’ roles	Activities	References
Generating ideas	Analyzing and/or synthesizing information about an idea to a challenging technical problem.	Pelz and Andrews (1966)
Gatekeeper	Collecting and channelling information about significant changes in internal and external environment settings	Allen (1977)
Entrepreneuring champion	Recognizing, proposing, pushing, and demonstrating a new technical idea for formal management approval.	Roberts (1969)
Project leading	Planning and coordinating the diverse sets of activities and people involved in moving a demonstrated idea into practice.	Marquis and Rubin (1966)
Sponsoring or coaching	"Behind-the-scene" support-generating function or guiding and developing of less experienced personnel in their critical roles	Roberts (1969)

Collaboration and innovation research

Innovation and collaboration occur in different ways and vary throughout the supply chain and project stages, whether for a small specialist sub-contractor or for a multinational construction contractor (Abbott *et al.*, 2008). But what is the status quo of the industry in terms of collaboration and innovation? The answer is not clear, and it depends on *what* is considered innovation and *how* collaboration is adopted.

On one hand, some authors consider the construction industry to be a conservative sector that has difficulty adopting innovations from other sectors (Harty, 2008; Serpell & Alvarez, 2014). On the other hand, it has been claimed that engineering and construction projects are inherently innovative (Pries & Janszen, 1995; Tatum, 1984,

1986) and that the basic nature of the construction industry makes every project unique insofar as each project represents an opportunity for new approaches (Veshosky, 1998). Regardless of whether the construction industry is innovative or not, there are concerns over the weakness of current indicators and metrics used to capture the reality of innovation in the construction industry (NESTA, 2006).

Table 13. Research studies that focus on “innovation"

How	How innovation can be implemented in construction projects	(Slaughter, 1998; Tatum, 1987; Winch, 2003)
	How construction companies manage the innovation process based on some conceptual models	(Dikmen *et al.*, 2005; Seaden & Manseau, 2001)
	How construction companies manage the innovation process based on some case studies	(Koskela & Vrijhoef, 2001; Sexton & Barrett, 2003; Slaughter, 1993)
	Conceptual model for the analysis of innovation in construction	(Seaden & Manseau, 2001)
	Conceptual framework to investigate value innovations within construction companies in the Turkish construction industry	(Dikmen *et al.*, 2005)
	How the drivers of change for innovation can offer benefits to construction firms in North Cyprus if appropriate strategies are adopted.	(Yitmen, 2007)
Why and who	Why is Construction so backward?	(Woudhuysen & Abley, 2004)
	Why has innovation not been a high priority in the construction and property industry?	(Brandon, 2008)
	Why do firms use sustainability-related innovations?	(Thorpe *et al.*, 2008)
	Who is being drawn (or excluded) into negotiations around the innovation process?	(Harty, 2008)
	Who collaborates and innovates in architecture and urban design projects?	(Lizarralde *et al.*, 2012)
	Who has the vision for change and encourages innovation among all the actors in the process?	(Brandon & Lu, 2008)

The construction industry scores poorly in standard measures of innovation used in other sectors (NESTA, 2006) such as Research & Development (R&D) statistics (Kulatunga *et al.*, 2006), quantity of products, methods patented or even the number of trademarks (Slaughter, 1993). Do these measures reflect the reality of the construction industry? Ozorhon *et al.* (2010) show that there is a gap between practice and measurement in construction innovation. They have pointed out that much of the wide range of innovation that occurs in construction projects is hidden from conventional metrics. The research was typically focusing on “how” innovation occurs while innovative activities and the effects of innovation can much better be analyzed when studying “why” innovation takes place (drivers) and “who” innovates (actors) as well as the external environment in which the innovation occurs (see Table 13).

Collaboration and innovation in integrated project delivery approaches

While some authors argue that innovation and collaboration are needed in order to deal with the increasing complexity of design problems and constraints introduced by sustainability, (Gluch *et al.*, 2009; Rekola *et al.*, 2012), others have suggested the need for an integrated approach with closer interaction among suppliers, professionals, and users (Rekola *et al.*, 2012; Sodagar & Fieldson, 2008). Table 14 summarize the literature on this subject. Articles were selected that identified contingencies that limit innovation and collaboration in the construction industry. Drawing on the work outlined above, the key themes found in the literature were extracted and identified.

Even if the product of the construction process is considered an object that can be physically examined, the different perceptions of the stakeholders' collaboration in the construction process can be understood as socially constructed phenomena (Sutrisna & Barrett, 2007). The performance of a project is influenced by the way stakeholders interact with each other (Cherns & Bryant, 1984). In other words, effective communication and collaboration between stakeholders leading to trust and common focus are key factors in a project’s success (Adams *et al.*, 2006; Chinyio & Olomolaiye, 2009).

Table 14. Literature review of contingencies that limits innovation and collaboration in integrated project delivery approaches

	Field of studies	authors
Lean	Barriers towards the sustainable implementation of Lean Construction in the United Kingdom construction organizations	(Bashir *et al.*, 2010)
	Barriers to Implementing Lean Construction in the UK Construction Industry	(Sarhan & Fox, 2013)
	Improving performance through measurement: the application of lean production and organizational learning principles	(Lantelme & Formoso, 2000)
IPD	Transitioning to Integrated Project Delivery: Potential barriers and lessons learned	(Ghassemi & Becerik-Gerber, 2011)
	Integrated project delivery: the obstacles to implementation	(Fish, 2011)
	Understanding Construction Industry Experience and Attitudes toward Integrated Project Delivery	(Kent & Becerik-Gerber, 2010)
	What Is So Integrated About Integrated Project Delivery? Exploring the Role of Integration Mechanisms in IPD Projects	(Carrillo & Chinowsky, 2013)
IDP	Facing the Challenges of Integrated Design and Project Delivery	(Hellmund *et al.*, 2008)
	Exploring barriers to the integrated design and production of resilient buildings in Israel	(Sever *et al.*, 2012)
	Challenges for Integrated Design and Delivery Solutions	(Owen *et al.*, 2010)
CE	Overcoming barriers to the implementation of concurrent engineering	(Maddux & Souder, 1993)
	Barriers to the Implementation of Concurrent Engineering Practices within the UK Construction Industry	(Manewa *et al.*, 2015)
	Benefits and Barriers to Successful Concurrent Engineering Implementation	(Chikwendu, 2017)
	Barriers and Challenges in Employing of Concurrent Engineering within the Norwegian Construction Projects	(Zidane *et al.*, 2015)
ID	Limits and scope of innovation and collaboration in integrated design practices.	(Leoto *et al.*, 2014)
	The management of requirements; What causes uncertainty in Integrated Design Approaches?	(Zerjav *et al.*, 2011)
	Challenges for the Implementation of Integrated Design in the Planning Practice	(Kovacic & Müller, 2014)

Innovation is a non-linear process that requires intensive collaboration between stakeholders during different stages of a project's lifecycle, including the design, construction, and maintenance of the building (Gerlach, 2003; Owen *et al.*, 2010; Ozorhon *et al.*, 2010). For this reason, the researcher needs to consider the entire life cycle of the project when studying collaboration and innovation in construction projects (Cole *et al.*, 2011; Dickinson *et al.*, 2005). The reason for this is that the effects of actions related to innovation and collaboration that occur in a specific phase of construction sometimes can only be seen at a later stage. As a result, a fragmented analysis might overlook innovations (Ozorhon *et al.*, 2010), and mask the collaboration between stakeholders (Kalay *et al.*, 1998).

2.5.3. Buildings' environmental impacts

The document entitled *Our Common Future*, also known as the *Brundtland Report* (1987), provided the widely-accepted definition of sustainable development, namely: "development that satisfies the needs of the present generation without compromising the chance for future development generations to satisfy theirs" (WCED, 1987). However, it was only in Rio de Janeiro in 1992, with the publication of Agenda 21 (UN, 1992) that the importance of sustainable development was emphasized. Sustainability covers three interdependent and mutually reinforcing pillars which are environmental responsibility, economic return (wealth creation), and social development (Ding, 2008). Since Rio, the concept has gained popularity, enthusiasts, and supporters, but it also has been criticized. Carvalho (2001) found contradictions in the Brundtland Report, saying that it emphasizes resource limits but fails to address the social and economic dimensions of sustainability. The author goes further and concludes that the Brundtland Report merely aims at "humanizing and making more environmentally aware the workings of the present international economy," (p. 70) resulting in further destruction of the world's resource base and the exploitation of less-developed peoples.

Notwithstanding different definitions and points of views about sustainability, the concept of sustainable development has undoubtedly influenced the construction industry (Hopwood *et al.*, 2005). Despite the importance of social and economic needs and constraints, some authors stress that the health of the biosphere will remain the limiting factor for sustainability in the building sector (Cole, 2011). The increasing costs of energy and the international pressure to address climate and environmental degradation changes are forcing some major shifts in high-performance building strategies (Kibert, 2007). Recent studies show that the building and construction sector has an enormous impact on the built environment in terms of energy used, GHG emissions and waste (Mao *et al.*, 2013). Thus, the construction industry is seen as a key player in the move towards a more sustainable society (Harkema & Golriz, 2012).

Sustainability in the built environment challenges professionals, clients, and all members of the design and construction industry to find new modes of operation to respond to society's new aspirations (Bonham, 2013). Whereas traditional construction used to focus on cost, schedule, and quality, sustainable design envisions low energy consumption, users' health, waste and pollution reduction, environmental protection as well as social justice, among other objectives (Bonham, 2013; Vanegas *et al.*, 1995). Government also plays a key role through environmental policy and regulations to encourage the best practices in the sector, as for example:

- By implementing national environmental policy plans to show a preferred direction for the nation, inhabitants, and businesses (Kivimaa & Mickwitz, 2006; Raynsford, 1999).
- By issuing laws and regulations (Berndtein, 1996; Bon & Hutchinson, 2000; Bradley & Kibert, 1998).
- Negotiating sustainability agreements with firms in the industry (Gann & Salter, 1998; Raynsford, 1999).
- Through financial incentives and pressure (Berndtein, 1996; Raynsford, 1999).

Key terms to understand global warming and climate change

Greenhouse gases (GHGs) are gas molecules that absorb and radiate thermal infrared radiation back to the earth's surface. These gases allow the sun's rays to pass through the atmosphere and warm the earth. However, they also prevent this warmth from escaping our atmosphere into space.

The increase of GHG molecules raises the planet's surface temperature, provoking a ''greenhouse effect''. Greenhouse gases have different effects on the environment. Each gas molecule has a unique atmospheric lifetime and heat-trapping potential. This creates the need for a way of comparing the net effect of emissions of different greenhouse gases, which has led to widespread use of the so-called *Global Warming Potential* (GWP) (Lashof & Ahuja, 1990).

The GWP metric is a measure of how much energy the emissions of 1 ton of gas will absorb heat in the atmosphere relative to carbon dioxide (CO2 eq.). CO2 is responsible for 61% of greenhouse effects, followed by 15% for methane (CH4), 12% for Chlorofluorocarbons (CFCs) and 4% for nitrous oxide (N2O). Other gases cause the remaining 8% of effects (van de Vate, 1996).

Although these terms are sometimes used interchangeably, global warming is just one aspect of climate change. *Global warming* refers only to the rise in global temperatures due to the increasing concentrations of greenhouse gases in the atmosphere. *Climate change*, however, includes other effects of human activities on nature. The term refers to ongoing changes in climate measures over a long period of time. It encompasses changes in wind patterns, ocean currents, rain and snowfall, and extreme weather events (Walther et al., 2002).

Environmental assessment in building

Different interpretations of sustainability shape its application and the criteria for its operationalization (Davidson & Venning, 2011). Despite calls for a holistic view, sustainable construction approaches as well as most sustainable assessment methods have often provided a limited view of sustainability by focussing on only one of the three dimensions of SD, namely the environmental dimension (Berardi, 2012; Herazo & Lizarralde, 2015).

Green building certifications, for example, emerged in the 1990's as a way of measuring the environmental performance of buildings (Herazo & Lizarralde, 2015). The Leadership in Energy and Environmental Design (LEED) green building rating system, the most widely-used rating system in North America, has been criticized due to its accounting and checklist format. LEED is considered by many scholars as incapable of radically changing building design or of establishing positive links with a given local context (Cole, 2012; Du Plessis, 2012; Mang & Reed, 2012). Other authors have criticized the fact that the certifications do not adequately stress the social and economic components of sustainable development (Pearl & Cole, 2007; Plaut *et al.*, 2012). Here a useful list of the tools' shortcomings:

- Premised on creating gradual, incremental change, and not transformational change (Pearl & Oliver, 2014).
- Performance criteria that fail to preserve resources through a conscious cyclical process of regeneration (Fisk, 2009).
- A generic approach that does not profoundly address local or regional qualities, and excludes projects' impacts and benefits across multiple scales (Pearl & Oliver, 2014).
- An omission of many measurable negative impacts as well as many potentially positive ones (Birkeland, 2012).
- A reduction of a project into a series of isolated measures instead of striving to improve synergies within interstitial spaces (physical, social, cultural, etc.) between buildings (Pearl & Oliver, 2014).
- No requirements for the involvement of stakeholders or occupants in the creation, implementation, and operation of projects even though such involvement is what strengthens social resilience (Cutter *et al.*, 2008; Plaut *et al.*, 2012).
- The true social and cultural potential of a design project may be inhibited by rewarding minor incremental improvements as being 'better than nothing' (Pearl & Oliver, 2014).

Other scholars defend Life Cycle Assessment (LCA) for buildings as a way of measuring the impacts and improvements made by the industry (Fava *et al.*, 2009; Lee *et al.*, 2009; Saunders *et al.*, 2013; Zabalza Bribián *et al.*, 2011). These authors defend the relevance of LCA saying that a buildings' impacts the environment not only when it consumes energy, resources and material during its construction, but also during operation, maintenance, demolition, and dismantling (whole life-cycle).

Evaluating the construction effects on the environment during the entire course of a building’s life span, however, is a complex task typically practiced only by experts and takes considerable time and effort (Lee *et al.*, 2009).

Some LCA-based whole-building assessment tools currently available promise to calculate and evaluate environmental performance of a particular design iteration and to help designers measure effects over the complete building life-cycle (Haapio & Viitaniemi, 2008). These software applications seem to be powerful tools, but they emphasize a series of isolated and non-transparent results (Pearl & Cole, 2007). In summary, the construction industry is still relying on quantitative accounting methods, such as green certifications and Life Cycle Assessment, as a way of measuring and analyzing sustainability.

2.5.4. Project Management performance

A project is defined by Turner (2009) as ‘‘a temporary organization to which resources are assigned to do work to deliver beneficial changes’’ (p. 2). Project management is the process by which a project is completed successfully (Crawford, 2011). The theoretical foundation of project management as espoused in the PMBOK® Guide by The Project Management Institute (PMI) is the most commonly used in practice. The Guide defines project management as “the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements” (PMI, 2013, p. 6).

The PMBOK® Guide defines the *project life cycle* as the steady progression of a project from its beginning to its completion. The guide distinguishes five processes: initiating, planning, executing, controlling and closing (PMI, 2013). The project management phases may differ among industries. In the construction industry, the project concept (the appraisal and design brief) is developed during initiation. The project concept, design and technical solutions are developed during planning. The project implementation (mobilisation and construction) is carried out during execution. This phase includes the completed facility commissioning and its handing-over to the owner. Monitoring and controlling are not linear, they hover over the entire project (Burger, 2013).

The Royal Institute of British Architects (RIBA) divided project development into eleven stages, grouped in five phases: preparation, design, pre-construction, construction and use. In 2013, RIBA overhauled the stages of a construction project to better meet the needs of the industry. The structure of the RIBA Plan of Work organises the process into eight stages:

- Strategic Definition: Identify client's needs and strategic brief. Evaluate if refurbishment or extension, or indeed a rationalised space plan, may be more appropriate than a new building.
- Preparation and brief phase: Develop project objectives, including budget, quality, sustainability aspirations and develop initial project brief.
- Concept Design: Prepare architectural, structural and building services system design. This phase outlines specifications and preliminary cost information.
- Developed Design: Coordinate and update proposals for structural design, building services systems, outline specifications, cost information and project strategies.
- Technical Design: Technical details from specialist subcontractor, design and specifications, are included in all design plans.
- Construction: Offsite manufacturing and onsite construction in accordance with the construction programme.
- Handover and Close Out: Minimum testing is performed before the building is turned over for operations. The project team and results are evaluated, and the documents and reports completed.
- In use: Includes post-occupancy evaluation and the review of project performance as well as new duties that can be undertaken during the in-use period of a building.

Most building projects in Canada follow a traditional method of project delivery where the owner hires an architect to prepare the design and then hires a contractor for the construction. The *Canadian Handbook of Practice for Architects* divides the architect's role into five sequential phases of a project: a) schematic design; b) design development; c) construction documents, d) construction, e) bidding and negotiation;

e) construction phase and contract administration (Hobbs & Royal Architectural Institute of Canada, 2009).

However, a building possesses a long life-span consisting not only of its construction, but also its operation. Buildings have an enormous impact on energy consumption and other natural resources throughout their life cycle (Lee *et al.*, 2009). Poor decisions and lack of communication made in the design influence the construction phases, leading to higher first costs and/or long-term inefficiencies throughout the operation phase of the building (Krygiel & Nies, 2008). This poor performance is noticed by clients only during the building's operation phase (Malina, 2012). Achieving more sustainable buildings requires a paradigm shift from short-term business cycles and a project-to-project culture to a built-environment transformation where stakeholders' take more responsibility in project (Newton *et al.*, 2009).

Integrated Project management

The response of project management to this fragmentation of construction in the life-cycle of a building is Integrated Project Management (IPM). The term 'integrated project team' is first mentioned in the Egan Report and subsequently referred to as integration management in PMBOK®. A higher level of integration among the multidisciplinary team eliminates fragmentation between design and construction and between the client and the project team (Fewings, 2013). Integrated Project Management (IPM) is a holistic approach that promotes maximum synergy between stakeholders to find new forms of work to add value to the project. Previous research has shown that more integration in the construction industry, through integrated process, improves a project's performance.

Sustainable Project Management

Integrated Project Management (IPM) adds performance requirements established by the client (Rodríguez & Fernández, 2010) to the traditional objectives of cost, quality and time, but does not aim to meet sustainability goals (Hope & Moehler, 2014). Some authors have noted that a theoretical model called Sustainable Project Management (SPM) can fill this gap (Moehler *et al.*, 2018; Sánchez, 2015; Silvius & Schipper, 2014).

This process aims to achieve traditional PM objectives as well as the three dimensions of sustainable development (Rodríguez & Fernández, 2010; Sánchez, 2015). Silvius and Schipper (2014) have described SPM as “the planning, monitoring and controlling of project delivery and support processes, with consideration of the environmental, economic and social aspects of the life-cycle of the project's resources, processes, deliverables and effects, aimed at realizing benefits for stakeholders, and performed in a transparent, fair and ethical way that includes proactive stakeholder participation” (p.79).

2.5.5. Stakeholders involved in construction projects

Buildings are designed by temporary coalitions of stakeholders, known as temporary multi-organisations (TMOs) (Cherns & Bryant, 1984). Construction projects have significant coordination and integration problems due to the extreme specialization of functions and/or the involvement of various stakeholders (Nam & Tatum, 1997). The PMBOK® describes stakeholders as individuals and organizations that are actively involved in a project or whose interests may be affected as a result of project execution or project completion (PMI, 2013). For Freeman (1984, p. 46), stakeholders can be “any group or individual who can affect or is affected by the achievement of an organization’s objectives”. From a narrower viewpoint, Bourne and Walker (2005, p. 651) define a stakeholder as “those who have an interest, essential in people-oriented project cultures and effectively managing these stakeholders is essential at all points in the project from “initiation” to “closeout”.

Construction projects are complex; they normally involve large and diverse stakeholders throughout the different stages of the project (Newcombe, 2003; Smith & Love, 2004). Stakeholders can be categorized into two groups: (a) Internal stakeholders - which refer to those who are members of the project coalition, providing finance or having a legal or contractual relationship with the project; (b) External stakeholders – stakeholders that can influence or can be influenced by the project (Chinyio & Olomolaiye, 2009; Leung & Olomolaiye, 2010). Table 15 summarizes all stakeholders and their influence in construction projects.

Table 15. Stakeholders normally involved in a construction project [adapted from Chinyio and Olomolaiye (2009); Leung and Olomolaiye (2010); Newcombe (2003); Smith and Love (2004)].

Internal stakeholders		
Categories	Individuals/groups	Objectives and roles
Clients	Owners	Work on the front line to ensure that the project is successfully completed in terms of quality, time, and cost.
	Public clients	Allocate funds to the project; serve the public interest and ensure that public funds will be properly used.
	Users	One person or a company that uses or makes use of the utilities of the building or buildings.
Project professionals	Architect	Develops the design of the project; drawings and specifications
	Project manager	Advises client on financial and budgetary matters; monitors costs during construction and seeks to understand valuation and measurement
	Structural engineer	Designs building structure
	Mechanical engineer	Designs electrical and mechanical building service systems
	Interdisciplinary experts	Give advice on special studies and surveys for design development; collaborate with the design team
Contractors / suppliers	General contractor	Carries out and completes the work designed by consultants to meet time, cost, and quality objectives; supervises and manages operations on site.
	Subcontractors	Carry out work assigned by main contractors
	Manual worker	Finishes tasks assigned, earns a living, learns skills
	Suppliers	Supply, install, and commission the hardware.

External stakeholders		
Categories	Individuals/groups	Objectives and roles
External public parties	Government authorities	Ensure that the project abides by laws and regulations; may be indifferent to any project so long as it complies with codes
	Consultation bodies	Ensure the local communities' requirements will be reflected in the project
	Town planning board	Ensures the project will be in line with district planning
	Employers' association	Influences the conduct of its members (privilege protection function)
	General public	Participates in and contributes to the project representing society
	Media	Influence project decisions (influence company reputations)
	Professional institutions	Influence upon their members' activities through rules of conduct, education, conditions of engagement, and fee scales
External private parties	Community representatives	May fear a decline in amenity, therefore against the project
	Local landowners	Own land; ensure that their interests will not be hurt by the project
	Archaeologists	Concerned about the loss of important historical artefacts
	Pressure groups	Wish to protect the environment from destruction or pollution
	Competitors	Seek to gain competitive advantage
	Visitors and customers	Actors who will benefit from the project
	Others	Directly or indirectly support the operations of a project, though their connection may be unclear

Slaughter and Cate (2009) find that among all stakeholders, the clients play a determining role in establishing the incidence and rate of innovation in construction projects. They also suggest that it is fundamental for the client to develop and successfully implement innovative approaches and to establish and communicate the superordinate goals that bind the project team members early on in the process. Brandon and Lu (2008) claim that the manner with which clients respond to innovation can influence their willingness or reluctance to drive the innovation process, thus allowing them to fall into several different categories: Impede, Impartial, Interest, Influence, Inaugurate and Insist. In order to better organize this information, Table 16 integrates Brandon and Lu (2008) and Slaughter and Cate (2009) ideas about client importance to successful innovation.

Table 16. Understanding client importance to successful innovation (Brandon & Lu, 2008; Slaughter & Cate, 2009).

↑ **Clients' attitude to driving innovation**	Insist	Small but influential group. Innovation is part of the whole marketing process and enjoyment of the experience (shock from novelty). Some promote innovation in order to deliver sustainable buildings.	↑ **successfully implement innovation**
	Inaugurate	Occurs when the clients are confident about their knowledge of the process. They accept greater risk with an innovative process believing that a faster work pace will also accelerate and increase revenues.	
	Influence	They do not have the knowledge to drive innovation, but they do want to see the best process and products used for their benefits.	
	Interest	They are open to innovation. They normally have a background in other, more innovative industries.	
	Impartial	They are not driving the innovation, but they are open to discussing it and its possible advantages.	
	Impede	"Risk averse": they do not want to be used as experiments in the construction process. The comfort of knowing that a traditional process has been followed with an experienced team is a primary value.	

The Temporary Multi-Organization (TMO)

- Construction projects are a multi-organization (Cherns & Bryant, 1984)
- Highly fragmented and culturally diverse organizations that are influenced by markets, contracts, networks, and pressures (Wild, 2002).
- Effective communication is essential for TMO performance (de Blois & Lizarralde, 2010)

- Project stakeholders are divided into four groups (users, client organization, operators, and participants) and six configurations (classical, cooperative, user-driven, integrated, developer, and institutional) (Lizarralde *et al.*, 2011).
- Configurations and stakeholders' roles change throughout the project phases (Wild, 2002)

Relations between the project design and Temporary Multi-Organization

The emergence of new categories of customers and users as well as the increased participation of new actors - with different or conflicting interests - requires the architect to be able to anticipate and combine the needs and expectations of various actors (Terrin, 2005; Terrin, 1998). However, the actors in a construction project have weak links with each other (Smith & Love, 2004). In fact, in the construction sector, professionals, contractors and subcontractors come together in accordance with selection procedures dictated by the client's project management strategy (Davidson & Abdel-Meguid, 1998). This strategy determines the distribution of responsibilities between the various actors: architect, urban planner, designer, contractor, subcontractors, etc. The resulting group is a Temporary Multi-Organization (TMO). It is a "multi-organization" because of its necessarily multidisciplinary composition (Cherns & Bryant, 1984; Rowlinson & Cheung, 2008). It is temporary because it lasts for only one project, at the end of which the members disperse.

Construction TMOs are often highly fragmented with culturally diverse organizations co-ordinated through a combination of markets, contracts, networks and pressures (Wild, 2002). A multi-organization is the combination of parts of several organizations that represent their own interests in the project (Stringer, 1967). Authors like de Blois and Lizarralde (2010) have identified at least four main characteristics in multi-organizations:

1. To perform its tasks adequately, effective communication is essential.
2. Relations in a TMO are conditioned by tasks central to the project goal.

3. Participants in the TMO have other interests apart from the building in question and once it is complete, the reason for their collaboration disappears.
4. Legal frameworks and procurement strategies describe only the ‘formal’ system and do not provide the full representation of the dynamic network of the TMO.

The complexity of the relationship between the client and the rest of the TMO remains underestimated (Green, 1996; Winch, 2003). The concept of a single client is often too simplistic and inappropriate (Walker, 2007). Indeed, the actors or entities that are part of the customer's environment (the stakeholders who have something to gain or lose in the project) can greatly influence the construction project from the point of view of the approach and the final quality. Considering the complexity of the client and the fragility of the links between the TMO actor’s, this study aims to identify and understand the relations created and their consequences for Integrated Design (ID) projects.

3. RESEARCH METHODS

This section provides a brief overview of the research process and highlights the research design and rationale behind the case selection, data collection methods, and data analysis. Additional descriptions of specific research methods and tools can also be found in each publication; this section offers readers an overview of the research project.

3.1. The case study method

The methodological approach adopted for this research is the case study method. The case study is a reliable method for capturing rich information for the purpose of the investigation by allowing the investigators to retain the holistic and meaningful characteristics of real-life events (Barrett & Sutrisna, 2009; Yin, 2003). The method is useful when the researcher seeks to understand complex social phenomena, such as construction projects, over which the investigator has little or no control (Rubin & Babbie, 2011). Creswell (2012) tells us that case study research explores a program, event, activity, or individual as a "system" bounded by place and time. The method is also useful to understand a decision or a set of decisions, how they were implemented and to what effect (Yin, 2003).

Exploratory case studies

More specifically, this research project proposes the exploratory case study as its method. The exploratory case study can be the first step when the topic of research has not been the subject of extensive empirical examination (Mayer & Greenwood, 1980; Yin, 2003). This strategy is employed to inductively generate, rather than deductively confirm, insights regarding the phenomenon to be studied (Ogawa & Malen, 1991). In an exploratory case study, qualitative data analysis generally involves an iterative process going from the general to the more specific (Mills *et al.*, 2010).

This iterative and cyclical process gives the researcher the opportunity to go back into the field, refine questions and develop further hypotheses that might serve for further investigations (Mills *et al.*, 2010). The exploratory case study methodology enables researchers to conduct an open-ended search for relevant information in order to identify the major themes and patterns associated with the phenomenon (Ogawa & Malen, 1991; Pan & Scarbrough, 1999). The distinctive features of the exploratory case study methodology (Lofland *et al.*, 2006; Ogawa & Malen, 1991; Patton, 2015; Yin, 2003, pp. 22-24) can be summarized as follows:

- Grapples with complex phenomena in real-life contexts.
- Recognizes that the complex nature and, at times, the contemporary character of the phenomena under investigation diminish the degree of control that can be exerted by the investigator.
- Incorporates multiple sources of data to corroborate observations regarding the phenomenon of interest.
- Tends to rely heavily, albeit not exclusively, on qualitative data.
- Aims at providing a cogent, detailed portrait of the phenomenon — the attributes it assumes, the variations it displays, the ways it appears to operate, and the combinations of factors that shape the patterns observed in natural settings.

3.2. Research process and publications

The objective of this dissertation is to understand the extent to which ID improves the quality of buildings and their relationship with the environment. To do so, I first generated answers to the research questions in a pilot case study. These initial findings were then presented at a series of international academic conferences. After validating the findings in three case studies, the results were published in three peer-reviewed articles.

Conference article 1 examined, both theoretically and empirically, the contingencies that limit ID's capacity to achieve innovation and collaboration goals. The results from the pilot case study are presented in Chapter 4.1.1. The iterative processes used in this thesis provided new knowledge and provoked new questions, one of which was answered in publication 1. This publication also explored one of the bodies of knowledge isolated during the extensive literature review: effective collaboration and innovation in ID. The results from the three case studies are presented in Chapter 4.2 (Publication 1).

Conference article 2 measured the environmental impacts of the innovations implemented in the pilot case study by applying Life Cycle Assessment (LCA). The results from the pilot case study are presented in Chapter 4.1.2. Publication 2 explored the decision-making process and measured the impact reductions of the innovative strategies implemented by design professionals. The results are presented in Chapter 4.3 (Publication 2).

Conference article 3 assessed to what extent ID improves project management practices (reducing fragmentation between project phases) and outputs (reducing a building's environmental impact). The results from the pilot case study are presented in Chapter 4.1.3. Publication 2 explored opportunities for project managers to enhance the ID process during charrettes and throughout the subsequent project phases, presenting its results in Chapter 4.4 (Publication 3).

The choice of conferences and journals was an important part of the methodology. I chose peer-reviewed conferences linked to one of the knowledge fields identified in the course of the literature review. The objective was to have feedback from other academics and practitioners in each of the international conferences.

I chose a different journal for each publication, focussing, once again on the three knowledge fields: project management, construction, and sustainability. Feedback from the guest editors of the *Journal of Construction Management and Economics*, the *Building and Environment Journal*, and the *Architectural Engineering and Design Management* as well as a total of nine anonymous reviewers contributed to the final version of the publications.

As can be seen in Figure 12, the research followed a spiral process in which the results of each article generated new questions, perspectives, and ideas that helped to build new knowledge. An interaction between empirical analysis and literature was constant, allowing each individual publication to be enriched by previous results.

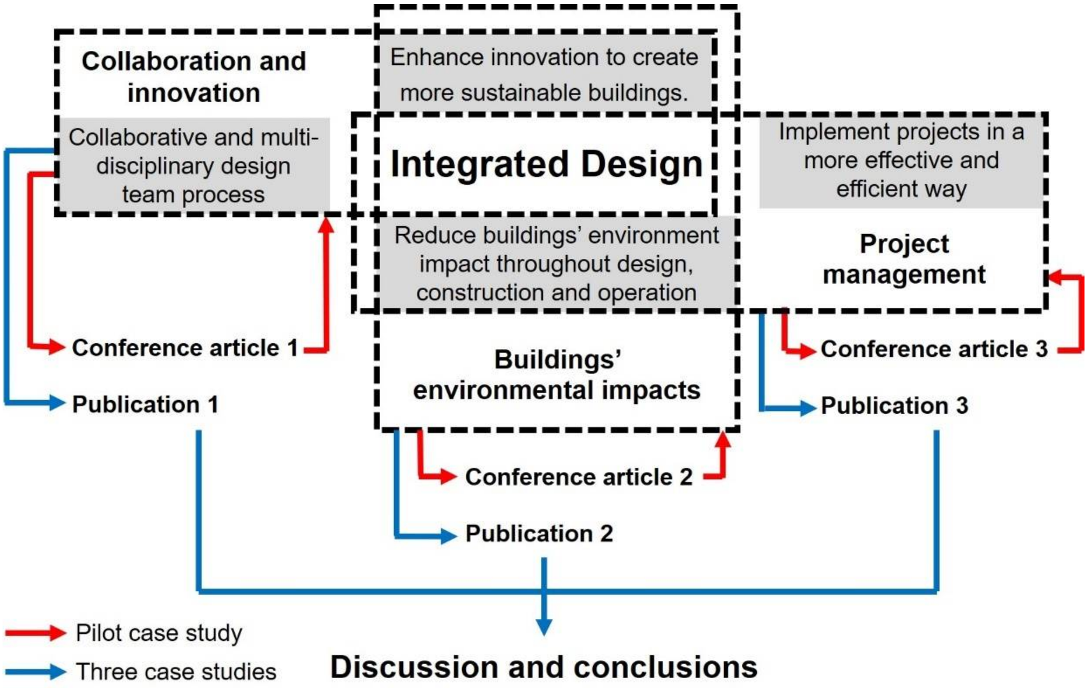

Figure 12. Interactive process between empirical analysis and literature

3.3. Research design, methods and tools

This section examines the research decisions made in order to solve a specific research problem. In considering the appropriate research design, researchers must first clarify their own beliefs as well as the epistemological and ontological assumptions of their research (Fellows & Liu, 2008; Remenyi, 1998). Researchers need to have a wide knowledge of research methods and approaches before selecting a method (Creswell, 2003; Zou *et al.*, 2014). In our case, methods in the fields of collaboration, innovation, sustainability, and Integrated Design were reviewed. The objective was to learn more about the prevailing methods in the field, the substantial contributions to methodology, and their strengths and shortcomings. The next step was to choose the approach that would be most appropriate for our project. I present here the general methods used in this doctoral project. Additional descriptions of specific research methods and tools can also be found in each publication

Research methods in the social sciences can be divided into three major categories: qualitative, quantitative, and mixed methods (Creswell, 2003; Zou *et al.*, 2014).

Quantitative research is typically characterized by collecting numerical data (measurements) and studying the link between theory and research (findings). It expresses a preference for a natural science approach (positivism) to explain social phenomena and usually has an objectivist conception of social reality (Bryman, 2003; Fellows & Liu, 2008). This dominant methodology in construction research is represented by two research designs: surveys and experiments (Zou *et al.*, 2014). A purely quantitative approach, however, would be inadequate in responding to the research questions that I have raised and is incongruent with the interpretivist paradigm.

The qualitative approach is a form of social inquiry that provides an in-depth, interpretive understanding of the social world of the research participants by learning about their sense of their experience, their material circumstances, perspectives, and histories (Bryman, 2003; Fellows & Liu, 2008). It emphasizes meaning more than quantitative studies (Zou *et al.*, 2014).

Some authors argue that mixed methods should be used to fill the gap between theory and practice in construction (Zou *et al.*, 2014). Bryman (2003) describes three approaches to mixed methods research: a) triangulation or the use of quantitative research to corroborate qualitative research findings and vice versa; b) facilitation: using one research methodology to complement research using another research methodology; c) complementary: using two research methodologies where different aspects of an investigation can be merged. To summarize, in Table 17, I compare the strengths and shortcomings of each approach.

Table 17. Strengths and shortcomings of three approaches in the research methods literature.

	Strengths	Shortcomings
Quantitative	- Results are relatively independent of the researcher, decreasing the risk of researcher bias. - Reliability: aims at controlling or eliminating extraneous variables within the internal structure of the study, thus allowing the data to be assessed by standardized testing. - Data collection and analyses are less time-consuming and provide precise, quantitative, numerical data.	- Fails to distinguish people and social institutions from the natural world. - Ignores the fact that people interpret the world around them; cannot be found among the objects of the natural sciences. - Bias may occur in quantitative research as the respondents' actual behaviour may differ from their answers
Qualitative	- Capacity to take in rich and holistic qualities of real-life circumstances and describe personal experience of phenomena - Flexibility in design and procedures allowing adjustments in the process. - Sensitivity to meanings and processes of artefacts and people's activities. - Appropriate for conducting cross-case comparisons and analyses	- Challenge of dealing with vast quantities of data. - Few guidelines or step-by-step procedures established. - Lacks objectivity and tends to use personal opinion instead of evidence to support arguments. - The use of limited samples to build an argument is a weakness, particularly concerning the representativeness and generalizability of the research
Mixed methods	- Qualitative research can compensate for the weaknesses of quantitative research and *vice versa*. - Improves the validity and reliability of the resulting data and strengthens causal inferences: observing data convergence or divergence in hypothesis testing. - Can provide insights and understanding that might be missed when only a single method is used. - Can increase generalizability of the results.	- Can confront contradictory quantitative and qualitative results. - More expensive in terms of time, money, and energy. - Critics argue that methods carry different epistemological commitments that should not be merged (e.g., problems of paradigm mixing, how to qualitatively analyse quantitative data, how to interpret conflicting results).

This research proposes a case study, a qualitative research method, to fill the gap between theory and practice in construction. I also used quantitative approaches to corroborate qualitative research findings. This is consistent with what Dainty (2007, p. 9) describes as “a more expansive outlook towards mixing methodologies and research paradigms could yield deeper insights into, and understanding of, the way that practitioners ‘do’ management in the construction sector”.

3.4. Case selection

An important step in the development of case studies is defining the case or unit of analysis (Knight & Ruddock, 2008). One challenge for our study was to select building projects where the clients would allow access to documentation, professionals, and stakeholders. Stakeholders in building projects are often protective of the information and knowledge they share (Smyth & Pryke, 2008). Another challenge was to select organizations that “at least in theory” intended to adopt the ID approach from the outset of the project. Other criteria for our case selection included projects that: (1) had a significant engagement with sustainability principles; (2) achieved a high level of Green Building Certification; (3) were launched by institutional clients (private, public, or NGO organizations); and (4) were recent and concluded projects, within the past seven years, to have access to at least three years of operation data (real performance). Three case studies that respected these considerations were selected.

3.4.1. Case study A - Center for Sustainable Development (CSD)

Case study A is the Center for Sustainable Development (CSD), (*Maison du développement durable* in French), (photo 1). The project was carried out by Equiterre between 2004 and 2011. In 2007, Equiterre and seven other environmental organizations formalised an alliance, and created the CSD, a non-profit organization (NGO). The CSD’s mandate was to deliver an exemplary ecological building in downtown Montreal. The objective was to become a social and environmental innovation hub bearing a LEED Canada-New Construction 1.0 Platinum Certification. It comprised features that, it was hoped, would inspire action on behalf of the general public and decision-makers in real estate and construction. The project expected to reduce its energy consumption by 60% and its drinking water by 56% (compared to the Canadian Model National Energy Code for Buildings - MNECB)

The project is the result of an ID process in which the client (Equiterre) actively participated. Équiterre and all stakeholders worked in integrated and multi-disciplinary design teams to reach innovative solutions. This innovative project integrates alternative methods in terms of the design, construction, and operational features of the building. The 60,000 square-foot, 5-storey building opened its doors in September 2011 as a place for reflection, innovation, education, and the meeting of minds on sustainable development. The CSD is the first commercial building in the downtown core of a major Canadian city to receive the LEED® Platinum certification in the category of a new construction. Moreover - something seldom seen - the ID process as well as the process for building and operating the CSD has been thoroughly documented allowing relevant information to circulate to all stakeholders.

Figure 13. Photo case study A - Centre for Sustainable Development in Montreal, Canada (author: Jacques Nadeau)

3.4.2. Case study B - Rio Tinto Alcan Planetarium (RTAP)

Case study B is the Rio Tinto Alcan Planetarium (photo 2). In 2000, after public consultation, the city of Montreal launched a feasibility study to expand the Planetarium. In 2003, however, the city concluded that the building was obsolete and that the best solution was either: a) its complete demolition and reconstruction, or b) to construct a new building in a new location. The city decided to relocate, close to the Biodome within Montreal's Olympic Park. In 2008, the city launched an international architectural competition to select a proposal based on quality. They included two requirements for teams that entered the competition: to target LEED Gold certification and to apply the ID process to develop the project. Of the 61 teams, the city chose a Montreal-based architecture firm. Its team was comprised of landscape, civil, and mechanical firms.

Figure 14. Photo case study B - Rio Tinto Alcan Planetarium (Raymond Jalbert)

The building was inaugurated in 2013 and cost $48 M. The multidisciplinary project team worked collaboratively to meet the functional and technical requirements of the project. The team's main objective was to create a connexion between nature and science and to improve the overall experience for visitors. A unique accessible green roof integrates the Planetarium with the public park area. A geothermal energy system and the use of many renewable materials helped to reduce energy consumption and greenhouse gas emissions. The new Planetarium is the second LEED® Platinum in Québec and one of Canada's largest natural science museums.

3.4.3. Case study C - Montreal Soccer Stadium (MSS)

Case study C is the Montreal Soccer Stadium (MSS) at the Saint-Michel Environmental Complex (photo 3). The project began in the mid-1990s, when Concordia, a Montreal-based regional soccer association (ARSC), announced that an indoor soccer stadium was vital to the development of the sport in the City. The project was finally launched in 2009 and became operational in July of 2015. The city decided to choose the architect through an international competition. Competitors were informed that they would be engaged in the ID charrettes in the following phase. Other professionals, from landscape, civil, and mechanical firms were hired once the city had determined its choice based on the lowest bid.

Figure 15. Photo case study C - CESM Soccer Center in Montreal Stephane Groleau)

The 12,600 square-meter floor houses a full-size soccer field that can be divided into two or three smaller play areas. The architects made a bold architectural proposition to the city: to cover the 69-meter stadium span with cross-laminated timber (CLT) beams and panels. The stadium seats 750 spectators and has an event room, administrative offices, and service areas. The complex is complemented by an external field with a synthetic coating and stands that can accommodate 650 people. This LEED Gold project includes innovative and energy-efficient measures to help optimize environmental performance. This is reflected in a 54% reduction in energy consumption compared to ASHRAE 90.1 - 2007 and 33% savings in drinking water in comparison to the 2009 LEED-NC system reference. Table 18 summarizes the main characteristics of the three projects.

Table 18. Summary of the main characteristics of three case studies.

Characteristic	Case study A	Case study B	Case study C
Type of client	NGO	Government (cultural)	Government (sport)
Main use	Offices	Museum & entertainment	Soccer stadium
Functional programme	Offices, meeting rooms, amphitheatre, and a cafeteria	Theatres, exhibition rooms, administrative offices, auditorium, and a boutique	Two full-size soccer fields, administrative offices, training rooms, a cafeteria, and retail space.
Built area	6,500 m² on five levels	8,000 m² on three levels	12,600 m² on two levels
Cost	\$27 million (CAD)	\$48 million (CAD)	\$52 million (CAD)
Design tender process	Short invitation	International competition	International competition
Construction	2010 to 2011	2011 to 2013	2013 to 2015
Certification	LEED® Platinum	LEED® Platinum	LEED® Gold
Version	LEED Canada NC 1.0	LEED Canada NC 1.0	LEED Canada NV 2009
obtainable / possible	59/70 points	55/70 points	64/110 points
Obtained, year	2013	2015	2017
Main green strategies	Geothermal heating and cooling system, bio-wall, thermal envelope, displacement ventilation, and green roof	Collection and reuse of rainwater, thermal envelope, natural ventilation	Geothermal energy, roof made by local and prefabricated cross-laminated timber (CLT)
Funding	Mortgage, private and public donations	Public with private donations	Public
Number of ID charrettes	14	5	8
Time devoted to charrettes	68h30	38h	77h

3.5. Data collection and analysis

Researchers can gather and integrate qualitative and/or quantitative data sources to reach a more holistic understanding of the phenomenon under investigation (Baxter & Jack, 2008). This convergence of methods strengthens findings, promotes a greater understanding of the case and enhances data credibility (Patton, 2015; Yin, 2003). Table 19 presents our concerns regarding the sources of data used to fulfil the research objectives.

Table 19. Types of data sources used in this research [based on Yin (2003)]

	Strengths	Weaknesses
Documentation	Stable and broad coverage: repeated review, long time-span, many settings Unobtrusive: exists prior to the case study Exact: names, references, and details of events.	Retrievability: can be low, difficult Biased selectivity: if the collection is incomplete Reporting bias: reflects author's bias Access: may be blocked
Archival Records	Same as for documentation (above) Precise and quantitative	Same as for documentation (above) Privacy might inhibit access to information
Interviews	Targeted: focuses on case study topic Insightful: provides perceived causal inferences	Bias: due to poorly constructed questions. Response bias: induces errors Inaccuracies: due to incomplete recollection Reflexivity: interviewee answers what interviewer wants to hear
Participant Observation	Reality: covers events in real time Contextual: covers event context Insightful into interpersonal behaviour	Selectivity - might miss facts Reflexivity - observer's presence might change event Cost: many hours of work - Time-consuming Bias: due to investigator's manipulation

The use of multiple sources of information can also address construct-validity problems. The triangulation of sources was used to capture and analyze data from multiple perspectives to verify the repeatability of an observation or interpretation (Forgues & Koskela, 2008; Stake, 1995). For the descriptions of specific data collection strategies used in the doctoral project, see Table 20). More detailed information can be found in each article.

Table 20. Numbers of documents analysed in each case study.

Document	Case A	Case B	Case C
Client/owner Functional and Technical Program (FTP)	3	1	1
Annual reports and public consultation process	5	3	4
Project meeting proceedings	13	2	7
Published Case study reports	12	7	5
LEED® Green building certification reports	3	3	5
Press releases, videos and magazine articles	28	13	22
Email exchanges	40	3	11
Chronograms and contracts	4	1	2

Documentation and archival records: Case studies rely on multiple sources of evidence and typically combine different data-collection methods for reducing the potential for bias (Dainty, 2008). The first step in carrying out the case studies consists of analyzing the data from the project, namely documents, ID reports, email exchanges, contracts between stakeholders, chronograms, photos, videos, memoranda, agendas, administrative documents, newspaper articles, press releases, or any documents that are relevant to the investigation.

Observation: For the case study A, Equiterre allowed the researcher to participate in the construction and operation phase of the project. The researcher had a workspace and a supervisor throughout the years covered by the research project. More than just relying on documents or interviews, the researcher was able to personally investigate and confirm much of the information. This experience and the information and knowledge gathered were useful for triangulation. I was, for example, able to use evidence gathered for the formulation of questions in the interviews.

Interviews: This research included 28 semi-structured interviews (Table 21) with professionals, clients, and other stakeholders involved in the projects. Interviewees from different backgrounds, roles, and positions were chosen in order to obtain an overall picture of the case (Eisenhardt & Graebner, 2007). The interview questions were prepared and classified according to the issues identified within the conceptual framework. The interviews allowed for triangulation of the information gathered and summarized in the document analysis (Creswell, 2003). With regards to consent, participants signed a participant consent form approved by the Université de Montréal's ethics committee before the interviews.

Table 21. Summary of stakeholders who were interviewed.

