IDENTIFYING THE KEY INNOVATIVE AND COLLABORATIVE STRATEGIES OF INTEGRATED PROJECT DELIVERY METHOD TO ACHIEVE OWNER GOALS IN HOUSING PROJECTS

by

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B.Eng., Gujarat Technological University, 2016

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Civil Engineering)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

April 2019

The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, the dissertation entitled:

Identifying the key innovative and collaborative strategies of Integrated Project Delivery method to achieve owner goals in housing projects

submitted by Divyarajsinh Chudasma in partial fulfillment of the requirements for

the degree of Master of Applied Science

in Civil Engineering

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Abstract

The fragmented nature of tradition project delivery in the Architecture, Engineering, and Construction industry causes many inefficiencies and results in missed project goals and expectations. Integrated Project Delivery (IPD) is new procurement method that has a potential to address these inefficiencies by overcoming traditional fragmentation and fostering collaboration through new contractual arrangements. As IPD is an emerging construction delivery method that is highly driven by the owner's initiative, vision, and continuous involvement, there are very few IPD projects that focus on large-scale residential or multi-unit housing projects. This led to a finding that IPD implementation is not very common in housing projects and related case-studies are not widely available in Canada. In addition, there is a lack of information about key characteristics of IPD that facilitates success of the project.

The focus of this research is to address a current research gap by developing and analyzing housing project case studies that implemented IPD principles or adopted formal IPD approaches. The overall objective of the research is to assess the implementation of key IPD principles on the housing projects and to identify the key innovative and collaborative strategies of IPD through case study analysis.

To analyze IPD/IPD-like projects and to develop detailed case studies, a case study framework was developed for this study. The thesis documents four IPD/IPD-like Canadian housing projects, namely priMED Mosaic Centre, St. Jerome's University Student Residence and Academic Centre, UBC Brock Commons, and Jacobson Hall at Trinity Western University. The case study for each project has been documented using the developed framework. The project

case studies document project context, organizational setup, processes, technology implemented, and project outcomes in detailed.

This research summarizes key features and lesson learned from the four case studies through cross-project analysis. The identified IPD-like innovative and collaborative strategies in this research can be considered for implementation in future housing projects to obtain better outcomes.

Lay Summary

Integrated Project Delivery (IPD) is relatively new construction procurement method offering collaborative strategies that help to efficiently achieve owner's goals. The goal of this study was to investigate the key innovative and collaborative strategies of IPD. The main contributions of this study are (1) the development of a case study framework that helps to analyze IPD / IPD-like projects, (2) the development of four IPD / IPD-like Canadian case studies, namely: priMED Mosaic Centre, St. Jerome's Student Residence and Academic Centre, UBC Brock Commons, and Jacobson Hall, Trinity Western University, (3) documented lessons-learned of the key innovative and collaborative strategies of IPD.

Preface

This thesis is based on author's work with a Vancouver based consulting company, Brantwood Consulting, under the direct supervision of Dr. Sheryl Staub-French. This work was supported by Mitacs through the Mitacs Accelerate Program.

All images, figures and tables used in this research include references to the owners. Any figures without acknowledgements were developed and created by the author.

The Human Ethics approval for "IPD Project" (application number: H18-02360) was obtained from UBC Research Ethics Board prior conducting this research.

The work presented in this thesis is intended to be published with slight modifications, under the guidance of industry partner (Brantwood Consulting) and Dr. Sheryl Staub-French.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AEC: Architecture, Engineering, and Construction

AIA: American Institute of Architects

AIA CC: American Institute of Architects California Council

BC: British Columbia

BIM: Building Information Modeling

CCDC: Canadian Construction Documents Committee

CII: Construction Industry Institute

CLT: Cross-Laminated Timber

CM: Construction Manager

CM+: Construction Management at Risk

DfMA: Design for Manufacturing and Assembly

GLT: Glued-Laminated Timber

IPD: Integrated Project Delivery

IPDA: Integrated Project Delivery Alliance

KPI: Key Performance Index

LCI: Lean Construction Institute

LOD: Level Of Development

LVL: Laminated Veneer Lumber

MEP: Mechanical, Electrical and Plumbing

PIT: Project Implementation Team

PMT: Project Management Team

PPC: Percentage Plan Complete

RFI: Request For Information

RFP: Request For Proposal

SMT: Senior Management Team

TVD: Target Value Design

TWU: Trinity Western University

UBC: University of British Columbia

VDC: Virtual Design and Construction

Acknowledgements

I would like to express my sincere gratitude to my supervisor Dr. Sheryl Staub-French and co-supervisor Dr. Puyan Zadeh for their constant support, guidance and motivation throughout this study. This opportunity would have never been come to me without their continuous efforts and support. I am also thankful to Dr. Thomas Froese for his periodic guidance and feedback on my work.

I owe a special thanks to my industrial supervisors and mentors, Helen Goodland and Albert Lam, who showed constant faith in me and providing technical and motivational moral support. Their expertise, invaluable guidance, patience, constant encouragement and feedback added special flavor to this research.

I take this opportunity to express my deep sense of gratitude to the faculty, staff and colleagues at UBC who constantly provided their support and embraced my UBC journey.

I am deeply grateful to my late father who shaped part of my vision. Finally, I must express wholehearted gratitude to my family and friends who stood by me in all situations and provided their moral support.

Dedication

To my Family…

Chapter 1: Introduction

1.1 Background

In the Architecture, Engineering, and Construction (AEC) industry, the success of a construction project can be measured based on the level of achievement of the owner's goals and expectations. The owner's goals are usually to construct a high-quality project within the targeted cost and schedule (Choi et al., 2019). However, the fragmentation between design and construction professionals causes many inefficiencies that hinder the achievement of the project goals and expectations (Hanna, 2016; Lichtig, 2006). The reason behind the inefficiency in the AEC industry is the fragmented working environment caused mainly by traditional project delivery methods (AIA, 2007). This usually results in errors in designs, increased errors and dispute, higher costs and inefficient work practices and costly changes in the construction stage (Konchar & Sanvido, 1998; Kent and Becerik-Geber, 2010; Mesa et al., 2019).

To address project-related inefficiencies, innovative approaches such as Building Information Modeling (BIM), Integrated Project Delivery (IPD), lean construction and off-site construction, have emerged over the past three decades (Poirier, 2015). As construction projects are becoming more complex and competitive, it is becoming essential to adopt these innovative approaches. For this objective, the project teams must rethink how they organize themselves and collaborate with each other to deliver the project.

As a consequence, there is a growing interest among owners in understanding the relationships between the key decision makings (e.g. choosing the delivery method, the contract types, and the team selection process) and their impact on the project success, including cost, schedule, and building performance. Many studies have been conducted to investigate and compare the performance of various project delivery methods like design-bid-build, design-build, and construction management at risk to inform and help owners and decision-makers to choose the best-suited delivery method for their project (Konchar & Sanvido, 1998; Molenaar & Songer, 1998). These studies also outline how to efficiently organize the project teams for different projects. Nevertheless, the traditional delivery methods and contracting approaches create the fragmentation of knowledge, expertise and responsibilities that incorporate inefficiencies during hands-off from one organization to another (AIA, 2007).

Integrated Project Delivery (IPD) is a novel project delivery method that breaks these traditional AEC silos and enforces more collaboration between the project participants through a novel contractual arrangement. IPD is an innovative building project procurement strategy that requires early involvement of key participants, who share risks and rewards through multi-party contracts, to achieve improved project outcomes (AIA, 2012; Kent & Becerik-Gerber, 2010) and enforces the contractual framework to align the project participants' success with the project success.

1.2 Motivation

In recent years, IPD has gained significant interest and some organizations are starting to adopt IPD as their delivery method. The rise in adoption stems from the potential benefits for AEC projects and project team's ability to engage with innovation.

Many studies have been conducted that identify the potential benefits of IPD on project outcomes (AIA, 2012; Kent & Becerik-Gerber, 2010; Molenaar et al., 2015; Cheng, 2015; Bilbo et al., 2015). These studies have identified several driving factors and situations (like co-location, Big Rooms, shared risk/reward, etc.) that enable highly collaborative behavior among project participants and yield superior project team performance. These driving factors are consistently highlighted across all the case-studies and assessed, such as:

1. The impact of shared risk/reward and early involvement of project participants on project outcomes (AIA, 2012; Kent & Becerik-Gerber, 2010; Molenaar et al., 2015).
2. The impact on project performance due to project participant's level of experience and owner's experience with IPD (AIA, 2012; Cheng, 2015; Kent & Becerik-Gerber, 2010; Molenaar et al., 2015).
3. The impact of using innovative technologies and processes (such as building information modeling and lean processes) on the project outcome (AIA, 2012; Cheng, 2015; Kent & Becerik-Gerber, 2010; Molenaar et al., 2015).
4. Increased productivity, construction quality, and owner's satisfaction, together with reduced project cost and time, (Cheng et al., 2016; AIA, 2012; Molenaar et al., 2015).

Therefore, the motivation for this research came from the consideration of the novel nature of IPD in the construction industry and its positive impacts on project outcomes as shown in previous research.

All the above-mentioned studies looked at the impact of IPD adoption on projects by assessing the project outcomes. Moreover, these studies did not focus on the adoption of IPD in the housing sector. Furthermore, there hasn't been any study which identifies the key innovative and collaborative strategies of IPD that help the construction projects in the housing sector to achieve owners' goals efficiently.

As IPD is an emerging construction delivery method that is highly driven by the owner's initiative, vision, and continuous involvement, there are very few IPD projects that focus on large-scale residential or multi-unit housing projects. This led to a conclusion that IPD implementation is not very common in housing projects and related case-studies were not widely available in Canada. As there was only one completed housing IPD project in Canada while this study was conducted, the aim was to analyze the implementation of IPD principles on IPD/IPD-like housing projects. IPD-like projects are the traditional projects—such as Construction Manager at Risk and Design-Build projects—that incorporate some of the IPD principles to achieve enhanced level of collaboration without using multi-party contract (Kenig et al., 2010; Hanna, 2016).

This study was aimed at assessing the key IPD principles that helped in achieving owner's goals and facilitated adoption of innovative approaches.

1.3 Research Objectives

The overall objective of the research was to assess the implementation of key IPD principles on the housing projects and to identify the key innovative and collaborative strategies of IPD to achieve owner's goals through case study analysis.

The following were the specific research objectives of this research:

1. To develop a case study framework that would help in assessing the IPD principles and collaborative practices in the construction projects that supported innovation.
2. To analyze housing projects which implemented formal IPD or showed IPD-like characteristics, and to develop detailed case studies using the proposed framework.
3. To identify key innovative and collaborative strategies of IPD that can be adopted on any housing projects to efficiently achieve owner's goals without implementing formal IPD method.

Finally, the thesis identified some of the challenges for IPD adoption in the Canadian housing sector.

1.4 Research Scope

The focus of this research was to assess the adoption of IPD principles on housing projects that support innovative preconstruction and construction processes for efficiently achieving owners' goals. In addition, the scope of this research was to identify different levels of implementation of IPD principles on projects through to cross-project analysis.

The research developed the case study framework and documentation for all the case studies. The aim of each project case study was to identify the owner's goals for the project, onboarding process of the project team, preconstruction process to establish collaboration, various innovative technologies, and techniques implemented throughout the project, along with project outcomes and lessons learned.

The research did not aim to investigate the rationale behind the design development and permitting processes of any project. The commissioning process and operational performance of projects were also outside the scope of work. Instead of analyzing the construction process steps in detail, the intent was to analyze the coordination and communication processes among the project participants that helped the construction process.

1.5 Thesis Outline

The thesis consists of 9 chapters. Chapter 2 contains background and literature review on innovations in construction focusing on BIM, prefabrication, lean construction, and IPD. It introduces these innovations in the construction industry. Chapter 3 identifies the research methodology employed for this study including the case study selection criteria, data collection, and analysis. Chapter 4 presents the case study framework developed to narrate and analyze project case studies. It also recognizes the selected projects for this research and presents data collection method for each project.

Chapter 5, 6, 7 and 8 portrays four case studies in detail, namely priMED Mosaic Centre, St. Jerome's University Student Residence and Academic Centre, UBC Brock Commons, and Jacobson Hall. Each case study has been analyzed through the framework developed in Chapter 4.

Finally, the cross-project analysis of four case studies is presented in Chapter 9, which cross-compares the innovative project delivery characteristics of case studies. It also includes lessons learned and proposes recommendations related to IPD characteristics for the housing projects.

This chapter also identifies the challenges and barriers of IPD adoption in the housing sector in Canada. The chapter concludes with a discussion of future work.

Chapter 2: Research Background

This chapter provides background and literature review of relevant innovations in construction such as IPD, Building Information Modeling (BIM) and Virtual Design and Construction (VDC), prefabrication, and lean construction.