Stakeholder role	Case A	Case B	Case C	Others
Client/owner	3	1	1	
Users	1		1	
Architects and engineers	3	3	2	
Facilitators	1	1	1	
General contractors	1		2	
LEED® consultants	1	1	1	
Project managers	1	1	1	1
Totals	11	7	9	1

3.6. Data analysis and quality in case study

In an exploratory case study, all sources of information are relevant and the data collection and analysis are carried out concurrently (Paré, 2001; Yin, 2003). The comparison of documentary data (reports, archival records) with the results of the interviews allowed information triangulation (Fellows & Liu, 2008). When inconsistencies were discovered between what the interviewees said and what was recorded in documents, I questioned the interviewees further (by email). Table 22 shows the ways used in this research to enhance validity and reliability in this study.

Table 22. Case study tactics employed to assure quality in this research project.

Case study tactic		
Reliability	Participant's error	Case selection from a data-rich partnering environment; selection of correct interviewees by analyzing the information flow patterns and relationship held with the client.
	Participant's bias	Selection of participants from various parties (e.g. construction manager, client, professional, etc.) to minimize bias.
	Observer's error	Use of semi-structured interviews to understand perspectives from the participant’s point of view.
	Observer's bias	Verification of transcripts by the interviewees.
Construct validity	Multiple sources of evidence	Data triangulation through multiple sources, including interviews; collection of data from both client and other participants to understand both perspectives; document reference.
Internal validity	Explanation building	Establishment of links between stakeholder’s behaviour and the ID process with the support of the direct quotations from the interviewees.
	Pattern matching	Generation of conclusions supported by literature where applicable.
External validity	Use of replication logic in multiple case studies	Testing and verification (or change) to the analytical framework in single case studies.
		Use of replication logic in two other case studies.

Pilot Case Study: The purpose of the pilot case study was to better understand the factors that affect ID projects in particular. The case study A, the Centre for Sustainable Development (CSD) was chosen to study the ID process of building because I had access to abundant information on it. Moreover, the fact that Case A was the first building to use ID and to obtain a LEED Platinum Certification in Montreal corroborates its relevance regarding the purpose of the study. All ID charrettes were recorded, and all data were accessible to researchers. The data analysis included ID project-meeting proceedings, newspaper and magazine articles, email exchanges, project reports, meeting minutes, and contracts between stakeholders.

The pilot study was studied as follows. First, the doctoral project and research questions were presented to the supervisor and the research group. Second, an iterative process, that entailed shifting from the literature review (chapter 2) to the empirical information from the pilot study, resulted in the preparation of three conference articles. Each conference article was related to one construct (body of knowledge) identified in the literature review and answering two research questions (Figure 16).

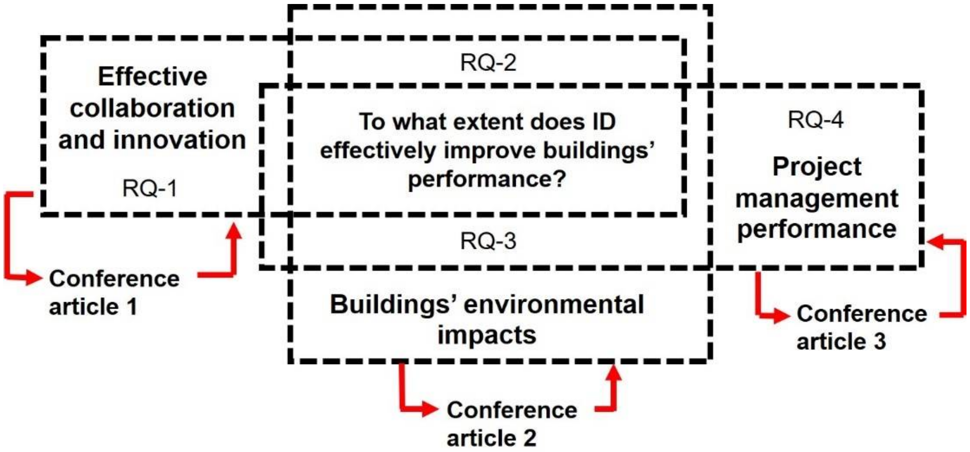

Figure 16. Principle contributions of conference articles to understanding the limits and opportunities of integrated design in sustainable buildings.

Project phases of a construction project: The originality of this research lies in the fact that ID process and its achievements were analyzed not only during planning but throughout the three project phases of the project, namely: (a) planning and design, (b) construction, and (c) building operations. This is a dynamic process in which each step interacts with the other. The impacts of ID must therefore be viewed through the lens of the entire life cycle of the building. The objective therefore consists of analyzing the process and the values created by the ID process throughout the building's entire life cycle. The project's life-cycle and the three relevant bodies of knowledge identified in chapter three served as "lenses" to help us reveal and understand the inherent tensions that arise from ID practices (conflicts, controversies, dilemmas, etc.). The pilot case study provided the perfect setting for exploring the three project phases as well as access to documents from the three project phases (Figure 17).

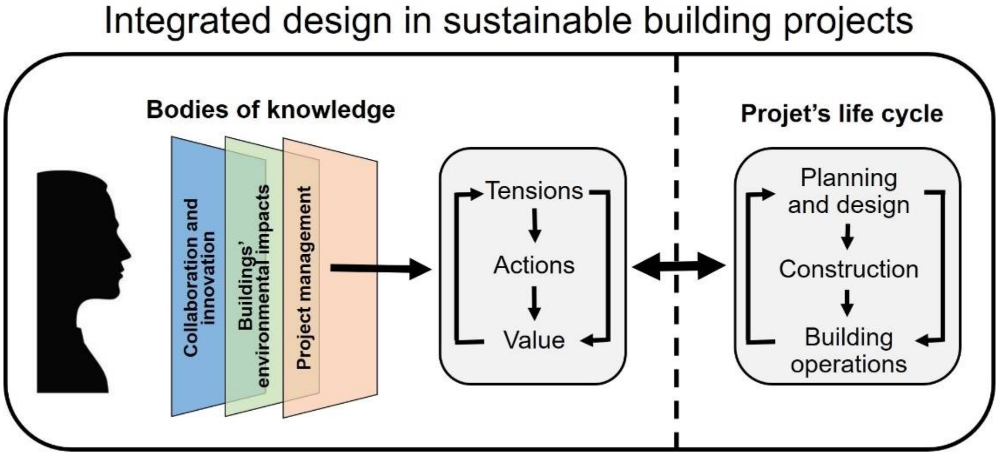

Figure 17. Representation of the procedure to study the pilot study based on Lizarralde *et al.* (2013).

Replication in two other case studies: After analysing the pilot case, I compared the results found in each of the two other cases to draw out the initial patterns. Following Yin (2003) approach to obtaining analytical generalisations, I compared these patterns with those found in the literature (further detail below).

Explanation building: Yin (2003) defines this strategy whereby the researcher attempts "to make casual links based on existing theory or sound iterative analysis of data" (internal validation) (Mills *et al.*, 2010). In this sense, the final explanation is the result of this interactive analysis and may differ from the one defined at the beginning of a study. The construction of an explanation is a process geared to improve original ideas, “in which an important aspect is again to entertain other plausible or rival explanations” (Yin, 2003). Yin describe the process used to build a final explanation (p.121) as follows:

- Making an initial theoretical statement or an initial proposition about policy or social behavior
- Comparing the findings of ‘an initial case’ against such a statement or proposition
- Revising the statement or proposition
- Comparing other details of the case against revision
- Comparing the revision to the facts of a second, third or more cases
- Repeating this process as many times as needed.

Pattern matching: Patterns were first identified in each case study and compared to each other in order (see Figure 18) to identify what Yin (2003) calls “analytic generalization”. Pattern-matching links data to propositions whereby patterns of relationships between the constructs obtained from each of the case studies are compared with those predicted (hypothesized) by the theory to answer the proposed research question (Mills *et al.*, 2010; Yin, 2003).

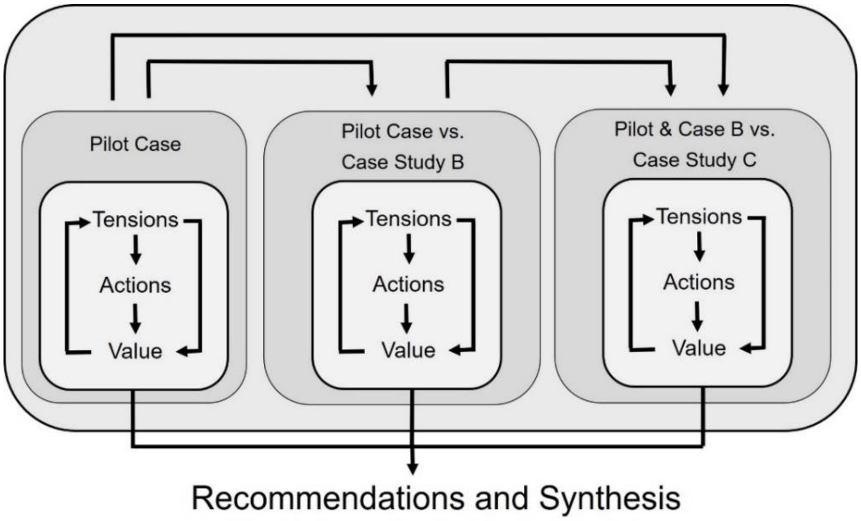

Figure 18. Schematic diagram illustrating comparison between cases (pattern matching / analytic generalization).

3.7. Ethical considerations

An ethical protocol was developed and approved by the Université de Montréal. The participants of each case study were informed about the study and were required to sign a consent form before interviews or meetings (Annex II. Ethics approval and consent form). This protocol included all the procedures to ensure the interviewer anonymity, privacy, and confidentiality as well as the protection and security of data. However, because we decide to present three well-known case studies, it is possible to identify some stakeholders in the case studies. The interviewers were informed of this risk and they decided to continue to participate.

4. RESULTS

4.1. Pilot case study results

The pilot study was an iterative process, that entailed shifting from the literature review (chapter 2) to the empirical information from the pilot study (see Figure 19). The articles were submitted to relevant conferences and peer-reviewed by the committee of the international conference where the articles were presented.

- Article 1 - 2014 UIA World Congresses, Durban, South Africa
- Article 2 - 2016 41st IAHS World Congress, Algarve, Portugal
- Article 3 – 2017 World Sustainable Built Environment Conference, Hong Kong

The results were validated by other academics and practitioners participating in the international conferences. Next section summarizes each article: 1) the question that initiated the debate; 2) the article title and the conference to which it was submitted; and 3) the questions (results) that each article raised and were applied to three case studies (publications in journal).

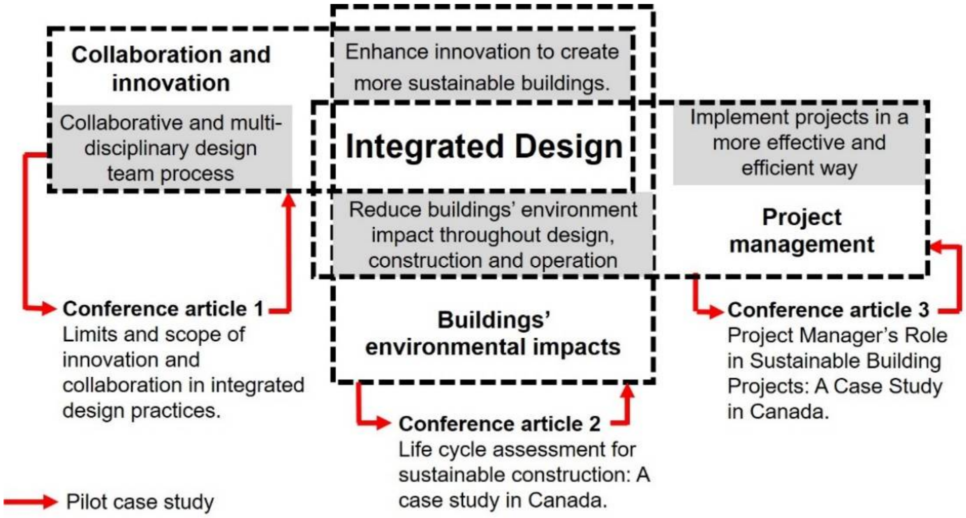

Figure 19. Main contributions from conference articles to understand the limits and opportunities of integrated design in sustainable buildings.

4.1.1. Effective collaboration and innovation (Conference article 1)

Question: While the need for ID has been sufficiently established in the literature, its scope and limitations have been insufficiently explored. ID promises to enhance collaboration, and subsequently innovation, to achieve more sustainable buildings. Researchers have found, however, that ID does not always perform as expected. They claim that ID often fails to reach its full potential as a facilitator of collaboration and as a promoter of innovation. The objective of this article is to examine, both theoretically and empirically, the contingencies that limit Interactive Design's capacity to achieve innovation and collaboration goals.

Conference Article: Leoto, R., Herazo, B., & Lizarralde, G. (2014). Limits and scope of innovation and collaboration in integrated design practices. In A. Osman, G. Bruyns & C. Aigbavboa (Eds.), *XXV International Union of Architects World Congress* (pp. 500-514). Durban, South Africa: UIA 2014 Durban.

Results: A detailed case study emphasised and confirmed the importance of three factors: risk perception, stakeholder commitment, and waste in the design process. The contingencies were found to have three important empirical effects: (1) clients can positively influence all team members by establishing their willingness early and clearly to take risks in order to innovate, but the opposite is also true; (2) the early development of a sense of a common goal can increase the willingness of the parties to collaborate for effective innovation; (3) the improvement of the delivery process can reduce waste in the design process. This implies appropriate preparation of project meetings and charrettes, clear definition of roles and the duration of each meeting, and the importance of having a facilitator responsible to set the stage for effective communication throughout the design process by instilling effective communication skills within the group and fostering an atmosphere of lasting respect and trust.

Questions that arose for further enquiring:

- Why these factors influence the effectiveness of collaboration and innovation between stakeholders during ID?
- What tensions arose during ID charrettes?
- How were these tensions particularly challenging in ID process performance?
- How are they addressed by practitioners?

4.1.2. Buildings' environmental impacts (Conference article 2)

Question: Life Cycle Assessment (LCA) is a method to aid professionals in evaluating the environmental impact of project during its whole lifetime. However, lack of knowledge about LCA principles, tools and benefits seems to be a significant barrier to its adoption. ID, in theory, helps to significantly decrease GHG emissions by reducing embodied emissions – materials impacts and consumption – and operation emissions – in terms of building energy-consumption. Previous research, however, has found that ID – when used to obtain building certifications – does not necessarily result in environmental impact reductions This study aims to explore the use of LCA during ID process in a recent office building in Canada.

Conference Article: Leoto, R., Thibodeau, C., & Lizarralde, G. (2016). *Life cycle assessment for sustainable construction: A case study in Canada*. 41st IAHS World Congress: Sustainability and Innovation for the Future, Albufeira, Algarve, Portugal.

Results: The results of this research revealed that overall, the strategies applied in this project led to an 87% reduction in total fossil fuel consumption, as well as a 50% reduction in the global warming potential when compared to the reference building. This study, however, revealed some limitations when applying LCA that must be highlighted: (1) the restriction in the inputs that were allowed by Impact Estimator for Buildings (IE4B) – an LCA tool, (2) the IE4B's hidden datasets – that cannot be consulted or parameterized. Although IE4B has gaps and at times lacks precision, its use can help practitioners to overcome some of the existing barriers and dissemination of LCA results in a case-study format facilitates a better understanding of its to evaluate, predict and diminish the impact in the environment.

Questions that arose for further enquiring:

- To what extent does ID reduce a building's environmental impacts?
- How are decisions made in ID projects to achieve these reductions?
- How effective is ID in achieving impact reductions and what are the factors involved?
- How significant is embodied potential impacts in sustainable and energy efficient buildings?

4.1.3. Project management performance (Conference article 3)

Question: Green building certifications propose ID to improve the environmental performance of buildings. There remains, however, significant gaps between the sustainable building expectations at the design stage and the actual, subsequent performance. ID aims at integrating otherwise fragmented outputs and processes to improve a building's performance throughout all phases - design, construction, operation, and occupancy. This improved interaction between stakeholders and project phases promises reductions in the buildings' impacts throughout its whole life cycle. This performance improvement of sustainable construction in ID has been promoted, however, without empirical validation. The objective of this paper is to explore the role of project managers in ensuring that project and process fragmentation are reduced and that the sustainability goals set by the design team are effectively achieved.

Conference Article: Leoto, R., & Lizarralde, G. (2017). *Project Manager's Role in Sustainable Building Projects: A Case Study in Canada*. World Sustainable Built Environment Conference 2017: Transforming Our Built Environment through Innovation and Integration: Putting Ideas into Action, Hong Kong.

Results: This research shows that even if fragmentation in the design phase is reduced, it still occurs during the construction process and the operation phase. Three opportunities for project managers (PM's) to reduce fragmentation and to improve sustainable performance in buildings, were identified: (1) the PM and the key members of the project team need to be hired early in the project's feasibility stage, (2) the PM needs to help the client by organizing project design "charrettes" and the proper use of new tools and techniques related to sustainable goals, (3) the project team led by the PM needs to follow the operation phase of the building. This case study indicates that, even when the entire team participated in the documentation and the commissioning phases, it was not able to successfully transfer project knowledge, or to anticipate future issues. This research revealed major tasks in which project managers can play a significant role that goes beyond the implementation of technical solutions, and which requires social and "soft" skills.

Questions that arose for further enquiring:

- How is project management effectively implemented in green projects that adopt ID?
- To what extent does ID, as an innovative process, influence traditional project management practices in sustainable projects?
- How does ID enhance collaboration between stakeholders during the different construction project life-cycle phases?
- What are the challenges stakeholders face when seeking to reduce a building's energy and environmental performance?

In the next step of the research, I compared the results found in the pilot case with two other cases to extract the initial patterns. I present the overall results in three publications. The publications answer the initial questions of this doctorate as well as those that arose in the three conference articles. Figure 20 illustrates how these three publications articulate the next chapter of this thesis.

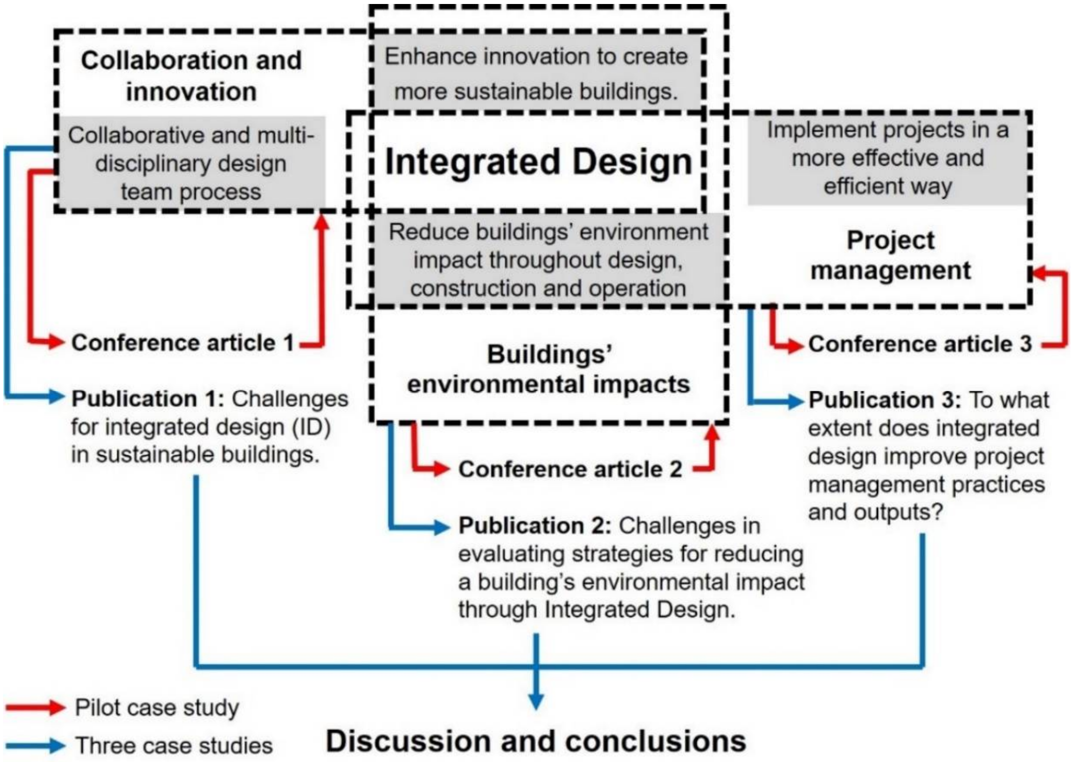

Figure 20. Main contributions from publications to understand the limits and opportunities of integrated design in sustainable buildings.

4.2. Challenges for integrated design (ID) in sustainable buildings (Publication 1)

Authors: Leoto, Ricardo and Lizarralde, Gonzalo (2019),

Published in the Journal: Construction Management and Economics, 1-18

4.2.1. Abstract

It is often argued that Integrated Design (ID) is a powerful way to enhance collaboration in construction projects. This collaboration is seen as a way of improving innovation to create more sustainable buildings. Contrary to the traditional silo-type and linear design process, ID is based on upfront stakeholder involvement and a holistic approach to project decision-making. Although ID's premises are theoretically-founded, a close empirical look at its practices shows that numerous challenges compromise its results and efficiency. This study examines the ID process through an iterative process that includes the construction of a conceptual framework and its empirical validation. We examine three green construction projects in Canada. Based on the analysis of 26 interviews with key project stakeholders and more than 198 construction documents, the study assembles – and ultimately applies – a multi-lens framework based on four themes: the fragmented nature of construction; risk perception; stakeholders' commitment; and efficiency in the design process. Results show that three tensions arise in ID practices: between collaboration and process efficiency, between short-term and long-term goals, and between integrated methods and traditional ones. Theoretically, the results challenge the relevance and value of ID to improve project performance and reduce buildings' impacts on the environment. From a practical perspective, the results reveal the ways construction industry stakeholders can improve their interactions to achieve more appropriate interventions in the built environment.

Keywords: Integrated Design, architecture projects, collaboration, innovation, efficiency in design process.

4.2.2. Introduction

Increasing attention to sustainability has led construction industry professionals to search for innovative and collaborative design methods. Both academics and practitioners have noted that the traditional silo-type, linear, and fragmented design process creates a significant barrier to collaboration. Fragmentation is also seen as a significant barrier to innovation in construction (Belloni *et al.*, 2009; Mossman *et al.*, 2010). Hence, alternative design methods, such as Integrated Design (ID), are becoming increasingly popular (Kibert, 2013).

ID is a holistic process that involves the simultaneous participation of several stakeholders (professionals, builders, experts, and even clients and users) through intensive collaborative design workshops called “charrettes” (Zimmerman, 2004). Unlike the traditional design process, ID allows participants to work together from the beginning of the project, making decisions collectively and integrating otherwise fragmented decisions and outputs. The process aims at enhancing collaboration in order to satisfy the aspirations and needs of society and clients (Owen *et al.*, 2010). This collaboration becomes a facilitator of innovative practices required to respond to those aspirations and needs.

Within this context, it is expected that ID will enhance collaboration, and subsequently innovation, to achieve more sustainable buildings (Forgues & Koskela, 2009; Larsson, 2002). However, researchers have found that ID does not always perform as expected (Fedoruk *et al.*, 2015; Kovacic & Müller, 2014). They claim that ID often fails to reach its full potential as a facilitator of collaboration. Similar studies have also found that ID often fails to create innovation (Fedoruk *et al.*, 2015; Forgues & Koskela, 2009). As a result, the sustainable buildings that are produced through ID practices are often less efficient than anticipated (Ghassemi & Becerik-Gerber, 2011).

What produces these unsatisfactory outcomes? In this paper, we seek to identify factors that affect ID projects and to uncover obstacles to both collaboration and innovation during ID projects. The first section of this article presents a literature review of the global construction industry and identifies factors that affect collaboration, and those that affect innovation. The study then builds on the multi-lens model proposed by Van de Ven (1986) and applies it specifically to ID process. Van de Ven's approach is based on two principles. First, one must identify the factors that inhibit or facilitate innovation. Second, one must understand how these factors affect innovation and how they are addressed by practitioners. In other words, "understanding the process of innovation is to understand the factors that facilitate and inhibit innovation developments" (p.591). The model congregates these factors into four central problems or themes. These themes, in term, serve as lenses with which to examine how and why these problems occur and influence the effectiveness of innovation.

In the second section of this paper, we present a pilot case-study that helped us validate and reduce the list of construction-industry factors we initially found to a shorter list of factors affecting ID process projects in particular. This was an iterative process that entailed shifting from the literature review to the pilot study and back again. This process eventually allowed us to identify four main themes. They served as lenses for the remaining phases of the study. In the third section, we explain how we conducted the empirical study and the iterative process of investigation. In the fourth section, we present the results of applying these themes as lenses to analyse three case studies. The fifth section – discussion – identifies three tensions underlying these factors and explains why they are particularly challenging in ID process performance. The final section presents the theoretical and practical implications of this argument.

Collaboration and Innovation in the Construction Sector

The purpose of this paper is to uncover factors and tensions that hinder collaboration, as well as those that affect innovation during ID projects. To do so, we review the general literature on construction industry and create a list of factors that influences collaboration and innovation in this sector.

The construction industry is often considered to be conservative with regards to both innovation (Kulatunga *et al.*, 2011) and collaboration (Kvan, 2000), notably when compared to other areas, such as the aerospace, technology and automobile sectors

(Toole *et al.*, 2013). Some authors argue that the construction industry needs innovation to deal with the increasing constraints introduced by sustainability (Gluch *et al.*, 2009; Rekola *et al.*, 2012). Others stress the need for a more collaborative and integrated approach in order to address the increasing complexity of design problems (Poirier *et al.*, 2016; Sodagar & Fieldson, 2008).

We know that innovation plays a significant role in sparking and sustaining growth among companies (Gopalakrishnan & Damanpour, 1997) and the national economy (Porter, 1991). It creates value and competitive advantages for firms (Baregheh *et al.*, 2009). Slaughter (1998) defines innovation as the "actual use of a non-trivial change and improvement in a process, product, or system that is novel to the institution developing the change" (p. 1). Innovation does not necessarily imply the implementation of radically new ideas. It also reframes old practices in new ways (Einstein & Infeld, 1961). In fact, it is quite difficult if not impossible to talk about innovation in the construction industry without referring to collaboration as a mechanism for facilitating the sharing of information, resources, and knowledge in both radical and incremental innovation processes (Crossan & Apaydin, 2010). Liedtka (1996) defines collaboration as a "process of decision-making among interdependent parties; [involving] joint ownership of decisions and collective responsibility for outcomes" (p. 21). Innovation and collaboration can be seen as two independent goals. In practice, however, innovation encourages, and often requires, a collaborative environment capable of creating value for multiple stakeholders (Toole *et al.*, 2013). In addition, collaboration between stakeholders is a key source of innovation (Von Stamm, 2004). Confronted with environmental challenges, several authors have argued that today's professionals need to collaborate to innovate and to innovate by way of collaboration (Bossink, 2012; Du Plessis, 2016; Ozorhon *et al.*, 2010; Thorpe *et al.*, 2008).

The review of innovation and collaboration concepts in the construction sector has led us to identify three common premises. First, collaboration is needed to achieve the high levels of innovation needed in sustainable buildings (Magent *et al.*, 2009). Second, innovative ways of collaborating are currently a much-needed means to achieve real project performance (Rekola *et al.*, 2009). Third, innovation does not emerge naturally or spontaneously in the building sector (Smyth & Pryke, 2009). Van de Ven (1986) argues that to better understand the industry's reluctance to innovate, it is necessary to identify the factors that facilitate and inhibit innovation and collaboration. To identify these factors, our research team conducted an extensive literature review of articles published between 1990 and 2016 on collaboration (42 articles) and innovation (105 articles) in the construction industry in general. Based on this meta-analysis of prior work, we identified the most common factors that facilitate and inhibit collaboration and innovation in the global construction industry (Table 23).

Table 23. Summary of the factors that influence innovation and/or collaboration in the construction industry.

Variables	Description	Innovation		Collaboration		Authors
		Inhibit	Facilitate	Inhibit	Facilitate	
Bidding practice	Traditional price-driven (lowest bidding) selection procedures	X		X		1, 2, 41
Champion	Champion acts as gatekeepers to drive innovation		X			3, 7, 33
Client support	Client / owner support and leadership for change		X		X	4, 5, 33
			X			6, 7
Commitment	The proactive involvement and commitment of the client		X			4, 8
	Stakeholders commitment to encourage and try new ideas		X			2, 9, 10
Communication	Effective communication between parties involved in the project				X	11
Conflicts	Willingness and ability to manage conflicts		X		X	12, 13
Early involvement	Early collaboration diminishing fragmentation between project phases		X		X	14
	Early contractor's involvement in the design stage				X	15, 33
Efficiency	Clear understanding and distribution of the stakeholder's responsibilities and roles				X	2, 11, 29
	Construction industry is inefficient to meet new customer needs	X				14, 16, 18, 28
Fragmentation	High fragmentation on construction industry inhibits project improvement	X		X		16, 17, 18, 19
	Linear, sequential, and silo-type hampers interaction between professionals	X		X		20, 21
Goals	Clear identification of goals and objectives				X	22, 23
Isolation of disciplines	Isolated optimization by discipline without considering the whole project	X		X		1, 24
	Integration problems (rework) due to extreme specialisation of functions			X		13, 25, 26
Knowledge	Availability of knowledge and technical capacity		X			35, 36, 44
	Low investment (time and resources) in R&D and design competencies	X		X		2, 9, 26
Leadership	Effective leadership is essential to improving construction process		X			4, 7, 27

	Good leadership is required to encourage a collaborative team environment				X	2, 14, 28
Organizational culture	A stimulating climate for the generation and implementation of new ideas		X			23, 29
	The organisation sends positive signals to project team members		X			2, 4
Participation	Active stakeholders' participation in design phase		X		X	4
Procurement	Partnering and framework agreements reducing fragmentation		X		X	16, 19, 30
	Traditional procurement processes reinforce socio-cognitive barriers	X		X		16, 18, 21
Project based culture	Temporary nature of construction projects inhibits the transfer of lessons	X				31
Regulation	The construction industry's conservatism and it's strict technical regulations	X		X		2, 32, 33
Resources	Have an experienced project team with necessary technical capabilities				X	8, 12, 34
	Little innovative capability of small firms	X				25
Risk	Aversion to risk related to innovation implementation	X				8, 25
	A climate of sharing and tolerance to risk		X		X	22, 35, 36
	The willingness of the client to assume risk related to innovation process		X			2, 4, 6
Shared vision	Shared vision of goals, values, and objectives among stakeholders		X		X	33, 37, 38, 39
Teamwork	Interdisciplinary team capable of working together		X		X	9, 33
	Effective partnering between stakeholders with "win-win" approach				X	16, 18, 40
	Teambuilding depends on qualified facilitators				X	30
Trust	Stakeholders mutual respect and trust		X			6, 41
	Open and frequent communication				X	30, 42
	Mutual understanding creates relationships between individuals		X		X	2, 4
Uncertainty	Concerns among "unknown" and at-risk contexts in complex projects	X				8
	Identify activities that can reduce uncertainties and risk		X			23, 43
	Perceived low return on investment	X		X		23, 36

1-Love *et al.* (1998), 2-Dulaimi *et al.* (2005), 3-Tatum (1989), 4-Kulatunga *et al.* (2011), 5-Dulaimi *et al.* (2002), 6-Brandon and Lu (2008), 7-Nam and Tatum (1997), 8-Ivory (2005), 9-Ling (2003), 10-Love *et al.* (1999), 11-Akintoye and Main (2007), 12-Hausman (2005), 13-Chiocchio *et al.* (2011), 14-Kent and Becerik-Gerber (2010), 15-Erik Eriksson *et al.* (2009), 16-Egan (1998), 17-Barrett (2009), 18-Latham (1994), 19-Green *et al.* (2004), 20-Cole and Larsson (1999), 21-Koskela *et al.* (2006), 22-Stiles (1995), 23-Slaughter (2000), 24-Magent *et al.* (2009), 25-Reichstein *et al.* (2005), 26-Poirier *et al.* (2016), 27-Nam and Tatum (1992), 28-Lu and Sexton (2009), 29-Hartmann (2006), 30-Bresnen *et al.* (2005), 31-Gann and Salter (2000), 32-Gottlieb and Haugbølle (2013), 33-Gambatese and Hallowell (2011), 34-Laborde and Sanvido (1994), 35-Slaughter (1993), 36-Egbu (2004), 37-Slaughter (1998), 38-Tatum (1986), 39-Bossink (2012), 40 Kaatz *et al.* (2006), 41-Kulatunga *et al.* (2006), 42-Lorange and Roos (1991), 43-Blayse and Manley (2004), 44-Bossink (2004).

Table 19 presents a long list of general factors that affect the construction industry. Some of these factors may also play a role in ID performance. We therefore realized at this stage that we were embarked on an exploratory study, rather than a hypothesis-testing study (Eisenhardt & Graebner, 2007). We decided to conduct a pilot study to validate and narrow down the list to one that contains only the factors that affect ID projects.

4.2.3. The Pilot Study and the Iterative Inquiry:

We chose to study the ID process of the Centre for Sustainable Development in Montreal, Canada (henceforth known as Case A). Not only did we have access to abundant information on it, but this was the first building in the city to adopt ID to obtain a LEED® (Leadership in Energy and Environmental Design) Platinum Certification. Our study relied on two sources of information: 1) an in-depth analysis of fourteen ID reports and 54 hours of recording of ID charrettes and 2) interviews with key project stakeholders: two with client's representatives and three with design professionals. The interviews began with the following question: "Which factors, in your opinion, favour or hinder innovation in ID in sustainable projects? Which one affect collaboration?". Respondents were also encouraged to describe their own experiences and to prioritise the factors that influence ID performance. Their answers were used to validate the pertinence of the factors we had found in literature and to organize them into the most relevant themes. Table 24 summarises the findings of this step.

Table 24. Summary of the factors and themes that influence both,innovation and collaboration in ID.

* (A) ID charrettes report; (B) Interviews with client representatives; (C) Interview with design professionals.

Themes	Variables	Pilot Study			Evidence from pilot case study report and interviews
		A	B	C	
Fragmented nature of the construction industry	Fragmentation	X	X		A - The ID was a great tool, but, in the end, the project team worked as usual, acting in isolation, working independently on the parts of the project.
	Organizational culture	X	X	X	A - The required effort to operate ID goes beyond the professionals' comfort zone.
	Project based culture		X	X	C – In this project we had enough time to conduct research in order to provide innovation, but that is rare in our projects.
Risk perception	Risk	X	X		A - The ID process (charrettes) helped to significantly reduce the risks of the project.
	Uncertainty	X	X	X	C - Innovation has sometimes led us to an unknown field, which is more subject to risk.
	Client involvement	X	X		A - Early involvement helped the client to better understand the project and make better decisions.
	Early involvement	X	X		
Stakeholders' commitment	Commitment	X	X		B - Stakeholder participation in all meetings does not on its own entail that there is true collaboration and a sharing of information among professionals.
	Trust			X	C - Wasn't clear for professionals who would be responsible for possible failure related to innovative technologies.
	Teamwork			X	A - Active participation of all teams (professionals, clients, and consultants): 22 persons and 80% participation in 14 charrettes.
	Champion	X		X	C – The client representative acted as a green champion in this project.
	Shared vision	X	X		A – Different visions of innovation: The client believed that innovation could be incremental while professionals believed in radical innovation (clear departure from existing practices)
Efficiency in the design process	Efficiency	X		X	C - The meetings were too long, and without a break between them in order to give us time to work on the data.
	Knowledge	X	X	X	B - We had as many stakeholders as possible, as early as possible, but we still didn't know how to coordinate their specific contributions.
	Isolation of disciplines	X	X		B – At the end of the process, the project team was tired; each one started to work in isolation, working independently, joining the parts only during the meetings.
	Resources			X	C - I had never participated in a project with so many professionals in the same room, we were 22 people in total.

Our analysis included an iterative process of empirical enquiry and conceptualisation. Following Van de Ven (1986), we ultimately found that the most pertinent factors could be clustered in four main themes, which are common in the literature and frequently present in the empirical work. We adopted them as lenses that we deployed in the remaining phases of the study. This analysis can thus be considered simultaneously as the result of the first stages of the study, and as the tool we used later on to conduct additional empirical investigation about ID. Let us now explore the four themes.

The fragmented nature of the construction industry

The traditional building design-process typically applies what Evbuomwan and Anumba (1998) call the “over-the-wall” approach. In this approach, the design outputs of each speciality are prepared separately and assembled at an advanced stage of the process. Sequential communication among participants is the norm: structural design, for instance, does not begin until completion of architectural drawings. Both need to be completed before mechanical systems design begins (Fabricio, 2002). There are meetings, but they are mainly devoted to output coordination rather than having professionals design together (Cole *et al.*, 2008). Besides, the design team almost never includes the same people as the construction team. They also have different priorities: the design team emphasises design quality, whereas the construction team often focuses on timely project completion (Moore & Dainty, 2001).

Several authors have argued that the fragmented nature of the industry, (including lack of coordination, and a discontinuous, project-based way of working) is the most significant barrier to collaboration, and thus, eventually to innovation (Barrett, 2009; Egan, 1998; Latham, 1994). This fragmentation leads to a conflict between the expected and the actual project quality, which then results in buildings that operate below their optimum potential (Jayasena & Senevirathna, 2012). Four types of fragmentation have been identified in construction (see Table 25); all of them hinder collaboration throughout the construction process.

Table 25. Forms of fragmentation in the construction sector.

Forms	Summary	Authors
Construction industry (CI) fragmentation	The industry is mostly composed of a vast number of small- and medium-sized enterprises that work together for only short periods of time. This is a barrier to the creation of sustained partnerships and alliances.	(Mossman *et al.*, 2010).
	There is also a strong division of labour, poor coordination among project participants, and significant amounts of subcontracted work.	(Gottlieb & Haugbølle, 2013; Ofori, 2000).
Procurement fragmentation	It is believed that conventional procurement methods and contracts create adversarial relationships between parties reinforcing socio-cognitive barriers that hinder team efficiency and a collective search for new ideas.	(Forgues & Koskela, 2008; Mossman *et al.*, 2010).
Design fragmentation	The disjointed and sequential character of traditional design practice, as well as the increasing specialisation of roles, and rework in design and construction lead to sub-optimal solutions, poor constructability, and operability.	(Magent, 2005; Nam & Tatum, 1997).
Labour fragmentation at construction site	Certification for construction workers fragments the workforce by trade, sector, and geographic area.	(Globe-Advisors, 2013).
	The increase of certified trades in the construction industry due to new performance-based codes and highly specialised labour and the growing number of trade workers focusing on sector-specific skills (152 different required skills in total) delay the process and increase construction costs.	(Gautier, 2015; Lizarralde & Davidson, 2008).

Risk perception

Risk occurs when two conditions – threat and vulnerability – overlap. In the construction industry, a threat is often informally defined as an objective that cannot be achieved. Vulnerability occurs when people are confronted with new technologies, contexts, or methods (Taroun, 2014). While some degree of risk of failure and uncertainty is inevitable in innovative processes, researchers have found that the risk-averse culture of the construction industry often hinders innovation (Ivory, 2005). A company considering innovation needs to consider a systematic approach to identify the activities that can reduce avoidable uncertainty and risk (Slaughter, 2000). But risk-reduction requires extra initiative, time and resources (Jalonen & Lehtonen, 2011).

Slaughter and Cate (2009) find that clients play a crucial role in establishing the incidence and rate of innovation in construction projects. According to Kulatunga *et al.* (2011)the willingness of clients to share risks and their commitment and leadership in project planning and execution are critical for innovation achievement. They also suggest that it is fundamental for the client (in order to develop and successfully implement innovative approaches) to establish and communicate the superordinate goals to project team members early in the process. Clients’ early active involvement throughout the project increases the generation of cost-effective ideas and mitigates risk (Osipova & Eriksson, 2011).

Determining innovative goals for all team members early in the process can also “bridge the gap between the client, designers, and builder in recognition of those goals despite (sometimes) misaligned agendas.” (Slaughter & Cate, 2009, p. 153). In this way, despite risks, both clients and professionals benefit from innovation. The client benefits from an innovative solution and improved project performance. The builders and professionals benefit from innovation through potential application in subsequent projects (Slaughter & Cate, 2009).

Stakeholders' commitment

Developing a sense of common objectives in the early stages of the project can increase the willingness of stakeholders to collaborate, especially when they perceive value in this interaction (Slaughter, 2000). Kaatz *et al.* (2006) highlight that strong collaboration and teamwork guided by a common project vision are essential to developing the necessary commitment to implement sustainability in construction. Teamwork is defined by Chiocchio *et al.* (2011) as a “team-level construct corresponding to how team members work to combine their thoughts, actions, and feelings to coordinate and adapt, and to reach a common goal.” (p.80) According to D'Amour *et al.* (2005)it implies collective action “in a spirit of harmony and trust” (p. 116). Trust is therefore reached through fulfilling commitments (Ashcraft, 2008) and must be a common thread running through the entire program, providing the foundation for effective collaboration (Jalonen & Lehtonen, 2011).

Kulatunga *et al.* (2011)contend that clients’ leadership is key to encouraging teamwork among project participants. Good leaders or champions typically show extraordinary confidence in their mission, encouraging and inspiring others (Hayton & Kelley, 2006). This synergy fosters a better understanding of stakeholders and their competencies that can enhance mutual trust among them. Improved mutual understanding reduces antagonism and increases the parties' ability to foster innovation through better integration. The decision to innovate often relies upon the actions of a particular leader who is willing to shepherd the innovation throughout the process (Slaughter, 2000).

Efficiency in the design process

Traditional project processes are often freighted with unnecessary rework, delays, changes, and overproduction (Horman *et al.*, 2004). Wasteful activities, such as the production of incomplete and provisional plans, absorb resources without generating value (Kamara *et al.*, 2007). Waste in the design process refers to activities unnecessary for task completion (Huovila *et al.*, 1997). Therefore, improvements in the delivery process can reduce costs and increase efficiency. Identifying and purging wasteful activity from a process can improve performance, enhance competitive advantage, and increase profitability (Horman & Kenley, 2005). Magent (2005)identified the primary forms of waste and described the three most prevalent causes of it in the sustainable building design process (Table 26).

Table 26. Categories of waste in the in the sustainable building design process according to Magent (2005).

Categories	Causes of waste in the design process
Missing design competencies	The presence of key design competencies is critical for sustainable projects which require additional and greater distribution of functional skills among team members. Lack of relevant competencies during the design process will decrease the project's chances of success.
Poor timing of decisions	Postponing a decision allows the team to collect additional information and perform analyses which can lead to a better decision. However, if downstream decisions depend on the results of previous decisions, a cost may be associated with that delay. Developing a mechanism to evaluate the timing of decision-making in the sustainable building design process can help identify and reduce the waste associated with ill-timed decisions.
Missing information for decisions	Decisions made without sufficient information can lead to waste including changes in design decisions and the breaking of commitments on which others have relied.

Waste in design processes not only results in higher initial costs, but also hinders the overall building performance (Magent, 2005). Moreover, a multidisciplinary design team that includes different skills is crucial to increase efficiency in the design process and quality in the construction output (Egan, 1998). A better-integrated design process (Zimmerman, 2004) and an accurate design that meets customer needs (Greenwood, 2003) are both crucial to reducing waste during the construction and operation phases. Having developed this conceptual framework, we decided to test it on three additional case studies that required additional empirical methods.

4.2.4. Detailed Empirical Methods

A case-study approach is a reliable means of capturing rich information in complex situations, such as construction projects since case studies allow the investigator to retain the holistic and meaningful characteristics of real-life events (Barrett & Sutrisna, 2009; Yin, 2003). This strategy is employed to inductively generate insights regarding the phenomenon to be studied (Ogawa & Malen, 1991). In an exploratory case study, qualitative data analysis involves an iterative process of observation, analysis, and reflexion on categories of analysis (Mills *et al.*, 2010).

In our study, we first identified patterns in the case studies. We then confronted the patterns with the four themes identified above. This is a strategy that Yin (2003) defines as “explanation building,” whereby the researcher “makes causal links based on existing theory or sound iterative analysis of data.” Yin (2003) notes that this approach is akin to external validity in the framework of multiple case studies. In this sense, our findings are the result of an interactive analysis between the conceptual framework and the cases studied.

An important step in the development of case studies is defining the case or unit of analysis (Knight & Ruddock, 2008). The criteria for our case selection included projects that: (1) achieved a high level of certification in the LEED® Green Building Rating System (“gold” or “platinum”); (2) were launched by institutional clients (private, public, or NGO organizations) within the past seven years; (3) sought to integrate innovative practices or products; (4) intended to adopt the ID approach from the beginning of the design phase; and (5) provided sufficient access to data, reports, and stakeholders. In this study, we did not define what should or should not be considered ID. We recognised that ID has, in practice, many interpretations. Whereas professionals often claim to be committed to ID, in practice, teams typically integrate just a few features that characterise ID. Nonetheless, the professionals’ intention to use ID was deemed acceptable for our purposes. We did not judge the value of the ID processes under investigation before conducting the empirical study. We recognise that future studies can do this.

Case study A explored, in more detail and with additional data, the pilot study, the Centre for Sustainable Development (Tables 6 and 7). The subject of Case study B is the Rio Tinto Alcan Planetarium. The project started in 2003 when the city of Montreal decided to relocate its obsolete Planetarium. A multidisciplinary project team worked collaboratively to deal with the functional and technical complexity of the project. This building is the second LEED® Platinum in Québec and one of Canada's largest natural science museums. Case study C is the Montreal Soccer Stadium. Launched in 2009, and put into operation in 2015, the project responded to a growing need for indoor space for soccer practice. This LEED® Gold project includes innovative and energy-efficient measures to help optimize environmental performance. Table 27 summarises the main characteristics of the three projects that we selected.

Table 27. Summary of the main characteristics of three case studies retained.

Characteristic	Case study A	Case study B	Case study C
Type of client	NGO	Government (cultural)	Government (sport)
Main use	Offices	Museum & entertainment	Soccer stadium
Functional programme	Offices, meeting rooms, amphitheatre, and a cafeteria	Theatres, exhibition rooms, administrative offices, auditorium, and a boutique	Two full-size soccer fields, administrative offices, training rooms, a cafeteria, and retail space.
Built area	6,500 m² on five levels	8,000 m² on three levels	12,600 m² on two levels
Cost	$27 million (CAD)	$48 million (CAD)	$52 million (CAD)
Design tender process	Short invitation	International competition	International competition
Certification	LEED® Platinum	LEED® Platinum	LEED® Gold
Construction	2009 to 2011	2011 to 2013	2009 to 2015
Main green strategies	Geothermal heating and cooling system, bio-wall, thermal envelope, displacement ventilation, and green roof	Collection and reuse of rainwater, thermal envelope, natural ventilation	Geothermal energy, roof made by local and prefabricated cross-laminated timber (CLT)
Funding	Mortgage, private and public donations	Public with private donations	Public
N. of ID charrettes	14	5	8
Total time - charrettes	68h30	38h	77h

The use of multiple sources of documentation in case-study research enhances data credibility (Patton, 2015). Consequently, following Yin (2003)we examined and assessed documents regarding their purpose, coverage, and quality (see Table 28 for a summary of data). In each of the documents, we identified elements that indicate intentions, actions, or decisions related to the four “constructs” (themes) previously delineated.

Table 28. Numbers of documents analysed in each case study.

Document	Case A	Case B	Case C
Client/owner Functional and Technical Program (FTP)	3	1	1
Annual reports and public consultation process	5	3	4
Project meeting proceedings	13	2	7
Published Case study reports	12	7	5
LEED® Green building certification reports	3	3	5
Press releases, videos and magazine articles	28	13	22
Email exchanges	40	3	11
Chronograms and contracts	4	1	2

We also conducted 26 interviews with stakeholders involved in the three projects (see Table 29). Interviewees from different backgrounds, roles, and positions were chosen in order to obtain an overall picture of the case (Eisenhardt & Graebner, 2007). As in the pilot study, we asked stakeholders to explain the how and the why of the factors that influence ID’s capacity to achieve both, collaboration, and innovation goals in sustainable buildings. We then followed a semi-structured format to collect individuals’ narratives, as suggested by Walsham (1995). The interviews lasted between 40-120 minutes. Table 30 shows the questions that guided the conversation. But we remained open to identifying additional problems or subjects that we had not anticipated.

Table 29. Summary of stakeholders who were interviewed.

Stakeholder role	Case A	Case B	Case C
Client/owner	3	1	1
Users	1		1
Architects	3	2	1
Engineers		1	1
Facilitators	1	1	1
General contractors	1		2
LEED® consultants	1	1	1
Project managers	1		1
Totals	**11**	**6**	**9**

The comparison of documentary data (reports, archival records) with the results of the interviews allowed us to triangulate information (Fellows & Liu, 2008). When we discovered inconsistencies between what the interviewees said and what was recorded in documents, we questioned the interviewees further (by email). After analysing the cases, we compared the results found in each case to draw out the initial patterns. Following Yin’s (2003) approach to obtaining analytical generalisations, we then compared these patterns with those found in the literature.

Table 30. Examples of questions formulated to understand the tensions that arise from ID practices.

Interviews questions
• How does the early involvement of all stakeholders help to eliminate (or diminish) fragmentation in the construction industry? • How can the ID process contribute to integrating processes in the construction industry? • What or who influences the stakeholders’ willingness to take risks on an innovative project? • How can the ID process help to diminish the stakeholders' risk perception? • What are the benefits for stakeholders from the development of common-sense objectives early in the process? • How can the ID process help reduce (or eliminate) waste in the design phase of the project? • What benefits does it offer to the other phases of the project?

Interviews were useful to validate and compare data obtained through project documents. The interviews allowed us to validate the pertinence of the method and to examine empirically *how* and *why* these problems influence the effectiveness of collaboration, as well as innovation. But they also led to unexpected results, such as the impact of tensions on the ID process performance. The results are presented in the following subsection.

4.2.5. The results of the case studies

Fragmented nature of the construction industry

Interviewees confirmed that the norm in traditional design methods is to prepare drawings separately and assemble them just prior to the construction phase. Professionals meet only for coordination proposes. As expected, two differences are often found in the ID process: first, higher levels of labour specialisation, and second, the early involvement of all professionals. In each case, several specialists participated in the design charrettes. These specialists were hired to meet requirements in energy-consumption reduction and innovation and they joined the charrettes early on in the process (see Table 31). Interviewees confirmed that, in traditional projects, such specialists would only participate after the design definition.

Table 31. Professionals and specialists involved in project charrettes during the design phase of the case study projects.

Stakeholders involved in charrettes		**Case A**	**Case B**	**Case C**
Experts who typically participate in traditional project design	Clients, architects, civil engineers, structural engineers, electrical engineers, mechanical engineers, project managers, and landscape architects.	X	X	X
Additional experts who participate in ID processes.	Commissioning team, users, contractor, LEED® consultants and geothermal energy consultants.	X	X	X
	Users, energy efficiency specialist, Green roof, operation team, and museologists	X	X	
	Building envelope consultants, researchers, Green wall, and ergonomist	X		
	Leak detection specialist, Planetarium theatres, and scenographer		X	
	BIM manager and engineered wood consultant			X

The client in Case A wanted the building to be an international example of green construction and therefore engaged additional specialists to guarantee performance, including a building envelope specialist, an ergonomist, and a workplace assessment consultant. Moreover, the expected energy savings (60% less energy consumption than a standard building) required the project to have an energy specialist present during all charrette sessions. The client invested time and money to guarantee collaboration among all professionals, specialists, and researchers. In all, 14 ID charrettes were organised, and, on average, 19 people participated in each of them (see Table 32).

Table 32. Charrette themes and professionals' participation

* Number of charrettes (NC); Number of experts and professionals' participation (NP); Percentage of experts and professionals' participation (PP).

Charrette themes	**Case A**			**Case B**			**Case C**		
	Total of 22 professionals			Total of 12 professionals			Total of 16 professionals		
	NC	NP	PP	NC	NP	PP	NC	NP	PP
Brainstorming	5	17	77%	3	4	33%	2	2	13%
Design charrette	3	16	73%	3	4	33%	4	8	50%
Coordination	4	17	77%	4	10	83%	7	12	75%
Value engineering	1	22	100%	1	6	50%	1	10	63%
LEED®	1	17	77%	2	6	50%	1	12	75%

The main green feature in project B was an accessible green roof that covers 70% of the building. Understandingly, a green roof specialist was hired. To guarantee implementation, the specialist selected plants that grow on an extremely light soil-free substratum. This solution was proposed jointly with engineers so that the slab would not require additional reinforcement. To reduce water consumption, the engineers proposed a porous pavement and a system to store rainwater for irrigation.

The project also included a theatre for astronomy presentations. Three companies specialised in “star balls”, that combine optical and electro-mechanical technology, were hired to assure show performance. The goal was to have the most advanced equipment and technology in astronomy. The client in Case C invested in an unprecedented innovation in Canada: the use of Cross Laminated Timber (CLT) beams to cover the entire span of the soccer stadium. To meet this challenge, the architect hired a wood specialist to advise the team from the conceptual to the construction phases. The 68.5-meter free-span was ultimately achieved using 13 CLT beams.

Innovation was also required for external walls. Glazed facades were used to offer unobstructed views. But curtain wall systems often have a negative impact on heat control and energy consumption. The architect thus worked closely with various specialists in building energy simulation, curtain walls, and mechanical engineers. The final solution integrated temperature control, curtain ventilation, and digital printing in the curtain wall. Experts’ participation and collaboration in ID charrettes were crucial to integrate these innovations successfully.

There is a pattern among the three green projects. They not only involved more stakeholders (compared to standard projects) during the design phase, but professionals spent a lot of time in ID charrettes (see Table 10). Case studies show that, as innovative buildings become increasingly complex, they require higher levels of labour specialisation, potentially (and paradoxically) leading to increased design fragmentation (Barrett & Sutrisna, 2009). Yet this fragmentation was overcome by collaboration in project charrettes, which eventually fostered integration of innovative ideas. But, as anticipated, this collaboration happened neither naturally nor without difficulties. A similar pattern was also found for innovation. The next section unveils these challenges.

Risk Perception

Clients in the three cases were highly committed to innovation from the early phases of the projects. In Case A, the client explicitly announced his intention to innovate at the very outset of the process. The project brief made clear that the objective was to create an "ecological and demonstrative building to inspire the public and decision makers in real estate and construction." In Case B, the client announced a willingness to choose "an architecture and engineering innovative firm to achieve the highest level of ecological certification." Similarly, in Case C, the architectural competition program stipulated that the stadium should be "an innovative [piece of] architecture and an example of sustainable development." Furthermore, the brief clearly stressed the need for a structure with an unobstructed span over the playing field. These procedures confirm previous research findings which claim that clients minimise innovation risks when they clearly communicate projects goals to team members early in the process (Kent & Becerik-Gerber, 2010).

However, interviews and documents from the charrette sessions in Case A show contradictory information about the stakeholders' willingness to share risks. Uncertainty about professional liability issues during the charrette sessions generated conservative reactions among professionals. "The line between professionals' and client's responsibility in possible failure in projects related to innovative technologies or solutions was not very clear," said a client representative. He added: "From our point of view, we could use wood for the structure, but professionals appealed to technical arguments to convince us that concrete was the better solution in a building exceeding four stories." The client then, noted that a concrete structure could be made "eco-friendlier" by replacing 30% of the cement of concrete mix with powdered glass. This experimental innovation, however, was rejected by engineers who considered it too risky. In addition, professional codes of practice became a barrier to innovation. One respondent explained: "Getting into an unknown field is risky, and not all professionals are willing to do it." Moreover, interviews showed that professionals did not agree on the definition of innovation during charrettes. The client believed that innovation could be incremental, notably by using eco-friendlier materials or integrating solutions available on the market. Professionals believed instead in a clear departure from existing practices and argued that only new technical solutions could create more energy-efficient buildings.

In Cases B and C, the client joined the charrettes only after the architectural design competition. In both cases, professionals believed that if innovative proposals were chosen, it was because the client had accepted implementation risks. The first three charrettes in Case B were dedicated to exploring energy performance and contextual conditions. “It was the first time that we had complete information about neighbouring buildings,” the architect said. In fact, this synergy between professionals eliminated uncertainty in innovation implementation. The team decided to use the neighbouring building’s geothermal system surplus to eliminate expensive equipment to heat and cool the new building. “More synergy between stakeholders during charrettes brought alternative solutions that generated economies in building operation,” argued a professional.

In Case C, two charrettes were dedicated to reducing risks related to the CLT roof structure. Two issues were discussed. First, were the higher costs compared to a conventional steel structure and second, there were technical issues concerning the installation of a 68.5-meter long and a four-meter-deep CLT roof structure. Even though the client clearly favoured an innovative roof solution and a clear departure from existing practices, the risks that were raised compromised the viability of the project. According to a charrette participant, “the discussion during charrettes helped to find solutions for the CLT implementation and also to justify higher costs. But then, little time remained for further discussion.” Stakeholders thus abandoned other project innovations. “Due to budget and maintenance issues, professionals eliminated innovations initially proposed to the parking lot, and we obtained a more standard solution,” a professional explained.

However, the ID charrette sessions affected stakeholders’ risk perception differently in the three cases. Projects A and C did not reach the level of innovation initially anticipated. In Case A, the interviewees recognised that the charrettes could have taken them much further. The excessive amount of innovation proposed by the client generated a conservative reaction from the professionals. As many as six professionals said that the risk of failure and the fear of exceeding the client’s budget hindered innovation. In Case C, the duration and number of meetings were limited. Thus, the charrettes were restricted to the evaluation of the CLT roof structure. The other innovations were not implemented, resulting in more traditional solutions. In project B, stakeholders were satisfied with the level of innovation achieved. Although these charrettes were less organised, they promoted risk-sharing among participants, which enhanced innovation.

Stakeholders' commitment

ID advocates argue that engaging stakeholders early in the design process increases team willingness to collaborate. Case A confirms this claim. Instead of choosing only the architectural firm, the client decided to choose an entire team and adopted an innovative bidding process. Five large architectural companies were invited to form a team, including design professionals, a contractor, and other specialists. Then, shortlisted teams were invited for an interview with client representatives, which lasted half a day. In the interview, teams were required to work on a problem-solving exercise for one hour. During that time, the client observed team exchanges and assessed team members’ ability to work together and their openness to innovation.

In Case B, the set-up for team creation was different. The architect chose a landscape architect, a mechanical engineer and a civil engineer to join him in the architectural design competition. The contractor and other specialists were hired directly by the client through the lowest bid procedure. In Case C, the architect chose only a wooden roof specialist to join the architectural design competition team. The other professionals, including landscape architects, mechanical and civil engineers, other specialists, and the contractor were hired by the client through a lowest bid tender.

Differences in the way teams were assembled influenced the synergies between stakeholders. In Case A, the client was satisfied with the professionals' generous participation in the 14 charrettes. The client noted, however, that “the mere participation of professionals in all meetings does not necessarily imply that true collaboration and sharing of information happened.” One architect contends that “the meetings were too long, without a break between them in order to give us time to work on data.” The client revealed a possible reason for this problem: “Even though the level of participation was significant, the ID sessions could be better organized.” Another professional expressed a different point of view: “Integrated Design is the only way to ensure synergy among stakeholders. We integrated experts early in the process, which normally would not happen, and their collaboration in the project was very valuable.”

In Cases B and C, the client first launched an architectural competition to choose a preliminary design. The ID charrettes took place only after the winner of the competition was chosen. In Case B, the project settled on an area where other museums were already built. Thus, charrettes were used to integrate the client, the neighbouring building operations team, a specialist in planetarium theatres, and a commissioning expert. The synergy created between them during charrettes helped to enhance overall project performance. The initial design relied on expensive solutions to achieve 30% in energy savings required for the LEED® platinum certification. To reduce energy use, the charrettes focused on finding opportunities for sharing energy with neighbouring buildings. This teamwork resulted in an Integrated Energy Management system between the Planetarium and the neighbouring museum building called the “Biodome”. Geothermal specialists determined that the Biodome’s geothermal system could supply the Planetarium’s need, eliminating the needs for its own system. In another round of discussions, the team adopted a natural ventilation strategy to be used when the outside temperature is moderate. “The fact that all stakeholders were aligned helped us to find innovative solutions without compromising architectural design,” argued the architect. In this case, all interviewees highlighted the fact that the clients' participation in the decision-making process during the charrettes was fundamental to its success.

In Case C, the architectural design was also the result of a design competition. But the architect only started working with other stakeholders when they were hired, separately, by the client. Interviews showed that this was not the initial plan. According to the project manager, “this project was planned to be a true ID, where professionals would make a joint proposal, and be hired as a team to develop the project, starting from scratch.” The client tried to overcome difficulties writing an agreement, or “project charter” to ensure that all stakeholders were aligned. This document, signed by all stakeholders, guided all decisions and changes to the proposals during ID charrettes sessions. Yet, our analysis shows that despite the client’s efforts to push innovation, the charrettes were more of a tool to reduce expenses and achieve budget targets. “The synergy between stakeholders was not exactly what we thought we would achieve. Fortunately, the team members collaborated, even if they entered late in the process,” the client argued.

Efficiency in the design process

ID specialists often claim that involving team members and their respective competencies early on in the design process increases design performance. However, interviews showed that in Case A, no consensus existed on how to operationalise stakeholders’ collaboration. According to an ID report, the clients knew that they needed to have as many stakeholders collaborating as early as possible. But, as one of the client representatives argued: “we still didn’t know how to coordinate their specific contributions, how to foster innovative ideas and how to overcome the feelings of some people that they were wasting their time.” Our analysis shows that improvisation and the excess of novelty and research made professionals feel that the process was a “waste of time.” We were able to identify specific moments when the team was rather discouraged with the process. One designer argued:

> “Charrettes must be only for professionals. In the case of this project, there were a lot of people who were not professionals. All the time, we had to explain each project detail. It really took a long time. When non-experts were included in the design process, it was not a design anymore; it was a communication plan to engage the public.”

In Case B, the contractor representative was integrated into the charrette process when all the important decisions had already been made. The contractor representative missed debates over sequences of slab demolition, the construction of central elements, and their impact on neighbouring buildings. Therefore, he did not add value to the process. However, we did identify improvements in the delivery process. Charrette sessions helped to reassure the client that some architectural solutions were not too risky. According to the client representative: “A green roof in almost half of the building scared our maintenance team." The solution was to include an electric and permanent alarm system capable of identifying leaks in real time. The architect argued, however, that an ID charrette with all stakeholders before the design competition could have avoided waste in the design proposal. Another professional observed:

“We changed radically the design proposal after contacting the client and the operators of the neighbouring buildings. For example, the two central building structures changed from wood to steel. Also, to be able to use the neighbouring building geothermal system surplus, technical rooms were moved to the opposite location.”

In Case C, the design team did not include a contractor representative in the charrettes. Yet, the fact that there was a wooden structure specialist in the charrettes enabled the client to proceed with a CLT solution. “It was in the construction phase that we realised the importance of having an experienced contractor in the ID charrettes,” argued the project manager. In fact, documents show time delays, design changes, and cost increases related to this decision. The winning design team had to completely change the main access to the stadium. According to a charrette participant, “the entrance was nice, but it would not work. It was impossible to enter from the ground level [...]. The public access is always from the stadium level.” “Why didn't they ask for my opinion before?” added one expert in stadium operations. Furthermore, the presence of a geotechnical engineer during the charrettes could have helped to avoid gas leaks on the site (the ground was previously used as a dump site). The gas leaks delayed construction for more than a month. It also became necessary to review the design project by adding a waterproofing membrane to prevent additional leaks.

4.2.6. Discussion

In this paper, we examine the factors that limit ID's capacity to achieve collaboration in construction projects. This collaboration is seen as a way of improving innovation to create more sustainable buildings. We apply a multi-lens framework based on four themes to examine how and why these problems influence the effectiveness of collaboration, and innovation in three case studies. In doing so, we found that collaboration in the context of innovative projects is not static. The empirical analysis uncovered unexpected tensions, conflicts, controversies and dilemmas that emerged in the three ID processes studied. This section analyses these tensions and the actions undertaken by stakeholders. The objective is to reveal how these tensions interact with the factors previously identified.

Tension between collaboration and process efficiency (time and effort)

Our results show that innovative and sustainable projects tend to have more stakeholders involved in design, compared to the traditional process. They also confirm findings by previous studies that show that higher levels of specialisation are required (Herazo & Lizarralde, 2015). Multidisciplinary and highly specialised team collaboration is thus essential to the success of innovation in this type of project (Adams *et al.*, 2006). ID also encourages the participation of a wider variety of experts in charrettes. Findings show that the client, users, and specialised researchers who usually do not participate in traditional design practices, obtain decision-making power in ID projects. Professionals, however, sometimes oppose their interference, arguing that charrettes must be for informed specialists only. They argue that it takes too long to explain technical details to non-experts and adds no value to the project. Professionals are also less enthusiastic about co-design practices with researchers, users, or "non-experts." The rationale for this reluctance is liability. Professionals rationally avoid risking their reputation by implementing unorthodox solutions.

Our findings confirm that the collaboration needed to foster innovation generates tensions in ID. Some authors argue that it is the lack of collaboration and integration between stakeholders that hinders innovation (Poirier *et al.*, 2016). Our study uncovers that, in fact, poorly-prepared meetings and ineffective discussions lead stakeholders to lose interest in innovation. Professionals do not always see the benefit of collaboration if the price is too high in terms of time, resources or reputation. In fact, time and resources invested are not always seen to generate value for all stakeholders. A tension thus exists between the imperative to collaborate and process efficiency. A balance must be sought between the need to involve stakeholders, and monetary and non-monetary costs.

Tension between short-term and long-term benefits

The case studies exposed three relationships between the professionals' efforts to innovate and the reward for their accomplishment. First, traditional construction management focuses on cost, schedule, and quality. Our findings show that – similarly to patterns found in previous research – sustainable project management emphasises low energy consumption, users' health, waste and pollution reduction, and environmental protection (Bonham, 2013). Second, the construction industry depends on short-term business cycles and a project-based culture. In contrast, sustainable project designers are interested in the whole life-cycle of the building, including the operations phase (Newton *et al.*, 2009). Third, innovation helps to reduce energy consumption and a healthier environment, which is measured in long-term benefits.

Innovation is risky for professionals, who are concerned about their professional liability. In fact, the contractual arrangements used in the construction industry primarily punish professionals in the case of error. Consequently, professionals have incentives to adopt traditional technologies. Establishing a reward system for innovation can remove this barrier (Ashcraft Jr, 2014; Toole *et al.*, 2013). Better contracts can integrate long-term project performance requirements. The American Institute of Architects in California (AIAC) is, in this sense, a source of inspiration. In 2007, it created a series of documents on special procurement methods. These contracts regulate the profits shared among stakeholders based on project performance (achieved or exceeded). ID practices need to find new ways to favour effective stakeholder commitment to achieve benefits in the entire project life cycle.

Tension between ID and traditional practices

Design professionals in traditional practices usually “insulate themselves from, or try to control the interactions with, builders and aspects of construction; users and their concerns; and the many other project stakeholders that may pose a challenge to their authority or interfere with the conceptualisation process” (Klopp, 2012). Our findings show that ID proposes a radical departure from these practices. Bringing together interdisciplinary experts and key stakeholders through intensive charrettes at the same time and in the same place is a form of challenging professionals and favouring collaboration. This change of paradigm does not take place naturally or without criticism. Findings show that some professionals see ID as an extreme alternative. Too many design options from multiple stakeholders sometimes make them feel disoriented.

Adams *et al.* (2006) emphasise that communication and collaboration are key factors for project success. Our findings corroborate this, but recognise that ID needs significant process improvements. Magent (2005) argues, however, that few tools exist to help ID project teams. A tension between ID process and traditional practices hinders collaboration. In return this tension also hinders innovation. It is thus important to identify value generated by stakeholders through collaboration. Professionals need to be heard in order to improve ID. Charrette methodologies need to be revised in order to increase their capacity to share and develop knowledge rather to exchange, aggregate, and storage information. Table 339 summarises the tensions and areas where new knowledge is needed to avoid conflicts during ID.

Table 33. Tensions and areas where new knowledge is needed to avoid conflicts during ID.

Tensions	Analyses	Stakeholders' actions to improve ID performance
Tension between collaboration and process efficiency (time and effort)	• More stakeholders involved in the design process compared to the traditional design process • Presence of a wider variety of experts and highly specialised professionals in the project team • ID promotes a shared decision-making power between the client, professionals, users, and experts • Presence of non-experts in design charrettes	• Professionals are worried about co-design practices (liability, avoid risking their reputation) • Professionals are sometimes opposed to non-experts' interference, arguing that charrettes must be for professionals only, arguing that it takes too much time to explain technical details to them. • Poorly prepared charrettes meetings and ineffective discussions lead stakeholders to lose interest in innovation. • Professionals do not benefit from time and resources invested in ID charrettes
Tension between short-term and long-term benefits	• The ID process is not only concerned with cost, schedule and quality, but also with increasing performance in the building operation phase. • The construction industry depends on short-term business cycles and ID focuses on the entire life-cycle of the building • The construction industry still applies traditional contracts with no project performance requirements. • Fragmentation still exists in ID process projects between project, construction, and operation phase	• Innovations that help reduce energy consumption are riskier for professionals. • A new standard of contracts should regulate profit-sharing among stakeholders based on the entire life project performance (achieved or exceeded). • Current contractual arrangements only punish professionals in case of error. • ID charrettes occur only in the design phase. The charrettes are not scheduled for the construction nor the operation phases.
Tension between ID and traditional practices	• Architect leadership is replaced by a facilitator. Design professionals share the control with other stakeholders, including non-experts (client and users). • Involves an interdisciplinary team from all project phases (including construction and operation) in the design process. • Initial charrettes are dedicated to research and brainstorming before beginning the design process.	• Too many design options from multiple stakeholders make design team feel disoriented. • Professionals cannot recognise the value generated in the ID process. • Few new tools are implemented to help ID project teams to take decisions. • Charrettes need to be well-prepared to be able to share and develop knowledge, rather than to exchange, aggregate, and store information.

4.2.7. Theoretical and practical implications

This study has three main theoretical implications. First is the development of a multi-lens framework capable of providing a more in-depth analysis of current ID practices. Based on the model proposed by Van de Ven (1986), we uncovered four main themes-related factors that challenge current ID process performance. Second, the study validated the relevance of, and examined how and why, these factors influence the effectiveness of innovation using three case studies. Finally, the multi-lens framework proved to be useful for uncovering inherent tensions, conflicts, controversies, and dilemmas within collaborative and innovative design projects. It also illustrates how those factors interact with the tensions and highlights areas where new knowledge is needed to avoid conflicts during ID.

There are also practical implications of these results. First, the study shows three examples of the ways in which stakeholders in the construction industry use ID. Notably, it highlights the gaps that exist between the theoretical intentions behind ID and its actual benefits, results, and efficiency. Second, in exploring current challenges and tensions, the study shows how practitioners can intervene in ID implementation to improve project performance. Likewise, by providing an in-depth representation of both collaboration and innovation in practice, the study stresses the importance of reviewing ID practices to enhance a sustainable project life-cycle.

However, this study also has several limitations. First, the research focused on projects that aimed at obtaining a LEED® certification (gold and platinum). Other types of green buildings certifications must also be analysed (e.g., Living Building Challenge, WELL, BREEAM). Second, the case studies were concentrated in a particular geographical (Montreal) and institutional (funded by government or an NGO) context. Future research should evaluate the conclusions drawn here in the context of more representative cases (e.g., private real-estate projects) and locations. Finally, although this research highlighted the abilities of ID to enhance sustainable building projects, further research is still needed to empirically measure how ID processes (as compared with traditional processes) affect the environment.

4.2.8. Conclusion

ID is a participatory method that aims at enhancing collaboration an—by doing it—at producing innovative solutions. It is increasingly adopted in sustainable buildings, and is, at least theoretically, a powerful tool to change the construction industry's somewhat conservative approach. But ID is not without flaws. This study uncovered novel findings concerning ID's limitations through a multi-lens framework based on four themes: 1) the fragmented nature of construction; 2) risk perception; 3) stakeholders' commitment; and 4) efficiency in the design process. These categories of analyses served as lenses to reveal and understand the inherent tensions that typically arise in ID, namely:

- Tensions between collaboration and process efficiency (time and effort), where the balance between the needs for involving stakeholders and costs measured in time, risk, effort, and money is difficult to obtain.

- Tensions between short-term and long-term objectives and results that prompt reflection on how to facilitate effective stakeholder commitment to long-term benefits during the whole project life cycle, particularly in an industry characterised by a short-term, project-based way of working.

- Tensions between new and traditional practices, recognizing the benefits of ID, but also the urgency for improvements in its implementation. We found that ID needs to favour the sharing and development of knowledge, rather than just the exchange, aggregation, and storage of information.

The four lenses and the three tensions identified in this paper shed light on the limits of ID. The conceptual framework proved effective in helping us identify and better understand the tensions that arise in ID and that limit its capacity to achieve collaboration. It also allowed us to understand the factors that affect innovation goals in sustainable building projects. The findings can help improve ID processes and protocols to better achieve sustainability objectives. From a theoretical point of view, the results validate the relevance and value of ID, but also shed light on its limits, and help to identify the conditions that allow for the creation of value for all stakeholders. From a practical point of view, the results highlight ways stakeholders in the construction industry can improve interactions among themselves in order to design buildings that are better for both society and the environment.

4.3. Challenges in evaluating strategies for reducing a building's environmental impact through Integrated Design (Publication 2)

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4.3.1. Abstract

To reduce a building's impact on the environment, governments and certification boards encourage the use of innovative and collaborative design processes such as Integrated Design (ID). ID proposes upfront, stakeholder-engagement and collective decision-making to improve life-cycle building performance. Although ID's potential is theoretically well-founded, there is little empirical evidence of its effectiveness. This study seeks to validate the extent to which ID effectively improves project performance in terms of its reduction of environmental impacts. Three Canadian building projects, certified LEED and integrating various environmental strategies, are examined. The research team first identified and evaluated strategies aimed at reducing the buildings' impacts. Then, it analysed the decision-making process and measured impact reductions comparing reference buildings, schematic designs and construction documents - using Life Cycle Assessment (LCA) tools and Building Energy Simulations (BES). Results show a 60% reduction in global warming potential (GWP) and 62% in energy consumption in the case studies. They also underline five challenges for ID practices: tool complexity and accuracy, missing information, reducing embodied energy in high-performance buildings, poor environmental design decisions, and decision-making based on green certification credits. Opportunities to overcome these challenges include deepening professionals' knowledge of Life Cycle Assessments and developing more effective energy simulation tools. The findings can help improve ID processes and protocols to reduce a building's impact on the environment.

Keywords: environmental impact; integrated design; life cycle assessment; building energy simulation; sustainable construction.

4.3.2. Introduction

The construction industry produces significant damage to the environment. In Canada, construction is responsible for 40% of energy consumption, and 17% of greenhouse gas (GHG) emissions (Government of Canada, 2016). Public pressure to address climate change and environmental degradation, however, is forcing major shifts in the building sector (Bak, 2017; Kibert, 2007). Radical improvements in building design are required to help reverse these impacts. Whereas traditional construction focuses on cost, schedule, and quality, sustainable projects must also consider environmental protection, users' health, low-carbon emissions, and low-energy consumption (Bonham, 2013).

To foster this shift, governments and certification boards in Europe and North America encourage the use of innovative and collaborative design processes, such as Integrated Design (ID) (Cohen, 2010; Natural Resources Canada, 2015). ID entails a holistic approach where building performance is optimized through an iterative process that implicates all members of the design team from the early stages of the design process. ID engenders a closer interaction between designers, contractors, suppliers, and users (Rekola *et al.*, 2012). Environmental performance assessment tools are usually applied to aid in the decision-making process during ID collaborative sessions called "charrettes".

Within this context, it is often expected that ID will help to significantly decrease GHG emissions by reducing embodied emissions (materials) and operation emissions (building energy consumption). Previous research, however, has found that ID – when used to obtain building certifications – does not necessarily result in environmental impact reductions (Anand & Amor, 2017; Zabalza Bribián *et al.*, 2009). In fact, buildings designed through ID may not necessarily perform as expected (Hellmund *et al.*, 2008; Kovacic & Müller, 2014). In addition, their predicted performance and consumption data are rarely available to the public (Turner & Frankel, 2008). Access to this information would help construction industry leaders to understand the flaws in ID. The previous statement raises the following question: To what extent does ID reduce a building's environmental impacts? How are decisions made in ID projects to achieve these reductions? How effective is ID in achieving impact reductions and what are the factors involved? These questions guided the study reported in this paper.

This article is organized into seven sections including this introduction. Section 2 summarises the most important published contributions in ID and building performance, and Section 3 describes how we analysed the case studies. Sections 4 and 5, present and discuss the case studies – highlighting the challenges and opportunities that professionals face during ID charrettes to reduce a building's environmental impact. Section 6 presents the theoretical and practical implications and provides recommendations for future research and Section 7 summarizes the answers to the project's questions.

Integrated design in sustainable building projects

In order to understand how ID reduces GHG and energy use in sustainable building projects, we first conducted an extensive review of previous studies on sustainability, collaborative, and innovative project-delivery approaches in the building sector. We analysed 64 articles on ID, 115 articles on building assessment methods and tools, 42 articles on collaboration and 105 articles on innovation. The results helped us to understand how ID operates and how GHG and energy-use reduction strategies are applied.

The Integrated Design Process, or IDP, was developed by Natural Resources Canada (NRCan) in the C-2000 program that ran from 1994 to 2003. The core principle of IDP is to bring together interdisciplinary experts and key stakeholders in intensive charrettes (Forgues & Lejeune, 2011). Team members are expected to share and develop new knowledge that leads to improved building performance (Ghassemi & Becerik-Gerber, 2011). ID proponents argue that all issues that impact sustainable building performance need to be discussed, understood and confronted from the beginning of the design process (Cole & Larsson, 1999).

Governments and green building certifications consider ID a promising method to help the project team to avoid low-performing designs (Herazo & Lizarralde, 2015). ID encourages stakeholders to consider all design options and to evaluate the life-cycle impact of the project. In ID, performance evaluation tools are often used to measure and monitor design outputs (Ofori-Boadu *et al.*, 2012). Recent research shows a tendency to use quantitative assessment methods (Lützkendorf, 2018).

The standard quantitative tools used during charrettes are Building Energy Simulations (BES) and Life Cycle Assessments (LCA) (Malmqvist *et al.*, 2018; Rivard, 2006). BES is software-based tool used to model the impact of design options on annual energy consumption. LCA evaluates the potential environmental impact of design options over their entire life cycle: resource extraction, production, transport on site, building operation and building deconstruction (Singleton, 2012). The goal of using these tools is to ensure that the architectural elements and the engineering systems work together to reduce impacts on the environment (Ürge-Vorsatz *et al.*, 2007).

Building Energy Simulation (BES)

A BES predicts a building's energy performance (Coakley *et al.*, 2014). BESs have become popular since they became mandatory for energy-rating systems and third-party environmental performance assessment systems such as the USGBC LEED certification (USGB-Council, 2014). When used in the design phase, the tool can play a significant role in optimising performance by allowing users to undertake detailed calculations of the operating energy required to achieve a given performance (Kibert, 2013).

BESs, however, do not measure the energy indirectly needed to acquire, process, manufacture and transport products used to construct buildings (the "embodied energy"), or the embodied impact (e.g. GHG emissions). In conventional buildings, the operation energy typically accounts for 70 to 90% of total life-cycle energy, while the embodied energy accounts for 10 to 30% of that total (Ramesh *et al.*, 2010). This reality changes as the industry increasingly moves towards low-energy buildings (Cubi & Bergerson, 2014). The share of embodied energy tends to increase and reaches nearly 60% in net-zero energy buildings (Chastas *et al.*, 2017). Hence the growing importance of a life cycle assessment (LCA).

Life Cycle Assessment (LCA)

LCA is a method that seeks to determine the potential environmental impacts of a product or service over its entire life cycle. In the construction sector, LCA predicts how a building will perform over its lifetime, a process that includes raw material extraction, manufacturing, construction, operation, maintenance, repair, replacement, and demolition (Berggren *et al.*, 2013). In building case-studies, the common lifespan adopted in an LCA is 50 years. Since 2009, several green building programs – LEED, BREEAM, Living Building Challenge, Green Globes, CASBEE – have incorporated LCA into their evaluation systems. The preferred framework for LCA studies – ISO 14040 – prescribes four phases (Fig. 21) for the process:

1. Define the goal and scope of the LCA by selecting the life-cycle steps, building parts, and flows needed to the pursued goal of the study. The goal is to capture the environmental impacts of a reference building based on predicted operational energy and to compare it with the environmental impacts of new building alternatives.
2. Create an inventory of data (inputs and outputs) for the materials including the quantity of the primary building-materials, the energy consumed in the construction phase, the energy and water consumed during the building operation, and the end-of-life pathways for the materials after deconstruction or demolition.
3. Carry out an environmental impact assessment by translating inventory data into environmentally-sensitive outcomes.
4. Interpretation of the results. Verify consistency and completeness and validate the solution by determining whether it aligns with the goals of the study.

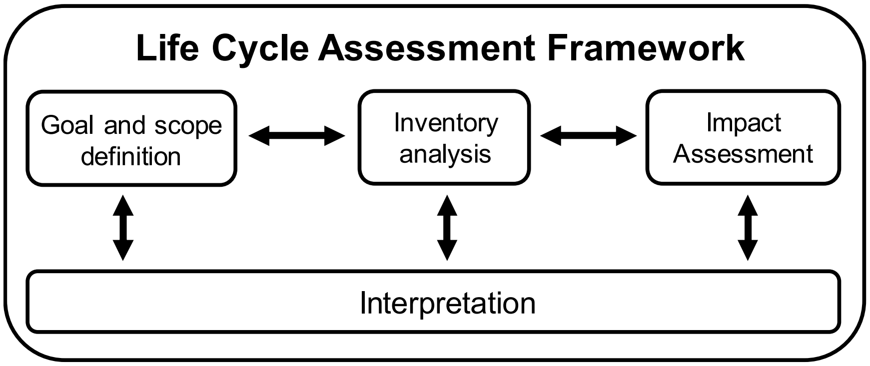


Figure 21. ISO 14040 framework for life cycle assessment (ISO, 2006)

LCA is an effective tool to guide professionals during ID. Architects and building designers can compare design alternatives and facility managers can anticipate the influence of users' behaviour and implement appropriate measures during the operation phase. Building owners and users can assess the performance of their assets (Hollberg & Ruth, 2016).

This being said, the construction industry lags behind others sectors in the adoption of LCA (Hollberg & Ruth, 2016). Previous studies (Lee *et al.*, 2009; Saunders *et al.*, 2013; Zabalza Bribián *et al.*, 2009) have revealed the potential barriers to the adoption of LCA tools. These include: poor knowledge about environmental impacts, the perception that LCA is overly-complex, lack of interest and demand from owners, lack of adequate LCA tools to optimise building design, and lack of knowledge about how to calculate potential environmental impacts. It is commonly argued that to overcome these barriers, user-friendly LCA tools, that professionals can use without having complex measurement skills, are necessary. It should be noted that several LCA-based assessment software tools are already available – although they are not widely used (Haapio & Viitaniemi, 2008). Four LCA tools are avaiable in Canada, and the U.S. that use domestic data resources: Athena Impact Estimator for Buildings (IE4B), ATHENA EcoCalculator, BEES, and EIO-LCA.

LCA tools to measure building life cycle impact

The Athena Impact Estimator for Buildings (IE4B) is a simplified and user-friendly tool, developed for architects and building designers to assess the life-cycle impact of new or existing buildings. It has a comprehensive dataset, allowing for easy comparison between many building alternatives (Reza *et al.*, 2014). The IE4B provides background data representative of both the Canadian and American contexts that are in accordance with ISO 14040 standards (ISO, 2006). Athena's datasets take into account: (a) material manufacturing (resource extraction and recycled content), (b) material transportation, (c) on-site construction, (d) energy consumption, (e) maintenance and replacement, and (f) demolition and disposal (Lucuik, 2014). The IE4B presents the environmental impacts with the help of the TRACI impact assessment method and displays two resource-use categories – Total Primary Energy Consumption and Fossil Fuel Consumption. The following section explains how the research team investigated the ID process and how we used these tools.

4.3.3. Research methodology

Our research seeks to understand how ID improves project performance. More specifically, it seeks to identify strategies developed to reduce a building's impact on the environment (henceforth called "mitigation strategies"), to analyse the decision-making process, and to measure effective GHG and energy-use reductions. In order to meet these objectives, we adopted an exploratory case-study approach. This strategy is employed to inductively generate, rather than deductively confirm, insights regarding the phenomenon to be studied (Ogawa & Malen, 1991). A case-study approach is a reliable means for capturing rich information in complex situations such as construction projects (Barrett & Sutrisna, 2009; Yin, 2003).

An important step in the development of a case study is defining the case or unit of analysis (Knight & Ruddock, 2008). The research team selected three Canadian projects: (1) in which project stakeholders were committed to a search for reductions in potential impacts on the environment during the project's entire life cycle, (2) that adopted ID; (3) that obtained a green building certification (LEED®), and (4) that offered sufficient access to data, reports, and stakeholders. Table 34 summarises the main characteristics of the three construction projects that were ultimately selected.

Table 34. Main characteristics of three case studies.

Characteristic	Case study A	Case study B	Case study C
Type of client	Non-governmental organization (NGO)	Government (cultural)	Government (sport)
Main use	Offices	Museum and entertainment	Soccer stadium
Floor numbers	5 storeys	3 storeys	2 storeys
Functional programme	Offices, meeting rooms, amphitheatre, and a cafeteria	Theatres, exhibition rooms, administrative offices, auditorium, and a boutique.	Two full-size soccer fields, administrative offices, training rooms, a cafeteria, and retail space.
Built area	6,500 m² on five levels	8,000 m² on three levels	12,600 m² on two levels
LEED version	LEED Canada NC 1.0	LEED Canada NC 1.0	LEED Canada NV 2009
LEED points obtainable / possible	59/70 points	55/70 points	64/110 points
Certification	LEED Platinum	LEED Platinum	LEED Gold
Obtained, year	2013	2015	2017
Main green strategies	Geothermal heating and cooling system, bio-wall, thermal envelope, displacement ventilation, and green roof	Collection and reuse of rainwater, thermal envelope, natural ventilation	Geothermal energy, roof made by local and prefabricated cross-laminated timber (CLT)

While numerous documents were made available, only 150 architectural plans and a little more than 100 documents proved pertinent and were analysed for the study of the three cases (Table 35). The use of multiple sources of documentation in case study research enhances credibility (Patton, 2015). Consequently, following Yin (2003), we examined and assessed documents in terms of their purpose, coverage, and quality. In each of the documents, we identified mitigations strategies and analysed elements that indicate intentions and actions related to decision-making processes during ID charrettes. We eventually built a qualitative explanation for each project. Case A had a large amount of information about the project which enabled a more in-depth analysis. The limited amount of information available in cases B and C compelled the authors to seek missing information from the professionals involved in the projects through interviews and/or by requesting additional information by e-mail.

In the next step, the team compared the results from each case. First, the researchers created a reference building (RB) for each case study. RBs are baseline projects used as benchmarks. They are the same size as the case study projects and they comply with the Canadian national code for new buildings (NECB-97) but have standard construction solutions. RBs do not integrate improvements discovered during ID charrettes.

Table 35. Numbers of documents analysed in each case study.

Document	Case A	Case B	Case C
Client/owner Functional and Technical Program (FTP)	3	1	1
Public consultation process report		2	3
ID project meeting proceedings	13	2	7
LEED Green building certification reports	3	3	5
Newspapers and magazine articles	12	8	15
Energy simulation reports	3	1	1
Lifecycle products analyses	3		2
Initial plans (architectural competition and or from first ID charrettes	1	2	2
Final architectural plans	107	20	23
Emails and interviews with design professionals	3	5	6

Then, we compared the RB to two scenarios: Schematic Design (SD) and Construction documents (CD). The SD builds on the vision developed in Pre-design phase, just after the brainstorming ID charrettes. In this scenario, the professionals think “outside the box” to explore innovative technologies and new ideas to attain the clients’ goals and objectives for the project. The second scenario, the CD, is the final design prepared for construction after all the ID charrettes. The CDs include all the innovations implemented in the project to reduce energy consumption and GHG emissions.

After, we applied the selected tools (LCA and energy simulation) to each scenario – RB, SD and CD. The energy simulation results came from the analyses of reports produced by the original engineers in each project. The LCA were produced by the authors using Athena IE4B for the three cases for two reasons. First, all three cases provided little information regarding LCA analyses (as showed in Table 36). Second, we sought to determine whether or not the necessary information was present in all LCA studies, in order to validate the comparative analysis between the cases (Table 32). The IE4B reports the potential environmental impacts of the building using the TRACI impact assessment method. However, the absence and / or inconsistency of the Athena IE4B data for the ozone depletion impacts forced us to omit this category in the results. The quantitative results from LCA and BES helped to put the qualitative information obtained from documents in perspective. The mixed method strategy produces deeper insights and improves validity and reliability of research outcomes, a positive effect previously found by Zou *et al.* (2014).

Table 36. Description and differences between the Reference and Conceptual design buildings.

	Reference Building (RB)	Schematic Design (SD)	Construction Documentation (CD)
Brief Description	A baseline building that respects the Canadian national code for new buildings.	Schematic Design builds upon the vision developed in Pre-design (Case A) or for the architecture competition (Case B and C)	Project integrates various strategies to diminish potential environmental impacts of the building on the environment
Goal	Evaluates and identifies which strategies reduce the potential environmental impacts on LEED-certified building.		
Scope	Includes the impact categories defined by the latest TRACI methodology: global warming potential, acidification potential, human health respiratory effects potential, ozone depletion potential, smog potential, and eutrophication potential. It includes fossil fuel consumption reports.		
Functional Unit	A 50-year building lifespan and total construction area in square meters including all floors (excluding external areas)		
Annual Energy Use	Based on ASHRAE Code for electricity (kWh) and natural gas (m3) consumption.	Building energy simulation files for LEED for electricity (kWh) and natural gas (m3) consumption.	
System Boundary	The user is not required to define the system boundary for the LCA as this information is embedded in the ATHENA tool.		
Tools Used	ATHENA® Impact Estimator for Buildings v5.2.0119, EE4v1.7-2 and eQuest v3.64 for energy calculation, and MS-Excel for tabulating the quantities.		

The team then combined the qualitative and quantitative results to produce a single narrative for each case. It compared the patterns found with patterns previously identified in the literature. Yin (2003) defined this strategy as “explanation building”, wherein the researcher “makes causal links based on existing theory or sound iterative analysis of data”. Yin (2003) notes that this approach is akin to external validity in the framework of multiple case studies. In this sense, the findings are the result of an interactive analysis between the conceptual framework and the cases studied. This strategy allowed us to produce what Yin calls “analytical generalisations,” that is, results that can help predict behaviours and events in similar cases. The next section presents the characteristics and results of each case.

4.3.4. Case study results

The research team first examined project documentation to identify mitigation strategies for each case study. Tables 37, 38 and 39 summarise the innovative strategies adopted and their benefits for each case study. The case studies A, B and C, their description and the intentions and actions related to decision-making processes are presented in the following subsection.

Table 37. Strategies used and benefits in case A.

	E	M		Reference Building	Schematic Design	Construction Documentation	Final benefits
Energy efficiency (EE)	X	X	Elevators	3 conventional elevators	3 Gearless/ room-less elevators	2 Gearless / room-less elevators	Less and eco-elevators reduced 30% energy use.
	X	X	Ventilation system	Air distributed in metal ducting	Raised Floor Plenum ventilation system		15% energy savings / increase user comfort and easy when renovating
	X		Energy recovery unit	Energy recovery from air exhaust	Energy recovery from air exhaust	HI-efficient energy recovery	80% effectiveness in the summer and 90% in the winter.
	X		Energy source	Electricity and gas only	Geothermal System + electricity back-up source	Geothermal System + gas back-up source	42,500 kWh and 6,435 m^3 / year savings
	X		Lighting System	Standard light system	Automated tools and LED lights	Efficient lighting devices	47,055 kWh / year savings
Improved isolation (II)	X	X	800 m^2 Roof	elastomer-base waterproofing membrane only	Intensive Green Roof (12 inches)	Ultra-extensive Green Roof (3 inches)	Reduced heat island effect and reduce energy consumption
	X	X	Building Envelope	R18 – Code performance	R30 –High-performance		14.458 kWh / year savings. Superior thermal resistance.
	X	X	Windows	Doubled glazed with argon gas	Triple glazed with argon gas		
Ecological materials (EM)		X	Structural choice	Standard Concrete	CLT Wood structure	Replace 10% to 20% of cement with fly ash.	Reduced 174 t of cement use, reducing greenhouse gas (GHG) emissions.
		X	Reduced material use	Concrete columns covered	Concrete columns not covered		Eliminated 1.200m2 of gypsum and 4.6 km of drywall studs
		X		Acoustic ceiling tiles	No acoustic ceiling tiles - exposed concrete ceiling		
		X	Kitchenette countertops	Melamine countertops		93% recycled glass.	Uses recovered materials. Avoids the manufacture of new parts (reusing old parts).
		X	Wall covering	Gypsum	Glass and gypsum	Reclaimed wood from rivers	
Water efficiency (WE)			Water supply	Treated water for toilets	Building's toilets use rainwater		947 litres / day savings (35% drinking water and wastewater requiring treatment reduction).
			Women and men toilets	Urinals with water	Waterless urinals		1.208 litres / day savings (100%)
				Standard toilets	Dual-flush toilets use 3.4 litres and 4.8 flush.		938 litres / day savings (21% reduction)
				Standard faucets	Faucets with infrared sensors		400 litres / day savings (28% reduction)

E = Energy consumption M = Material Use

Table 38. Strategies used and benefits in case B.