2.1 Integrated Project Delivery

The American Institute of Architect, California Council defines IPD as:

> "IPD is a procurement method that integrates people, systems, business structures, and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction." (AIA, 2014)

IPD is an innovative building project procurement strategy that requires early involvement of key participants, who share risks and rewards through multi-party contracts between a minimum of the owner, the architect and, the contractor, to achieve improved project outcomes (Figure 2-1). As IPD aligns the stakeholders' goals with the project goals, their success depends on project success (AIA, 2012; AIACC, 2013). According to (Ashcraft, 2012; AIA, 2012), IPD consists of five factors, which are discussed below.

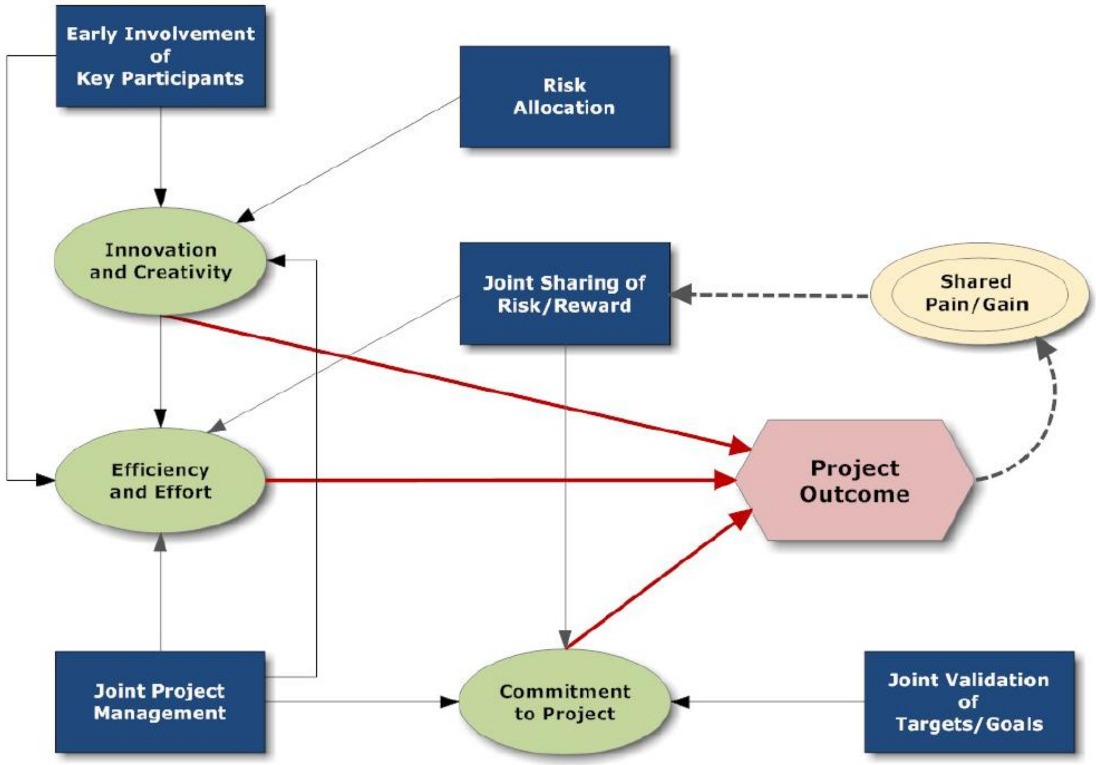


Figure 2-1 IPD elements and outcomes (Ashcraft, 2012)

2.1.1 Early Involvement of Key Participants

The most essential element of IPD is the early involvement of key participants. The key participants are defined as the project participants who may have the highest influence for the success of the project (Ashcraft, 2012). In addition to the owner, architect, and contractor, other key participants can be mechanical and electrical design consultants, as well as subcontractors that may provide critical knowledge and positively affect the design development (Ashcraft, 2012). These key participants must collaborate early to:

- improve effectiveness and/or constructability of the design,
- run the project smoothly,
- avoid rework, and
- reduce waste.

Key participants may vary from the project to project based on their capability to influence the design development (Ashcraft, 2012). Usually, the owner, architect, and contractor collaborate from the inception of the project, while the rest of the team may or may not be required to be on-boarded. The key participants must be involved in the project when their participation would benefit the project and their contribution would greatly influence the project outcome (Ashcraft, 2012).

2.1.2 Shared Risk and Reward based on Project Outcome

In the IPD model, the key participants know and accept the costs incurred by each party, including overhead and profit (AIA, 2007). It is important to stress that not all project stakeholders need to be involved in the multi-party structure and, even within the most collaborative IPD projects, many contractors and trades continue to bid and complete their work using conventional procurement methods.

In the IPD project setup, the architect, contractor and other core project participants who are involved in the risk/rewards pool would agree to a fixed amount of profit based on their work or services (Ashcraft, 2012). Although these project participants would be paid for their fundamental costs and time commitment in the project, their profit would be at risk depending upon the project outcome/success (AIA, 2007). The sum of the project participants' profit is "pooled" to serve as a means of managing risk and incentivizing performance.

Together, the project participants agree to the target cost for the project separate from the profit pool. The project participants receive their initially agreed-upon profit percentage if they achieve the project cost equal to target cost (Ashcraft, 2014). If they deliver the project for less than the target cost, the savings are shared between the owner and the rest of the project team in addition to the profit (Ashcraft, 2014). Conversely, if the project costs more than the target cost, the project participants' profit is reduced – potentially to nothing (Figure 2-2) (Ashcraft, 2014).

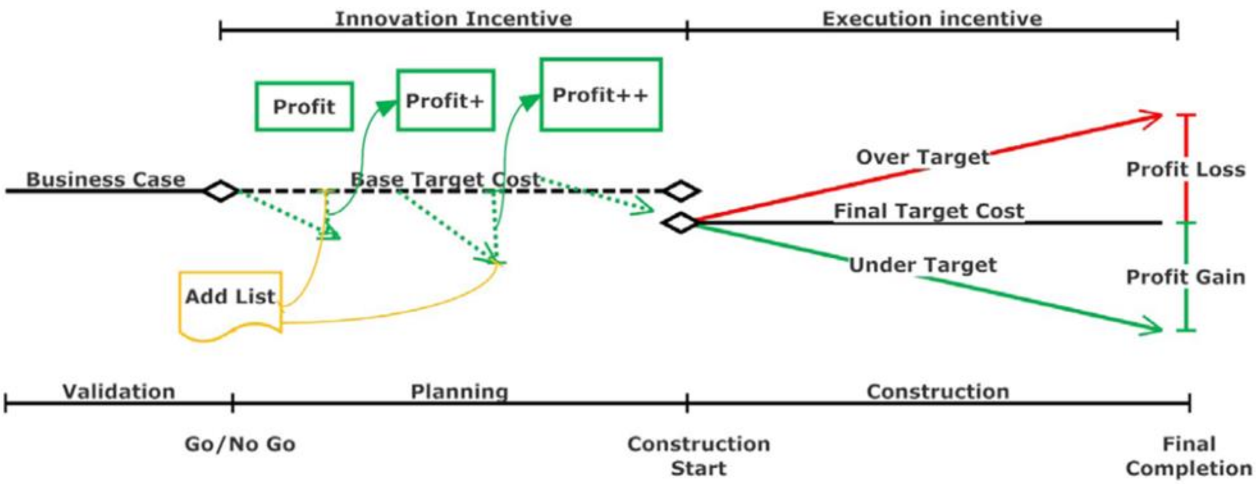


Figure 2-2 Risk and reward sharing setup in IPD (Ashcraft, 2014)

The shared risk and reward compensation structure in IPD helps to align the project participants' goals with the project goals (Ashcraft, 2012). It discourages putting self-interest ahead of the project's benefit. With everyone's profit based on project outcomes, team members are committed to the project and motivated to suggest or assist others for better end results.

2.1.3 Joint Project Control

Joint project control sets up an effective team structure whereby project participants can communicate their concerns and/or issues to the project team (Ashcraft, 2012). Because participants accept the risks related to successful project delivery, they also need to be involved in key decision-making.

Joint project control is achieved by forming a Project Management Team (PMT) which is comprised if at least the owner, architect and contractor (Ashcraft, 2012). The PMT is authorized to manage the project to achieve the jointly agreed objectives and to take decisions that are in best interest of the project (Ashcraft, 2012). If the project decisions are not unanimous at the PMT level, those decisions are elevated to the Senior Management Team (SMT). The SMT is comprised of executive-level members from every party that signed the IPD contract (Allison et al., 2018). The SMT generally handles and resolves disputes if the PMT is unable to reach a decision. The SMT decides the issue by majority vote which is binding and unappealable, unless the owner decides to override the decision by issuing an owner's directive (Allison et al., 2018).

2.1.4 Reduced Liability Exposure

Cross-discipline communication is important in all projects, and especially where situations are complex and innovative approaches are being deployed. In traditional delivery methods, concerns about liability hinder the free exchange of information among project participants because of the fear of being found responsible for errors or omissions that might cause loss or damage to others (Ashcraft, 2012). In IPD, a liability waiver is established to support free communication within the project team, which encourages creative and innovative project approaches and ideas (Ashcraft, 2012). Liability waivers can also reduce litigation costs and project delays, especially at the handover (Ashcraft, 2012).

It is common in traditional procurement situations for bidders to add some contingent cost by assessing and quantifying their risks due to their liability exposure (Ashcraft, 2012). The intention is to cover (at least some of) their exposure to liability. Reducing their liability exposure helps to reduce the project cost by eliminating many contingent costs added by many bidders in the project (Ashcraft, 2012).

Liability concerns also discourage project participants to adopt an innovative approach in terms of design, technology, technique, material, etc. as they are comfortable and confident with working in a traditional way which may be costly and inefficient (Ashcraft, 2012). Reducing liability exposure supports the easy adoption of new tools and techniques to achieve innovations in project efficiently (Ashcraft, 2012).

2.1.5 Jointly Developed and Validated Targets

In IPD, the key project participants work collaboratively to develop the project objectives and targets which are then validated by other project participants (Ashcraft, 2012). These targets serve as metrics for compensation adjustment (Ashcraft, 2012) and as goals for Target Value Design (TVD) in the later stages.

As the project targets are developed jointly by the project team, each project participant owns the project objectives and is committed to achieving them (Ashcraft, 2012). Jointly developed targets may include program criteria, standards, target cost, schedule, profit distribution, key project milestones for periodic profit distributions.

2.2 Building Information Modeling and Virtual Design and Construction

Kunz and Fischer (2012) defined VDC as:

"Virtual Design and Construction (VDC) is the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives. Models are a representation of reality. VDC models are virtual because they show computer-based descriptions of the project. The VDC project model emphasizes those aspects of the project that can be designed and managed."

Whereas "BIM is a set of technologies, processes, and policies enabling multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space" (BIMDictionary, 2019). BIM is not just a design tool, but it is a process that enables the project team to effectively collaborate throughout the project, from the early design development through occupancy (Eastman et al., 2008). BIM is the development and use of a data-rich, object-oriented and parametric digital model of a facility that needs to be constructed (The Associated General Contractors of America, 2006).

The detail included in BIM can be assessed by the standard Level of Development (LOD) metric. Yoders (2013) specifies LOD in the following five levels:

> LOD 100 – Conceptual design: modeled elements are "at a conceptual point of development and are generic representations, signifying the existence of a building component, but not its shape, size, or location."

LOD 200 – Schematic design: modeled elements are “graphically represented within the model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation.”

LOD 300 – Detailed design: modeled elements are “graphically represented within the model as a specific system, object, or assembly in terms of quantity, size, shape, location, and orientation.”

LOD 350 – Construction documentation: modeled elements are “graphically represented within the model as a specific system, object, or assembly in terms of quantity, size, shape, and orientation and interfaces with other building systems.”

LOD 400 – Fabrication & Assembly: modeled elements are “graphically represented within the model as a specific system, object, or assembly in terms of size, shape, location, quantity, and orientation, with detailing, fabrication, assembly, and installation information.”

LOD 500 – As-built: modeled elements are “representative of as installed conditions and can be utilized for ongoing facilities management.”

The implementation of BIM/VDC also helps in establishing effective collaboration between project participants, which leads to improved project performance and better value (Eastman et al., 2011). In addition, the application of BIM/VDC has been seen to support prefabrication process of building components by establishing efficient collaboration between the designers and contractors (Yoders, 2014). Many studies have analyzed the BIM/VDC workflows in the design and construction process to enable digital prefabrication (Staub-French et al., 2018; Building and Construction Authority, 2016).

2.3 Prefabrication

Prefabrication is an off-site construction process in which building components and units are built in an off-site manufacturing plant and transported to the construction site (Kim et al., 2012; Hong et al., 2014; BC Housing, 2014). In recent years, off-site construction has attracted growing attention from the AEC industry due to its many advantages (Yin et al., 2019), such as shorter construction schedule, cost savings, improved safety and quality, higher efficiency and reduced waste (Kamali & Hewage, 2016).