	E	M		Reference Building	Schematic Design	Construction Documentation	Final benefits
Energy efficiency (EE)	X	X	Ventilation system	Air distributed in metal ducting	Hydronic heating manifolds, natural ventilation, and raised floor	natural ventilation, and raised floor plenum ventilation system	15.857 kWh in energy consumption reduction (30% energy reductions and increases user comfort)
	X		Energy recovery unit	Energy recovery from air exhaust	Energy recovery from air exhaust	HI-efficient energy recovery	90% effectiveness to recuperate energy from the exhaust system, reducing energy use (683 kWh)
	X		Energy source	Electricity only	Electricity and Geothermal System	Electricity and neighbouring building Geothermal System	511,265 kWh / year savings
	X		Lighting System	Standard light system	High-performance lighting devices (T5 and LED) and natural light in common areas		170.810 kWh reductions (49% savings)
Improved isolation (II)	X	X	569 m^2 Roof	elastomer-base waterproofing membrane only	Accessible extensive green roof with rustic drought-resistant plants (6 inches)	Non-accessible ultra-extensive Green Roof (3 inches)	Reduced heat island effect and 18.419 kWh in energy consumption
	X	X	Building Envelope	RSI 3 – Code performance	RSI 4.5 – High-performance		46% energy savings
	X	X	Windows	RSI 0.35 – Code performance	Triple glazed + argon RSI 0.66	Double glazed + argon RSI 0.48	
Ecological materials (EM)		X	Structural choice	Concrete for the columns and mezzanine, and steel for the roof	CLT Wood structure	Steel for the mezzanine, columns and roof	55% GWP reduction compared to concrete structure
			Structural reuse	New columns and slabs	Reuse of 75% of existing structures		6,100 m2 of existing structures were recovered
		X	Recycled content	New material	Recuperated aluminium in facade composite panels		250m² of aluminium foam panel and 70% recycled material in exterior walls
		X		Standard product	Fiberglass insulation = 70% recycled materials		
		X	Recycling	No recycling material from demolition	Recycle and reuse the concrete that was broken		Recycled 2,630 ton (1,143 m3)
			Wood provenance	Standard product	95% of the wood comes from FSC-certified forests.		For all plywood and wood used in the project
			Material provenance	Standard product	80% of local materials sourced locally		
Water efficiency (WE)			Water supply	Treated water for toilets	Recuperate rainwater from paving for toilets	Treated water for toilets	Could reduce municipal sewage dump by 60% (not achieved)
				Treated water for irrigation	Drip green roof irrigation system		Reduced potable water consumption by 50 per cent
			Low Flow Plumbing	Standard toilets	Toilets use 4.8 L/use, Urinals use 0,5 L/use and sink use 3.8 L/m		Saves 19% drinking water and wastewater requiring treatment

E = Energy consumption M = Material Use

Table 39. Strategies used and benefits in case C.

	E	M		Reference Building	Schematic Design	Construction Documentation	Final benefits
Energy efficiency (EE)	X	X	Ventilation system	Air distributed in metal ducting	Radiant floor and Dehumidification (air) system	Dehumidification (air) system	56,389 kWh / year (45% reduction in air conditioning needs)
	X		Energy recovery unit	Energy recovery from air exhaust	Efficient energy recovery from air exhaust		65% effectiveness to recuperate energy from the exhaust system, reducing energy use (683 kWh)
	X		Energy source	Electricity only	Electricity and Geothermal System		170,908 m³ reductions (70% HVAC reduction)
	X		Lighting system	Standard light system	Automated intensity control and efficient lighting devices (T5 and LED)		44,722 kWh / year (60% lighting system savings)
					Natural light - 80% fenestration		
Improved isolation (II)	X	X	9 000 m^2 Roof	Elastomer-base black membrane (RSI 3.00)	White membrane - reflects up to 90% of sunlight – with increased isolation (RSI 3.70)		reduction in air conditioning needs (reduced energy consumption)
	X	X	80% fenestration	Code performance (RSI 0.35)	Double glazed + argon (RSI 0.71)	Doubled ceramic fritted glass with argon gas (RSI 0.65)	
Ecological materials (EM)		X	Structural choice	Steel columns and beams	CLT Wood structure	Improved CLT Wood structure	69% GWP reduction compared to steel structure
		X	Reduced material use	Steel columns covered	Steel columns not covered		Eliminated 890m2 of gypsum and 3.4 km of drywall studs
		X		Ceiling tiles in all area	No ceiling tiles	Ceiling tiles only in locker rooms	
			Material provenance	Standard product	41% of local materials sourced locally		Transport impact reductions
Water efficiency (WE)			Water management	Not planned	Rainwater reuse from the water retention system installed in the roof		Saves 33% drinking water and wastewater requiring treatment.
			Water supply	Treated water for toilets	Building's toilets use rainwater		
			Plumbing	Standard toilets	Toilets use 4.8 L/use, Urinals use 0,5 L/use and sink use 2 L/m and shower 5.7 L/m		

E = Energy consumption M = Material Use

Case study A: The Centre for Sustainable Development

This project aspired to be the most efficient building in Quebec with regards to energy consumption. Equiterre, a Canadian non-governmental organisation (NGO), pursued the project between 2004 and 2011. It is a demonstration green building that seeks to be a social and environmental innovation hub. Its design is the result of 14 charrettes and more than 68 hours of intensive Integrated Design (ID) sessions. Most of the meetings were dedicated to brainstorming (5 in total) and coordination (4 in total). The design integrated innovative methods for the construction and operation of the building.

Integrated Design in case A

The client, an environmental group, participated actively in all of the ID charrettes. From the first charrette, the client representatives made it clear to the professionals that their objective was to deliver an exemplary building in terms of energy consumption and environmental impacts. To achieve this end, the stakeholders discussed and produced innovations during the five first IDP charrettes (brainstorming). Initially, the stakeholders chose SBTools (developed by iiSBE) as guidelines for charrettes and project development. The methodology included modelling a reference building that complied with existing regulations. In the next phase, the team was invited to challenge and exceed the reference building in terms of energy savings and life cycle benefits. Given the cost constraints and the stakeholders' limited knowledge of this tool, the project team ultimately abandoned the SBTools and following the brainstorm ID charrettes, the project turned exclusively to the LEED certification tool.

Building Energy Simulation in case A

Mechanical engineers collaborated during ID charrettes to develop a strategy to build the most efficient building in Quebec. To achieve the highest level of LEED certification (platinum), the team set as a target the accumulation of all points related to energy savings. First, they generated a base model following the ASHRAE rules. Next, some of the energy-saving strategies were inserted into the modelling software EE4. Some limits of EE4 were encountered, such as the impossibility of modelling all energy gains. In order to estimate these benefits, the engineering team made parallel calculations and added them to the final results. Strategies that required parallel calculations included: the geothermal system, the green wall, the high-performance exhaust system, displacement ventilation, and the heat recovery unit. The BES show that the Construction documentation (CD) is, theoretically, 65% more energy efficient than the Reference building (RB) – which uses 36% less electricity and 96% less natural gas consumption than RB. However, the team couldn't achieve the SD target of eliminating gas use in the building. The consumption values are showed in next Table 40.

Table 40. Characteristics of RB, SD and CD in case A.

	Reference Building (RB)	**Schematic Design (SD)**	**Construction Documentation (CD)**
Electricity	1,121,968 kWh/year	718,923 kWh / year	721,954 kWh / year
Gas	113,645 m³ / year	Eliminated	4,206 m³ / year
Calculation based on	ASHRAE 62.1 + plug load	EE4 v1.7-2 + plug load	EE4 v1.7-2 + plug load

Life Cycle Assessment in case A

This project focused on obtaining LEED V1.0 certification, without consideration of LCA. The project team focused on integrating local and recycled materials. Even though LCA was not required for LEED V1.0 certification, it was applied during critical moment in the project, for example, during the charrettes dedicated to evaluating the structural approach. The ID team was not sure which of the wood, concrete, or steel systems would have the lowest impact on the environment. Wood, with its usually lower carbon footprint, was the retained as the option for SD. At that time, however, the local construction code banned the use of wood in buildings with more than five floors. Obtaining derogations would have been difficult and taken time. Given the time constraints, the team opted for a concrete structure. The structural engineer eventually proposed replacing 30 per cent of the cement with fly ash, a waste product from the incineration industry that produces lower carbon emissions than cement. Fig. 22 presents results comparing the impacts scores of the three design options.

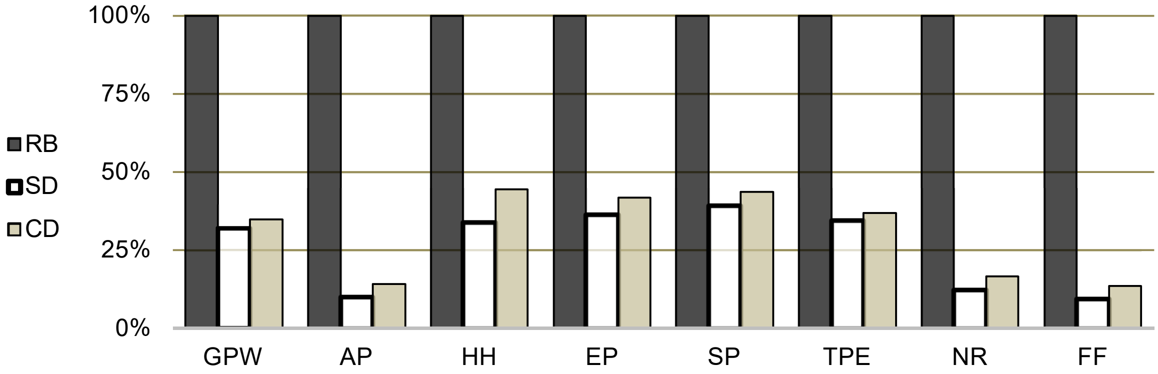
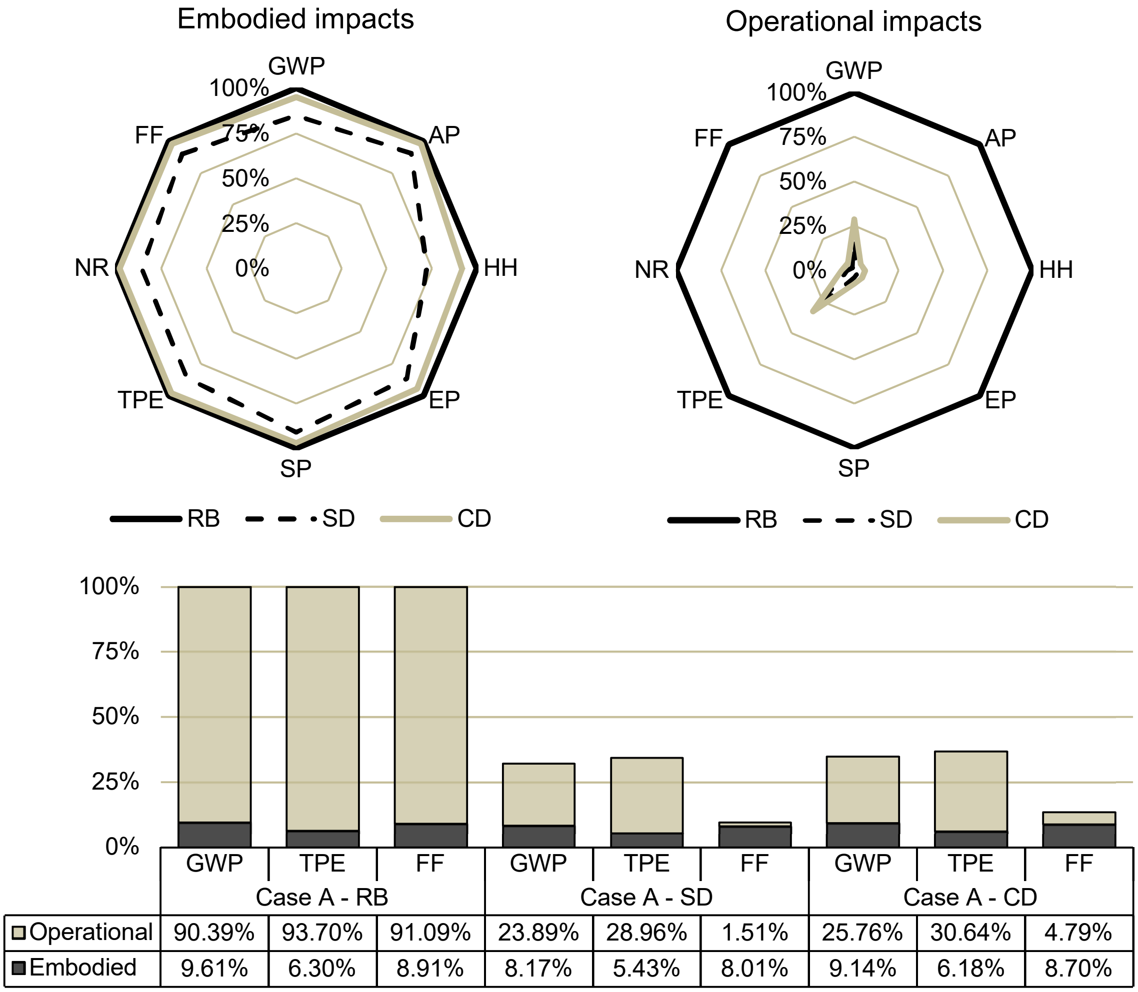


Figure 22. Reduction scores of embodied impact mitigation strategies in case A comparing RB, SD and CD.

* Global Warming Potential (GWP), Total Primary Energy (TPE), Acidification Potential (AP), Human Health Particulate (HH), Aquatic Eutrophication Potential (EP), Smog Potential (SP), Non-Renewable Energy Consumption (NR) and Fossil Fuel Consumption (FF).

Operational Vs. Embodied potential impact comparison in case A

Fig. 23 shows that case A had the most audacious energy-consumption reductions among the three cases. The project team proposed a 70% reduction in the SD through the use of geothermal energy and the elimination of gas use. Due to limitations in the electricity supply, however, the final project (CD) reintegrated gas as a source of energy. The wood structure would have provided a 15% reduction in embodied energy in the SD. The unfeasibility of the use of wood, however, led the professionals to use concrete for the structure. Both decisions impacted negatively on the GWP impact in the final project (CD) when compared with the SD – 12% higher embodied impact and 25% higher operational impact.

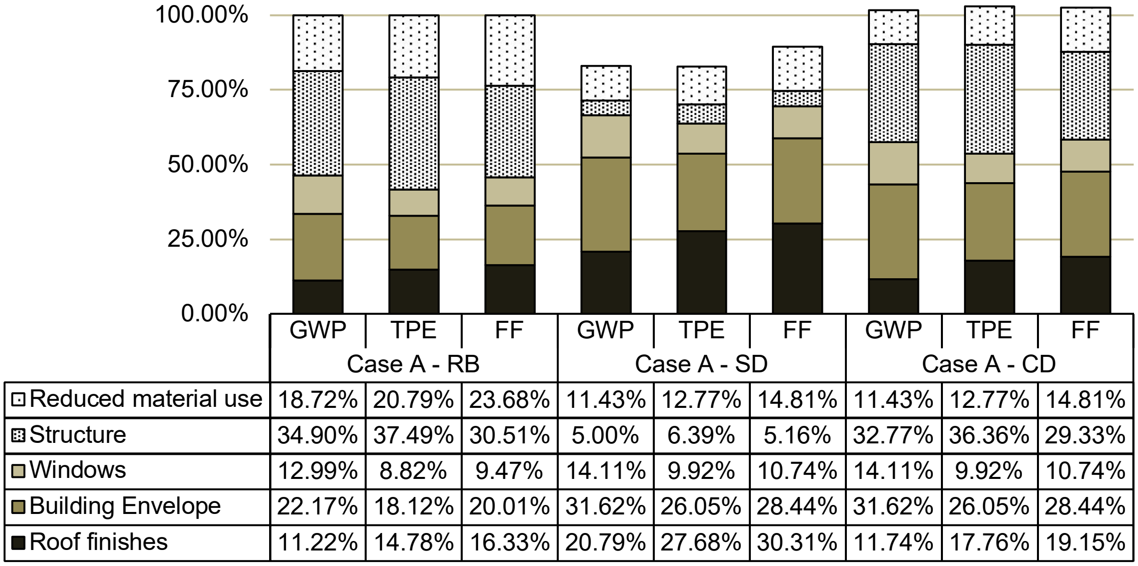


	GWP	TPE	FF	GWP	TPE	FF	GWP	TPE	FF
	Case A - RB			Case A - SD			Case A - CD		
▨ Operational	90.39%	93.70%	91.09%	23.89%	28.96%	1.51%	25.76%	30.64%	4.79%
■ Embodied	9.61%	6.30%	8.91%	8.17%	5.43%	8.01%	9.14%	6.18%	8.70%

Figure 23. Operational vs. embodied impacts in case A

The environmental impact of building materials in case A

Case A used LCA to analyse only the structure and one exterior finishing (fibre cement versus brick). Our study showed, however, that LCA would also have been helpful to avoid an increase in the embodied impacts for case A. Fig. 24 shows that some strategies used to reduce energy consumption (windows, building envelope and roof) increased embodied impacts (GWP, TPE and FF). The results in the section above showed that by using wood (CLT), case A would have reduced embodied impacts. However, due to technical problems (delivery time and the construction code), the engineers and architects opted to use concrete that replaced 30% of the cement by fly ash – reducing GWP by only 6% whereas wood reduced GWP by 85%. In the case of triple-glazed windows, the GWP is 10% higher than double-glazed windows. The ultra-extensive green roof and the high-performance envelope (CD) also have a higher impact than the standard solutions (RB) – the GWP is 5% higher for the green roof and 43% higher for the high-performant envelope. The advantage of both is an improved R-value that reduced energy consumption and operational impact (as presented in Fig.24).



	GWP	TPE	FF	GWP	TPE	FF	GWP	TPE	FF
	Case A - RB			Case A - SD			Case A - CD		
◻ Reduced material use	18.72%	20.79%	23.68%	11.43%	12.77%	14.81%	11.43%	12.77%	14.81%
▩ Structure	34.90%	37.49%	30.51%	5.00%	6.39%	5.16%	32.77%	36.36%	29.33%
▨ Windows	12.99%	8.82%	9.47%	14.11%	9.92%	10.74%	14.11%	9.92%	10.74%
▦ Building Envelope	22.17%	18.12%	20.01%	31.62%	26.05%	28.44%	31.62%	26.05%	28.44%
■ Roof finishes	11.22%	14.78%	16.33%	20.79%	27.68%	30.31%	11.74%	17.76%	19.15%

Figure 24. Embodied impact reductions due to material improvements strategies in case A.

Case study B: Rio Tinto Alcan Planetarium (RTAP)

The project began in 2003 when the city of Montreal decided to relocate its obsolete Planetarium. After having chosen a site close to the Biodôme (a facility that replicates four North American ecosystems) within Montreal's Olympic Park, the city launched an international architecture competition. A Montreal-based firm was chosen in 2010. Its team included a landscape architect, a civil engineering firm and a mechanical engineering firm. The multidisciplinary project team worked together to meet the project’s functional and technical needs. An accessible green roof integrates the building with a neighbouring park. A geothermal energy system and the use of renewable materials helped to reduce energy consumption and greenhouse gas emissions. The new Planetarium is the second LEED® Platinum building in Québec and is part of one of Canada's largest natural science museums. Table 38 summarises all the innovative strategies adopted in the project.

Integrated Design in case B

This project was initially drafted during the architecture competition. The client was not involved in design activities at this stage. But client officers developed a “project charter” to establish the architectural program and energy-savings targets. The design team organised ID charrettes to draft the preliminary concept (SD). The city wanted to develop an area that lay between two existing buildings and above a two-floor underground parking lot. The winning team, however, instead of building new columns and slabs, proposed to install 75% of the museum area in the existing underground parking space. As a result, the new construction area was substantially reduced. They also proposed the use of Cross-Laminated Timbers (CLT), an engineered wood panel, for the new structures: a small mezzanine and the roof. The final project (CD), however, used steel instead of CLT due to technical issues (more detail in the following sections). The greatest innovation of this project was turning almost all the roof into a large green area integrated with the nearby park.

Building Energy Simulation in case B

The mechanical engineers' work can be divided into two phases. The first was preparation for the architectural competition. Here, for the SD, the team relied on expensive solutions to achieve the 30% in energy savings required for LEED. The second phase took place after the proposal was chosen. In this phase, the client and the building operator team of the neighbouring property (Biodôme) joined the ID charrettes. The synergy among these professionals allowed the team to achieve a 45% savings with a much cheaper solution. For example, in the CD, they eliminated all geothermal energy equipment and hydronic heating manifolds and replaced them with the neighbouring building's surplus in geothermal energy. They had, however, difficulties modelling the savings stemming from the proposed innovative solutions using the Hourly Analysis Program (HAP) v4.51 energy simulation tool. HAP v4.51 could not evaluate natural ventilation, the geothermal gain of the neighbouring building, and the green roof. All three strategies were estimated and entered manually into the simulation. The analyses regarding each building characteristic (Table 41) show that the Construction documentation (CD) is theoretically 40% more energy efficient than if the building was constructed to meet only the requirements of the MNECB 1997.

Table 41. Characteristics of RB, SD and CD in case B.

	Reference Building (RB)	Schematic Design (SD)	Construction Documentation (CD)
Electricity	2,109,463 kWh / year	1,766,543 kWh / year	1,255,278kWh / year
Gas	49,640 m³ / year	Eliminated	Eliminated
Calculation based on	ASHRAE 90.1 + plug load	EE4 v1.7-2 + plug load	HAP v4.51 + plug load

Life Cycle Assessment in case B

No evidence was found that LCA was used in this project as a decision-making support tool. The architect, however, was deeply involved in searching for low impact products such as aluminium on the facades. Aluminium is a material with high recycled content. There was also a rigorous follow-up by the project team to ensure maximum LEED points related to recycling content and local products. The first architectural proposition submitted to the competition – the SD – included wood for all columns and the roof structure. After analysing existing conditions, the engineers proposed replacing the wood with a steel structure. The reason for this substitution was to avoid the need for new foundations. Fig. 25 presents results comparing the three scenarios.

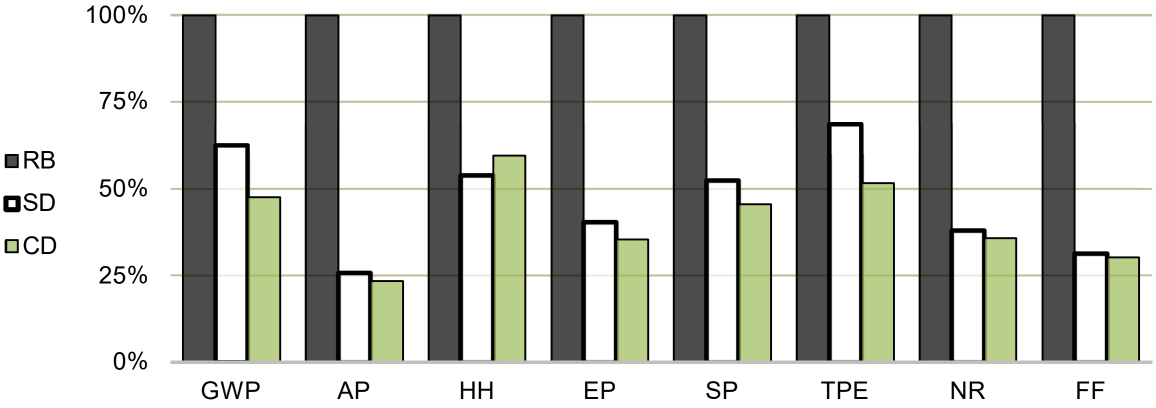
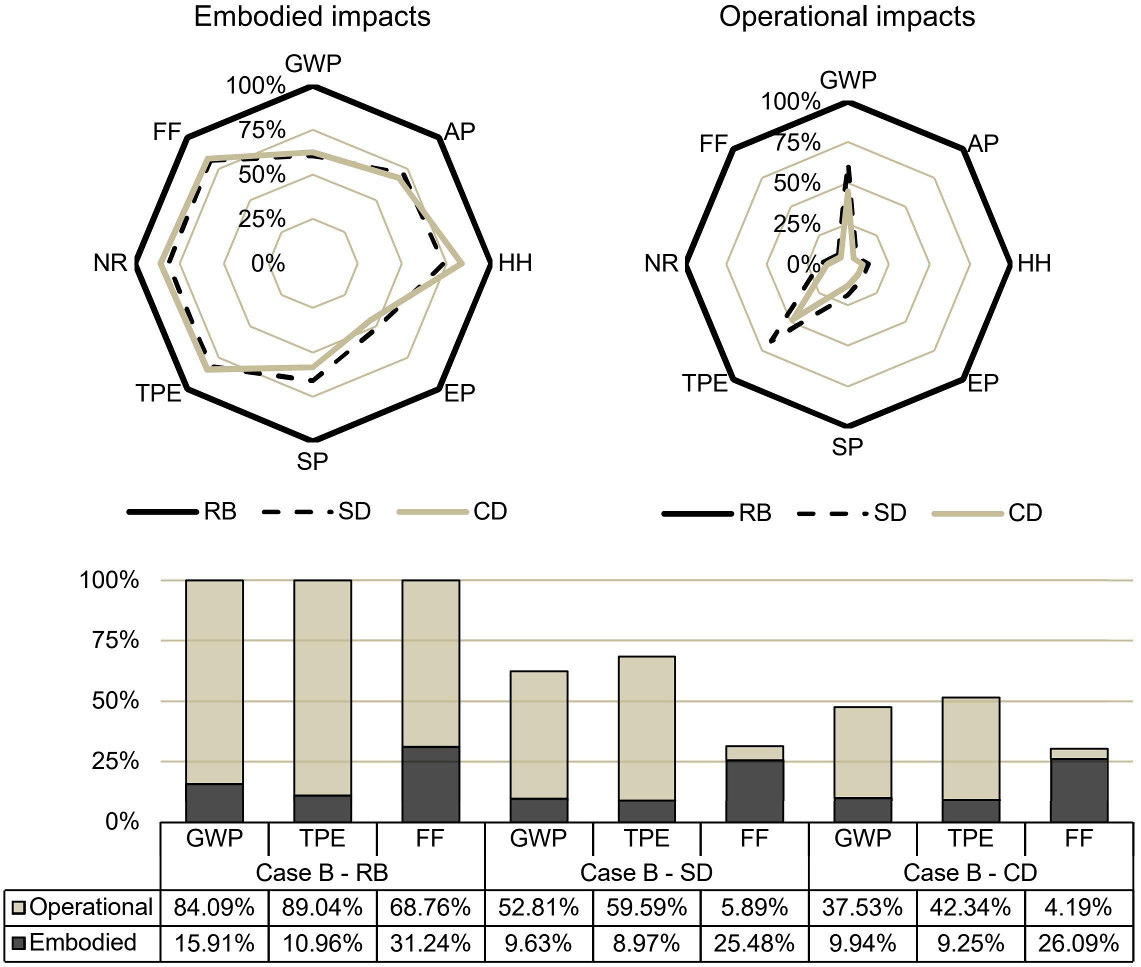


Figure 25. Reduction scores of embodied impact mitigation strategies in case B comparing RB, SD and CD.

Operational Vs. Embodied potential impacts comparison in case B

Mitigation efforts in this project produced 55% fewer operational emissions and almost 38% fewer embodied emissions than the RB for GWP impact. The reductions from operational energy improvements were based on a 50-year building lifespan. One of the reasons for the increased embodied impact, when comparing the SD to the CD, was the use of steel instead of CLT wood for the structure (Fig.26).

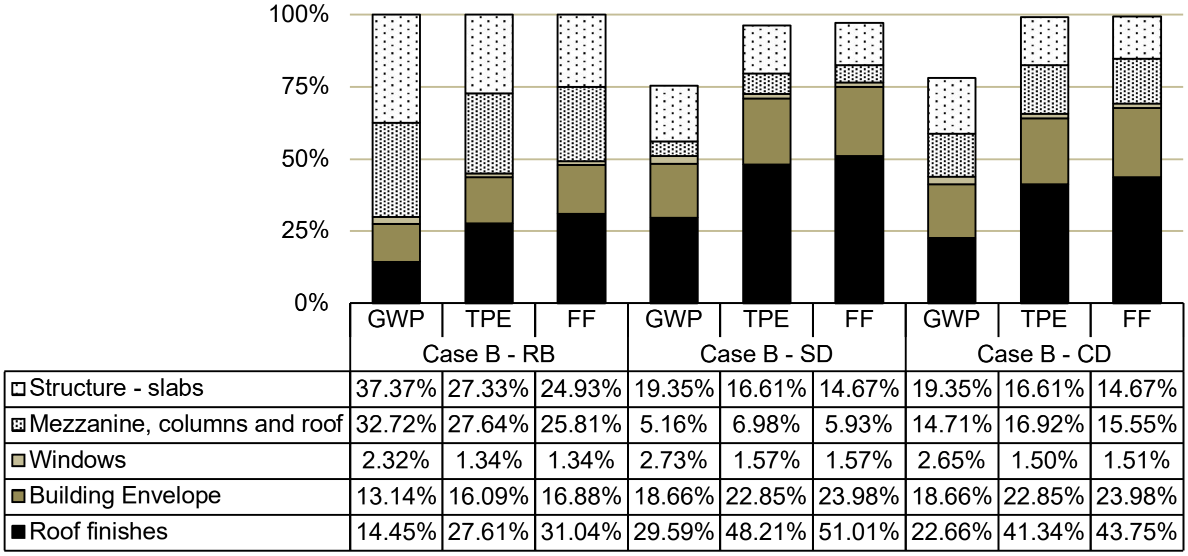


	Case B - RB			Case B - SD			Case B - CD		
	GWP	TPE	FF	GWP	TPE	FF	GWP	TPE	FF
▨ Operational	84.09%	89.04%	68.76%	52.81%	59.59%	5.89%	37.53%	42.34%	4.19%
■ Embodied	15.91%	10.96%	31.24%	9.63%	8.97%	25.48%	9.94%	9.25%	26.09%

Figure 26. Operational vs. embodied impacts in case B

The environmental impact of building materials in case B:

Case B reduced GWP by 53% when the RB was compared to the CD. The most impactful decision in this case was to use 75% of the existing structure instead of building a new slab, a strategy that reduced the GWP by 55% (Fig. 27). Case B might also have achieved an 84% GWP reduction if they had chosen wood to build the new mezzanine, columns and roof. Instead, they used steel that only reduced GWP by 55% when compared to the concrete used in the RB. One of the project's strengths is its large green roof area. However, the decision increased the roof GWP by 55%. Despite this huge impact, the extensive green roof used in the CD produces a 23% reduction in GWP when compared with the intensive roof proposed in the SD.



	Case B - RB			Case B - SD			Case B - CD		
	GWP	TPE	FF	GWP	TPE	FF	GWP	TPE	FF
□ Structure - slabs	37.37%	27.33%	24.93%	19.35%	16.61%	14.67%	19.35%	16.61%	14.67%
▩ Mezzanine, columns and roof	32.72%	27.64%	25.81%	5.16%	6.98%	5.93%	14.71%	16.92%	15.55%
▧ Windows	2.32%	1.34%	1.34%	2.73%	1.57%	1.57%	2.65%	1.50%	1.51%
▨ Building Envelope	13.14%	16.09%	16.88%	18.66%	22.85%	23.98%	18.66%	22.85%	23.98%
■ Roof finishes	14.45%	27.61%	31.04%	29.59%	48.21%	51.01%	22.66%	41.34%	43.75%

Figure 27. Embodied impact reductions due to material improvements strategies in case B.

Case study C: Montreal Soccer Stadium (MSS)

The MSS at the Saint-Michel Environmental Complex was initiated in 2009 and became operational in July 2015. The project responds to a growing need for indoor space for soccer in Montreal. The architectural design was chosen through an international competition. Two architecture firms, working in consortium, were chosen in 2011. Thereafter, the city hired other professionals in landscape, civil, and mechanical engineering, based on the lowest bids. This LEED Gold project includes innovative and energy-efficient measures to optimise environmental performance.

Integrated Design in case C

This project also started with an architecture competition. In this case, however, the team included only architects and a consultant in wood construction. The architects made a bold architectural proposition to the city: to cover the 69-meter stadium span with cross-laminated timber (CLT) beams and panels (the SD scenario). After the winning project was announced, other professionals and the client joined the ID charrettes. The charrettes helped the client to validate and optimise design innovations. As we can see in the CD scenario, in Table 39, team members did not adopt disruptive ideas. Most charrettes evaluated only the environmental and economic impacts of the architects' proposition and implemented incremental improvements.

Building Energy Simulation in case C

Mechanical engineers participated in the ID charrettes only after the architectural design proposition had been chosen (after the architecture competition). Professionals used energy simulations only to evaluate different propositions. They could not use the results to propose radical changes since the architectural concept had already been chosen. Only minor architectural improvements were implemented. For example, the team proposed a ceramic fritted and Low-E glass material for the curtain wall to control light transmittance and reduce solar heat gains. The team also proposed a natural air flow combined with heat recovery equipment for the soccer field to reduce the use of the air-conditioning system (used only in closed areas). The mechanical engineers faced several difficulties when modelling the savings achieved from both strategies – the ceramic fritted glass gain and the heat recovery equipment – forcing them to calculate both gains manually in order to include them in the simulation. Comparing the characteristics of both projects (Table 42) shows that the CD is at least 64% more energy efficient than the RB, and 18% more efficient when compared to the SD. More precisely, 31% of these savings come from electricity and 80% from a reduction in the consumption of natural gas.

Table 42. Characteristics of RB, SD and CD in case C.

	Reference Building (RB)	Schematic Design (SD)	Construction Documentation (CD)
Electricity	1,620,550 kWh / year	1,098,778 kWh / year	1,104,861 kWh / year
Gas	326,964 m³ / year	103,270 m³ / year	64,665 m³ / year
Calculation based on	ASHRAE 90.1 + plug load	eQuest v3.64 + plug load	eQuest v3.64 + plug load

Life Cycle Assessment in case C

The team hired a LCA consultant to evaluate the environmental performance of the CLT structure. The LCA report showed that the CLT structure had a lower carbon footprint compared to steel – 61% less GWP impact. For all other comparisons, however, wood had higher impacts than steel, such as 20% more smog potential and 13% more acidification potential. The report explained that there were two reasons for these results. First, CLT beams required longer transportation than steel. Second, compared to steel structural components, more equipment is required to lift and install CLT. The LCA results led the design team to rethink the structure during ID charrettes. Project optimization resulted in a reduction of material-use engendering a 40% reduction of the GWP in the CD compared to the original structure (SD). The overall results are presented in Fig. 28.

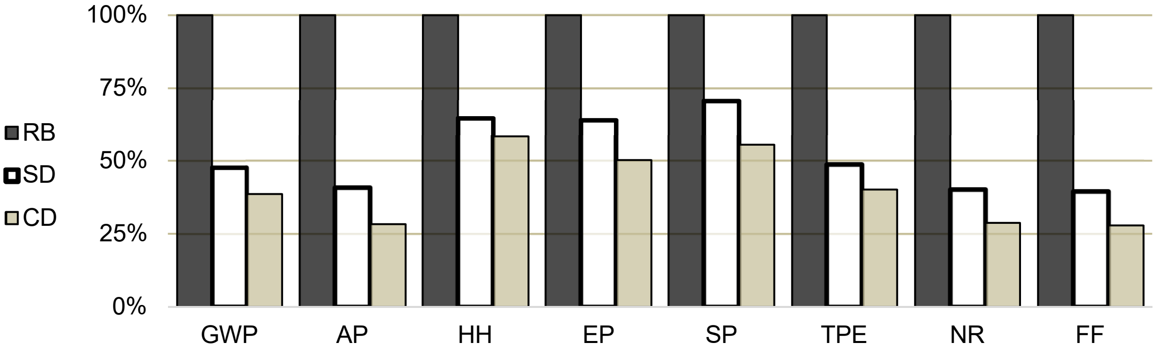
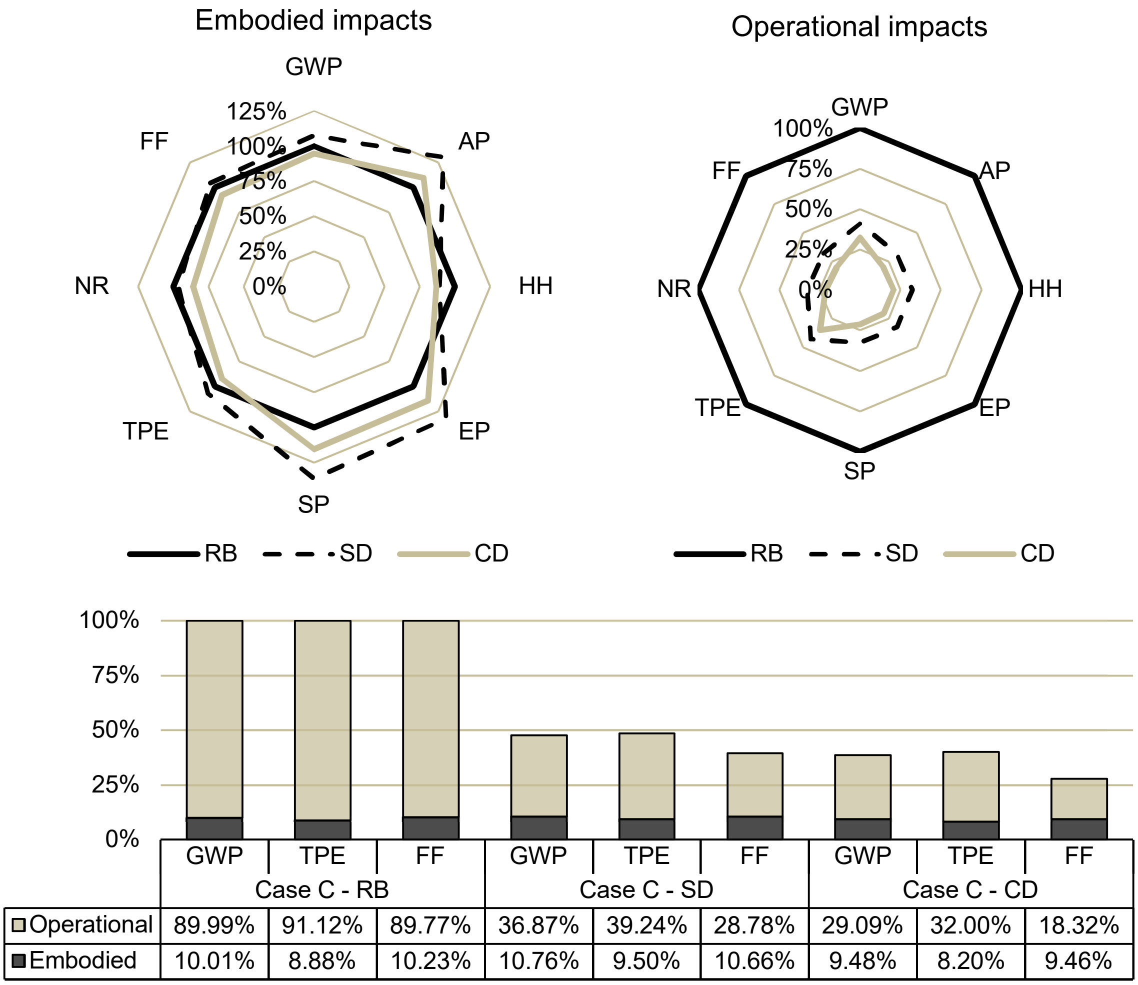


Figure 28. Reduction scores of embodied impact mitigation strategies in case C comparing RB, SD and CD.

Operational Vs. Embodied potential impacts comparison in case C

Implementing mitigation strategies in this case decreased GWP impacts for operational (58%) and embodied emissions (5%) compared to the RB (Fig. 29). The embodied chart also shows an increase for many impact categories (AP, EP and SP) when comparing the CD to the RB. Further analysis showed that this increased impact is due to the building fenestration – standard windows for the RB compared to double glazed to CD – even though it has a smaller impact than the SD which proposed triple-glazed fenestration.

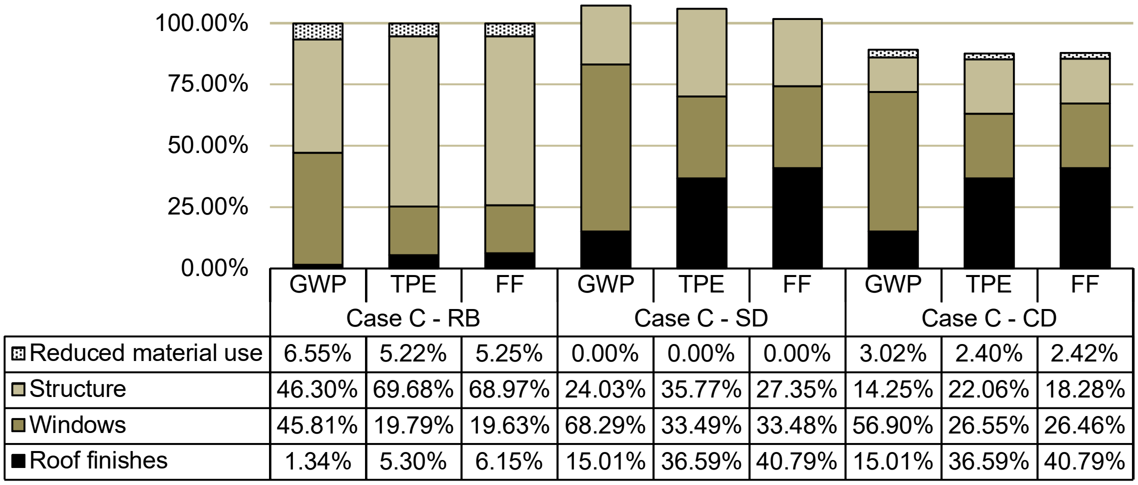


	Case C - RB			Case C - SD			Case C - CD		
	GWP	TPE	FF	GWP	TPE	FF	GWP	TPE	FF
▨ Operational	89.99%	91.12%	89.77%	36.87%	39.24%	28.78%	29.09%	32.00%	18.32%
■ Embodied	10.01%	8.88%	10.23%	10.76%	9.50%	10.66%	9.48%	8.20%	9.46%

Figure 29. Operational vs. embodied impacts in case C

The environmental impact of building materials in case C

The final project (CD) reduced GWP slightly when compared to the RB. While the CLT wood structure reduced GWP by almost 70%, the white roof with water retention tanks increased GWP 10-fold when compared to a standard metal roof used in the RB (Fig. 30). The ID charrettes proved to be useful in improving the initial architectural project (SD). The high cost of the CLT wood structure almost precluded its use. During ID charrettes, however, the team optimised the CLT wood structure reducing the cost and material use by 30%. The CLT impact consequently reduced the GWP by 40%. In addition, the decision to use doubled-glazed windows in the CD, as opposed to the triple-glazed solution for the SD, reduced the GWP by 17%. Further analyses of impact increases are presented in the next section.



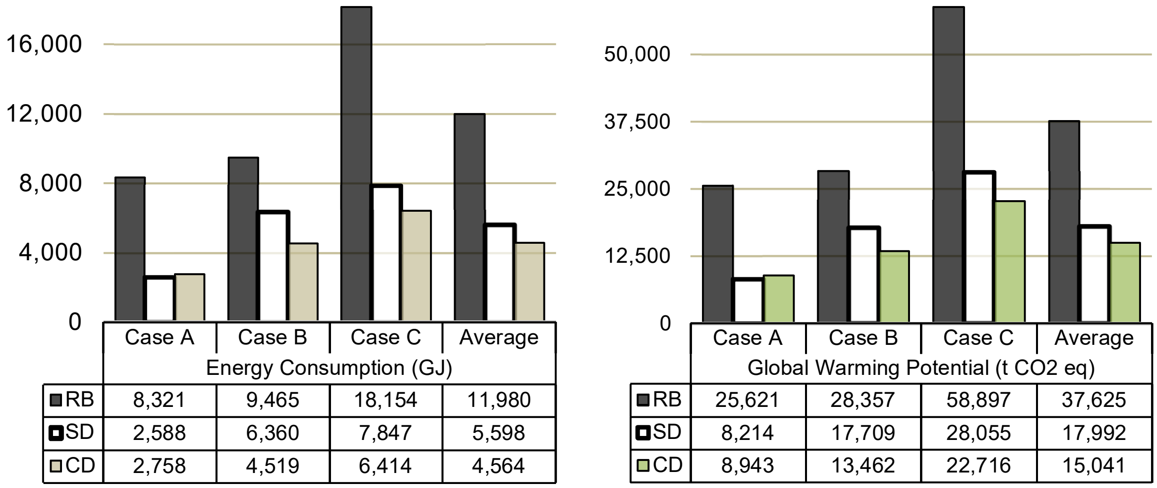
	GWP	TPE	FF	GWP	TPE	FF	GWP	TPE	FF
	Case C - RB			Case C - SD			Case C - CD		
▦ Reduced material use	6.55%	5.22%	5.25%	0.00%	0.00%	0.00%	3.02%	2.40%	2.42%
□ Structure	46.30%	69.68%	68.97%	24.03%	35.77%	27.35%	14.25%	22.06%	18.28%
▨ Windows	45.81%	19.79%	19.63%	68.29%	33.49%	33.48%	56.90%	26.55%	26.46%
■ Roof finishes	1.34%	5.30%	6.15%	15.01%	36.59%	40.79%	15.01%	36.59%	40.79%

Figure 30. Embodied impact reductions due to material improvements strategies in case C.

* SD "reduced material use" is 0.00% for all impacts due to the elimination of ceiling tiles and steel columns covering (see Table 6 for more detail)

4.3.5. Analysis of results and discussion

ID favours, at least theoretically, collaboration among professionals to improve project performance. The previous section identified mitigation strategies, analysed the decision-making process, and measured effective GHG and energy use reductions in ID charrettes in three case studies. The analysis showed that, when comparing the RB to the CD, the projects achieved, on average, a 62% reduction in energy use and 60% in GWP (Fig. 31).



Energy Consumption (GJ)

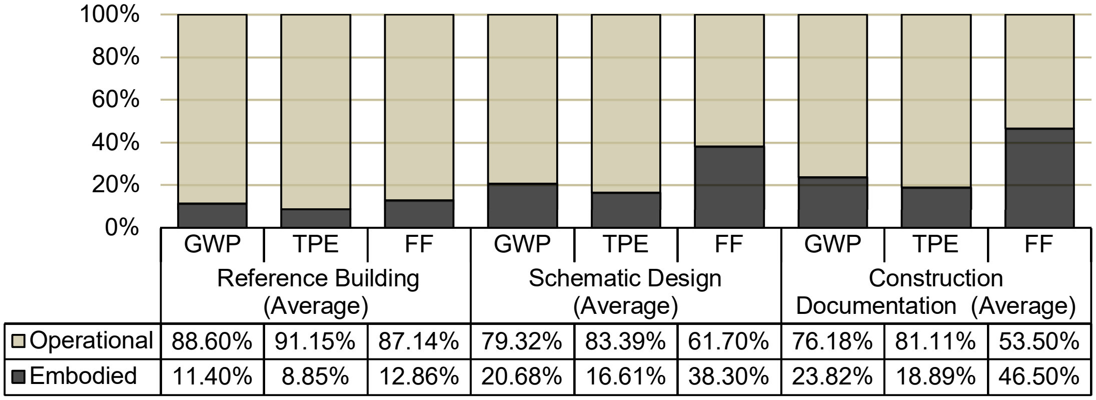
	Case A	Case B	Case C	Average
■RB	8,321	9,465	18,154	11,980
□SD	2,588	6,360	7,847	5,598
▨CD	2,758	4,519	6,414	4,564

Global Warming Potential (t CO2 eq)

	Case A	Case B	Case C	Average
■RB	25,621	28,357	58,897	37,625
□SD	8,214	17,709	28,055	17,992
🟩CD	8,943	13,462	22,716	15,041

Figure 31. Energy and GWP reductions in the three case studies.

This study shows that BES proved to be a useful tool to predict and optimise a building's energy performance. BES proved itself to be more popular than LCA since it is mandatory for energy-rating systems like LEED. This was not the case for LCA which was, in the projects studied, used only to help the design team to make some isolated material choices. LCA, however, should gain relevance as the industry increasingly moves towards low energy buildings since the share of embodied energy tends to increase. The comparative analyses of this study showed that LCA can be useful for calculating not only the emissions incorporated during the operation but also during the construction phase. Embodied emissions from the construction phase and future renovations cannot be ignored, especially in high-performance projects (Ibn-Mohammed *et al.*, 2013). Green and high-performance projects tend to decrease energy consumption and operational emissions, generating, therefore, a significant increase of embodied emissions (Chastas *et al.*, 2017). Results from our study confirmed the growing significance of the embodied impacts in the total life-cycle of the building (50-year lifespans). The reduction in energy consumption in the operating phase (by 62%) reduced the operational impacts by 71% when GWP, TPE and FF are taken into consideration. In comparison, the embodied energy fell by only 12% – comparing the RB to the CD. Fig. 32 shows that, as a consequence, the share of embodied impacts increase considerably during the CD's total life-cycle. The GWP impact-share increased, on average, from 11,4% in the RB to almost 24%. The FF impact-share increased almost fourfold, from 12,82% in the RB to 46,5%.



	Reference Building (Average)			Schematic Design (Average)			Construction Documentation (Average)		
	GWP	TPE	FF	GWP	TPE	FF	GWP	TPE	FF
□ Operational	88.60%	91.15%	87.14%	79.32%	83.39%	61.70%	76.18%	81.11%	53.50%
■ Embodied	11.40%	8.85%	12.86%	20.68%	16.61%	38.30%	23.82%	18.89%	46.50%

Figure 32. Operational vs. embodied impacts considering the three-case studies average.

The results of the case studies brought to light at least five challenges that professionals face when adopting LCA and BES tools in ID processes. This article will ultimately argue that these challenges make ID less effective.

Tool complexity and accuracy

The use of building energy-performance simulation tools is helpful in guiding practitioners towards lower carbon emissions solutions. Our results show, however, that during ID, LCA and BES are both seen by stakeholders as overly complicated. Previous studies have also suggested that these tools (notably LCA) provide excessive amounts of information and require specialised knowledge to interpret the results (Weytjens *et al.*, 2011). Nonetheless, engaging a life-cycle and energy specialist to test various design assumptions throughout the process is strongly recommended in order to provide objective information on key performance aspects (Kibert, 2013). In cases A, the client hired a company to compile LCA reports evaluating options for specific solutions. In case B, however, we found no evidence of use of LCA during ID charrettes. In case C, the client hired an LCA specialist to participate in some ID charrettes. The documentation analyses showed that the stakeholders asked for an LCA during ID charrettes in order to evaluate the impact of different technical and architectural options. As a result, case C engendered deeper debates and more informed decisions when compared to the other two cases.

The choice of the tool is also essential. Over-restrictive or oversimplified tools can result in models that do not represent reality. The software must also be adapted to the specific type of building being modelled. Other authors have found that these tools may have errors embedded in their equations leading to inaccuracies in predictions (Menezes *et al.*, 2012). This study used simplified LCA tools and Canadian and North America data. However, the data from Athena IE4B did not take into account the product's provenance or water-consumption impacts. Concerning BES, it was necessary in all three cases to analyse strategies through separate calculations. They could not be calculated directly using the BES tool and had to be added later.

Missing information

ID gives stakeholders an opportunity to assess different strategies to mitigate CO2 emissions. In all the case studies, the initial ID charrettes (2 to 5 sessions) were devoted to brainstorming. The main challenges emerged later when stakeholders had to decide which strategy to use. At this juncture, they did not have data that quantified the cost-benefits of each strategy – a problem previously noted by Ürge-Vorsatz *et al.* (2007). BES and LCA relevance depend on data assumptions. This includes the quality of construction, occupant behaviour, as well as the type of building services, management, and control that are established post-occupation. These assumptions are defined in the initial phase of the project when many building aspects, functions, and use are still unknown or uncertain. This was the case in our case studies. When information was available, it was too generic. In BES, the adopted building operation hours did not correspond to reality. In LCA, the strategies under investigation in ID charrettes were analysed based on generic building-product data (Anand & Amor, 2017). This resulted in oversimplified and /or unrealistic inputs, a problem that has also been noted by Menezes *et al.* (2012). These results suggest that more and better tools are needed in ID.

Reducing embodied energy in high-performance buildings

LCA and energy-consumption results often count on 50-year lifespans. The building operation phase, thus, has a prominent place in LCA. This phase typically represents 80% of the total environmental impacts – the remaining portion is the result of construction (Ramesh *et al.*, 2010). Although operations have a greater impact, significant efforts are required to reduce construction impacts (or embodied impact) for two reasons. First, because this 20% impact is typically created in one or two years, whereas the operation phase is spread out over 50 to 100 years. In other words, the construction phase produces impacts equivalent to almost 20 years of the building's operation. An even more important impact is found in Net-zero energy buildings (Net ZEB), where embodied energy accounts for 46% of total environmental impacts (Anand & Amor, 2017). This means that embodied energy in Net ZEB construction may represent impacts equivalent to 63 years of a building's operation.

High-performance buildings often use more materials and equipment in order to save energy in the long run (Ramesh *et al.*, 2010). This pattern was confirmed in our cases where the CDs had a 61% increase in GWP impact – when compared with RBs – due to additional materials used to improve roof, windows and buildings envelope with a higher R-value (a common insulation factor) for example. To deal with this problem, the professionals adopted mitigation measures. In Case A, they eliminated some materials (e.g. ceilings and wall finish) and incorporated recycled materials (reclaimed wood and rooftop anchors). In Case B, decision-makers chose to reuse 75% of the existing structure. In Case C, they decided to adopt lower standards in the envelope, using a double-glass instead of the triple-glass curtain wall proposed in the SD – thereby reducing embedded energy. In addition, they chose to allow greater internal temperature fluctuation, and thus accepted lower standards in terms of temperature comfort.

Poor environmental design decisions

In theory, ID charrettes favour stakeholder collaboration in the search for innovative and more environmentally-friendly solutions (Leoto & Lizarralde, 2019; Ürge-Vorsatz *et al.*, 2007). Our case studies validate this claim. More intense stakeholder interaction did occur; but most decisions were made intuitively and were rarely based on LCA results. When LCA was applied, it was used to validate a single material or strategy but not the overall impact of the building. For instance, in Case studies A and C, LCA was used only to compare structural materials (steel, wood, and concrete).

Our case studies also show that, even when ID was adopted, the decision-making process remained fragmented and decision-makers often neglected to undertake a thorough analysis of the overall impact of the project. In all cases, stakeholders had insufficient knowledge of LCA. In addition, ID charrettes require rapid information turnaround and decision-making. But, when data was not available on time (or at all) decision-making relied on intuition, past experience and “common sense.” This is not necessarily prejudicial. However, it confirms a pattern previously found by Russell-Smith *et al.* (2015), who argue that ID defenders often overestimate the objectivity and precision that the tools provide and underestimate the role that subjective judgement and expertise play in decision-making. Our inquiry also confirmed a pattern previously found by Peuportier *et al.* (2013) who argue that even though LCA has proven useful to inform building-design decisions, it is predominantly used to calculate the environmental impacts of buildings retroactively.

Decision-making based on green certification credits

Most green building certifications, such as LEED, encourage the use of ID as a method to achieve sustainability goals. LEED requires more building energy-reductions than the ASHRAE standards. But both are based on points given to individual strategies and sub-systems and fail to consider the overall building impact. Thus, a high score in these certifications does not necessarily imply lower environmental impacts. In our case studies, four ID charrettes became meetings used exclusively to verify certification scores, instead of spaces for effectively reducing overall building impacts. Moreover, the expanded range of LEED credits marginalised climate-change issues (Howard, 2017). For example, debates in many ID charrettes in our case studies concerned the percentage of recycled or renewable content in the materials. This led professionals in case study B to add 250m² of aluminium foam panel in all entrance exterior walls and inside elevators. They justified its use by considering its local provenance (from Toronto), its 100% recycled content, and its 100% recyclability. This choice resulted in three credits for just one product. In reality, the most effective environmental strategy would have been to reduce the use of materials.

From a climate-change mitigation point of view, materials with longer service-life should be favoured. This would reduce the need for maintenance and replacement. Following this reasoning, stakeholders in case A decided to eliminate ceilings. They also opted to use more durable carpet tiles instead of standard rollout tiles. Even though both solutions reduced the building's environmental impact, they did not garner LEED credits. Other impact reduction options that do not entail additional credits include reducing the building area, which, of course, reduces the use of materials. Our empirical studies confirm that green certifications often distort the decision-making process and rationale in ID. In some ways, they become a barrier to, and not an enhancer of, GHG reductions.

4.3.6. Theoretical and practical implications

Our results have three main theoretical implications. First, the empirical results underline the need for an analytical framework capable of producing empirical data about the real effectiveness of ID practices. This framework is needed to analyse the decision-making process and measure its real impact on the environment. Second, the study identified five challenges that prevent ID processes from achieving their full potential as a method to reduce carbon emissions. Finally, the results revealed the need for more longitudinal studies in which initial expectations and goals can be compared with effective outputs and long-term results.

There are also practical implications. First, the study uncovered ID decision-making processes in three projects that adopted different strategies. These ID strategies and their results can be useful as benchmarks for similar projects and studies. Second, in exploring current challenges faced during ID, the study suggests areas where practitioners need to expand their knowledge. Finally, this study confirms that a deeper professional knowledge of life-cycle analyses, for example, would allow ID to be even more effective in reducing a building's impacts on the environment.

This study has some limitations. First, the research focused mainly on projects that obtained a LEED certification (gold and platinum). Future research should include other types of green-building certifications (e.g. SbTools, Living Building Challenge, BREEAM and DGNB). Next steps might also investigate how the mandatory use of LCA – an aspect missing from LEED's framework – affects the decisions made during ID charrettes and the project outcomes. Second, the case studies arose in a particular geographical (Montreal) and institutional (projects funded by government or NGOs) context. Future studies might also compare the conclusions drawn here to those arising in the context of more representative cases (e.g., private real estate projects) and locations. Finally, although this research highlights the abilities and challenges of ID to reduce carbon emissions, research is still needed to measure actual environmental performance – that is, real energy and GHG reductions after construction.

4.3.7. Conclusions

ID is a participatory method increasingly seen as a useful means to reduce a building's impact on the environment. It has been increasingly adopted in sustainable buildings and is perceived as a powerful tool to reduce GHG emissions, embodied impact and energy consumption. This study examined three cases in which ID helped predict reductions of about 60% in GWP and 62% in energy use and uncovered novel findings concerning ID's opportunities and limitations. We revealed five factors that, if overcome, would allow ID to be even more effective in reducing carbon emissions:

- Tool complexity and accuracy – Professionals see LCA and BES as complex and time-consuming tools. In addition, inconsistencies and distortions in input and outputs often produce erroneous results. The buildings modelled rarely represent reality.
- Missing information – Lack of data concerning carbon reductions for each strategy (feasibility and pay-back) complicates the decision-making process.

More empirical data is needed to help professionals make more environmentally-friendly decision

- Reducing embodied energy in high-performance buildings – Stakeholders prioritize energy savings and neglect the impact of increased use of materials in the construction phase. This, in fact, is an oversight that can increase the building's carbon emissions during the year the building is under construction.
- Poor environmental design decisions – Sustainability assessment tools are usually applied to validate individual, stand-alone strategies. Important decisions in ID charrettes were often made intuitively. This approach often neglects the overall impact of the project.
- Decision-making based on green certification credits – Stakeholders in ID meetings spend much more time reviewing certification scores than thinking about strategies to reduce the building's overall impact.

Identifying and evaluating mitigation strategies and decision-making processes sheds light on the limits of ID. The analytical framework proved effective in helping the research team identify and better understand the five challenges that professionals face during ID charrettes. From a practical point of view, the results revealed the need for professionals to develop a deeper knowledge of, and familiarity with, life-cycle assessment and energy simulation tools in order to reduce GHG emissions. From a theoretical point of view, the results validate the relevance and value of ID to reduce GWP and energy use, but they also underscore the limits of ID.

4.4. To what extent does integrated design improve project management practices and outputs? (Publication 3)

Authors: Leoto, Ricardo and Lizarralde, Gonzalo (2019),
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4.4.1. Abstract

The building sector is responsible for a number of negative impacts on the environment. Increasing attention to sustainability and the reduction of fragmentation has led building-sector stakeholders to implement alternative design methods and tools such as Integrated Design (ID). There remains, however, a disconnect between the often-ambitious objectives identified in the early phase of sustainable projects and the results achieved in the operation phase. This study seeks to assess to what extent ID improves project management practices (reducing fragmentation between project phases) and outputs (reducing a building's environmental impact). We investigated three LEED-certified buildings in Canada. The empirical data, which includes extensive documentation, LCA analyses and 28 interviews, allowed us to analyse the processes and stakeholders' interest and expectations. The results show that adopting ID in the design phase alone does not completely eliminate fragmentation in the subsequent phases. Concerning outputs, the projects reduced the global warming potential (GWP) by 49% and the energy consumption by 47%. They failed, however, to achieve the expected performance. There was 11% less GWP reductions, and 19% less energy savings than predicted. The study reveals four challenges that practitioners must overcome to improve project management in ID projects: (a) insufficient participation in design charrettes, (b) increased project complexity in sustainable buildings projects, (c) fragmentation between project phases and (d) lack of feedback on building performance. The findings reveal opportunities to strengthening project managers' role in sustainable projects.

Keywords: Sustainable Project Management, Integrated Design Process, Sustainable Buildings, Project Manager Roles, Environmental Impact of Buildings

4.4.2. Introduction

Pressure to address climate changes and environmental degradation is forcing major shifts in the construction industry. As the sector is responsible for 35% of waste generation, 32% of energy consumption, and 19% of greenhouse gas (GHG) emissions (Solís-Guzmán *et al.*, 2009; Zhang *et al.*, 2017), the built environment has significant potential to contribute to reducing human impacts on the environment (Bakens, 2003). Both theory and practice, however, have shown that the traditional, linear, and fragmented silo-type design process is a significant barrier to improvement in the building sector (Magent *et al.*, 2005; Mossman *et al.*, 2010; UNEP, 2009).

The increasing focus on reducing a building's impact on the environment has led clients and construction industry professionals to seek new project management processes in order to address society's aspirations (Bonham, 2013). Governments and certification boards in Europe and North America, for example, encourage the use of innovative and collaborative design processes, such as Integrated Design (ID) (Cohen, 2010; Natural Resources Canada, 2015). ID aims at integrating otherwise fragmented processes to improve a building's environmental performance (Kovacic & Müller, 2014). Deutsch (2011) tells us that in "ID the focus is on the end results, the completed building, optimized for greater value and reduced waste" (p.139).

Deutsh's definition of ID highlights its holistic nature which includes not only the design phase, but also project-management tools and processes. As such, taking a holistic view of ID places it firmly in the construction project management domain. It has the potential to enhance collaboration and innovation between stakeholders throughout the whole life cycle of the building to reduce a building's impact on the environment. Unfortunately, researchers have found that ID – when used to obtain building certifications – does not always perform as expected (Chen *et al.*, 2015) and often fails to reach its full potential to reduce a building's impact on the environment (Fedoruk *et al.*, 2015; Lützkendorf, 2018). Regarding energy consumption, research shows that almost 90% are not able to reach their goals, and among these, 35% use more energy than their conventional counterparts (Newsham *et al.*, 2009).

The previous statement raises the following question: To what extent does ID, as an innovative process, effectively transform traditional project management practices in sustainable projects? How does ID enhance collaboration between stakeholders during the different construction project life-cycle phases? What are the challenges stakeholders face when seeking to reduce a building’s energy and environmental performance? The originality of this study lies in its analysis of the ID process and its achievements throughout the three phases of a building project, namely: design, construction, and the building’s operations.

In the first section, we present a literature review of project management and the challenges and opportunities that arise when managing sustainable projects. In the second section, we compare ID to traditional practices and detail the sequence of project phases undertaken to achieve a sustainable building. In the third section, we explain how we conducted the empirical study and the iterative process of investigation. In the fourth section, we present the results of the three case studies. The fifth section – the discussion – identifies three challenges that stakeholders face when seeking to improve a building’s energy and environmental performance. Finally, the conclusion draws together the theoretical and practical implications of our research findings. It underscores the need for significant changes in project management in order to create greater value for stakeholders and the final product.

Sustainability in project management

A growing number of studies in the management literature have explored the relationship between sustainability and project management (Eid, 2009; Gareis *et al.*, 2013; Silvius *et al.*, 2012). Eid (2009) has suggested that current standards for project management “fail to seriously address the sustainability agenda.” Silvius *et al.* (2012) have shown that the temporary nature of construction projects – in traditional project management approach – is not compatible with the concepts of sustainable development that considers long-term results. Gareis *et al.* (2013) have also concluded that the long-term orientation of sustainable development often overrides short and mid-term objectives.

Current project management methodologies are dominated by the “triple-constraint” variables of scope, time and cost, with an emphasis on profit (Silvius *et al.*, 2012). Sustainable project management, however, includes social and environmental aspects when measuring the success of the project (Craddock, 2013). Table 43 compares the key tenets of project management and sustainability demonstrating the evident tensions between traditional project management and sustainable objectives.

Table 43. Tensions between traditional project management and sustainable objectives –represented as continuous (Moehler, et al., 2018; Silvius, Schipper, Planko, & van den Brink, 2016).

Traditional Project Management		Sustainable objectives
Short-term oriented	↔	Long-term + short-term oriented
In the interest of sponsors/stakeholders	↔	Building actual and future generations
Deliverable-/result-oriented	↔	Life cycle oriented
Scope, time, budget	↔	People, planet, profit
Reduced complexity	↔	Increasing complexity
Top-down decision-making	↔	Consensus / From bottom up
Fact based	↔	Precautionary
Linear and mathematical analysis	↔	Systemic approach - Ecosystem
Net present value – Internal rate of return	↔	Triple bottom line

Silvius and others have argued that the traditional project management approach presented in the PMBOK® Guide – developed by the Project Management Institute (PMI) – to controlling time, budget and quality suggests a level of predictability and control that is incompatible with the complexity of sustainable projects (Eid, 2009; Labuschagne & Brent, 2005; Silvius *et al.*, 2016). Considering sustainable development principles in project management entails an “enlarged scope” for the project management field (Huemann & Silvius, 2017; Taylor & Jaselskis, 2010).

Fewings (2013) claims that a higher level of integration within multidisciplinary teams eliminates fragmentation between design, construction, and operation and consequently improves overall project performance. The author defines integrated project management (IPM) as a holistic approach that promotes maximum synergy between stakeholders to find new forms of work so as to add value to the project. However, even though IPM increases efficiency and communication at all stages while reducing costs, time and risk, the process ultimately fails to integrate sustainable issues.

At its World Congress held in 2008, the International Project Management Association (IPMA) declared that the future development of the project management profession would require professionals to take “responsibility for sustainability.” That implies that project managers need to take responsibility for the results of the project, including the sustainability aspects (McKinlay, 2008).

Some authors argue that Sustainable Project Management can fill this gap (Moehler *et al.*, 2018; Sánchez, 2015; Silvius & Schipper, 2014). Silvius and Schipper (2014) define Sustainable Project Management as: “the planning, monitoring and controlling of project delivery and support processes, with consideration of the environmental, economic and social aspects of the life-cycle of the project's resources, processes, deliverables and effects, aimed at realizing benefits for stakeholders, and performed in a transparent, fair and ethical way that includes proactive stakeholder participation” (p.79). In other words, this approach aims at achieving traditional project manager objectives while, at the same time, confronting the complexity of sustainable projects (Rodríguez & Fernández, 2010; Sánchez, 2015).

Sustainability in the construction industry

The construction industry consumes vast amounts of resources and energy. Enhancing its performance would thus have a significant effect on sustainability for society as a whole (Huovila & Koskela, 1998). In 1994, the Conseil International du Bâtiment (CIB), an international networking organization, established seven principles for sustainable construction: reducing resource consumption; reusing resources; using recyclable resources; assuring the protection of nature, eliminating toxic substances; applying life cycle costing; and focussing on quality. More recently, Kibert (2013) has defined sustainable green buildings as “healthy facilities designed and built in a resource-efficient manner, using ecologically-based principles” (p.8). Sustainable construction aims at reducing a building’s impact on the environment and increasing the quality of life of its occupants.

The traditional silo-type, linear, and fragmented structure of the industry throughout its production life cycle remains, nonetheless, a significant barrier to reducing a building’s impact on the environment (Reed & Gordon, 2000). In Rethinking Construction (1997), Egan suggested that an integration between phases and suppliers was necessary to increase the construction industry's efficiency. Evbuomwan and Anumba (1998) go further, criticizing the "over-the-wall" approach used in traditional design management that produces design documentation in a sequential and isolated manner. The design deliverables of each speciality are prepared separately by individual professionals or firms and assembled at an advanced stage of the process (Cole *et al.*, 2008). This leads to a conflict between expected and actual project quality. It also prevents the project team from pursuing system optimisation (Magent *et al.*, 2009). The isolation and fragmentation of disciplines during the design phase continues throughout the building construction and operation life cycle. Six different types of fragmentation arise during the entire building life cycle:

- Design project fragmentation: The disjointed and sequential character of traditional design practice as well as the increasing specialisation of roles lead to sub-optimal solutions, poor constructability, and operability (Huovila *et al.*, 1997).
- Procurement fragmentation: Conventional procurement methods and contracts create adversarial relationships between parties reinforcing socio-cognitive barriers that hinder team efficiency and the collective search for new ideas (Forgues & Koskela, 2008; Mossman *et al.*, 2010).
- Construction fragmentation: The industry is composed of a vast number of small and medium enterprises that work together for only short periods of time (Mossman *et al.*, 2010).
- Labour fragmentation: Accreditation for workers in construction (since 1969 in Canada) has fragmented the workforce by trade, sector, and geographic area. Highly specialized labour with a growing numbers of trades (152 different required skills in total) delay the process (Globe-Advisors, 2013; Kozhaya & Duhamel, 2016).
- Supply chain fragmentation: The temporary, project-based nature of construction projects hinders integration of construction supply chains (Cheng *et al.*, 2010). The supply chain is divided into a large number of different projects, suppliers, resources, and required equipment (Arrotéia *et al.*, 2015).

- Facility management fragmentation: Construction fragmentation leads to inadequate information exchange between project phases (Bonanomi, 2016). Disconnection between the design and facility management teams compromises whole-building performance (Wilde, 2018).

Integrated Design for Sustainable Building

ID emerged in the 2000's as an alternative to traditional practices for the design of high performance and sustainable green buildings (Busby Perkins+Will & Stantec Consulting, 2007). It aims at increasing the efficiency with which buildings use energy, water, and materials. ID promises to reduce a building's environmental impact "through better siting, design, construction, operation, maintenance, and removal – the complete building life cycle" (Robichaud & Anantatmula, 2011, p. 49). Defenders of ID claim that project integration improves building performance and helps to achieve sustainable building objectives.

ID is a participatory process that brings together interdisciplinary teams (professionals, builders, experts, users, and owners) through intensive work sessions – dubbed design "charrettes" – from the early phases of the project (Ghassemi & Becerik-Gerber, 2011). ID often requires a green champion, who integrates activities and stakeholders, and promotes sustainability (Lizarralde *et al.*, 2015). In ID, the project manager assumes the role of a facilitator allowing the team to truly collaborate throughout the charrettes. The objective of the project manager in this case is not only to control design production, but to organize and animate the charrettes (Zimmerman, 2004). The project manager prepares the "charter" with the principle values of the project, the framework for meetings and for guiding the ensuing explorations and discussions (Cole *et al.*, 2011). The project manager must have the vision, ability, and authority to ensure that the design reflects the values and aspirations of the project (Natural Resources Canada, 2015).

Green building certifications, such as LEED®, promote the adoption of ID to deliver sustainable projects (Herazo & Lizarralde, 2015). The decisions taken collectively in ID reduce fragmentation and improve the construction industry's efficiency (Forgues & Koskela, 2009). ID involves a holistic approach that relies upon every member of the project team working collaboratively to implement sustainability goals. The project team, in ID, must consider the whole life-cycle of the building, not just the initial capital investment in construction (Rekola *et al.*, 2012). By developing and sharing new knowledge, all stakeholders generate added value in the process and to the final product (Jayasena & Senevirathna, 2012).

Reed (2009) subdivides ID implementation into three phases: 1) discovery, 2) design and construction, and 3) occupancy, operations, and performance feedback. Similarly, the Roadmap for the Integrated Design Process (Busby Perkins+Will & Stantec Consulting, 2007) – an ID guide commonly used in Canada – proposes three project phases subdivided into ten stages. Mills and Glass (2009) show that in order to successfully deliver a sustainable building, project managers must possess the appropriate skills (i.e. teamwork, communication, leadership and knowledge). The authors also assert that a project can only be considered a Sustainable Building after post-occupancy evaluation and review of building performance. This enlarged scope for sustainable project managers can be visualized in Figure 33.

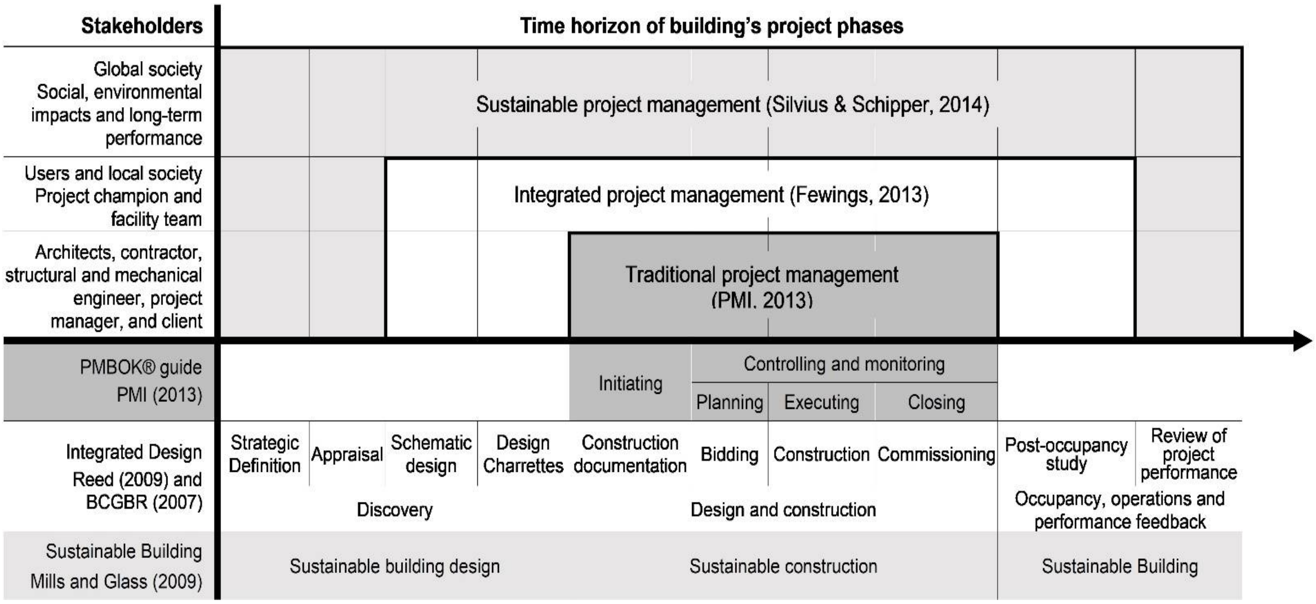


Figure 33. Project phases in traditional project management process practices in comparison to ID and the sustainable project management process based on Silvius, et al. (2012).

4.4.3. Research methods

This study seeks to assess to what extent ID, as an innovative process, improves the management of the project (process) and the performance of the building (outcomes). More specifically, it seeks to verify how ID influence traditional project management practice throughout project life-cycle phases and the project's improvements in terms of energy and environmental impact reductions. In order to meet these objectives, we adopted an exploratory case-study approach. This strategy is employed to inductively generate, rather than deductively confirm, insights regarding the phenomenon to be studied (Ogawa & Malen, 1991). A case-study approach is a reliable means for capturing rich information in complex situations such as construction projects (Barrett & Sutrisna, 2009; Yin, 2003).

An important step in the development of case studies is defining the case or unit of analysis (Knight & Ruddock, 2008). We selected three Canadian projects that: (1) have adopted Green Building Certification, more specifically LEED® (Leadership in Energy and Environmental Design); (2) explicitly adopted the ID approach, as stated at the beginning of their project development design; (3) searched for reductions in potential impacts on the environment (energy consumption and material use), and (4) allowed easy access to data, reports, and stakeholders.

Case study A, the Centre for Sustainable Development, is the first building in Québec to obtain a LEED® Platinum Certification. The project is a demonstration green building that seeks to become a social and environmental innovation hub. Case study B is the Rio Tinto Alcan Planetarium. This building is the second LEED® Platinum in Québec and one of Canada's largest natural science museums. Case study C is the Montreal Soccer Stadium. This LEED® Gold project caters to a growing need for indoor space for soccer practice. Table 44 summarises the main characteristics of the three projects that were ultimately selected.

Table 44. Summary of the main characteristics of three case studies retained for the research project.

Characteristic	Case study A	Case study B	Case study C
Type of client	NGO	Government (cultural)	Government (sport)
Main use	Offices	Museum & entertainment	Soccer stadium
Design tender process	Short invitation	International competition	International competition
Certification	LEED® Platinum	LEED® Platinum	LEED® Gold
Design competition, charrettes and construction documentation	2006 to 2009	2008 to 2010	2011 to 2013
Construction	2010 to 2011	2011 to 2013	2013 to 2015

We collected and analysed about 150 architectural plans and more than 100 documents, reports, articles, and other secondary sources (see Table 45). In each of the documents, we analysed ID charrettes, weighed their theoretical benefits for the project, and analysed the challenges that the PROJECT MANAGER faced in the construction and operation phases. The use of multiple sources of documentation in case study research is important to enhance credibility (Patton, 2015). The research team compared documentary data (reports, archival records) with interview data (Fellows & Liu, 2008). When inconsistencies occurred between the two, the interviewees were contacted to clarify the information. A total of 30 semi-structured interviews with stakeholders involved in the three projects – from different backgrounds, roles, and positions – provided researchers with a detailed picture of the three cases and their environments (Eisenhardt & Graebner, 2007).

Table 45. Numbers of documents analysed in each case study.

Document	Case A	Case B	Case C
ID project meeting proceedings	13	2	7
Energy simulation reports	3	1	1
Lifecycle products analyses	3		2
Client/owner Functional and Technical Program (FTP)	3	1	1
LEED® Green building certification reports	3	3	5
Initial plans (architectural competition ID charrettes) and final plans.	108	22	25
Press releases, videos and magazine articles	28	13	22
Email exchanges, chronograms, and contracts	44	4	13
Post-mortem studies and project evaluation	3	1	2

In the last step, we compared the building performance results from each case. To do so, we created a project baseline – used as benchmarks – named reference building (RB), a construction documentation (CD) which is the result of the case study’s IDP charrettes, and actual performance (AP) measurements, that calculate measured/real consumption (real energy consumption and GHG emissions). The characteristics and parameters of each model are detailed in Table 46 and are valid for all evaluations presented in this study. We then applied an LCA tool – ATHENA® Impact Estimator for Buildings (IE4B) v5.2.0119 – to evaluate the environmental impact for each scenario. The quantitative results from the LCA and energy consumption analyses helped to contextualize the qualitative information obtained from the documents. The results are presented in the following section.

Table 46. Characteristics of RB, CD and AP in case studies.

Case		Reference Building (RB)	Conceptual Design (CD)	Actual Performance (AP)
A	**Building based**	ASHRAE 62.1 and plug load based on NECB 2015.	EE4 v1.7-2 and plug load based on NECB 2015.	Real measurements from the first 3 first years' consumption.
	Building Characteristics	Theoretical project respects Canada Energy Code for Buildings 1997	LEED project; the innovative strategies are listed in Table 5.	LEED Platinum certified with 59 points out of 70
B	**Building based**	ASHRAE 90.1 including electrical equipment.	HAP v4.51 including electrical equipment.	Real measurements from the first 3 first years' consumption.
	Building Characteristics	Theoretical building based on ASHRAE 90.1 - 2007	LEED project; the innovative strategies are listed in Table 5.	LEED Platinum certified with 55 points out of 70
C	**Building based**	ASHRAE 90.1 including plug load.	eQuest v3.64 including plug load.	Real measurements from the first 3 first years' consumption.
	Building Characteristics	Theoretical building based on ASHRAE 90.1 - 2007	LEED project; the innovative strategies are listed in Table 5.	LEED Gold certified with 64 points out of 110

4.4.4. Results

This section analyses how ID influences project management practices in sustainable projects. We also analysed the stakeholder's participation in the three cases. The results will be presented in terms of the different construction project life-cycle phases as rendered by Mills and Glass (2009). The overall results are presented in Figures 23 to 25. In this study, the project manager is the individual hired by the client and the person responsible for understanding the client's goals and ensuring that the whole team is in line with them. The second part of this section analyses and compares the overall performance of the buildings in three project phases.

Project management practices analysis

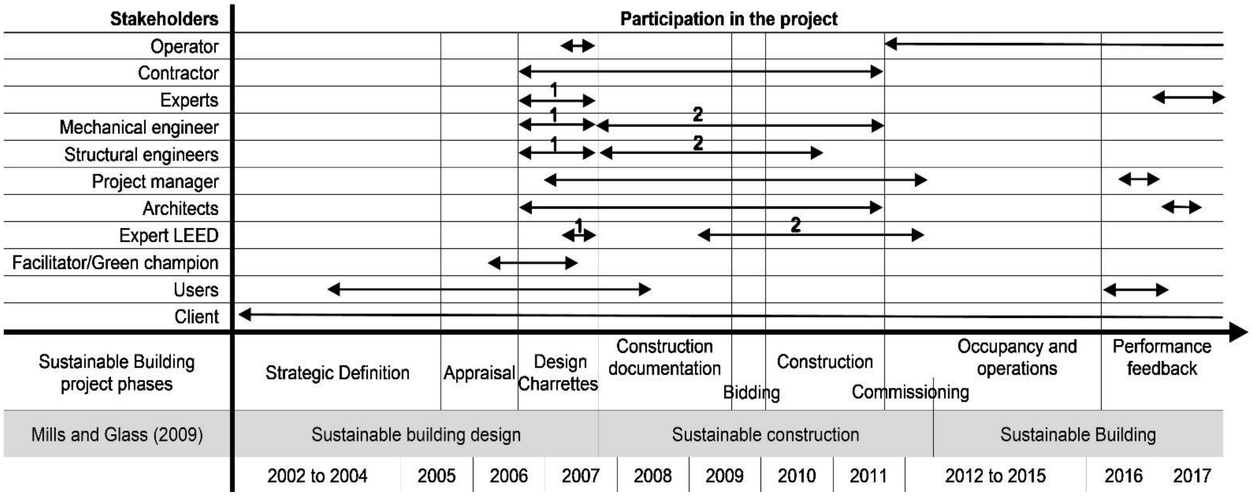
Case study A: The Centre for Sustainable Development

This project started in 2002 when Equiterre, a Canadian environmental non-governmental organisation (NGO), decided to move their offices. In 2004, seven socially and environmentally-minded organisations joined Equiterre to carry out a project that would be an example of sustainability for the City of Montreal: The Centre for Sustainable Development. But it was not until the end of 2005, when a piece of land was chosen, that the project truly got underway. The client started by hiring a green champion to guide them in the strategic definition phase (see Figure 27). A green champion is often required to "provoke and keep alive the activities and attitudes that enhance collaboration and innovation" (Lizarralde *et al.*, 2015). The green champion proposed to hire an entire team of professionals – including engineers and contractor – and not just an architect, as in traditional projects. This strategy was meant to enhance collaboration between stakeholders and prevent the project from being developed in a sequential and isolated way.

The multidisciplinary team was hired in November 2006. In total, 22 stakeholders participated in fourteen charrettes held in a university laboratory. During the first four charrettes, the stakeholders identified the project objectives and brainstorming. The next phase of the charrettes was dedicated to discussing the building functions, distribution, and benefits for future users. At this moment, the project manager was hired by the client. A life cycle analysis (LCA) was used to guide the team to make the choice of the type of structure and some of the building's materials. Building energy simulations (BES) helped the team to choose mechanical solutions for the building. The environmental strategies finally adopted are listed in Table 43.

The bidding process was launched at the end of 2009 and construction began in March of 2010. The client also hired a LEED expert to ensure that enough points were gained to achieve Platinum certification. The same design companies that participated in ID charrettes were also present during the construction follow-up meetings. The professionals representing them, for the architect, were then changed. The synergy and knowledge developed during design charrettes were lost and many issues needed to be re-discussed. The building was delivered in September 2011, as expected. The project respected the $27 million-dollar budget.

The project manager continued to work the project for six more months in order to archive the documents and close the contracts. There were, however, no post-mortem meetings and no reports were produced to evaluate the building's performance at this time. The facility management company, responsible for the building's operation, participated in only one ID charrette during design phase. And even though the team participated in commissioning, the company representatives did not adequately transfer the information to their staff. For example, inadequate operation of the gas heating system in 2013 made consumption more than nine times higher than in 2015 (see Table 48). The client undertook a post-occupancy study to verify building-performance seven years after project hand-over. The study analysed the social, environmental, architectural, and energy performance. The results showed an important gap between anticipated and achieved building energy-performance.



- Arrows represent the beginning and end of stakeholders' participation.
- The numbers signalize when a professional involved in the project changed.

Figure 34. Project phases and stakeholder's participation in Case A.

Case study B: Rio Tinto Alcan Planetarium

In 2000, the city of Montreal launched a feasibility study to expand the Planetarium. The city concluded that the best solution was the complete demolition and reconstruction of the existing building, or even its relocation. That same year, the Montreal Olympic Park organisation offered the city a piece of land in its complex. In 2001, the project manager representing the city conducted a cost and revenue analysis to establish the project's viability.

In 2005, another project manager representing the city worked three more years evaluating the project. He proposed to the city's executive committee: 1) to target a LEED Gold certification; 2) to apply ID in the project; and 3) to hold an architectural competition to select a proposal for its quality and not the lowest bid. In doing so, the City sought to ensure that the project stood out as a unique, ecological building. A consortium of architects, including mechanical and civil engineers, were asked to anonymously submit a design as well as an estimated budget, environmental impacts, and energy consumption analysis. The team's plans were evaluated by a jury mandated by the City of Montreal.

In June 2009, the winning architect's consortium was announced. The group worked in an integrated team from the initial phase of this project – with engineers (civil and mechanical) and a landscape architect. After the contract was signed, the city's project manager, the consultants, and the building operator joined the ID charrettes. The architect played the role of facilitator during all the charrettes. The team worked closely with the neighbouring facility's building team to optimise geothermal energy system, architectural, structural, and ventilation systems. The stakeholders decided to go further to achieve the highest level of LEED certification: Platinum. Twelve stakeholders participated in thirteen charrettes. Due to municipal regulations, however, the contractor was unable to participate.

In November 2010, the project faced two important setbacks. First, the project manager was replaced by another city employee (see Fig. 34). This change led to a review of plans and specifications and to the second setback: faced with exploding costs after a new project evaluation, the new project manager decided to reduce the quality of the project by 25%. The team, during charrettes, simplified the second astronomy-themed amphitheatre, originally planned to be equipped with removable armchairs and a projector, and reduced the size of the restaurant and shop. At this point, a LEED expert was hired to ensure that the LEED Platinum certification could be achieved. The strategies adopted in the final design are listed in table 47.

In June 2011, the construction contract was given to the lowest bidder and began. Documentation analyses show no further mention of ID processes during the construction phase. The construction process faced challenges that could have been avoided if the contractor had participated in the design charrettes. “The demolition of the slabs and the construction of the central elements of the new building impacted the neighbouring buildings, causing rework and delays. But the design was already finished when we were hired, too late for changes” explained one architect. Even with all the construction issues, the project was delivered only 12 days after the expected date, in the winter of 2013. The new Planetarium finally cost $ 46 million, $15 million more than initially planned.

After the building's inauguration, the Planetarium's director and the project manager spent 6 months testing the facility and in the commissioning process. During this time, they solved a number of disputes, especially those related to mechanical installations (ventilation and electrical). The operation team’s participation in the design phase facilitated the transition from handover to building operation. After 4 years of operation, the project still has the same facility team working in building operation, and with relatively successful results (see Table 48).

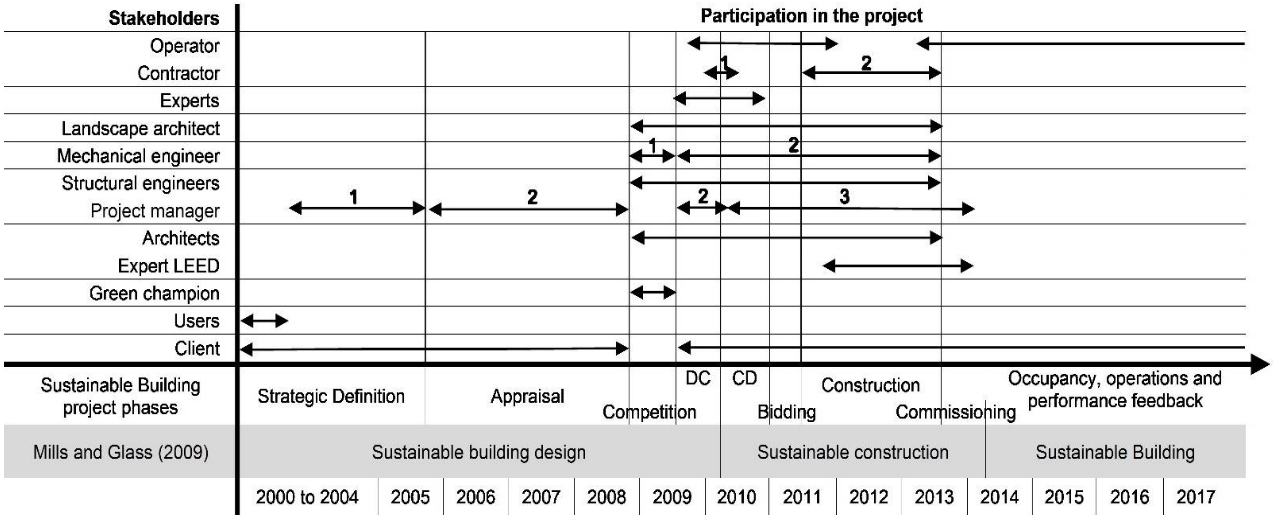


Figure 35. Project phases and stakeholder’s participation in Case B.

Case study C: Montreal Soccer Stadium (MSS)

This project began in the mid-1990s when Concordia regional soccer association (ARSC) showed that an indoor soccer stadium was vital to the development of the sport in Montreal. Almost 20 years later, in 2009, Montreal officially launched the project. The city project managers sought to hire an entire design team to work collaboratively applying the ID process to achieve a LEED Gold Certification for the building. In 2010, however, Montreal changed its plans. The city decided to choose the architect solely through an international design competition (launched in June 2011).

Competitors were informed that they would be engaged in the ID charrettes in the following phase. The winning design was chosen with little information with regards to construction costs, environmental impacts, and energy reduction strategies. Further project development was reserved for the ID charrette phase. Once the architect was chosen, the City hired the other professionals and experts based on the lowest bidder. The project manager, professionals, experts, and other stakeholders joined the architect in the ID charrettes at this point.

The charrettes were led by an external facilitator (see Fig. 36). Only five ID charrettes were initially planned. However, due to the complexity of the architectural solution – a CLT roof structure 68.5 metres long – the municipality was required to add more charrettes. Although the ID charrettes were intended to create a collaborative environment to find innovative solutions, stakeholders found that the ID did not work as intended. According to project manager: “It is difficult to implement radical innovative solutions after the architectural concept has already been adopted.”

In the end, 16 stakeholders participated in fifteen charrettes. During the ID charrettes, the project manager asked the LCA expert to compare structure impacts in order to measure GHG impact reductions comparing a CLT structure to steel. BES was applied to verify that the project met LEED certification targets regarding energy reductions. The ID charrettes’ phase took 6 more months than had been planned. The project manager favoured investing more time in ID charrettes to discuss and evaluate risky design aspects. The environmental strategies adopted by the team are listed in table 43.

The construction phase was launched after the contractor was chosen based on the lowest bid. The contractor's absence during the charrettes left him unaware of the project's limitations. For example, the ID charrettes underestimated the technical issues pertaining to the installation of beams. These issues caused delays and unexpected overcharges. The project was finally completed eight months later, in August of 2016, which constituted the launching of the closing phase.

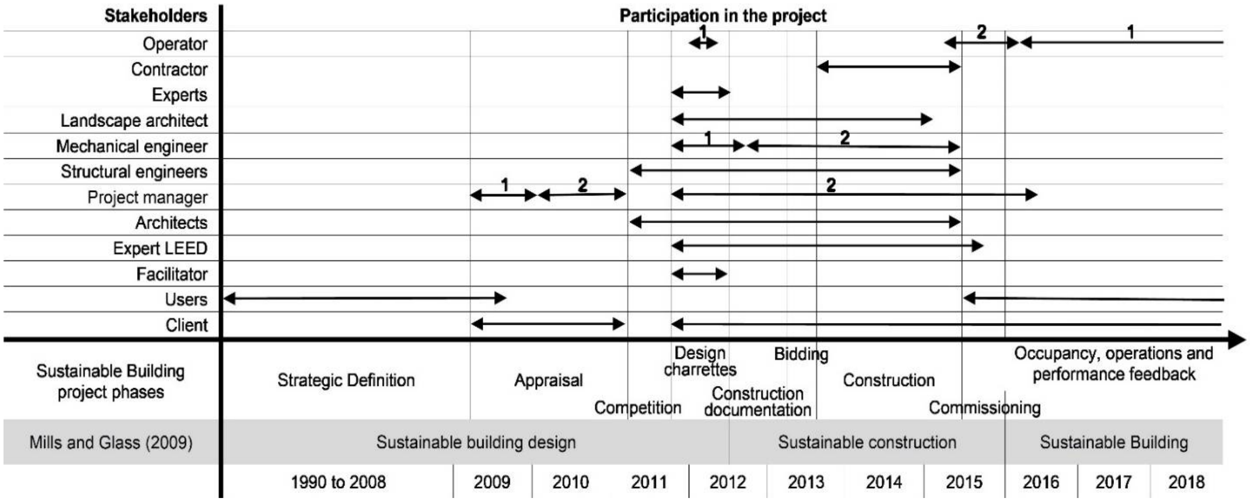


Figure 36. Project phases and stakeholder’s participation in Case C.