Based on the complexity of prefabricated components, they can be divided into 3 categories as shown in Figure 2-3 (Building and Construction Authority, 2016),

1. **Components:** Building components are comprised of a series of prefabricated building elements. For example: wall or floor panels, precast staircases, structural columns, structural reinforcement cages, etc.
2. **Integrated components:** Prefabricated assembly formed by aggregating different components in part or in full. For example, Prefabricated Bathroom Units (PBU), integrated prefabricated MEP, etc.
3. **Fully integrated components:** Prefabricated assembly of whole rooms, modules, or apartment units with internal finishes and fixtures which are constructed off-site and assembled on-site.

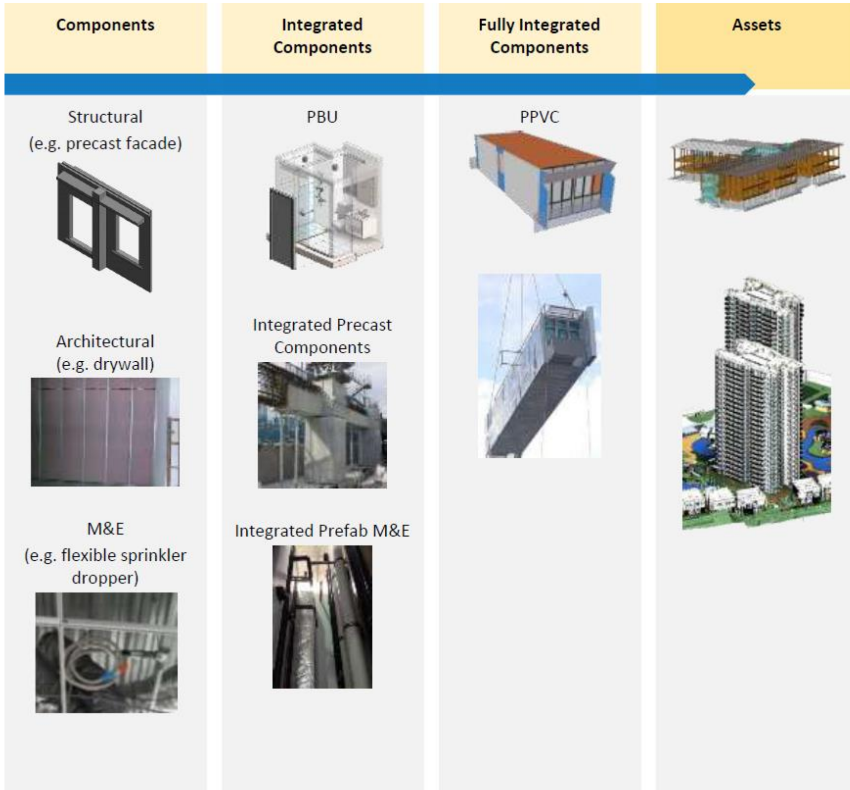


Figure 2-3 Classification of prefabrication level (Building and Construction Authority, 2016)

The off-site construction process has many advantages over traditional on-site construction. As off-site manufacturing processes are carried out in the indoor factory plant environments, they allow implementation of innovative processes, such as lean manufacturing principles, on the assembly line resulting in increased productivity. Because on-site construction and off-site manufacturing can be performed simultaneously, it has a definite advantage of shorter construction time. In addition, adverse weather does not have a significant impact on the off-site construction process (BC Housing, 2014).

Prefabricated construction also has less impact on the environment compared to traditional construction and requires many fewer on-site construction laborers (Jaillon & Poon, 2014; Li et al., 2014; Polat, 2008).

In recent years, the AEC industry has also realized significant productivity improvements in off-site construction processes through the application of BIM and Design for Manufacturing and Assembly (DfMA) principles relying heavily on unskilled workforce (BCA, 2016; Staub-French et al., 2018). According to Staub-French et al. (2018), the application of BIM and DfMA has greatly improved the performance of project schedules resulting in improved coordination between design office and the off-site fabrication facilities.

The use of BIM/VDC in construction projects helps to implement lean project delivery processes by allowing virtual process simulations and it improves the process by removing waste (Khanzode et al., 2006).

2.4 Lean Construction

The productivity of the construction industry has decreased worldwide in the last 5 decades, whereas the manufacturing industry and other non-farming industries have shown a great increase in their productivity (Teicholz, 2013). Lean construction has evolved through adopting lean principles from the manufacturing industry to construction. Lean construction focuses on concentrating effort on value-adding activities that contribute to the owner's goals and objectives through continuous process improvement.

The Construction Industry Institute (CII) has defined lean construction as "the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream, and pursuing perfection in the execution of a constructed project" (CII, 2005).

Lean construction is a new way to define design and construction that can be applied to any project and in any project delivery model (Lean Construction Institute [LCI] Canada, 2019). Implementing lean principles in design and construction processes can help the project team to uncover and eliminate waste. As shown in Figure 2-4, lean design and construction enhances project value by enabling the team to fully understand the owner's goals and pursue them throughout the project life-cycle (Bayer, 2015). Table 2-1 identify various types of wastes and their impact on construction.

Figure 2-4 Lean principles in design and construction (LCI Canada, 2019)

Table 2-1 Types of wastes in construction (Image source: Shift2Lean)

Waste	Definition	Impact
Defects	Producing goods/information not meeting requirements and requiring rework	Diverts workers from value-adding work, increases material cost and inspection requirements
Over Production	Producing more than what is required or sooner than required	Unnecessarily increase staff, storage and/or transportation requirements
Waiting	Workers waiting for work/materials or work waiting for workers	Interrupts the flow of work and impacts productivity and work hand-off
Non-Utilized Talent	Not taking advantage of all workers' talent, knowledge and skills	Reduces opportunity for improvement and learning of the team
Transportation	Unnecessary movement of people or goods within a process	Moving material in and out of storage or from one process to the next wastes time and energy
Inventory	Excess material or work that is not having value added to it	Excess stock increases the cost of storage and potential for damage
Motion	Unnecessary movement of people or goods within a process	Time wasted looking for material/tools or wasted time walking to understand work
Extra Procession	Processing beyond the standard required or inefficient processing	Adds cost and/or time that the customer has not defined as value adding

Lean methods are designed to improve the project management process by breaking down traditional fragmented working environments. It facilitates knowledge sharing within a highly functional team instead of the traditional approach where the performance of each project team member is primarily motivated by their own self-interest (LCI, 2019). The core values of lean construction are visibility/ transparency, collaboration, trust, commitment, achieving goals and knowledge sharing to make work better, avoiding waiting time of work and to make work safer (Bayer, 2015).

Lean design and construction processes (such as pull planning) are outcome-oriented and use backward planning from milestone to highly detailed plan. Lean practice requires the planned processes to be highly visual and encourages the involvement of downstream project participants in the planning stage to define work falling under their scope. This approach is more like developing efficient schedule collaboratively by leveraging the knowledge and experience from the trailer (superintendent, trade foremen, subcontractors, etc.) instead of imposing a schedule on them (Bayer, 2015).

As shown in Figure 2-5, lean design and construction differ from traditional practices in the following ways (LCI, 2019):

- It imposes more control on the project overall through the continuous monitoring of progress to ensure activities and milestones are being completed as planned. Lean recognizes the necessity of project metrics and KPIs to continuously improve workflow processes in order to reliably deliver predictable project outcomes.
- The goal of lean construction is to achieve all planned project outcomes holistically by maximizing value and minimizing waste at the project level instead of the traditional "best effort" approach to achieving individual goals (or not).

- The project value to the customer is defined, created and delivered throughout the life of the project. In conventional practice, the owner is expected to completely define requirements at the outset for delivery at the end, despite changing markets, technology, and business practices.
- It encourages coordinating action through pulling and continuous flow as opposed to traditional schedule-driven push with its over-reliance on central authority and project schedules to manage resources and coordinate work.
- It has decentralized decision-making through transparency, empowering project participants to take action by providing them with information on the state of production systems.

Figure 2-5 Characteristics of lean design and construction (LCI Canada, 2019)

BIM and lean construction are different delivery approaches which can be implemented on projects independently. While the adoption of both lean construction and BIM has the full potential to improve the construction process (Sacks et al., 2010), it requires effective collaboration between design and construction participants. IPD has the ability to integrate construction expertise in the design stage to leverage BIM and lean construction benefits (AIA, 2014).

Chapter 3: Research Methodology

A thorough literature review was conducted on IPD to undertake this research study. The identified knowledge gap in literature was the lack of comprehensive case studies of housing projects that implemented IPD principles. Another identified knowledge gap was the cross-project analysis of IPD characteristics for housing projects. This research addresses these gaps by studying the adoption of IPD or IPD principles in several case studies of housing projects in Canada. The overall objective of the research was to assess the implementation of essential IPD principles on housing projects and to identify the key innovative and collaborative strategies of IPD to achieve owner's goals through case study analysis. Figure 3-1 shows the research methodology and roadmap for this study. Figure 3-2 identifies higher-level activities performed in this research.