The City decided, initially, to operate the building with its own facility team. The team had participated in some ID charrettes and in the last two construction meetings. They also followed the commissioning process to avoid problems operating the building. The City changed its mind, however, and decided to hire an external team. Problems in transmitting important information doubled the gas consumption for 4 months in 2017, slightly decreasing the building's performance for that year.

The City also had an internal team to manage the soccer activities and equipment. This team regretted not being invited to the ID charrettes by the project manager. In fact, many inconveniences experienced by this team could have been easily avoided. One would have been to automate the curtains that divide the fields. An operation that takes 25 minutes and three people to be done manually, could be carried out automatically. Another change would have left one meter more on each side of the field to store the soccer goal when it is not being used. The absence of this space forces the team to carry the goal nets to the storage room with each change of layout. During the first year of operation, consultants were hired to prepare a report to evaluate the ID charrettes and the construction management process.

Projects' performance analysis

Table 47. Innovative strategies used in the three case studies

Innovative strategies	Case A	Case B	Case C
Green roof	X	X	
White roof			X
Raised Floor	X	X	
High-performance envelope	X	X	
Exhaust energy recovery	X	X	
Hybrid natural ventilation		X	
Dehumidification (air) system			X
Triple glazed windows	X	X	
Doubled glazed windows (ceramic fritted)			
Geothermal system	X	X	X
Gearless and room-less elevators	X		
Efficient lighting system	X	X	
Natural light - 80% fenestration			X
Fly ash replacing cement	X		
FSC-certified wood	X	X	
CLT wooden structure			X
Reuse existing structures		X	
Reduce use of material	X		
Local materials			X
Recycled-content products	X		
Recycling waste		X	
Reuse materials	X		
Rainwater recovery in retention basins	X	X	X
Waterless urinals	X		
Dual and low-flush toilets	X	X	X
Faucets with infrared sensors	X	X	X
Vertical living wall	X		
CO^2 control	X	X	X
Low VOC and no formaldehyde materials	X		X

Table 47 show all of the environmental strategies that were integrated into the three case studies. They were subsequently taken into account in the analysis of energy consumption and the environmental impact in the three case studies. The overall goal of a sustainable building is to achieve higher building performance – when compared to reference buildings. Therefore, this study also compares the targets defined during ID charrettes – to reduce building environmental impact – with actual data measured over three years.

Energy use

Table 48 summarizes energy consumption, comparing predicted reductions – the RB and the CD – to actual performance from the first three years of operation. Results shows that in all cases the current consumption (gas and electricity) is higher than in the simulation. There are, however, differences between the three cases. With regards to electricity, Case A consumes more than CD, and even more than RB. Case B consumes almost the same as that predicted by CD, and Case C a little less than the RB – and so, more than predicted by CD. As for gas, Case A consumes 4 times more than expected, but still 5.4 times lower than RB. Case C has almost reached the target established by the CD, and Case B eliminated the use of gas.

Table 48. Energy consumption of RB, CD and AP in case studies.

Case	Energy source		Reference Building (RB)	Construction documentation (CD)	Expected reduction	Actual Performance (AP)				Effective reduction	Gap
						1st year	2nd year	3th year	Average		
A	Electricity	GWh	1,122	722	36%	1,390	1,391	1,512	1,431	-28%	-63%
	Gas	m³	113,645	4,206	96%	10,644	29,046	25,223	21,638	81%	-15%
	Total	GJ	8,321	2,758	67%	5,406	6,103	6,394	5,968	28%	-39%
	Intensity	kWh/m2/year	356	118	67%	231	261	273	255	28%	-39%
B	Electricity	GWh	2,109	1,255	40%	1,500	1,500	1,500	1,500	29%	-12%
	Gas	m³	49,640	0	100%	0	0	0	0	100%	0%
	Total	GJ	9,465	4,519	52%	5,400	5,400	5,400	5,400	43%	-9%
	Intensity	kWh/m2/year	329	157	52%	188	188	188	188	43%	-9%
C	Electricity	GWh	1,621	1,105	32%	1,357	1,364	1,484	1,402	13%	-18%
	Gas	m³	326,964	64,665	80%	60,499	63,563	77,823	67,295	79%	-1%
	Total	GJ	18,154	6,414	65%	7,163	7,307	8,276	7,582	58%	-6%
	Intensity	kWh/m2/year	400	141	65%	158	161	182	167	58%	-6%

Environmental impact

The LCA tool called Athena® IE4B was used to compare the environmental performance of the three case studies. The characteristics of each building are detailed in Tables 46 and 47 and energy-use in Table 48. The LCA results are presented in Table 49 – for Case A, Table 50 – for Case B, and Table 51 – for Case C. LCA results indicate that all cases present a higher impact on the environment than expected. These quantitative results – energy consumption and LCA – contextualize the qualitative information obtained from the project management phases of each case. Discussion of both results is presented in the next section.

Table 49. Environmental impact of RB, CD and AP in Case A

Environmental impacts		Reference Building (RB)	Construction documentation (CD)	Expected reduction	Actual Performance (AP)	Effective reduction	Gap
Global Warming Potential	t CO2 eq	25,621	8,943	65%	16,283	36%	-29%
Acidification Potential	kg SO2 eq	132,552	18,676	86%	33,293	75%	-11%
HH Particulate	kg PM2.5 eq	13,152	5,857	55%	6,801	48%	-7%
Eutrophication Potential	kg N eq	1999.64	834.11	58%	991	50%	-8%
Ozone Depletion Potential	g CFC-11 eq	15.59	16.38	-5%	16.39	-5%	0%
Smog Potential	kg O3 eq	525,969	229,230	56%	274,032	48%	-9%
Total Primary Energy	GJ	488,841	180,024	63%	341,119	30%	-33%

Table 50. Environmental impact of RB, CD and AP in Case B

Environmental impacts		Reference Building (RB)	Construction documentation (CD)	Expected reduction	Actual Performance (AP)	Effective reduction	Gap
Global Warming Potential	t CO2 eq	28,357	13,462	53%	15,540	45%	-7%
Acidification Potential	kg SO2 eq	78,647	18,372	77%	18,919	76%	-1%
HH Particulate	kg PM2.5 eq	11,185	6,668	40%	6,732	40%	-1%
Eutrophication Potential	kg N eq	2,123.66	751.79	65%	763	64%	-1%
Ozone Depletion Potential	g CFC-11 eq	26.05	8.08	69%	8.19	69%	0%
Smog Potential	kg O3 eq	576,530	262,503	54%	267,006	54%	-1%
Total Primary Energy	GJ	581,411	299,946	48%	347,977	40%	-8%

Table 51. Environmental impact of RB, CD and AP in Case C

Environmental impacts		Reference Building (RB)	Construction documentation (CD)	Expected reduction	Actual Performance (AP)	Effective reduction	Gap
Global Warming Potential	t CO2 eq	58,897	22,716	61%	25,926	56%	-5%
Acidification Potential	kg SO2 eq	373,755	105,770	72%	112,700	70%	-2%
HH Particulate	kg PM2.5 eq	47,415	27,656	42%	28,068	41%	-1%
Eutrophication Potential	kg N eq	4,928.88	2,479.65	50%	2,743	44%	-5%
Ozone Depletion Potential	g CFC-11 eq	17.80	33.88	-90%	33.60	-89%	2%
Smog Potential	kg O3 eq	1,373,755	763,983	44%	896,793	35%	-10%
Total Primary Energy	GJ	1,100,282	442,393	60%	508,389	54%	-6%

4.4.5. Discussion

In this paper, we investigated to what extent ID improves project management practices and outputs. The previous section analysed the extensive documentation of the design, construction and operation phases and measured effective global warming potential (GWP) and energy use reductions in ID charrettes collected in three case studies. The data suggest that ID is an effective process in improving the delivery of more sustainable buildings. In terms of outputs, the three projects reduced the GWP by 49% and the energy consumption by 47% (Figure 37).

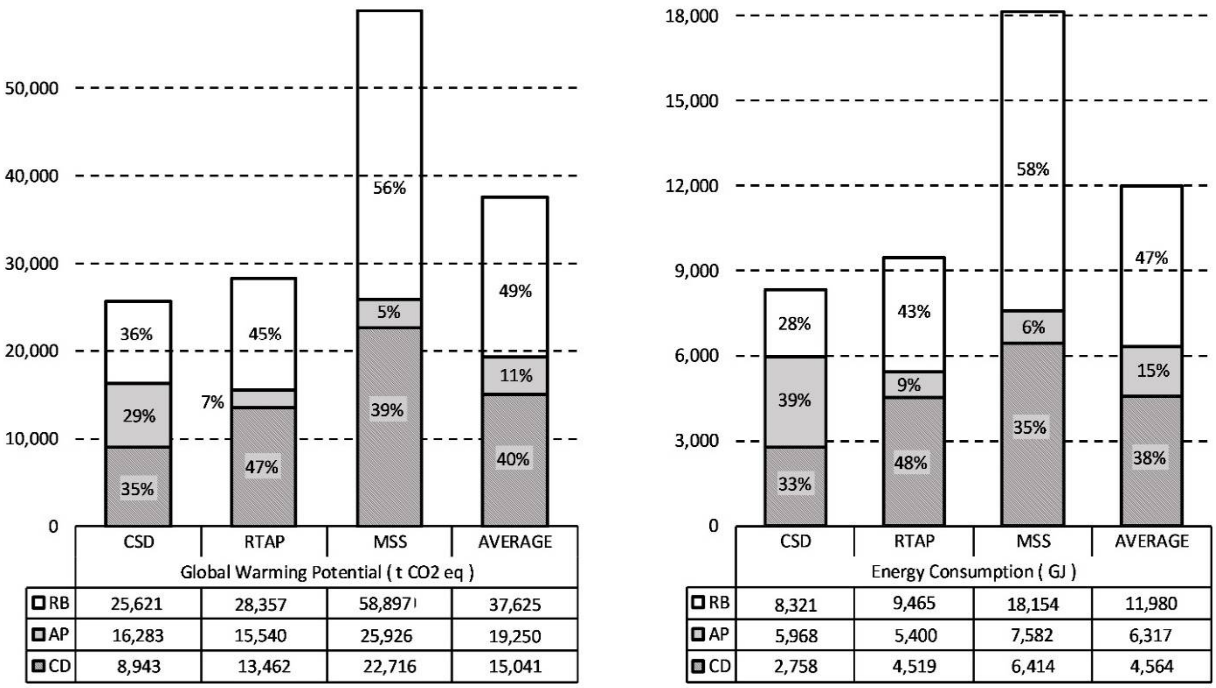


Figure 37. Energy and GWP reductions in the three case studies.

The results showed, however, a gap between anticipated and achieved performance. When comparing the CD to the AP, the projects were, on average, 11% less-performing in GWP and 15% less-performing in terms of energy savings. In terms of project management, the results show that ID was most influential during the design phase. The process alone does not completely overcome fragmentation between stakeholders and subsequent phases. A more in-depth analysis of the data obtained from the case studies highlighted three challenges faced by stakeholders and project managers during ID process. These challenges are viewed in this research as opportunities for project managers and stakeholders to improve project management practices and outputs in ID process.

Insufficient participation in design charrettes

In 2006, when the ID process in Case A was underway, no consensus existed on how to operationalise the ID “charrettes”. The stakeholders participated in 14 charrettes, whereas only seven were planned in the initial schedule. Documents show, and the interviews confirm that waste in the design process hid both innovation and collaboration. One architect contends that “the meetings were too long (some lasted more than 8 hours), and without a break between them to give us time to work on the data.” The client revealed a possible reason for this problem: “[even though] the level of participation was significant, the preparation and organization of meetings and work during the session’s ID could be pushed a little further.”

In Case B, only the design team participated in the first round of charrettes. “The synergy between the professionals was perfect,” said the architect. The second round of ID charrettes started after the architectural competition. With the design already defined, this second round of eight more charrettes included the project manager and all the stakeholders, except for the contractor. The architect organised the charrettes and acted as a facilitator. According to one participant: “We had efficient and successful meetings. The level of collaboration was great but could be better if the contractor had participated also.” The benefits from this synergy, especially between the design team and the future operator of the building, were reported in the results chapter.

Of all three cases, Case C had the most structured ID charrettes. The process was divided into three types of meetings: coordination, workshops, and charrettes. Each of the fifteen meetings were planned and reports were distributed after each meeting to all the stakeholders involved. The client (Montreal) project manager was not the facilitator but had a leadership role in the "steering committee", developing a "charter" and a roadmap with the essential values of the project. However, the ID process analysis showed that there was little room for collaboration and innovation. Interviews showed that despite the project manager's efforts, the meetings followed the traditional linear approach where engineers focused on adjusting solutions to the winning concept rather than proposing radical innovations.

Each of the three studies implemented design charrettes differently. The results corroborate previous research. Forgues (2013), for example, found that ID, in North America, never follows a standard procedure. We identified, in all three cases, a higher level of collaboration between stakeholders compared to standard project management process in design phase. The interactions, however, were short of what was initially planned. The level of success of a project depends on the organization of ID charrettes and the ability of stakeholders to communicate (Malina, 2012).

The organization of ID charrettes does have an influence on a project's success (Reed & Gordon, 2000). The project managers in the three cases, however, had no contractual engagements to organise the charrettes. Thus, the enlarged role of the project manager in sustainable building projects entails ensuring collaboration between stakeholders during ID charrettes. The project manager thus fills the missing role of planning and organising charrettes, and creates teamwork based on the values defined by the client. Not only the project manager but also the key members of the project team need to be hired earlier in the process, beginning with the project's strategic definition phase. The early development of a sense of a common goal can increase the willingness of the parties to collaborate and achieve sustainability goals (Slaughter, 2000).

Increased project complexity in sustainable building projects

All three projects invested heavily – in terms of time and resources – in the ID charrettes. Case A had 14 charrettes with the participation of 22 professionals. Case B had 13 with 12 professionals, and Case C 16 charrettes with the participation of 16 professionals. Each charrette lasted an average of 5 hours. The initial charrettes in all three cases were dedicated to research for new technologies during brainstorming. The other charrettes sought to analyse and collectively decide which innovations would be implemented. Design professionals are trained to look at functionality, design and aesthetics. In a sustainable building, however, they need to consider the wider context of delivering a low carbon sustainable building (Reed & Gordon, 2000). In other words, the design team needs to evaluate how the building will physically function, the challenges and constraints.

We observed that design teams chose innovative strategies based on little or non-existent performance data. In Case A, the raised floor chosen promised 13% energy reductions. After 5 years, the researchers returned to the building. They found improvements in air quality, but the strategy did not reduce energy use. In Case B, the hybrid natural ventilation promised to reduce air-conditioning needs. In practice, the system proved to be tricky to manage and was deactivated. The rainwater recovery for toilets is not operational. The pipe for transporting rainwater to the tank does not have the proper inclination and the system has been deactivated. All these problems could have been avoided if the facility team had been present during the brainstorming design charrettes. The facility team have know-how from previous projects and know the actual performance data and potential problems with each strategy (Mumovic & Santamouris, 2013). Their experience and feedback with regards to implemented strategies performance can empower professionals in the decision-making process during the design phase (Wang *et al.*, 2013).

During design charrettes, Sustainable projects face more than the usual project management constraints of scope, time, and cost. They also deal with environmental impact reduction (pollution, GHG, and energy). During the ID charrettes, a team of experts were present to compare each solution. However, documentation analyses and interviews showed that project managers were not familiar with the important new tools – such as LCA and BES – to analyse project sustainability strategies. Project managers in sustainable buildings need, therefore, to be familiar with environmental analysis tools to guide the customer in all of these more complex decision-making processes. These analyses usually consider the whole life-cycle of the project (product durability, energy consumption, professional liability, feasibility, maintenance).

Fragmentation between project phases

As described in the last section, all the case studies sought to eliminate silos and enhance synergy between professionals and other stakeholders in the design phase throughout charrettes. This collaboration among stakeholders, however, was not always achieved in the subsequent phases. The construction phase, in our case studies, were very similar to traditional construction management process. The meetings, during construction, were held to follow-up budgets, schedule, payments, and to discuss modifications and additions. One professional in case B said that: "the spirit of collaboration to innovate developed during the charrettes at the beginning of the project was replaced, during construction, by meetings that only sought to reduce costs and accelerate the construction." One new procedure – follow-up meetings to ensure LEED certification score – took place in all three cases. The LEED meetings involved only the design core team and failed to integrate the workers and supply chain representatives, researchers, LCA experts and facility team. The LEED meetings missed the opportunity to build teamwork with stakeholders participating in the construction phase. According to one client representative in case A: "In construction, professionals, workers and suppliers tend to blame others when things go wrong. If they can share problems or propose changes in meetings with the presence of all the stakeholders, they will feel part of the decision process helping to find best solution to achieve enhanced project performance."

Commissioning is an important process in sustainable buildings. Commissioning occurs when the components are tested for functional performance. It is the last phase before the close-out (handover). Case A had a marked fragmentation between the handover and the operation phase. More precisely, we identified fragmentation between the design and construction teams, and facility team. This project faced problems in the first three years of operation when energy consumption far exceeded predictions. When comparing the CD to the AP, case A increased the GWP impact by 29% and consumed 39% more energy. As one contractor in case A explained: “I know that the client had difficulties in the operation, but I was only hired for the construction. Participating in the operation phase was not part of our contract”. Cases B and C benefited from the fact that the facility team was internal to the city staff. “We took part in some meetings during construction”, explained the operation manager in case B. Researchers in England have proposed a soft-landing process “to smooth the entire construction process and mitigate the problems and discrepancies that arise” (Malina, 2012, p. 118). A soft-landing invites designers and constructors to stay involved with the project during firsts three years of operation, and post-occupancy and performance evaluations. It is three years of “continuous commissioning, encompassing planned preventative maintenance and aftercare.” (p.120) The design team help in the fine-tuning of the building. In return, the real data from the building generate valuable information for new projects.

The document analysis showed that the project manager’s contractual engagement in our cases was only to deliver the project on time and to respect the budget and the defined quality. The ID process also recommends enhanced project-manager participation to coordinate charrettes in order to create an environment that successfully explores innovation throughout project life cycle (Zimmerman, 2004). In practice, project managers are rarely hired before the beginning of the design phase. Indeed, it is not uncommon to hire project managers only during procurement and construction phases. Even if a project manager participates earlier in the processes, the case studies show that they did not have the mandate to guide the team throughout the entire project. The expanded role of the project manager in sustainable construction projects implies, however, more involvement in the integration of stakeholders and project phases.

Lack of feedback on building performance

Post-occupancy evaluations (POEs) and review of building performance are two important practices that need to be considered in sustainable building (Mills & Glass, 2009). To create buildings with a greater level of performance, the construction industry needs to create additional avenues of feedback in order to involve design professionals in a learning process (Reed & Gordon, 2000). “Very often, designers and contractor keep using the same strategies, not necessarily because it performed well, but only because they never received any negative feedback,” explained a consultant in case C.

Case A only analysed project performance after the 7th year of operation. Case B followed the project performance, but no formal report was produced. Case C hired an external organisation to evaluate only the design and management process. During interviews, we asked members of design team about the performance of the innovations that they implemented in the case studies (see the list in Table 5). It was relatively easy to obtain from the design team members and buildings’s owner the total final project cost and the real total consummation (water and energy). These data, however, were insufficient to individually analyse the strategies’ performance. In terms of costs, we were unable to isolate the investment by strategy. In terms of performance, we found equipment to measure temperature and CO2, but we were unable to verify COV emissions in any of the projects. None of the cases installed equipment to measure real energy or water consumption separately by strategy. According to the client in case A: “It’s just last year that we hired an expert to measure COV before and after the green wall, and the results showed little benefit. This performance information will help in new projects.” The energy consumption, in case B, was more difficult to calculate. As the building operator explained: “The equipment measures our consumption and that of the neighboring building. In order to have only our individual consumption, we calculated the increase in consumption after the implementation of the new building.” The case A client admitted: “I do not know the return on investment (ROI) of each strategy. For example, rainwater recovery. How much did it cost in concrete [for the retention basin]? And to have two separate pipes for the system? And yet, how much do I save on water each year? It is frustrating not to be able to have this data today.” In addition, some strategies applied – as for example the green wall or the CLT wooden structure – are innovations being used for the first time, and so it is extremely important to access real data performance. The real data – in total investments and actual consumption - is crucial for transparent decisions in low-carbon projects (Kuittinen, 2015).

Project managers in traditional projects rarely take sufficient account of how end-users operate the building (Goodhew, 2016). Because high-performance buildings are more dependent on advanced technological systems, it is important to measure and follow the building’s performance (Way & Bordass, 2005). Reed and Gordon (2000) claim that owners of buildings, designers and contractors should give more importance to the project’s feedback. They suggest that the feedback from real building data is useful in two ways. First, to fine-tune the building so that the building’s performance can be improved. Second, past project experience is useful to evaluate changes in new green projects. In sustainable buildings, project managers are invited to ensure that there is equipment in place to measure environmental strategies and to set up plans – or even be part – for post-occupancy evaluation (POE) for the first three years of occupation. The POE helps professionals involved in the project to uncover the factors of success and failure and to understand where measures fall short of expectations.

4.4.6. Conclusion

The primary purpose of this study was to assess to what extent ID improves project management practices and outputs in green projects. A mixed-method research design – case studies, LCA, and energy analyses – helped us reveal the dynamic character and complexity of the ID process. The data suggest that ID delivers more sustainable buildings when compared to a reference building. The three projects reduced the GWP by 49% and energy consumption by 47%. ID also enhanced collaboration and innovation during the design phase. The results show, however, a gap between anticipated and achieved performance – 11% less reductions for GWP and 15% les reductions for energy savings. In terms of project management, the ID process alone did not completely reduce fragmentation between stakeholders and subsequent phases. A more in-depth data analysis highlighted three challenges that can be seen as opportunities for project managers and stakeholders to improve project management practices and outputs in the ID process.

- Insufficient participation in design charrettes: Project managers in sustainable building projects can integrate the planning of ID charrettes into their contract. By being part of the project from the early phases, the project manager can work to ensure the development of a sense of a common goal that will increase the willingness of the parties to collaborate and achieve sustainability goals.
- Increased project complexity in sustainable building projects: Project managers need to be familiar with environmental analysis tools – such as LCA and BES – to guide the client throughout decision-making processes that consider the whole life cycle of the project (product durability, energy consumption, professional liability, feasibility, maintenance).
- Fragmentation between project phases: It is important for project managers to have the mandate to be the project green champions. This mandate implies the promotion of environmental protections measures and efforts to successfully explore innovation throughout project life cycle, from the strategic definition phase to post-occupancy and performance evaluations.
- Lack of feedback on building performance: Project managers can ensure that all necessary equipment is in place to measure environmental strategies. Is also important, in sustainable buildings, to generate feedback – to understand where things succeed or fall short of expectations – through post-occupancy evaluation and the review of a building's performance during the first three years of occupation.

There are significant theoretical implications of this study. Based on a literature review, this study developed an analytical framework that helps to understand the enlarged scope of project managers' role in sustainable buildings compared to traditional project management process practices. The study validated empirically the importance of ID process in reducing a building's environmental impacts. The identification of the gaps between sustainable project management theory and its practice enabled us to identify four areas where improvements are required.

A practical contribution of these results is their potential use by project managers to determine, analyse, and adjust sustainability objectives during project execution. More specifically, by becoming aware of common knowledge and performance gaps throughout the ID process, project managers can more easily anticipate potential conflicts and facilitate collaboration between project teams. Our results also reveal opportunities for project managers to strengthen their role in sustainable projects. This includes the need for project managers to develop a deeper knowledge of, and familiarity with, life-cycle assessment and energy simulation tools. All of this can help create better projects that achieve higher energy and environmental building performance.

5. DISCUSSION AND CONCLUSIONS

This chapter discusses the main contributions of this dissertation. It begins with a general discussion, revisiting the key findings of each article. This analysis helped me answer the research questions raised in the first chapter. In doing so, the dissertation provides new insight into innovation and collaboration in the built environment, the environmental impacts of buildings, and how to improve project management performance for greener construction.

In addition, this study complements existing research on Integrated Design (ID) by identifying gaps between high stakeholder expectations and effective project performance. The ID model - described in the introductory chapter - was applied to all three case studies in order to illustrate how ID operates in each project. The theoretical and practical implications are presented here alongside potential themes for future studies.

This research generated new understandings and insights about how ID operates in practice. The comparison between the theoretical objectives and the feasibility of ID led us to develop a new ID model - one that is not based on desirable eco-labels or theoretical gains, but on actual GHG reductions. This new model, based on six measures and two spheres of action, is explained later.

5.1. Primary research objectives

In this dissertation, I examined the scope, strengths, limitations, and critical success factors of Integrated Design (ID) in sustainable buildings in the construction industry from both a theoretical and an empirical point of view. Through my literature review, presented in chapter 2, I found that ID's potential to enhance a project's performance is theoretically well-founded. Using the results of the three case studies, this section discusses the empirical evidence of ID's effectiveness. In doing so, this dissertation attempts to fill a gap between understandings of ID theory and ID in practice.

Analyzing the case study results uncovered unexpected tensions, conflicts, controversies, and dilemmas that emerged from studying three applications of the ID process. I will present the results using Chapter 2’s multi-lens framework based on the three relevant bodies of knowledge: (1) innovation and collaboration in the built environment, (2) buildings’ environmental impacts, and (3) project management performance. Explaining the limits of ID would help construction industry leaders understand the flaws in the process and enable them to improve project performance and reduce building impacts on the environment. I analyzed the process as well the values created by the ID process throughout the building's entire life cycle.

5.2. Effective collaboration and innovation

Theoretically, ID favours collaboration among professionals to reduce fragmentation between stakeholders and improve project performance. The process starts in the early phases of the project by inviting all stakeholders (professionals, builders, experts, operators, clients, and users) to participate in intensive design workshops called charrettes (Zimmerman, 2004). The teams then continue to work collaboratively during the construction and operation phases.

The collaboration promoted by ID will ideally facilitate the implementation of innovative practices to achieve more sustainable buildings (Larsson, 2002). However, this theory has been defended without sufficient empirical evidence. In fact, other studies reveal that ID generally fails to achieve its full potential as a facilitator of collaboration (Forgues & Koskela, 2009) and faces difficulties generating innovation (Kovacic & Müller, 2014).

This section sought to understand how three Canadian sustainable projects using ID fostered collaboration and innovation. In the first publication (P1) I identified four factors that inhibit or facilitate collaboration, and subsequently, innovation: (1) the fragmented nature of the construction industry, (2) risk perception, (3) stakeholders' commitment, and (4) efficiency in the design process. I used these four factors as *lenses* to be used to understand *why* these problems occur and *how* they are addressed by practitioners (Figure 38). Finally, I found three tensions that emerged and frustrated the ID process in the three projects I studied:

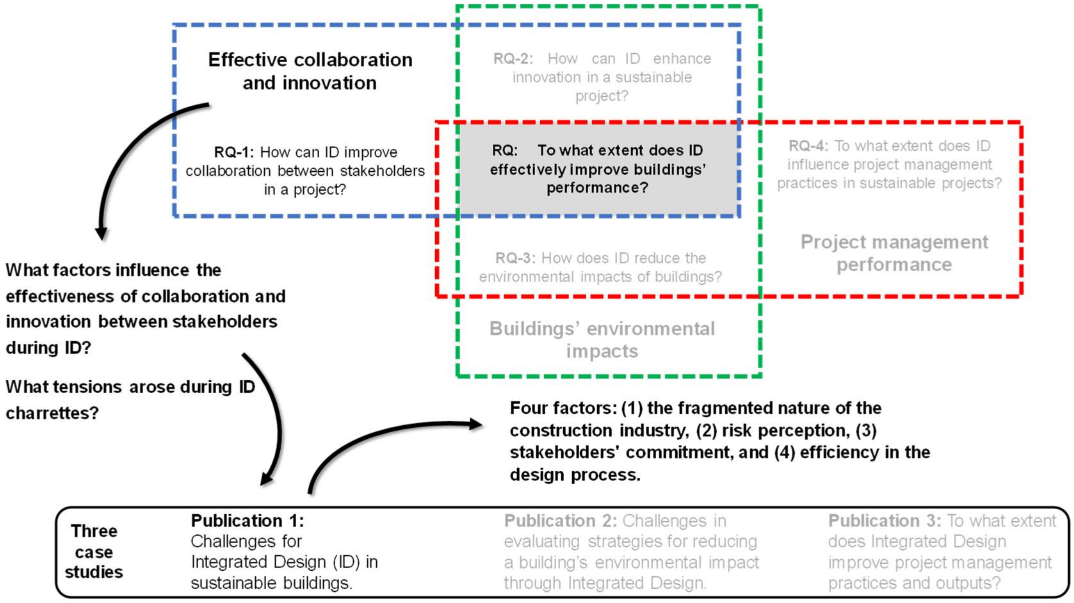


Figure 38. Four factors that inhibit or facilitate collaboration and innovation.

1) Tensions between collaboration and process efficiency (time and effort): I found that poorly prepared meetings and ineffective discussions during ID charrettes lead stakeholders to lose interest in innovation. Professionals do not always see the benefit of collaboration if the price is too high in terms of time, resources, or risk (errors affecting a firm's reputation). Participants do not always see that ID generates value for the project. A tension thus exists between the imperative to collaborate and process efficiency, which hinders charrettes from reaping the full benefits of ID. To realize the benefits of charrettes, stakeholders need to find a balance between the need to involve stakeholders and monetary and non-monetary costs.

2) Tensions between short-term and long-term objectives: Traditional construction management focuses on cost, schedule, and quality and typically involves short-term business cycles. Sustainable project management, however, emphasises low energy consumption, user health, waste, and pollution reduction which benefit the project in the long term. In ID, design professionals are invited to innovate in order to create long-term benefits for the project. However, from a short-term vantage point and the perspective of design professionals, these innovations, risky. I found that the contractual arrangements currently used in the construction industry punish professionals in the case of error. In this sense, Canadian governmental and

professional associations need to develop new contracts and agreements that regulate the sharing of risk and profits among stakeholders.

3) Tensions between new and traditional practices: I found that ID charrettes depart from traditional silo-type practices. This change of paradigm does not take place naturally or without criticism. Professionals see ID as an extreme alternative, encumbered with too many people and too many design options, making stakeholders feel disoriented. I found that design professionals agree that ID practices have the potential to improve project performance. They emphasise, however, that charrette methodologies need to be revised in order to increase their capacity to share and develop knowledge rather than to exchange, aggregate, and store information.

With these tensions under consideration, I identified and analysed the innovations that were applied in the three case studies in my second publication (P2). I analysed the decision-making process and measured the impact reductions of the innovative strategies implemented by design professionals. I analysed why innovation takes place (drivers) and who innovates (actors) as well as the external environment in which the innovation occurs. In doing so, I found that some challenges faced by stakeholders directly impacted the collaborative process to create innovation in sustainable buildings (Figure 38).

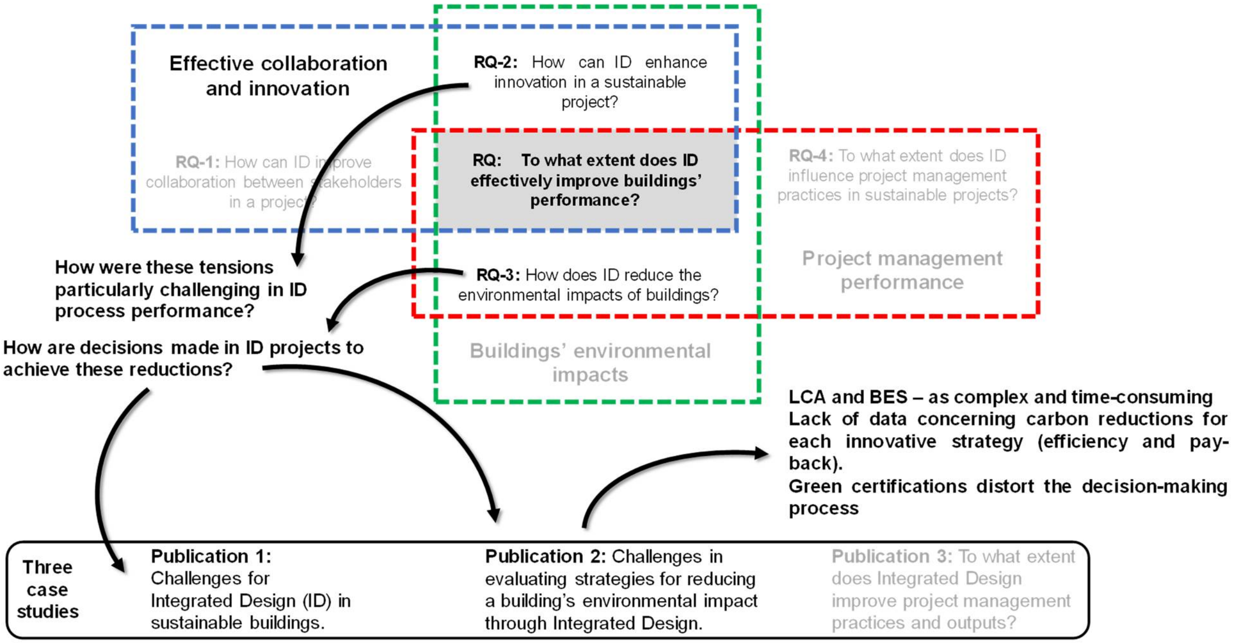


Figure 39. The decision-making process to reduce a building's impact

I found that professionals see the existing tools used to analyse a building's impact – LCA and BES – as complex and time-consuming. Integrating specialised professionals in both fields would fill this gap. They can provide objective information to design teams on key performance aspects during ID charrettes.

Professionals also reported a lack of data concerning carbon reductions for each innovative strategy (efficiency and pay-back). Professionals complained that without proper information, it was difficult to decide which innovation to implement among the ideas created during the brainstorming phase.

I also concluded that green certifications sometimes distort the decision-making process during ID. Discussions often turn to finding products or strategies that add points rather than proposing innovative materials or equipment that may not meet point criteria but have a longer lifespan in reality.

The third publication (P3) revealed opportunities in ID to enhance collaboration and innovation during the construction and operation phases. In theory, the collaborative environment created during the charrettes should continue throughout the project life cycle. I found that as currently practiced, the ID process primarily enhances synergy between professionals and other stakeholders in the design phase during the charrettes. However, the collaboration among stakeholders was not always maintained in subsequent phases.

In the three case studies, the construction and operational phases are very similar to those observed in the traditional construction management process. Professionals also reported during interviews that "the spirit of collaboration to innovate developed during the charrettes at the beginning of the project was replaced, during construction, by meetings that only sought to reduce costs and accelerate the construction." I noticed (in P3) the importance of having a green champion in the team to fill this gap between ID theory and practice (Figure 40). This new professional (or even a new role adopted by traditional project managers) will foster collaboration and innovation throughout the project lifecycle, from the strategic definition phase to the post-occupation and performance evaluation.

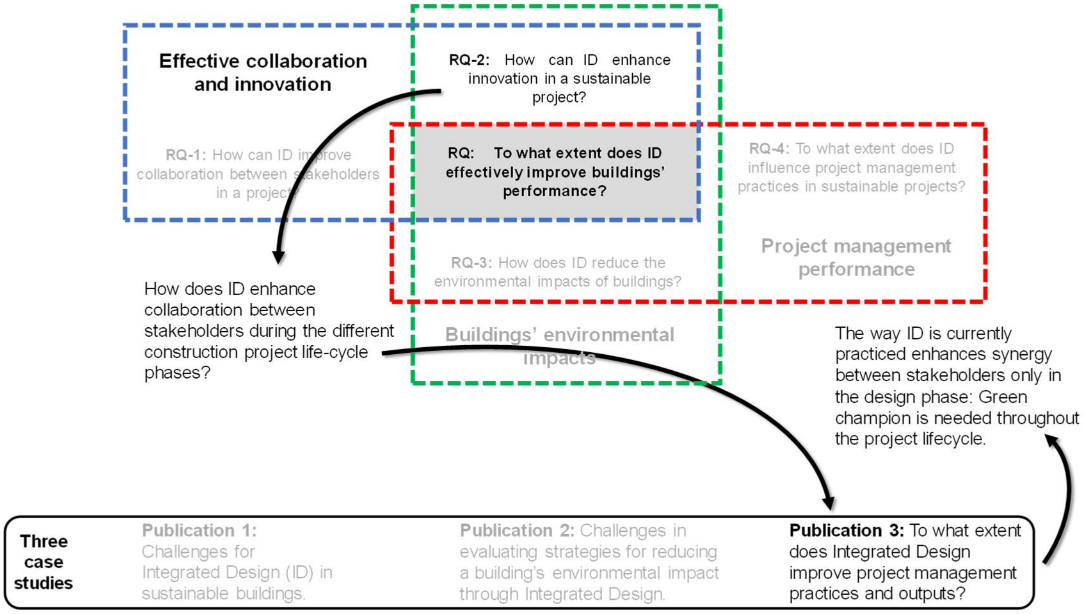


Figure 40. Foster collaboration and innovation throughout the project lifecycle

This section shows that ID can be a powerful tool to change the construction industry's somewhat conservative approach. This change of paradigm, however, does not take place naturally nor without difficulties. The three case studies uncovered novel findings concerning ID's limitations in the enhancement of collaboration and innovation. The results highlight ways stakeholders in the construction industry can improve interactions among themselves in order to promote collaboration and ultimately produce innovative solutions.

5.3. Buildings' environmental impacts

The objective of bringing together interdisciplinary experts and key stakeholders during ID is to share and develop new knowledge that improves building performance (Ghassemi & Becerik-Gerber, 2011). During the ID charrettes, all the issues that impact sustainable building performance are discussed, understood, and confronted from the beginning of the design process (Rekola *et al.*, 2012). The objective is to reduce a building's impact, not only during construction, but also during the operational phase (Natural Resources Canada, 2015).

The review of the literature identified two tools to evaluate a building's impact: Building Energy Simulations (BES) and Life Cycle Assessments (LCA) (Malmqvist *et al.*, 2018; Rivard, 2006). BES is a software-based tool used during the charrettes to model the impact of design options. This helps design professionals find strategies to reduce a building's energy consumption (Coakley *et al.*, 2014). LCA evaluates the potential environmental impact of design options over their entire life cycle: resource extraction, production, transport on site, building operation, and building deconstruction. LCA is theoretically useful for architects and building designers seeking to compare design alternatives. During the operation phase, facility managers can measure the users' behaviour and implement appropriate changes (Hollberg & Ruth, 2016).

It is expected, according to ID theory, that these efforts deployed during the ID process will reduce embodied emissions (material use) and operation emissions (building energy consumption). Other researchers have found, however, that when used to obtain building certifications, ID does not necessarily result in environmental impact reductions (Anand & Amor, 2017; Zabalza Bribián *et al.*, 2009). I also found that the real performance and consumption data from green buildings are rarely available to the public (Turner & Frankel, 2008).

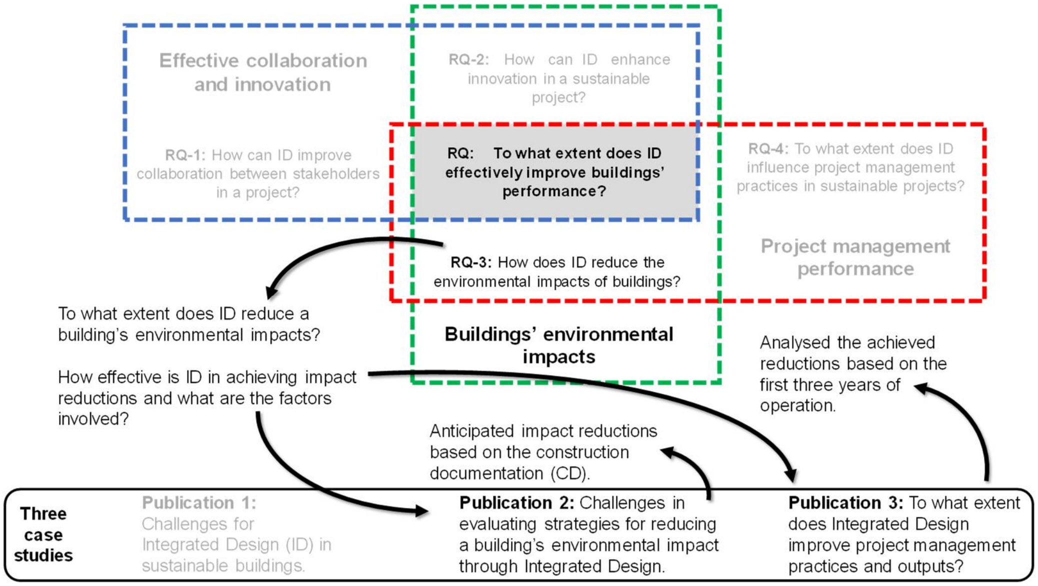


Figure 41. ID efforts to reduce embodied emission and operation emissions.

This section sought to understand to what extent ID reduces a building's environmental impact (Figure 41). The second publication (P2) analysed how decisions were made in the ID charrettes (in the three case studies) to reduce a building's impact. In the same publication (P2), I calculated the anticipated reduction of impact based on the construction documentation (CD). The third publication (P3) went further and analysed the reductions achieved after three years of operation. The tables and graphics below show all the data gathered from the three case studies. The tables compare the reference building to the subsequent project phases: schematic design (SD), or the project after ID charrettes; construction documentation (CD), or the documents and design prepared prior to construction; and actual performance (AP), measurements that calculate measured/real consumption.

Table 52. Energy consumption of RB, SD, CD and AP in case studies.

Case	Energy source		Reference Building (RB)	Schematic Design (CD)	Initial reduction	Construction Documentation (CD)	Expected reduction	Gap	Actual Performance (AP)	Effective reduction	Gap
A	Electricity	GWh	1,122	719	36%	722	36%	0%	1,431	-28%	-63%
	Gas	m³	113,645	0	100%	4,206	96%	-4%	21,638	81%	-15%
	Total	GJ	8,321	2,588	69%	2,758	67%	-2%	5,968	28%	-39%
	Intensity	kWh/m2/yea	356	111	69%	118	67%	-2%	255	28%	-39%
B	Electricity	GWh	2,109	1,767	16%	1,255	40%	24%	1,500	29%	-12%
	Gas	m³	49,640	0	100%	0	100%	0%	0	100%	0%
	Total	GJ	9,465	6,360	33%	4,519	52%	19%	5,400	43%	-9%
	Intensity	kWh/m2/yea	329	221	33%	157	52%	19%	188	43%	-9%
C	Electricity	GWh	1,621	1,099	32%	1,105	32%	0%	1,402	13%	-18%
	Gas	m³	326,964	103,270	68%	64,665	80%	12%	67,295	79%	-1%
	Total	GJ	18,154	7,847	57%	6,414	65%	8%	7,582	58%	-6%
	Intensity	kWh/m2/yea	400	173	57%	141	65%	8%	167	58%	-6%

Table 53. Environmental impacts of RB, SD, CD and AP in case A.

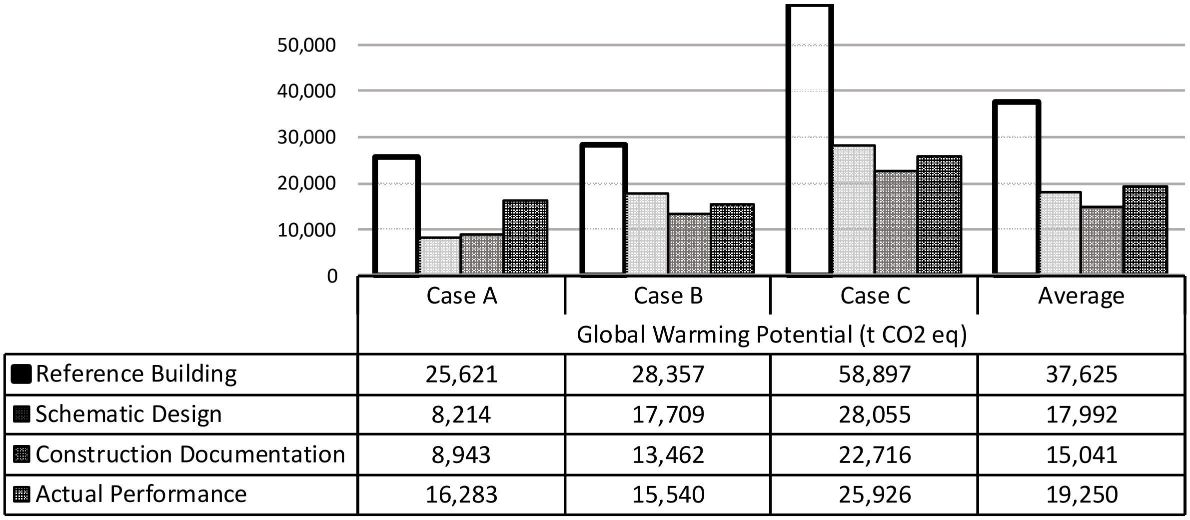
Environmental impacts		Reference Building (RB)	Schematic Design (CD)	Initial reduction	Construction Documentation (CD)	Expected reduction	Gap	Actual Performance (AP)	Effective reduction	Gap
Global Warming Potential	t CO2 eq	25,621	8,214	68%	8,943	65%	-3%	16,283	36%	-29%
Acidification Potential	kg SO2 eq	132,552	13,372	90%	18,676	86%	-4%	33,293	75%	-11%
HH Particulate	kg PM2.5 eq	13,152	4,440	66%	5,857	55%	-11%	6,801	48%	-7%
Eutrophication Potential	kg N eq	1999.64	726.42	64%	834.11	58%	-5%	991	50%	-8%
Smog Potential	kg O3 eq	525,969	205,797	61%	229,230	56%	-4%	274,032	48%	-9%
Total Primary Energy	GJ	488,841	168,136	66%	180,024	63%	-2%	341,119	30%	-33%

Table 54. Environmental impacts of RB, SD, CD and AP in case B.