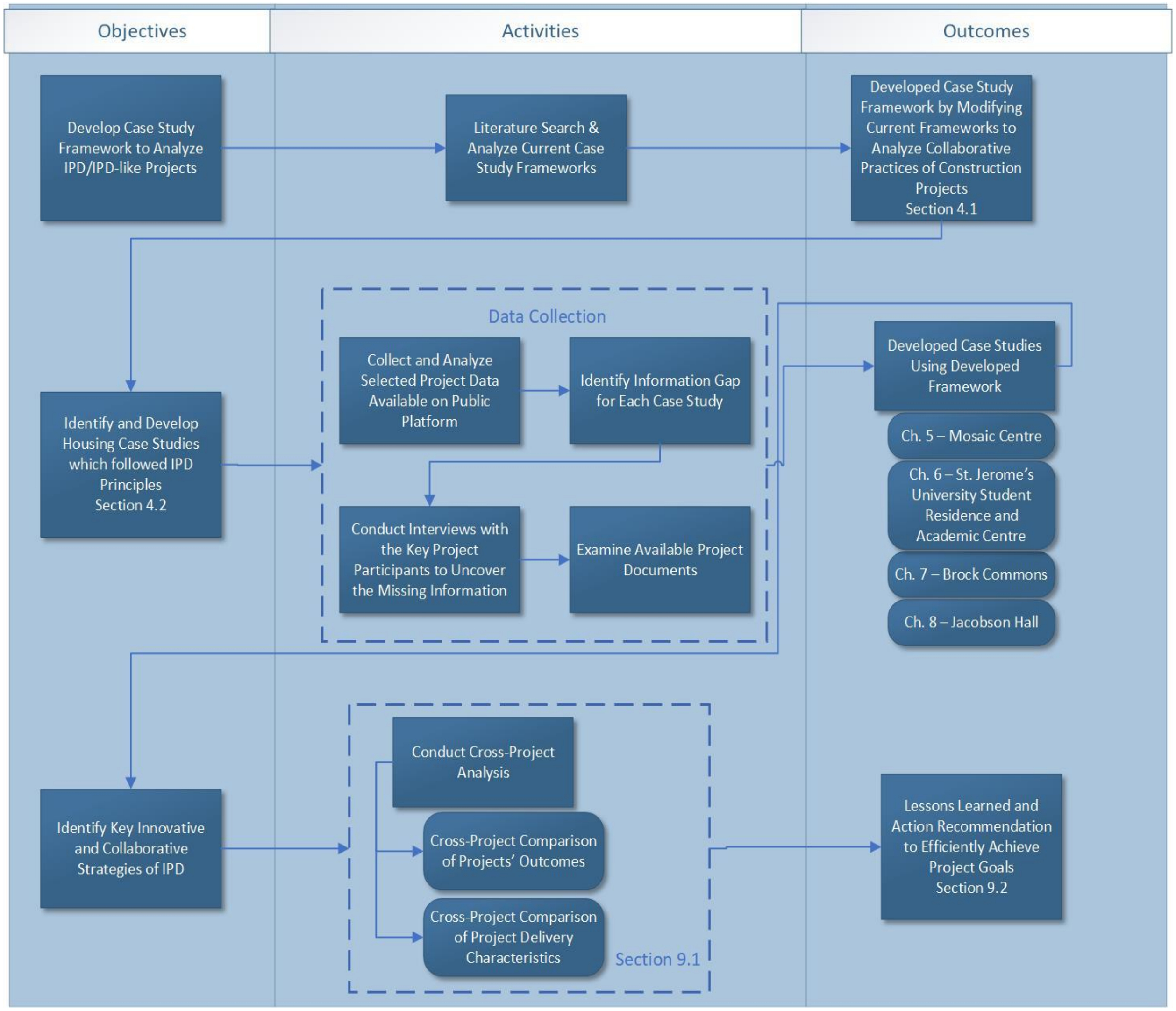


Figure 3-1 Research methodology and roadmap

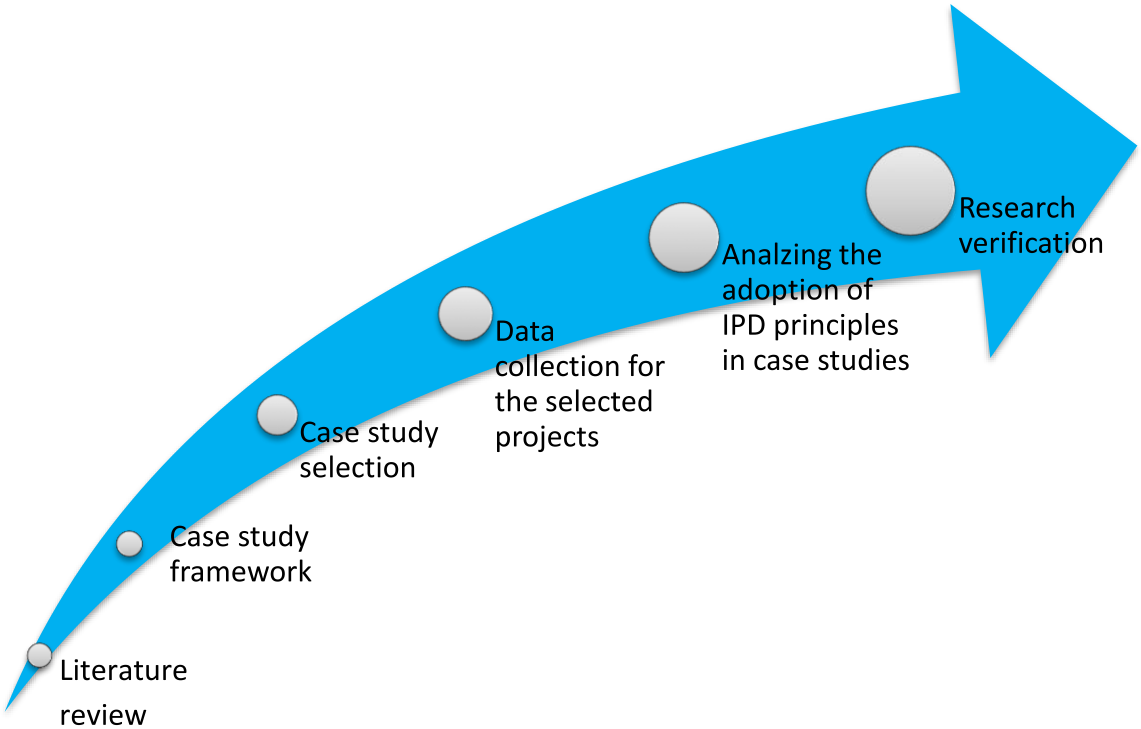


Figure 3-2 Main research activities

3.1 Case Study Framework to Analyze IPD/IPD-like Projects

The first step of this research was to develop a case study framework that could help with the assessment of IPD principles and collaborative practices implemented in Canadian construction projects. Chapter 4 explains the developed case study framework in detail.

3.2 Case Study Selection

For this research, the following criteria were considered for selecting the required case studies:

- The projects should be located in Canada so that research outcomes can be generalized to Canadian context.

- Another prime consideration for the project selection was that all the selected projects should be completed and should be in operation so that their construction outcomes can be assessed. In addition, the project team of each project should be willing to provide complete project data.
- The selected projects should be preferably housing or simple office building projects which are not complex buildings like hospitals, industrial, or institutional buildings.
- The project should either be an IPD project or have some form of IPD-like innovation in its organizational setup, processes, and/or technology use. That means projects are selected that either followed a full IPD process, complete with the multiparty agreement, or implemented at least three of the following IPD principles (introduced in Section 2.4):
    - Early involvement of key participants
    - Shared risk and reward based on project outcome
    - Joint project control
    - Reduced liability exposure
    - Jointly developed and validated targets
- The selected case studies should be possibly different in scope, size, structural typology (mass timber, wood frame, concrete, steel, or some combination), location (urban or rural/remote) and climate zones.

3.3 Data Collection for the Selected Case Studies

Explicit Data Collection

The preliminary data were collected from the online resources of the selected projects. This includes the project data available on owner and project participants' website. In addition, nonassociated resources that featured the selected projects in news articles, industrial presentations, etc. were also gathered. Any previous research work focusing on the selected case studies was also collected for analysis to identify the missing knowledge gaps for those projects.

Interviews

After analyzing available public information, the key project team members of each project were contacted to conduct 1-hour interviews through semi-structured open-ended questions to investigate each project in detail. Follow-up calls were made for fact-checking purposes. In total, 14 interviews were conducted and transcribed for this research.

The targeted role of project participants for an interview was the owner, project manager, architect, and contractor/construction manager. Furthermore, the interviewees were also requested to provide supporting project documents, such as RFPs, value-matrix, schedules, execution plans, contracts, etc.

3.4 Analyzing the Adoption of IPD Principles in Case Studies

The data collected prior and during this research were thoroughly analyzed for its completeness based on the developed case study framework. The collected information was sorted and condensed in the different sections of the framework as suited. Subsequently, the interviews were conducted to fill the identified information gap for each of the case studies. All the interviews were transcribed, and the collected information was used to complete the case studies. In addition, the collected project documents were analyzed to provide additional details and to verify the collected information.

Once all the case studies were developed, cross-project analysis was conducted to identify the similar patterns and characteristics of the case studies that enabled effective collaboration between project participants. This analysis was essential to identify the conclusions and to propose recommendations that enable more collaborative practices in construction projects.

3.5 Research Verification

To validate the findings and content of the case studies, the interviewees, project participants and project owners were provided with the draft copies of their case study project for review. Their comments and feedback were later incorporated in this study.

Chapter 4: Case Study Framework to Analyze IPD/IPD-like projects

4.1 Case Study Framework to Analyze IPD/IPD-like Projects

In order to collect the required information from the case studies in a structured way, it is necessary to develop a case study framework to investigate the project from the pre-planning efforts for assembling the project team through to project completion. The framework was developed by modifying the TOPiCS (Technology Organization Processes in Context across Stages) framework developed by (Staub-French et al., 2011), and IPDA's framework developed by (Cheng et al., 2016) (Figure 4-1 & Figure 4-2). The categories in the TOPiCS framework help to identify key considerations from construction case studies across different stages of projects (from design to construction). This framework was utilized to narrow the important priorities and issues related to the construction projects. The IPDA case study framework was utilized to explore project context and the pre-planning efforts that go into assembling the right team before the start of a project.