Environmental impacts		Reference Building (RB)	Schematic Design (CD)	Initial reduction	Construction Documentation (CD)	Expected reduction	Gap	Actual Performance (AP)	Effective reduction	Gap
Global Warming Potential	t CO2 eq	28,357	17,709	38%	13,462	53%	15%	15,540	45%	-7%
Acidification Potential	kg SO2 eq	78,647	20,277	74%	18,372	77%	2%	18,919	76%	-1%
HH Particulate	kg PM2.5 eq	11,185	6,017	46%	6,668	40%	-6%	6,732	40%	-1%
Eutrophication Potential	kg N eq	2,123.66	857.79	60%	751.79	65%	5%	762.62	64%	-1%
Smog Potential	kg O3 eq	576,530	302,017	48%	262,503	54%	7%	267,006	54%	-1%
Total Primary Energy	GJ	581,411	398,591	31%	299,946	48%	17%	347,977	40%	-8%

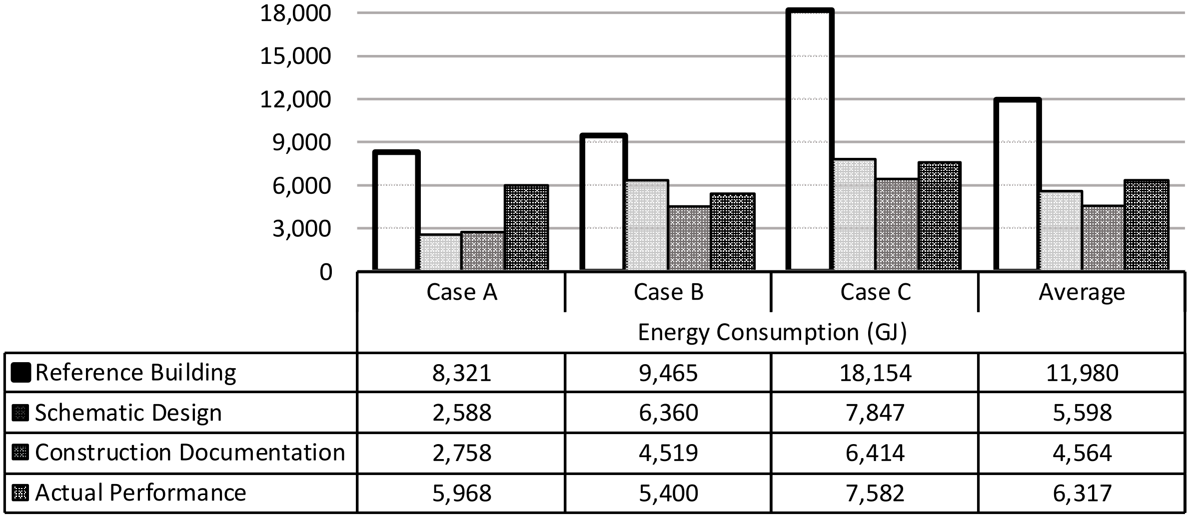
Table 55. Environmental impacts of RB, SD, CD and AP in case C.

Environmental impacts		Reference Building (RB)	Schematic Design (CD)	Initial reduction	Construction Documentation (CD)	Expected reduction	Gap	Actual Performance (AP)	Effective reduction	Gap
Global Warming Potential	t CO2 eq	58,897	28,055	52%	22,716	61%	9%	25,926	56%	-5%
Acidification Potential	kg SO2 eq	373,755	152,364	59%	105,770	72%	12%	112,700	70%	-2%
HH Particulate	kg PM2.5 eq	47,415	30,625	35%	27,656	42%	6%	28,068	41%	-1%
Eutrophication Potential	kg N eq	4,928.88	3,152.16	36%	2,479.65	50%	14%	2,743.10	44%	-5%
Smog Potential	kg O3 eq	1,373,755	967,743	30%	763,983	44%	15%	896,793	35%	-10%
Total Primary Energy	GJ	1,100,282	536,357	51%	442,393	60%	9%	508,389	54%	-6%



	Case A	Case B	Case C	Average
■ Reference Building	25,621	28,357	58,897	37,625
▨ Schematic Design	8,214	17,709	28,055	17,992
▨ Construction Documentation	8,943	13,462	22,716	15,041
▨ Actual Performance	16,283	15,540	25,926	19,250

Figure 42. GWP reductions in the three case studies.



	Case A	Case B	Case C	Average
■ Reference Building	8,321	9,465	18,154	11,980
▨ Schematic Design	2,588	6,360	7,847	5,598
▨ Construction Documentation	2,758	4,519	6,414	4,564
▨ Actual Performance	5,968	5,400	7,582	6,317

Figure 43. Energy consumption reductions in the three case studies.

One important contribution of this thesis is making all the predicted and real performance data from the three projects available to other researchers and professionals. The results from P3 show a 47% reduction in energy consumption and a 49% reduction in global warming potential (GWP) in the case studies when comparing the reference building to actual performance (the average between the three projects). The three case studies failed, however, to achieve the expected performance defined in the construction documentation, showing 15% less energy savings than predicted. The results are consistent with previous research showing that almost 90% of sustainable projects are unable to reach their goals, and among these, 35% use more energy than their conventional counterparts (Newsham *et al.*, 2009). I found the same gap for the GWP targets. There were 11% less GWP reductions than predicted in the construction documentation.

Another contribution of this thesis is that it explains why gaps in GWP and energy reductions targets occur. I engaged in an in-depth analysis of the data obtained from the case studies to identify the challenges faced by design professionals and how to overcome them (Figure 44).

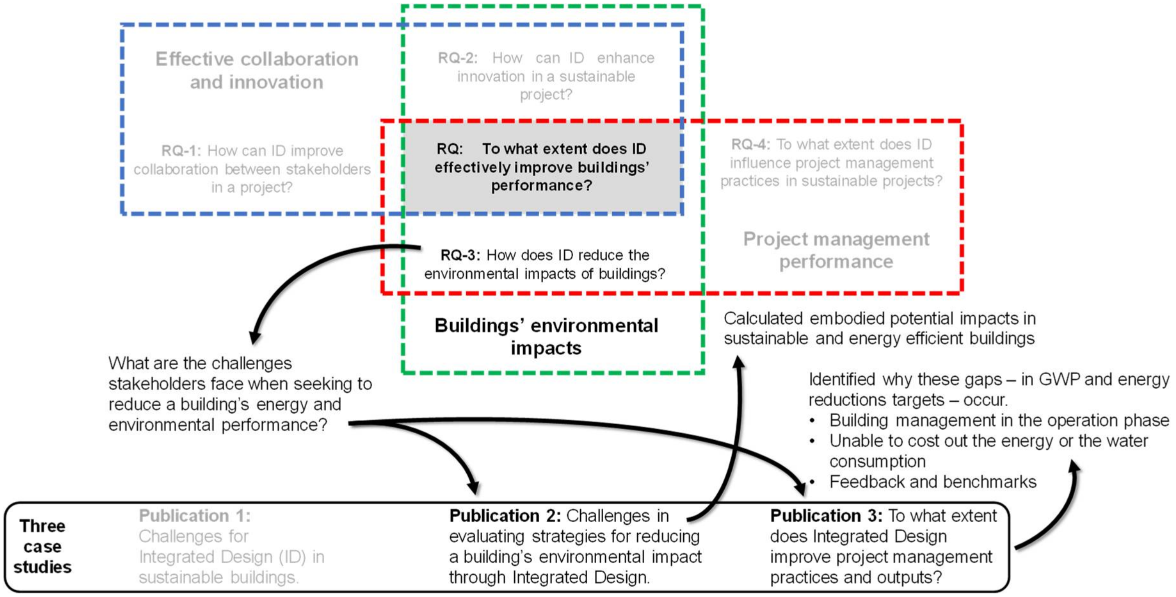


Figure 44. Challenges faced by design professionals to reduce a building's impact.

The second publication (P2) showed how the choice of tool influenced the ID charrettes' performance. I found that highly restrictive or oversimplified software results in models incongruent with reality. The problem is that inaccurate information leads design professionals to make the wrong decision. The software must also be adapted to the type of building being modelled.

The results from BES and LCA depend on data assumptions (input information related to building use). For example, in BES, the adopted building operation hours (P2) did not correspond to reality (P3). In LCA, the strategies and materials under investigation in the ID charrettes were analysed based on the generic building-product data. Comparing schematic design results (P2) and data from actual performance (P3), I realised that important project decisions hinged on incorrect inputs.

Each of the case studies can be considered high-performance buildings. To achieve this performance, they added more materials compared to the reference building (for example, to improve thermal insulation) with the objective of saving energy. The result (P2) is a 61% increase in a GWP impact on the construction phase when compared to the reference building. The ID charrettes must not only seek to reduce energy consumption, but also the embodied energy. The increase of embodied energy during the building construction is disastrous for the environment in the short-term, generating an increase of GHG, which impacts climate change. The search for credits in the certification system often leads to decisions that damage the environment. In the second publication (P2), I examined the addition of materials in case B to achieve the required percentage of recycled products. I found a more environmentally-friendly solution in case A that instead eliminated ceilings in all office areas.

P3 shows the importance of good building management in the operation phase to reach the expected reduction. All projects used more energy than predicted (comparing construction documentation targets to actual performance). I also examined the difficulty of verifying the individual performance of each innovation implemented in the case studies. In terms of costs, I was unable to isolate the required investment by strategy. In terms of performance, I was unable to cost out the energy or the water consumption by strategy. It is important to relay performance feedback from implemented innovations to designers and contractors, who may be using previously established strategies simply because they never received any negative feedback. The installation of real data measurements according to strategy is critical in order to help clients and design professionals make sustainable decisions in the ID process.

This section shows that ID can be a powerful tool to reduce a building's impact on the environment. I identified all strategies deployed in the three case studies, and I evaluated and presented the overall results. In P2, I evaluated the predicted reductions, and in P3, the achieved reductions. Both results will be useful as benchmarks for similar projects and future studies. The challenges confronting design professionals in ID point to areas where practitioners need to expand their knowledge in order to achieve even better results.

5.4. Project management performance

ID promises to reduce a building's environmental impacts "through better siting, design, construction, operation, maintenance, and removal – the complete building life cycle" (Robichaud & Anantatmula, 2011, p. 49). In promoting collective decision-making, ID promises to reduce silos between stakeholders and fragmentation between project phases. When making decisions, the design team must take into account not only the initial investment of capital in the construction, but also the entire life cycle of the building (Rekola *et al.*, 2012).

In practice, however, the process is embedded in a traditional project management environment, which directly influences its results. This section examines how ID effectively influences sustainable project management. First, I analysed other studies from 2008 to 2017 in sustainable project management. The authors of these studies address the need to promote changes in traditional project management to better respond to the demands of sustainability. Since 2008, the International Project Management Association (IPMA) has argued that project management professionals should take "responsibility for sustainability," which implies taking responsibility for the project's results, including its performance during the operation phase (McKinlay, 2008).

Some authors argue that Sustainable Project Management (SPM) can respond to traditional project manager objectives while simultaneously confronting the complexity of sustainable projects (Rodríguez & Fernández, 2010; Sánchez, 2015). Mills and Glass (2009) have suggested that, in order to successfully deliver a sustainable building, project managers must possess the appropriate skills (i.e. teamwork, communication, leadership, and knowledge). The authors also assert that a project can only be considered a Sustainable Building after post-occupancy evaluation and the review of building performance.

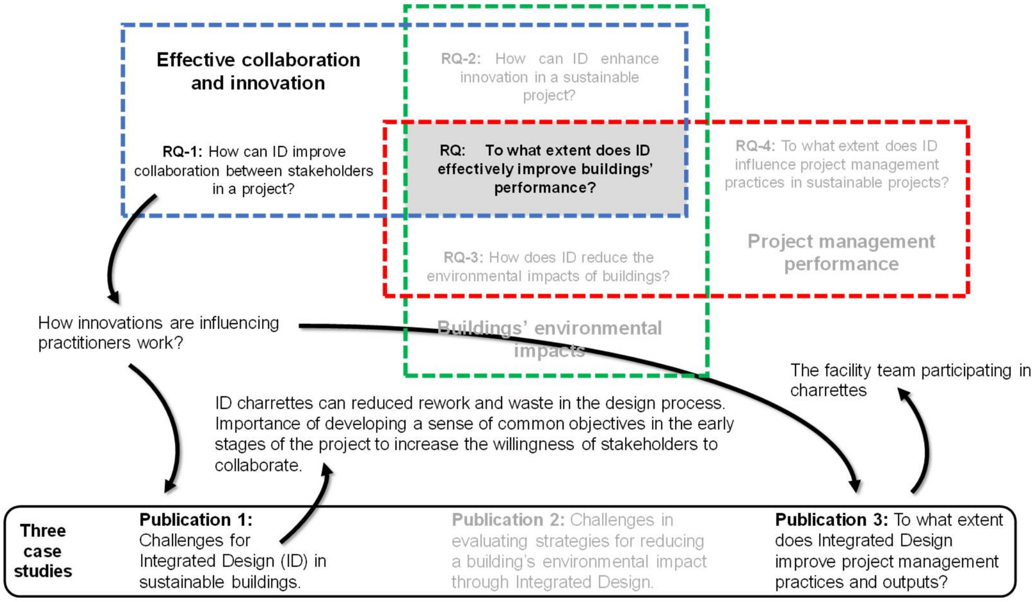


Figure 45. How innovations influence project management in sustainable projects.

After reviewing the theory, I analysed in three publications how ID influenced the management of sustainable projects in practice (Figure 45 and 46). In P1, I identified relevant factors that influence ID performance and uncovered the obstacles to both collaboration and innovation. The publications highlighted the importance of developing shared objectives in the early stages of the project to increase the willingness of stakeholders to collaborate. Collaboration during ID charrettes reduced silos and consequently the fragmentation typical to the traditional building design process. By making decisions collectively, stakeholders were more open to sharing risks when putting forward innovative ideas. The publications also revealed that well-planned ID charrettes reduced rework and waste in the design process. The results of P1 found, however, that this collaboration happens neither naturally nor without difficulty. I unveiled three tensions that occurred during ID, already discussed in the preceding section.

I observed that it would be important for project managers to collaborate in order to reduce these tensions. I developed this subject in my third publication (P3). I continued to study ID charrettes, revealing opportunities for project managers to enhance the ID process during charrettes and throughout the subsequent project phases. In theory, the ID process relies on enhanced project manager participation to organize and coordinate charrettes. This coordination is important for the creation of an environment that successfully explores innovation starting with the charrettes and continuing throughout the project life cycle.

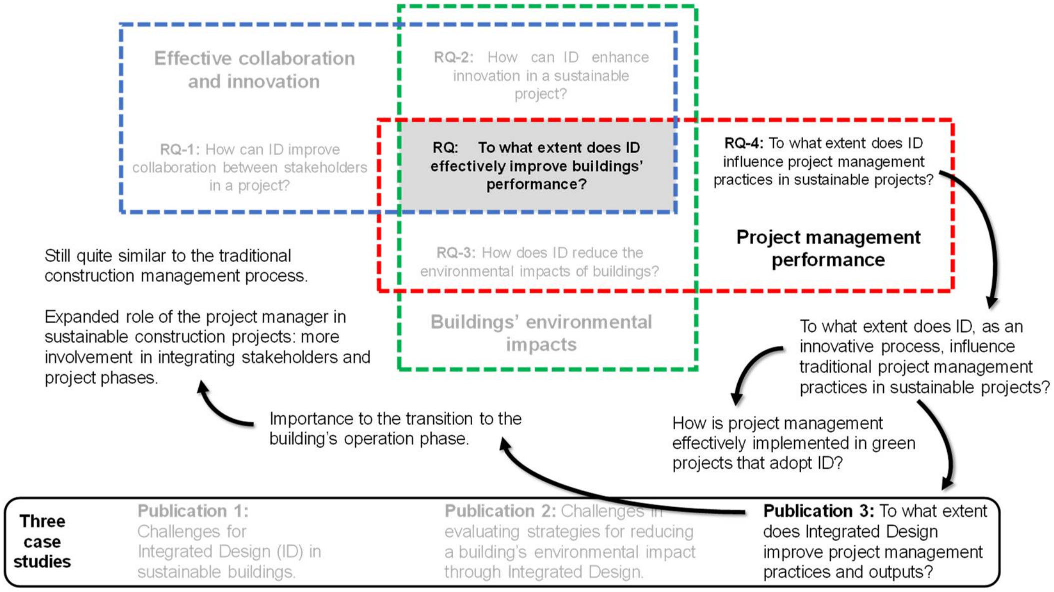


Figure 46. How innovations influence traditional project management practices.

I found, however, that ID in practice mostly enhanced synergy between professionals and other stakeholders in the design phase during the charrettes. Collaboration among stakeholders was not always achieved in the subsequent phases. In the three case studies, the construction and operational phases are quite similar to the traditional construction management process. The cases that I analysed showed that the project manager's contractual engagement was simply to deliver the project on time and to respect the budget and the defined quality. In fact, project managers are rarely hired prior to the beginning of the design phase, and it is not uncommon for project managers to work only during the procurement and construction phases. Even if a project manager participates earlier in the process, the person does not have the mandate to guide the team throughout the entire project. In this sense, the expanded role of the project manager in sustainable construction projects defended by the Sustainable Project Management theory has not been fulfilled in practice.

To change this reality, the contract binding project managers needs to include the new roles that arise in the ID process. In fulfilling these roles, the sustainable project manager ensures collaboration between stakeholders during all ID project phases. Giving project managers the mandate to organise and coordinate charrettes would also give them authority to promote a collaborative environment throughout the life cycle of the project. This is important because I found that the construction phase still adheres to traditional construction management processes. During construction, meetings were held to follow up on budgets, schedules, and payments, and to discuss modifications and additions.

Once the construction was completed, stakeholders did not pay attention to the transition to the building's operation phase. More specifically, the commissioning phase left gaps that negatively impacted the operation phase. Project managers should instead assume responsibility for a soft-landing process. This means being responsible for overseeing stakeholder collaboration in a smooth transition between the construction process and the operation phase, mitigating problems and discrepancies that arise. Being involved in the project during the first three years (the operation, post-occupancy, and performance evaluations) was beneficial to the project, the client designers, and the constructors. The design team helped fine-tune the building. In return, the real data from the building generated valuable information for designers in their new projects.

I also investigated how project managers could improve project outputs. The previous section analysed the impacts of buildings on the environment during the construction and operation phases. The results showed that ID, in all three projects, reduced the GWP by 49% and energy consumption by 47%. The results showed, however, a gap between anticipated and achieved performance. When comparing the construction documentation (CD) to the actual performance (AP), the projects performed on average 11% less performing in GWP and 15% less performing in terms of energy savings. P3 revealed that this gap is related to the increased project complexity in sustainable building projects making it more difficult to operate. Furthermore, I found that during ID charrettes design teams chose innovative strategies based on little or non-existent performance data. The facility team – who has valuable knowledge in actual operating equipment performance – participated in very few charrettes (only one or two in the case studies reviewed). ID theory sees facility team experience and feedback as valuable aids to make better decisions during charrettes. One interview participant from the design team revealed that very often they will continue to apply the same green solution without having data about its real performance or its return on investment (ROI).

To summarise, I concluded that in order to enhance ID process performance, the project manager's role should integrate more tasks and responsibilities. The expanded role of the project manager in sustainable construction projects implies more involvement in integrating stakeholders and project phases. The project manager needs to not only participate earlier in the processes, but also to adopt the mandate to guide the team throughout the entire project. This role – also called project green champion – includes the promotion of environmental protection measures and efforts to successfully explore innovation throughout the project life cycle, from the strategic definition phase to post-occupancy and performance evaluations.

5.5. An analytical model to understand ID in case studies

The first step was to analyze how each project was influenced by ID principles based on the model presented in Table 3 (Chapter 1, Introduction). Even though all projects used ID as a methodology to develop the project, the operationalization of ID was different in each case study. Indeed, some of the design process characteristics tended towards traditional methodologies. Table 55 and Figures 47 to 49 present a summary of the main statements and arguments for each concept.

Table 56. A summary of key ID principles analyzed in the three case studies.

Basis of analysis	Case A		Case B		Case C	
Teams	ID	The team assembled early in the process	P	Professionals assembled during competition	T	Team members assembled late in the process
Process	ID	Iterative process and formal ID charrettes	T	Linear process, non-formal charrettes	P	Formal ID charrettes with some stakeholders.
Organization design	ID	An open, collaborative, and integrated team of key players.	P	An integrated team during the competition only	T	Architect as the main designer for competition
Knowledge and expertise	ID	Shared openly and early in the process	P	Partially shared and late in the process	P	Shared late in the process
Optimization	ID	Full optimization during charrettes	P	Space for optimization late in the process	T	Little space optimization
Costs	P	Construction and operation cost analyses	P	Construction and operation cost analyses	P	Construction and operation cost analyses
Risk	ID	Collectively managed, shared with the client	P	Partially shared with the client	P	Partially shared with the client
Agreements	ID	Multi-lateral to foster collaboration	T	Standard agreements	T	Standard agreements
Measures	ID	Budget, consumption and environmental impact analyses	ID	Budget, consumption and environmental impact analyses	ID	Not only budget output but also environmental
Compensation / Reward	P	Team effort in project's success; non-value compensation	P	Team effort in project's success; non-value compensation	P	Team effort in project's success; non-value compensation
Culture	ID	Learning, continual improvement	P	Willingness for continual improvement	P	Willingness for continual improvement
Thinking	ID	Whole-systems thinking	P	Whole-systems thinking before the competition	T	Systems considered in isolation
Attitude to client	ID	Teamwork understanding users' concerns	T	Contractual and technical concerns	P	Some openness to understand users' concerns
Life cycle	ID	Included post-occupancy study	T	No feedback	P	Partial post-occupancy study
Communications / Technology	T	Digitally and paper-based (2D only)	P	Digitally based and non-integrated BIM	ID	Digitally based, BIM (3 dimensional).
Management practice	P	Opened only during charettes	T	Traditional managing for contract, program and budgets	P	Follow up during construction and first year
Decisions	ID	Decisions influenced by the broad team	T	Decisions influenced by the client.	ID	Decisions influenced by the broad team
Synergies team-members	ID	Time and energy invested early	P	Collaboration in the early stages	P	Partially after the competition

ID Integrated Design P Partial Integrated Design T Traditional Project Design

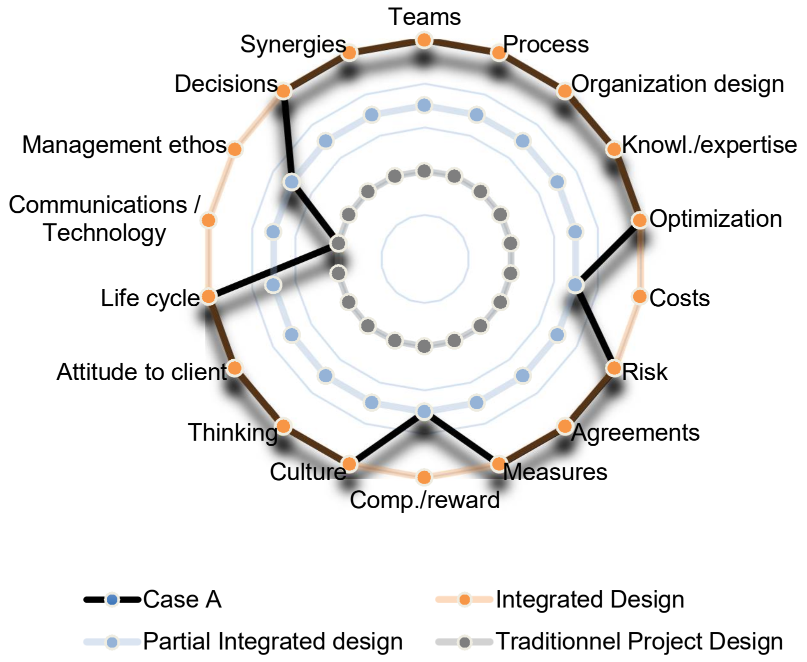


Figure 47. A summary of key ID principles analyzed in case A

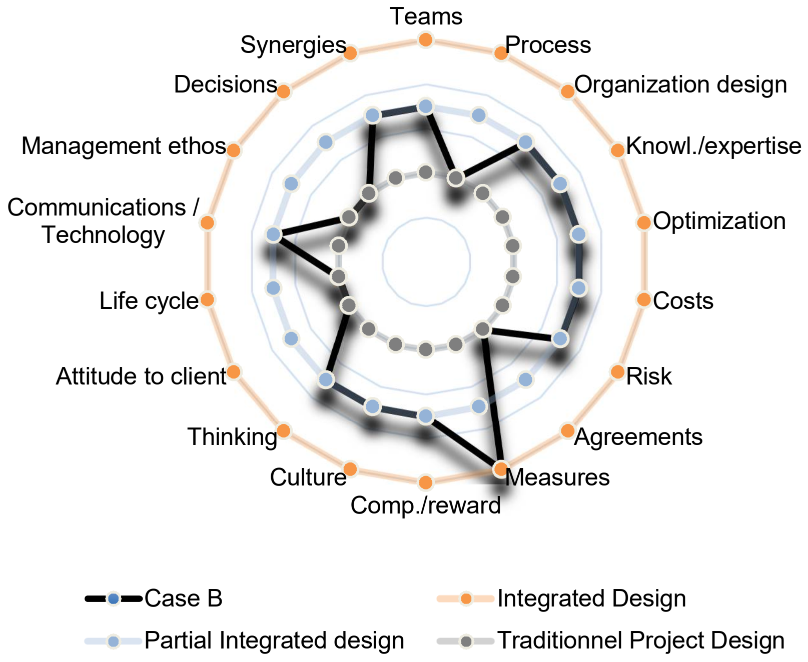


Figure 48. A summary of key ID principles analyzed in case B

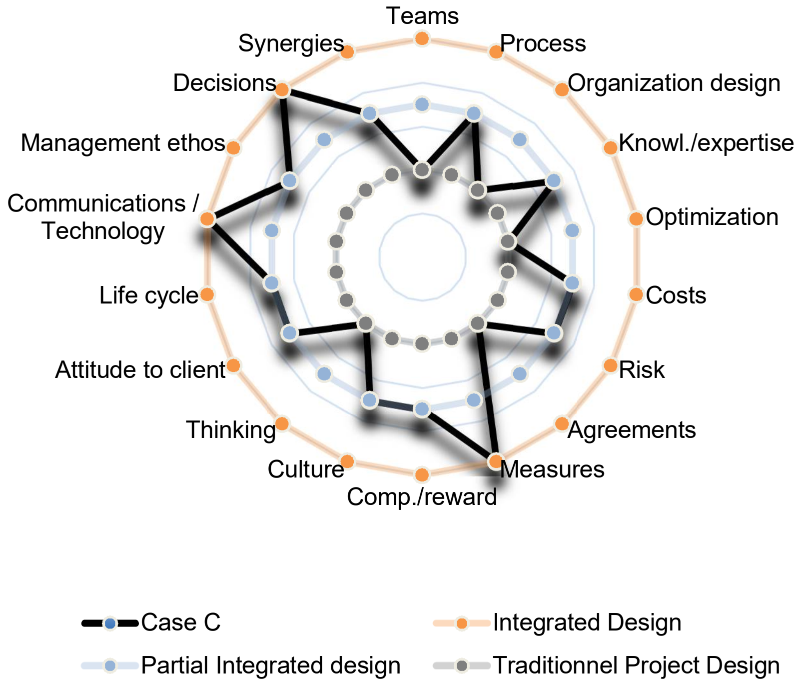


Figure 49. A summary of key ID principles analyzed in case C

5.6. Validity and reliability of the empirical research

I reviewed different research methods and approaches and identified the strengths and shortcomings of the case study method. According to Yin (2003), the validity and reliability of case study research can be evaluated through construct validity, internal and external validity, and reliability methods. I used three of these four tests, since the logic of internal validity is inapplicable to exploratory studies.

For construct validity, I applied triangulation, which implies the use of multiple sources of evidence and data collection strategies (Creswell, 2003; Yin, 2003). I also employed, for all publications, multiple sources of evidence, such as client reports, public documentation, construction documents, and interviews. In all cases, interviews were conducted with individuals who held different responsibilities during the project (design team, clients, users). In addition, I twice interviewed three participants and confirmed information by email with eight others in order to confirm important information. I used selected quotations in the publications to support the main findings. According to the ethical protocols, I will save the case study documentation and interview files for seven years.

Limited external validity is recognized as a weak point of the case study. For this reason, I decided to first test our method in a pilot case study and to subsequently confirm (and, in some cases, adapt) the findings in the three case studies. Multiple cases increase the external validity of the study (Saunders *et al.*, 2012) because replicated findings can be regarded as equivalent to multiple experiments. Before studying the cases, I reviewed the theory and compared it with findings from case studies, which is known to be an effective strategy to improve the generalisation of the results (Yin 2003). The three publications deployed the same three case studies, but used different viewpoints, thus increasing the validity of the study by comparing the effectiveness of the approaches.

Yin (2003) suggests the rigorous use of protocol and databases to ensure reliability in case studies. This is the reason why I described the case study methodology and pilot case study approach in Chapter 4 and Chapter 5. I also developed a protocol for the interviews (see Annex). I sent the ethical and interview protocols to the interviewees before the interviews, including the information concerning the objectives of my research. In addition, for each case study, I recorded and organised the data by themes. The case study database contains interview transcripts, recorded interviews, case study documents, design and construction plans, and initial case descriptions.

5.7. Limitations

Several limitations exist with respect to the examination of the results of this research.. First, the research focused only on three case studies. The small number is justified by the difficulty of finding case studies that can used for doctoral research. It is not easy to find a client and stakeholders who will make all the necessary information throughout the entire project life-cycle (design, construction, and operation) available.

Professionals and clients are often afraid of the results of research, and especially the consequences of such results for the image of their companies.

Second, I chose only projects that sought the LEED® gold and platinum certification, excluding other lower levels of LEED certification. I made this choice because LEED® is the most sought-after certification in Canada. Other types of green building certifications that demands the use of ID exist, for example SbTools, a green certification developed by iiSBE, a non-profit organisation that was created in partnership with Natural Resources Canada (NRCan). Future research studies should compare results from other alternative certifications, such as Sbtools, Living Building Challenge, WELL, BREEAM.

Third, the case studies were concentrated in a particular geographical area. I confined the choice of projects to the Montreal area. The reason here was to limit the variables to different contexts related to other geographical areas. For example, different construction codes, contract commitments or the construction stakeholders' culture.

Fourth, only a limited number of organisations and aspects of stakeholder management are explored in this dissertation. The three cases are institutional projects: two projects were mandated by the government and one by a non-profit organisation. I think that it will be important, in future research, to compare the conclusions drawn here with other contexts (e.g., private real-estate projects) and locations. All these factors limit the generalisations of my findings. Results, therefore, must be used with enough prudence in other contexts.

All the case studies use interview-based evidence. While interviews are an effective method to collect rich empirical data, they often also generate reactions pertaining to data subjectivity. This problem was solved by using other internal and external sources of information, public newspaper articles, and collecting evidence from public participatory meetings that were able to display the studied phenomena in different perspectives.

5.8. Theoretical implications

In this dissertation, I examined the scope, strengths, limitations, and critical success factors of Integrated Design (ID) in creating sustainable buildings in the construction industry through three case studies. Findings revealed that ID has benefits regarding the creation of innovation when the process encourages collaboration between stakeholders. The process also improved project management practices – reducing fragmentation between project phases – and outputs – reducing a building's environmental impacts.

The results showed, however, that the barriers and conflicts that arise during project realisation phases limit ID's potential. More specifically, regarding the first research question (RQ-1), publications 1 and 3 analysed how ID improves collaboration between stakeholders in a project. Results from Publication 1 validate the relevance and value of ID, but also shed light on its limits and help to identify the conditions that allow for the creation of value for all stakeholders.

I examined how and why four factors influenced the effectiveness of innovation in the three cases that I studied. This multi-lens framework that I developed proved to be useful for uncovering three tensions within collaborative and innovative design projects. I also illustrated how those factors interact with the three tensions that I identified, and I highlighted areas where new knowledge is needed to avoid conflict during ID. For example, there is a need to find a balance, in ID charrettes, between project benefits and stakeholders' investments in time, risk, effort, and money. I found that charrette methodologies need to be revised in order to increase their capacity to share and develop knowledge rather than to exchange, aggregate, and storage information.

In publication 3 (P3), I found that the collaboration among stakeholders that was initiated during the charrettes was not pursued in the subsequent phases. The results confirm my findings from P1 that highlighted the need to develop new procurement methods. New contracts are needed to regulate the sharing of profits among stakeholders based on project performance. This shift will facilitate effective stakeholder commitment to long-term benefits during the project's entire life cycle, particularly in an industry characterised by short-term, project-based ways of working. I found that to obtain feedback it is very important to have the stakeholder's collaboration during the operation phase. In practice, however, stakeholders have no contractual engagements to continue to collaborate with the project after the project hand-over.

Publications 1 and 2 answered my second research question (RQ-2) concerning how ID enhances innovation in a sustainable project. I found that in theory, the ID charrettes favour the search for innovative and more environmentally-friendly solutions. The three case studies validate this claim. More intense stakeholder interaction did occur; but most decisions were made intuitively, based on past experience and "common sense" and were rarely based on life-cycle analysis results. In publication 3, I found that real data from projects could fill this gap. But to have this valuable information, the projects must invest in post-construction evaluation. In doing so, real data can be made available to the design team when carrying out new projects.

The results from publications 2 and 3 answered my third research question (RQ-3). To understand how ID helps to reduce the environmental impacts of buildings, I first of all, in P2, enumerated all the innovations that were implemented. Afterwards, I analysed the decision-making process and measured impacts reductions comparing reference buildings, schematic designs, and construction documents – using Life Cycle Assessment (LCA) tools and Building Energy Simulations (BES). In P3, I continued the analysis, studying the building's actual performance.

The results validate the relevance and value of ID to reduce the GWP and energy use but also highlight the limits of ID. Comparing ID theory with its practice, helped me not only to understand how ID processes help to reduce the environmental impacts of buildings in practice but also to identify opportunities for its improvement. In fact, the choice of the most environmentally-friendly design alternative is diminished by challenges that the design professionals faced during the project: (1) the accuracy of the initial data, (2) the level of knowledge of design professionals, and (3) the analysis tools available during the design, construction, and operation phases. These challenges prevent ID processes from achieving their full potential as a method to reduce the environmental impacts of buildings.

Publications 1 and 3 answered the fourth research question (RQ-4), to understand to what extent ID influences project management practices in sustainable projects. Both publications developed analytical frameworks that helped to understand the enlarged scope of the project managers' role in sustainable buildings as compared to traditional project management process practices. The first publication (P1) concluded that ID is an effective way to reduce fragmentation between stakeholders during the design process. P3 analysed the construction and operation phases. I found that ID alone, however, did not completely overcome fragmentation between stakeholders during the construction and operation phases.

A more in-depth analysis of the data obtained from the case studies highlighted challenges faced by stakeholders and project managers during the ID process. These challenges are opportunities for project managers and stakeholders to improve project management practices and outputs in the ID process. I found that it is important to rethink the project manager's mandate by, for example, giving him/her the role of green champion. This mandate should include the promotion of environmental protection measures and efforts to successfully explore innovation throughout the project life cycle, from the strategic definition phase to the post-occupancy and performance evaluations.

Furthermore, project managers, in traditional projects, rarely take sufficient account of how end-users operate the building. Sustainable buildings, however, are more dependent on advanced technological systems. To achieve the expected building performance, it is important to measure and follow the building's consumption. Identifying these gaps between the sustainable project management theory and its practice enabled me to identify areas where improvements are required.

The four questions are all interconnected, even though each question has its own content, research, and expected results. The overall results answered the main question which was to understand to what extent ID improves a project. This thesis empirically established the importance of the ID process in improving project management practices and outputs. Identifying gaps in the integrated design theory allows us to point out areas where improvements are needed:

A shift of paradigm in the relationship between effort and effect throughout the life cycle of the project:

In the theory, ID is presented as a process that continues through the entire life cycle of the project. However, our review of the literature identified that importance is attributed only to the early phase of the projects, especially throughout charrettes. This fact can be illustrated by Pressman (2007) - presented in chapter 1 of this thesis, Figure 7. The benefit of early involvement of all stakeholders has been theoretically demonstrated by many authors as well as in this thesis.

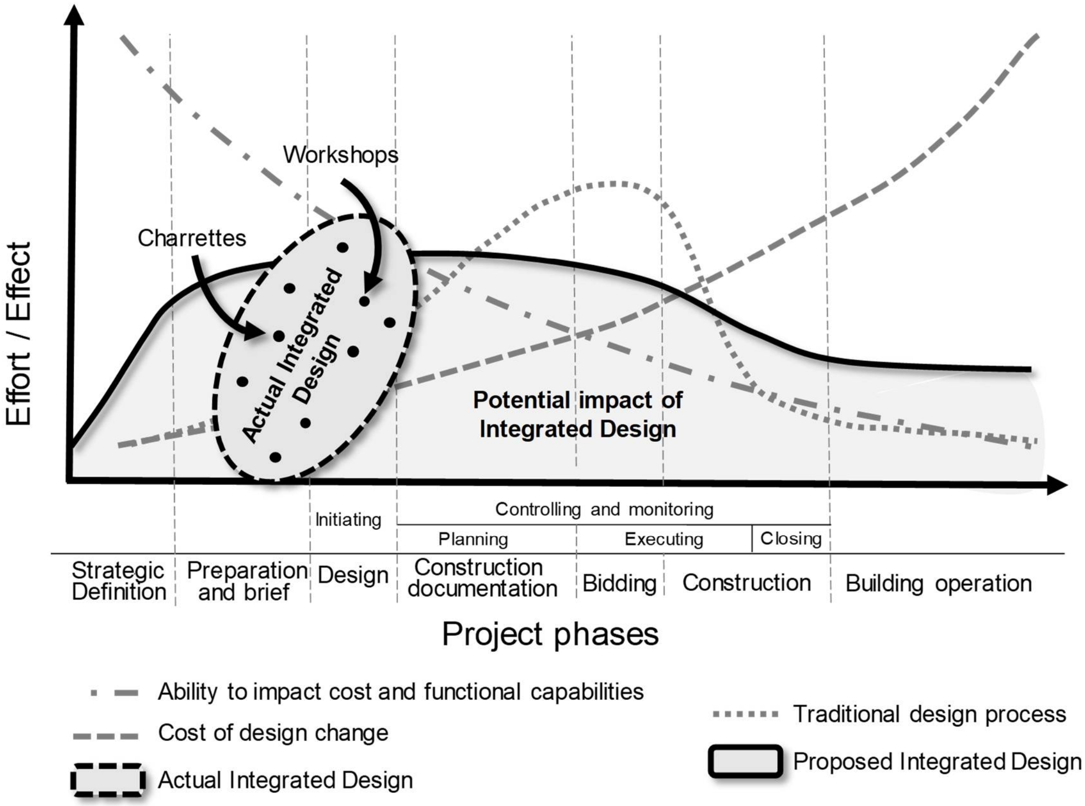


Figure 50. Continuous process throughout the project life-cycle.

However, the authors illustration (Figure 7) demands revision. In order to be effective and have an impact on project quality, ID needs to be a continuous process throughout the life cycle of the project (Figure 50). ID should be examined in its entirety in order for its “effects”, or benefits to be guaranteed. ID should not only be presented as a series of “charrettes” during the design phase but as a collective and continuous effort throughout the process of project realization. In this way, we can be assured that the project vision and performance objectives are maintained. Project quality and performance in ID cannot be guaranteed through piecemeal efforts.

Monitoring the tensions that affect project performance.

In its first publication (P1), this research identified 24 variables that influence innovation and collaboration in the construction industry. Among them, four were recognized, through a pilot project, as those that influence ID implementation most directly. The other publications (P2 and P3) showed that tensions influenced not only the project in its initial phase, but throughout the project life cycle. They also affected the quality of the project. As an example, consider the use of new tools in the realization of sustainable buildings. The LCA and BES tools, although applied in the initial phase, were abandoned in the construction phase. During construction, many materials were changed, modifications in the design were made that impacted and compromised project efficiency and the desired objectives. Similarly, innovative solutions can be abandoned during construction because they are considered risky or costly. They are eliminated without analysing the impact on the project. Recognizing these tensions and establishing a way to control and monitor these variables during the process is important for the improvement of ID performance (Figure 51). This task can be delegated to the champion or to the project manager. The important lesson is that the tensions, which act as push and pull factors, should be monitored in order to guarantee a project’s performance.

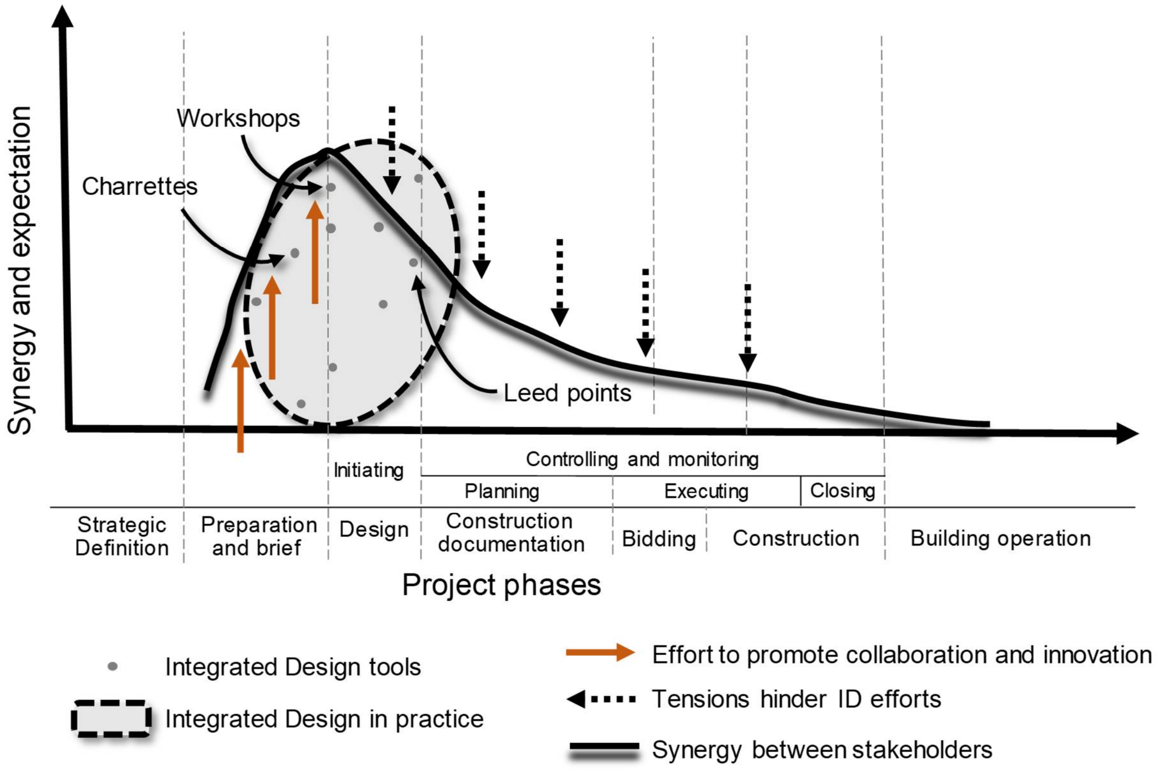


Figure 51. Tensions that affect project performance

Connecting strategic definition and project-performance review.

It is important not only to enlarge the ID procedures (strategic definitions and project performance's review) but also to integrate them. ID is now practiced in an environment saturated by the traditional project management approach. This approach is commonly represented by the Project Management Institute (PMI) and its guide (PMbok). For PMI, the project is initiated in the design phase and finished when the object, the building, is finished. The PMI approach fails to meet society's new aspirations to reduce the impact of buildings on the environment. The result is, and this is something that this research has also identified, is a frustrating environment. During ID, a huge amount of money and energy is invested. However, the initial goals are rarely met. Two changes must be made for ID to take a new approach. The process should start by defining and setting project performance goals during the strategic definitions phase (Target agreement). These principles should be followed throughout the project phases and measured after three years of operation (project-performance review). All the project processes and important lessons should be documented (Figure 52). If this review identifies a gap - between defined goals and actual performance – they will be identified to serve as a lesson. These procedures are critical to avoid mistakes for future projects.

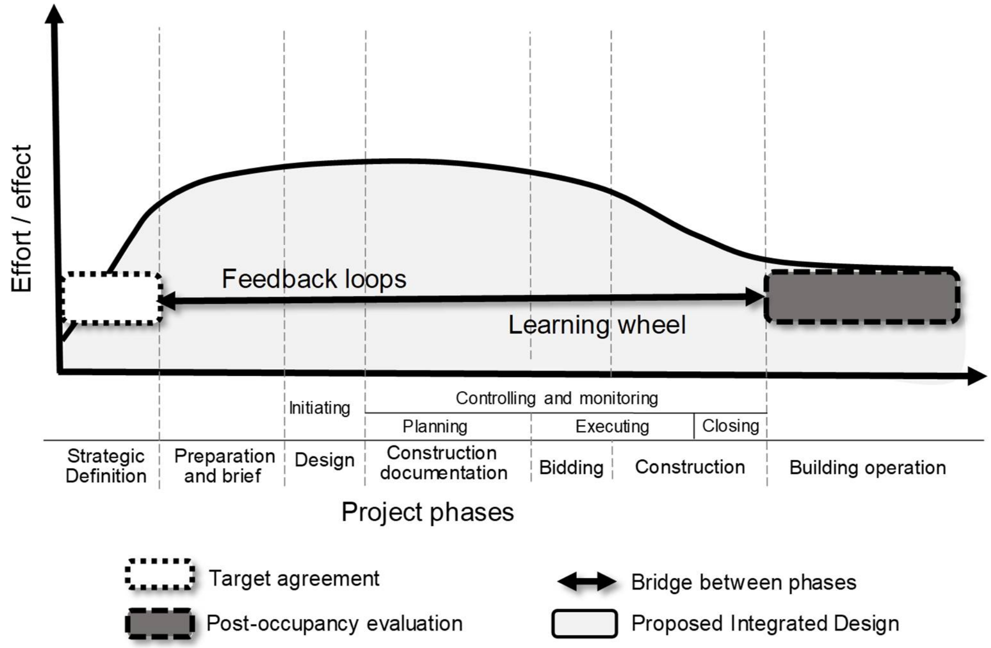


Figure 52. Gap between defined goals and actual performance

5.9. Practical implications

I proposed in this thesis to examine ID in three pertinent bodies of knowledge: (1) effective innovation and collaboration in the built environment; (2) buildings' environmental impacts; and (3) project management performance. I created three case studies in order to understand the way each project applied ID throughout all the project phases. Comparing the results obtained from each of the case studies with those predicted in the ID theory, I identified practical implications for each body of knowledge for ID practices.

In the first publication (P1), I identified the gaps that exist between the theoretical intentions behind ID – to enhance collaboration and the implementation of innovative ideas – and its actual benefits, results, and efficiency. In doing so, I uncovered inherent tensions, conflicts, controversies, and dilemmas within collaborative and innovative design projects. I also illustrated how stakeholders interact facing these tensions, revealing areas where new knowledge is needed to avoid conflicts during ID.

In the second publication (P2), I analysed the processes that each of the three projects applied to choose the strategies to reduce the building's impacts on the environment. The list of strategies and their outcome can be useful as benchmarks for practitioners in similar projects and other studies. Moreover, I found, when exploring the challenges that stakeholders faced during ID, areas where practitioners need to expand their knowledge. A deeper professional knowledge of life-cycle analyses (LCA), for example, would allow them to be even more effective in reducing buildings' impacts on the environment.

In the third publication (P3), I found that project managers are not using their full potential to determine, analyse, and adjust sustainability objectives during the project execution. By identifying performance gaps throughout the ID process, this study helps project managers to anticipate conflicts and facilitates collaboration among project teams. The results also reveal opportunities for project managers to strengthen their role in the ID projects. Their expanded role includes taking greater responsibility in leading the ID charrettes and promoting stakeholders' integration throughout all the project phases. Project managers should also assume the role of project green champions, promoting the environmental protection measures and efforts, from the strategic definition phase to the post-occupancy and performance evaluations.

This dissertation concluded that ID enhances collaboration and innovation and reduces a building's impact when compared to the traditional process. The process alone, however, did not completely reduce fragmentation between the stakeholders and the subsequent phases. The study suggests that project managers and the design team should assume new roles and take more responsibility in ensuring project outputs. To do so, new contractual arrangements between stakeholders need to regulate the sharing of profits based on project performance.

Reducing fragmentation between the stakeholders throughout the project's phases.

This research identified that ID alone did not reduce fragmentation among stakeholders in the subsequent stages of project development (Figure 53). Professionals do not understand the need to collaborate in project development in the phases where they are not engaged. Structural engineers, for example, see no need to be present in meetings where there is, as yet, no architectural diagram. Members of the facility team see no need to be invited to meetings where the ventilation system has yet to be determined.

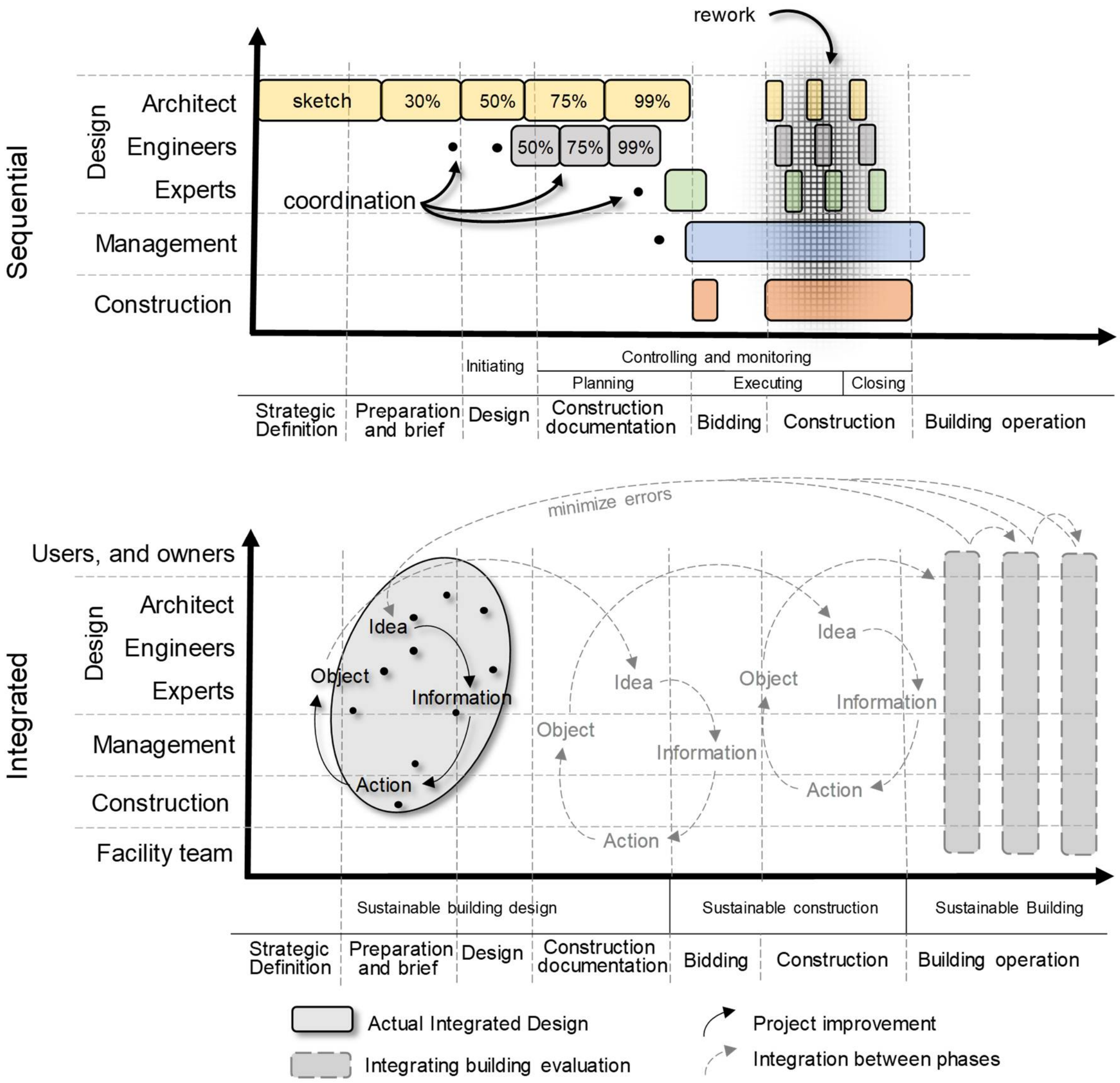


Figure 53. Reducing fragmentation between the stakeholders throughout the project's phases

Similarly, the builder has no interest in returning to his project three years after its completion. This culture of working in silos is still taught in professional schools (architects, engineers, etc.). This division is reproduced in practice. Collaborative culture needs to be part of the curriculum for professionals. Both the design and the operation teams' professionals will benefit from greater integration between the project phases. The design professionals' benefit by having access to valuable information when following and verifying the true building performance. This helps them to improve the performance in new projects. The facility team, when participating in the early stages of the project, help, with their experience, to minimize errors and enable the project to achieve the expected performance.

New roles for design professionals and project managers.

The current Canadian building codes target only energy savings (NRCan, 2016). However, this study identified the importance of reducing the embodied impact of green buildings. Embodied impact – primarily materials used in the construction phase – represents a huge impact in Net-Zero buildings. New buildings codes will include the embodied energy reduction targets (Government of Canada, 2016). Professionals and project managers, according to our results, are not prepared for this new reality. Training and special courses for new design professionals need to be developed in universities to train then to develop knowledge deploying user-friendly LCA tools. The design professionals and project managers should be prepared to assume new roles and take on greater responsibility in ensuring project outputs (Figure 54). They must also install equipment to monitor a building's performance. They are not currently integrating measurement equipment to evaluate the energy and GHG implemented-strategies' performance. Real performance information is crucial in the evaluation of green buildings' strategies to reduce a building's impact on the environment.

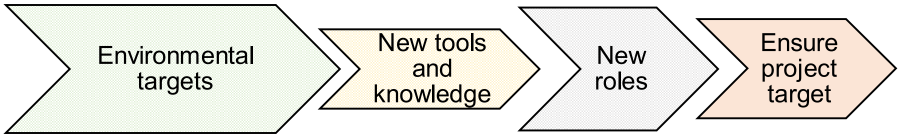


Figure 54. New roles for professionals to ensure project target.

New contractual arrangements to regulate the sharing of profits based on project performance.

The building sector has the potential to help Canada meet its emission reduction target. Buildings represent 17% of total Canadian GHG emissions, that is 126 Mt of CO2 eq. (Government of Canada, 2016). To reduce Canadian GHG emissions, we need new and innovative solutions. ID embedded strategies would help Canada to achieve its reduction commitment in the 2017 Paris agreement (30% below 2005 levels by 2030). However, the way ID is currently practiced offers few benefits to the team of professionals (Figure 55). On the contrary, all liability for errors under current contractual agreements is imputed to them. This research proposes no specific changes. However, the results suggest that there is an urgent need to develop new contractual arrangements to regulate the sharing of risks and profits – between stakeholders, - based on project performance.

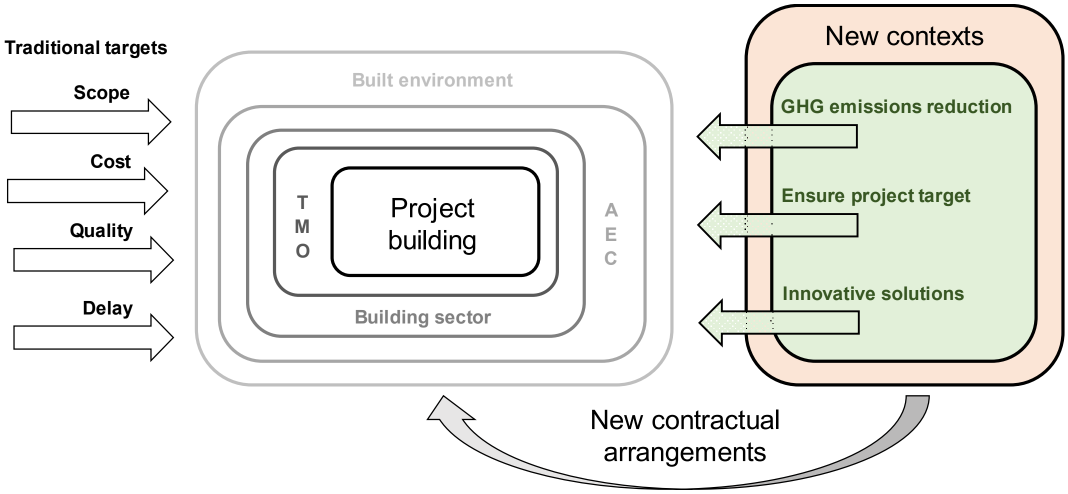


Figure 55. New contractual arrangements for professionals.

5.10. Further research

The research set out to understand the limits and opportunities of the use of ID in the construction of sustainable buildings. Although this research attained its objective, I have identified areas where further research will still be needed. Future research would include other representative cases (real estate projects, for instance) and locations. It might also include comparisons with other cases and studies in other geographical regions. Future research might also explore the causes of changes in stakeholder willingness to collaborate, including the role of internal leaders as well as different procurement methods and available technological tools.

Additional longitudinal case studies could also help scholars and practitioners to understand how stakeholders react in real life/time to the challenges described here. It would be interesting, based on the findings of this dissertation, to follow a new project that has the same concern for respecting the environment and uses ID in order test the hypotheses advanced in this research. Testing the findings from this thesis would not only be useful for practitioners but would also provide an original contribution to the literature.

Based in the three case studies, this thesis showed that, ID, one of the current strategies used in Canada to reduce GHG emissions in the building sector is encouraging collaborative and multidisciplinary processes in building design (Zimmerman, 2004). Other strategies have been the implementation of mandatory energy codes and the promotion of the use of green certifications. It would be useful to examine the interaction between these strategies and to detail their potential in helping Canada to reduce its Greenhouse Gaz (GHG) emissions by 30% below 2005 levels by 2030 (a commitment made by Canada in 2017 in Paris).

It would also be helpful to explore how current contractual arrangements and professional liability hinders the implementation of innovative solutions. As we discovered during interviews, some professionals seemed to be open to arrangements that included the sharing of risks and profits – between stakeholders, - based on project performance. Contracts including these types of arrangements have been applied in California. However, new studies are needed to evaluate their implementation in Canada.

5.11. Conclusion

This thesis is based on three case studies - green construction projects in Canada - that sought to understand the extent to which ID improves the quality of buildings and their relationship to the environment. I interviewed 26 key project-stakeholders and I analysed more than 198 construction documents. In this exploratory study, the qualitative data analysis followed an iterative process of observation, analysis, and reflection. I first identified patterns in the case studies and then compared the patterns to ID theory.

This research revealed that ID is a participatory method that aims at enhancing collaboration and, by doing so, at producing innovative solutions to reduce a building's impacts on the environment. ID is, at least theoretically, a powerful tool for change in the somewhat conservative construction industry. But ID is not without flaws. This study uncovered novel findings concerning ID's limitations through a multi-lens framework based on three bodies of knowledge: 1) effective collaboration and innovation; 2) analysis and evaluation of buildings' environmental impacts, and 3) project management performance.

The categories of analysis identified served as a framework to reveal and understand challenges that typically arise in the performance of ID, challenges that can be seen as opportunities for project managers and stakeholders to improve project management practices and outputs in the ID process. Here, presented according to the project phase, are the proposed improvements to the ID process:

- **Design phase:** ID charrettes are a huge investment in time, effort, and money for most stakeholders. Poorly-prepared meetings and ineffective discussions during ID charrettes lead stakeholders to lose interest in innovation. Charrette methodologies need to be revised in order to increase their capacity to share and develop knowledge rather than to simply exchange, aggregate, and store information. The focus of the meetings should change radically, from simply seeking ecological certification, to looking for solutions that will reverse global warming.

- **The construction phases** in ID are quite similar to the traditional construction management sequence. The contract defines the responsibility of each company to deliver the project on time, respecting the budget and the defined quality parameters. New contracts and procurement methods are needed to regulate the profits and the liability shared among stakeholders – based on project performance (achieved or exceeded) – in order to garner effective stakeholder commitment to achieve benefits in the entire project life-cycle. Construction industry regulation requires urgent change. New building-codes must consider embodied-energy reductions, labelling building systems, the obligation to install equipment to constantly monitor buildings' performance (energy, water and GHG) and so on.

- **Operation phase:** ID promises to reduce silos between stakeholders and fragmentation between project phases. In practice, however, the operation phase is embedded in a traditional project management environment which directly influences its results. This research identified a "wall" between design, construction and operation phases. As it is currently applied, ID continues to underestimate the value of performance measurements, feedback and post-occupation evaluations (POEs). Buildings, as they are presently constructed, do not integrate measurement equipment to evaluate the energy and GHG implemented-strategies' performance. Designers continue to use the same strategies in the absence of proof that the innovations are truly better solutions.

There are significant theoretical implications of this study. Based on a literature review, this study developed an analytical framework that furthers our understanding of the enlarged potential of ID in sustainable buildings as compared to traditional project management practices. The study validated empirically the importance of ID in reducing a building's environmental impacts. This research opens new horizons in ID which require further research. The identification of the gaps between ID process theory and its practice point to the need to change the construction industry regulation – such as professional liability, traditional price-driven (lowest bidding) selection procedures, labeling building systems, building codes, standards, and certifications –

if Canada truly wants to achieve the GHG reductions promised in the Paris agreement in 2017 – 30% below 2005 levels by 2030.

A practical contribution of these results is their potential use by stakeholders to determine, analyse, and adjust sustainability objectives during project execution. More specifically, by becoming aware of common knowledge and performance gaps throughout the ID process, stakeholders can more easily anticipate potential conflicts and facilitate collaboration throughout the entire project life-cycle.

Our results also reveal that stakeholders must take on new roles in sustainable projects. Training and special courses need to be developed, particularly in universities, so that future architects and engineers can deepen their knowledge of collaborative and multidisciplinary processes in construction projects. This includes the need for stakeholders to develop a deeper knowledge of, and familiarity with, life-cycle assessment, energy simulation tools and post-occupation evaluations. All of this can go a long way towards the creation of better projects that achieve higher energy-efficiency buildings and reducing buildings' environmental impact.

This research generated a new understanding and created new knowledge of how ID operates in practice. A comparison between theoretical ID objectives and practical achievement led us to develop a new ID model. The ID model currently applied was developed by the Canadian government in the C-2000 program. Today, 19 years later, the world faces a new reality, with even greater challenges. The need for GHG reductions is real, not just theoretical. What we are looking for today is a new model to follow, not just green labels or theoretical savings. This new model incorporates six measures divided into two spheres of action: one in operational terms and one in organizational terms.

Operational

1) A paradigm shift in the relationship between effort and effect throughout the life cycle of the project: Project quality and performance in ID cannot be guaranteed through piecemeal efforts. ID needs to be a continuous process throughout the life-cycle of the project.

2) Monitoring the tensions that affect the project performance: Tensions that influenced the design phase to persist throughout the project life cycle. These tensions, which act as push and pull factors, should be monitored in order to guarantee a project's performance.

3) Creating a bridge between strategic definition and project-performance review: The project performance goals defined during the strategic definitions phase (Target agreement) should be measured throughout the project phases and after three years of operation (project-performance review). All data will serve as a benchmark for future projects.

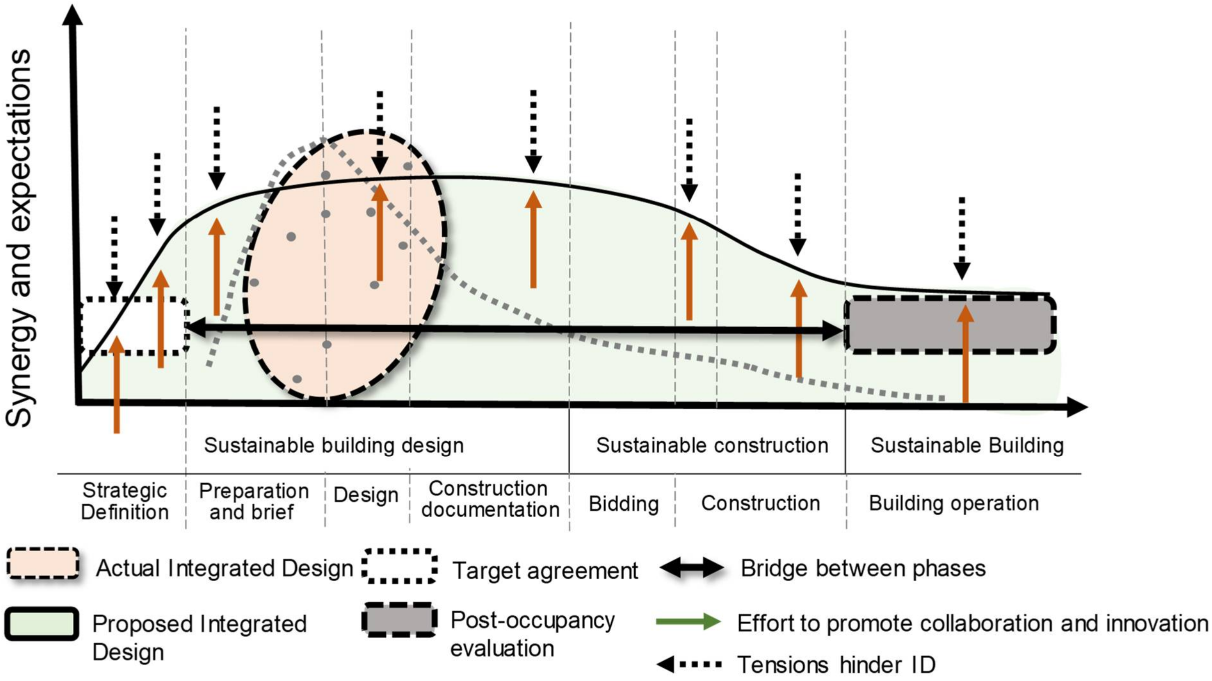


Figure 56. New model for integrated Design: operational terms

Organizational

1) Reducing fragmentation between the stakeholders throughout the project's phases: The culture of working in silos is still taught in professional schools (architects, engineers, etc.) and is reproduced in practice. Collaborative culture needs to be part of the curriculum for professionals. All stakeholders will benefit from more integration between projects phases.

2) New roles for design professionals and project managers: Net-Zero buildings and new building-codes will include the embodied energy reduction targets. Design professionals and project managers should be prepared (Training and special courses) to assume new roles and take on greater responsibility in ensuring project outputs.

3) New contractual arrangements to regulate the sharing of profits based on project performance: To reduce Canadian GHG emissions, we need new and innovative solutions. However, the way ID is currently practiced hinders innovation, imputing responsibility for errors only to professionals.

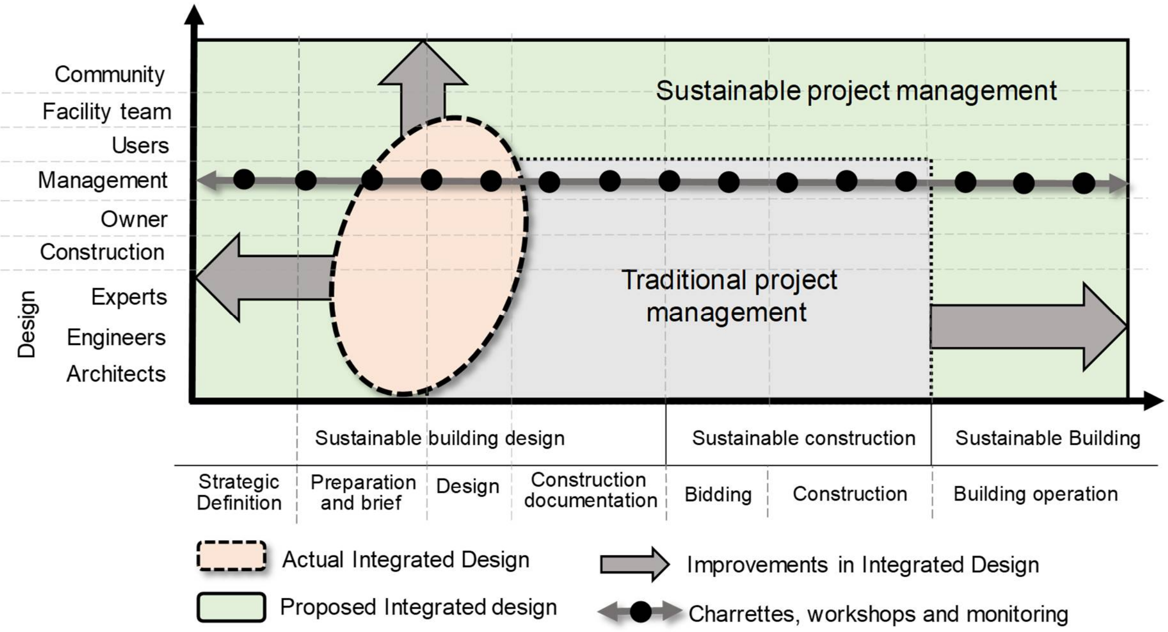


Figure 57. New model for integrated Design: organizational terms

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7. ANNEXES

Annex I. Glossary of terms

Most terms in this dissertation are used in the way they are typically used in professional practice by the architecture and construction community. Given the scope and objective of the dissertation and the existing long debates about semantics in the sustainable development field, we avoid dwelling on a discussion about the meanings and representations associated with terms in this field of knowledge – something we believe is a dissertation on its own. Certain specific meanings are described below:

Built Environment: Is an interdisciplinary field that addresses the design, construction, management, and use of these man-made surroundings as an interrelated whole as well as their relationship to human activities over time (rather than a particular element in isolation or at a single moment in time). The field is generally not regarded as a traditional profession or academic discipline in its own right, instead of drawing upon areas such as economics, law, public policy, public health, management, geography, design, engineering, technology, and environmental sustainability (Chynoweth, 2009).

Green design: A general term implying a direction of improvement in design, i.e. continual improvement towards a generalized ideal of doing no harm. Some people believe this is more applicable to buildings and technology (Reed, 2007).

Project management: Project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements (Project Management Institute, 2008).

Reconciliation design: This design process acknowledges that humans are an integral part of nature and that human and natural systems are one (Reed, 2007).

Regenerative design: This is a design process that engages and focuses on the evolution of the whole of the system of which we are part (Reed, 2007).

Restorative design: This approach thinks about design in terms of using the activities of design and building to restore the capability of local natural systems to a healthy state of self-organization (Reed, 2007).

Stakeholders: Stakeholders are individuals or groups who have an interest or some aspect of rights or ownership in the project, and can contribute to, or be impacted by, either the work or the outcomes of the project (Walker & Rowlinson, 2008).

Sustainable Building: Achieving a sustainable building is not just a matter of design and construction: what happens once the building is occupied is absolutely critical (Mithraratne *et al.*, 2007). A sustainable building can be defined as a healthy facility designed and built in a cradle-to-grave resource-efficient manner, that resorts to ecological principles, social equity, and life-cycle quality value, and promotes a sense of sustainable community (Berardi, 2013).

Sustainable Construction: is “the use of a more integrated team who consider all aspects of the building from cradle to grave” (Andrews *et al.*, 2006). Sustainable construction is the response of the building sector to the challenge of sustainable development (Huovila & Koskela, 1998)

Sustainable design: As a process, 'sustainable building design' happens prior to 'sustainable construction', delivers a 'sustainable building' and facilitates 'sustainable development'; as explained against the typical stages of a construction project (RIBA, 2013)

High-performance building: is one that minimizes resource consumption during design, construction, and over its life, and provides healthy and productive environments for occupants through the application of ‘sustainable’ or ‘green’ principles.” (Magent, 2005)

High-performance design: Design that realizes high efficiency and reduced impact in the building structure, operations, and site activities. This term can imply a more technical efficiency approach to design and may limit an embrace of the larger natural system benefits (Reed, 2007).

Annex II. Ethics approval and consent form

Université de Montréal
Comité plurifacultaire d'éthique de la recherche

28 septembre 2015

Monsieur Ricardo Ferreira Leoto
Candidat au doctorat
École d'architecture - Faculté d'aménagement

OBJET: Reconnaissance d'une approbation éthique

M. Ricardo Ferreira Leoto,

Le *Comité plurifacultaire d'éthique de la recherche (CPER)* a étudié le projet de recherche intitulé « Collaboration et innovation au sein des projets d'architecture durable: limites et opportunités du processus de conception intégrée. » et a délivré le certificat d'éthique demandé suite à la satisfaction des exigences précédemment émises.

Notez qu'il y apparaît une mention relative à un suivi annuel et que le certificat comporte une date de fin de validité. En effet, afin de répondre aux exigences éthiques en vigueur au Canada et à l'Université de Montréal, nous devons exercer un suivi annuel auprès des chercheurs et étudiants-chercheurs.

De manière à rendre ce processus le plus simple possible et afin d'en tirer pour tous le plus grand profit, nous avons élaboré un court questionnaire qui vous permettra à la fois de satisfaire aux exigences du suivi et de nous faire part de vos commentaires et de vos besoins en matière d'éthique en cours de recherche. Ce questionnaire de suivi devra être rempli annuellement jusqu'à la fin du projet et pourra nous être retourné par courriel. La validité de l'approbation éthique est conditionnelle à ce suivi. Sur réception du dernier rapport de suivi en fin de projet, votre dossier sera clos.

Il est entendu que cela ne modifie en rien l'obligation pour le chercheur, tel qu'indiqué sur le certificat d'éthique, de signaler au CPER tout incident grave dès qu'il survient ou de lui faire part de tout changement anticipé au protocole de recherche.

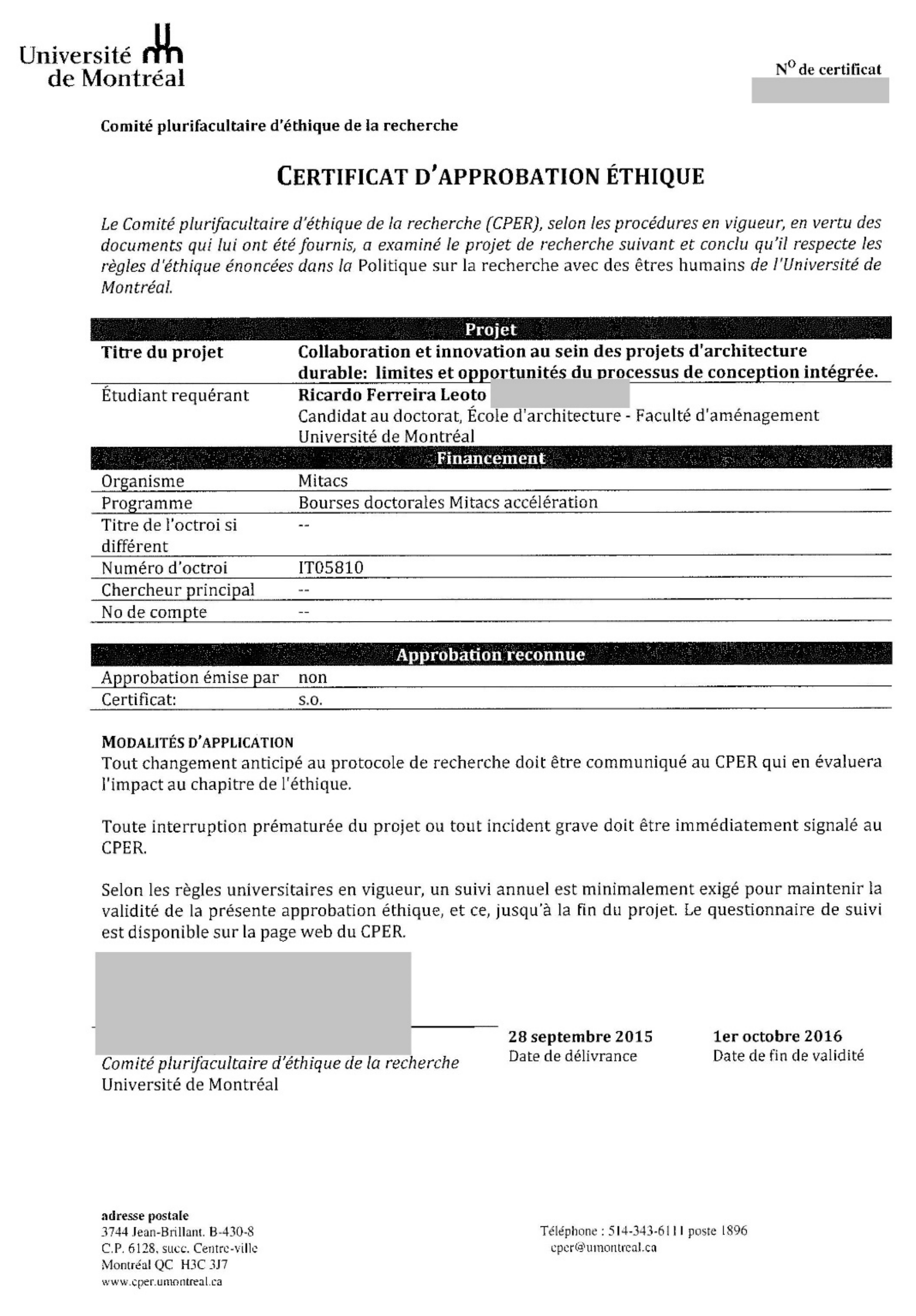
Nous vous prions d'agréer, Monsieur, l'expression de nos sentiments les meilleurs,

[redacted]

Comité plurifacultaire d'éthique de la recherche (CPER)
Université de Montréal

TP/OS/os

c.c. [redacted]
p.j.



Université de Montréal

N^O^ de certificat
[redacted]

Comité plurifacultaire d'éthique de la recherche

CERTIFICAT D'APPROBATION ÉTHIQUE

Le Comité plurifacultaire d'éthique de la recherche (CPER), selon les procédures en vigueur, en vertu des documents qui lui ont été fournis, a examiné le projet de recherche suivant et conclu qu'il respecte les règles d'éthique énoncées dans la Politique sur la recherche avec des êtres humains *de l'Université de Montréal.*

Projet

Titre du projet	**Collaboration et innovation au sein des projets d'architecture durable: limites et opportunités du processus de conception intégrée.**
Étudiant requérant	**Ricardo Ferreira Leoto** [redacted] Candidat au doctorat, École d'architecture - Faculté d'aménagement Université de Montréal

Financement

Organisme	Mitacs
Programme	Bourses doctorales Mitacs accélération
Titre de l'octroi si différent	--
Numéro d'octroi	IT05810
Chercheur principal	--
No de compte	--

Approbation reconnue

Approbation émise par	non
Certificat:	s.o.

MODALITÉS D'APPLICATION

Tout changement anticipé au protocole de recherche doit être communiqué au CPER qui en évaluera l'impact au chapitre de l'éthique.

Toute interruption prématurée du projet ou tout incident grave doit être immédiatement signalé au CPER.

Selon les règles universitaires en vigueur, un suivi annuel est minimalement exigé pour maintenir la validité de la présente approbation éthique, et ce, jusqu'à la fin du projet. Le questionnaire de suivi est disponible sur la page web du CPER.

[redacted]

Comité plurifacultaire d'éthique de la recherche
Université de Montréal

28 septembre 2015
Date de délivrance

1er octobre 2016
Date de fin de validité

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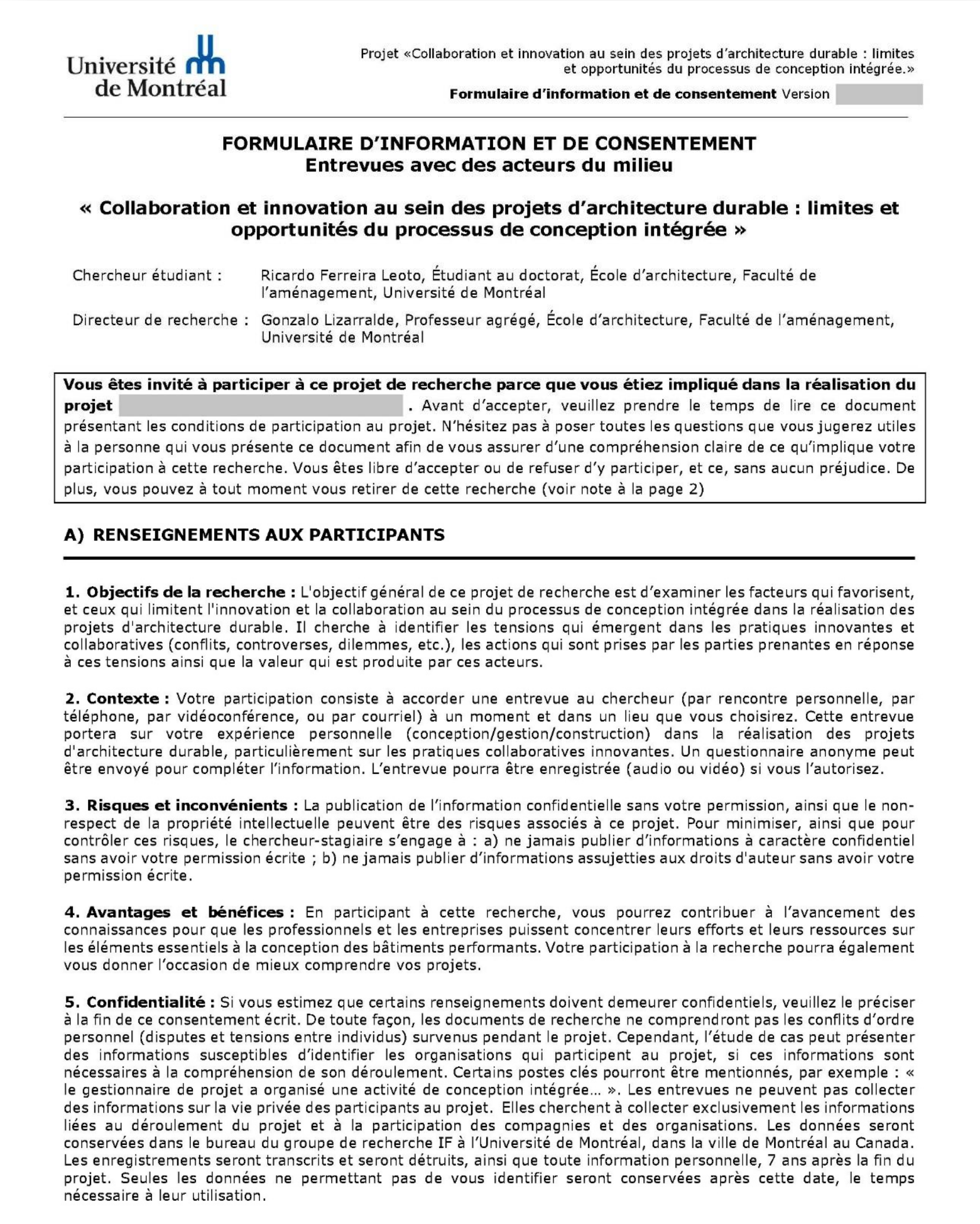
Téléphone : 514-343-6111 poste 1896
cper@umontreal.ca

Annex III. Consent form – Interviews



Université de Montréal

Projet «Collaboration et innovation au sein des projets d'architecture durable : limites et opportunités du processus de conception intégrée.»

Formulaire d'information et de consentement Version

FORMULAIRE D'INFORMATION ET DE CONSENTEMENT
Entrevues avec des acteurs du milieu

« Collaboration et innovation au sein des projets d'architecture durable : limites et opportunités du processus de conception intégrée »

Chercheur étudiant :	Ricardo Ferreira Leoto, Étudiant au doctorat, École d'architecture, Faculté de l'aménagement, Université de Montréal
Directeur de recherche :	Gonzalo Lizarralde, Professeur agrégé, École d'architecture, Faculté de l'aménagement, Université de Montréal

Vous êtes invité à participer à ce projet de recherche parce que vous étiez impliqué dans la réalisation du projet . Avant d'accepter, veuillez prendre le temps de lire ce document présentant les conditions de participation au projet. N'hésitez pas à poser toutes les questions que vous jugerez utiles à la personne qui vous présente ce document afin de vous assurer d'une compréhension claire de ce qu'implique votre participation à cette recherche. Vous êtes libre d'accepter ou de refuser d'y participer, et ce, sans aucun préjudice. De plus, vous pouvez à tout moment vous retirer de cette recherche (voir note à la page 2)

A) RENSEIGNEMENTS AUX PARTICIPANTS

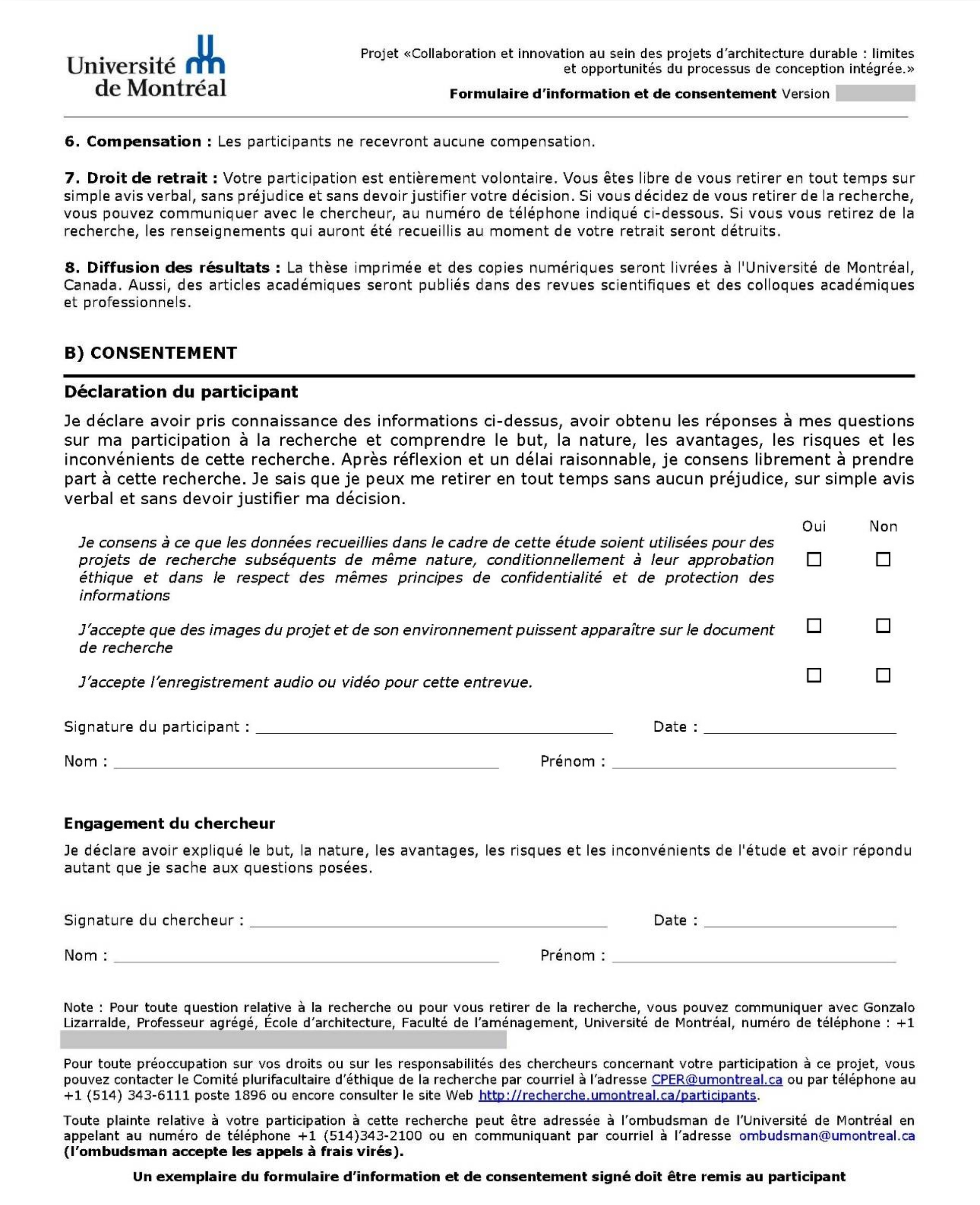
1. Objectifs de la recherche : L'objectif général de ce projet de recherche est d'examiner les facteurs qui favorisent, et ceux qui limitent l'innovation et la collaboration au sein du processus de conception intégrée dans la réalisation des projets d'architecture durable. Il cherche à identifier les tensions qui émergent dans les pratiques innovantes et collaboratives (conflits, controverses, dilemmes, etc.), les actions qui sont prises par les parties prenantes en réponse à ces tensions ainsi que la valeur qui est produite par ces acteurs.

2. Contexte : Votre participation consiste à accorder une entrevue au chercheur (par rencontre personnelle, par téléphone, par vidéoconférence, ou par courriel) à un moment et dans un lieu que vous choisirez. Cette entrevue portera sur votre expérience personnelle (conception/gestion/construction) dans la réalisation des projets d'architecture durable, particulièrement sur les pratiques collaboratives innovantes. Un questionnaire anonyme peut être envoyé pour compléter l'information. L'entrevue pourra être enregistrée (audio ou vidéo) si vous l'autorisez.

3. Risques et inconvénients : La publication de l'information confidentielle sans votre permission, ainsi que le non-respect de la propriété intellectuelle peuvent être des risques associés à ce projet. Pour minimiser, ainsi que pour contrôler ces risques, le chercheur-stagiaire s'engage à : a) ne jamais publier d'informations à caractère confidentiel sans avoir votre permission écrite ; b) ne jamais publier d'informations assujetties aux droits d'auteur sans avoir votre permission écrite.

4. Avantages et bénéfices : En participant à cette recherche, vous pourrez contribuer à l'avancement des connaissances pour que les professionnels et les entreprises puissent concentrer leurs efforts et leurs ressources sur les éléments essentiels à la conception des bâtiments performants. Votre participation à la recherche pourra également vous donner l'occasion de mieux comprendre vos projets.

5. Confidentialité : Si vous estimez que certains renseignements doivent demeurer confidentiels, veuillez le préciser à la fin de ce consentement écrit. De toute façon, les documents de recherche ne comprendront pas les conflits d'ordre personnel (disputes et tensions entre individus) survenus pendant le projet. Cependant, l'étude de cas peut présenter des informations susceptibles d'identifier les organisations qui participent au projet, si ces informations sont nécessaires à la compréhension de son déroulement. Certains postes clés pourront être mentionnés, par exemple : « le gestionnaire de projet a organisé une activité de conception intégrée… ». Les entrevues ne peuvent pas collecter des informations sur la vie privée des participants au projet. Elles cherchent à collecter exclusivement les informations liées au déroulement du projet et à la participation des compagnies et des organisations. Les données seront conservées dans le bureau du groupe de recherche IF à l'Université de Montréal, dans la ville de Montréal au Canada. Les enregistrements seront transcrits et seront détruits, ainsi que toute information personnelle, 7 ans après la fin du projet. Seules les données ne permettant pas de vous identifier seront conservées après cette date, le temps nécessaire à leur utilisation.



Université de Montréal

Projet «Collaboration et innovation au sein des projets d'architecture durable : limites et opportunités du processus de conception intégrée.»

Formulaire d'information et de consentement Version [redacted]

6. Compensation : Les participants ne recevront aucune compensation.

7. Droit de retrait : Votre participation est entièrement volontaire. Vous êtes libre de vous retirer en tout temps sur simple avis verbal, sans préjudice et sans devoir justifier votre décision. Si vous décidez de vous retirer de la recherche, vous pouvez communiquer avec le chercheur, au numéro de téléphone indiqué ci-dessous. Si vous vous retirez de la recherche, les renseignements qui auront été recueillis au moment de votre retrait seront détruits.

8. Diffusion des résultats : La thèse imprimée et des copies numériques seront livrées à l'Université de Montréal, Canada. Aussi, des articles académiques seront publiés dans des revues scientifiques et des colloques académiques et professionnels.

B) CONSENTEMENT

Déclaration du participant

Je déclare avoir pris connaissance des informations ci-dessus, avoir obtenu les réponses à mes questions sur ma participation à la recherche et comprendre le but, la nature, les avantages, les risques et les inconvénients de cette recherche. Après réflexion et un délai raisonnable, je consens librement à prendre part à cette recherche. Je sais que je peux me retirer en tout temps sans aucun préjudice, sur simple avis verbal et sans devoir justifier ma décision.

	Oui	Non
Je consens à ce que les données recueillies dans le cadre de cette étude soient utilisées pour des projets de recherche subséquents de même nature, conditionnellement à leur approbation éthique et dans le respect des mêmes principes de confidentialité et de protection des informations	☐	☐
J'accepte que des images du projet et de son environnement puissent apparaître sur le document de recherche	☐	☐
J'accepte l'enregistrement audio ou vidéo pour cette entrevue.	☐	☐

Signature du participant : ______________________ Date : ______________

Nom : ______________________ Prénom : ______________________

Engagement du chercheur

Je déclare avoir expliqué le but, la nature, les avantages, les risques et les inconvénients de l'étude et avoir répondu autant que je sache aux questions posées.

Signature du chercheur : ______________________ Date : ______________

Nom : ______________________ Prénom : ______________________

Note : Pour toute question relative à la recherche ou pour vous retirer de la recherche, vous pouvez communiquer avec Gonzalo Lizarralde, Professeur agrégé, École d'architecture, Faculté de l'aménagement, Université de Montréal, numéro de téléphone : +1 [redacted]

Pour toute préoccupation sur vos droits ou sur les responsabilités des chercheurs concernant votre participation à ce projet, vous pouvez contacter le Comité plurifacultaire d'éthique de la recherche par courriel à l'adresse CPER@umontreal.ca ou par téléphone au +1 (514) 343-6111 poste 1896 ou encore consulter le site Web http://recherche.umontreal.ca/participants.

Toute plainte relative à votre participation à cette recherche peut être adressée à l'ombudsman de l'Université de Montréal en appelant au numéro de téléphone +1 (514)343-2100 ou en communiquant par courriel à l'adresse ombudsman@umontreal.ca **(l'ombudsman accepte les appels à frais virés).**

Un exemplaire du formulaire d'information et de consentement signé doit être remis au participant