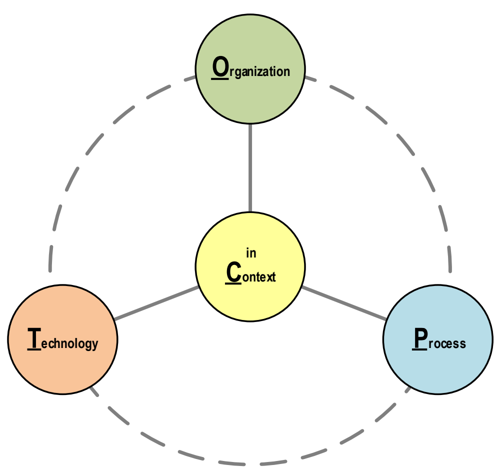


Figure 4-1 TOPiCS assessment framework (BIM TOPiCS, 2019)

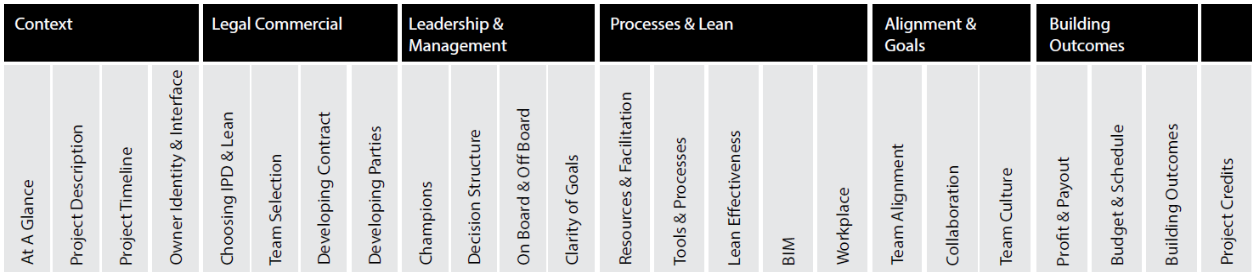


Figure 4-2 IPDA case study assessment framework (Cheng et al., 2016)

We developed a modified framework to collect and analyze the detailed information from the case studies (see Table 4-1 and Figure 4-3).

Table 4-1 Case study framework to analyze projects

Context	Organization	Processes	Technology	Project outcomes
• Project description • Owner identity	• Choosing project delivery method • Owner's goal • Team selection • Developing the contract • Project team structure • Champions • Decision-structure	• Execution plan • Training /workshops • Communication & workplace • Collaboration • Innovative practices	• Use of technology • Tools implemented • Scope and level of modeling • Information exchange	• Owner's requirements • Cost and schedule • Benefits • Challenges • Lessons learned

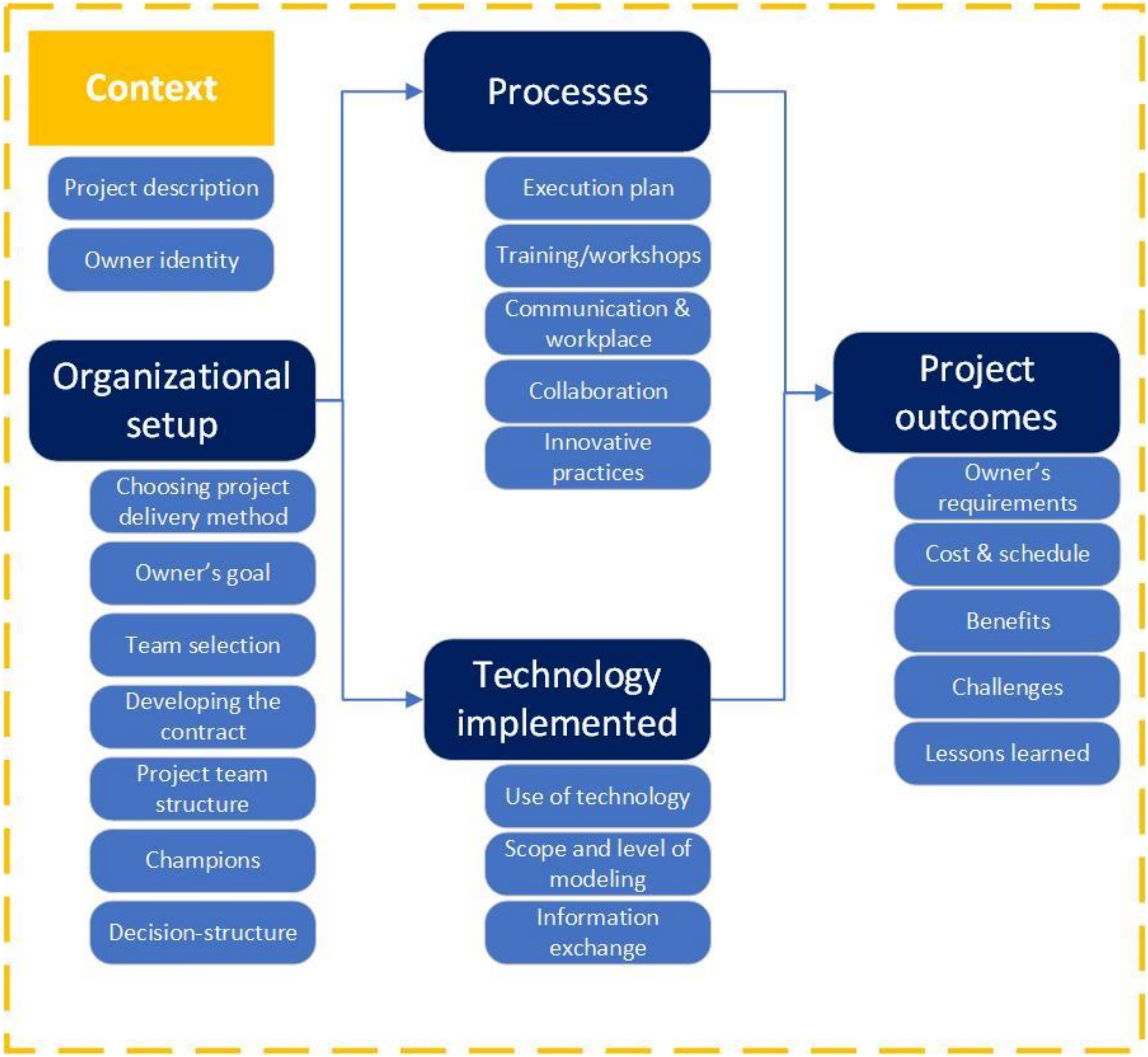


Figure 4-3 Case study framework to analyze IPD case study

4.1.1 Context

This section of the framework describes the project in terms of its size, location, cost, design and construction time, etc. It also identifies the project owner or owner's representative who were actively engaged in the project. Moreover, it provides the information about the owner's background, which is a necessary context to identify their capacity to engage with the project team. Thus, this section covers the following sub-sections:

- Project description
- Owner identity

4.1.2 Organizational Setup

All the projects were analyzed from the very inception of the team selection process. This measure identifies the owner's goal, project team selection process, and agreement development processes. This section also covers the rationale behind choosing a specific type of delivery method for the project. The project team structure and the decision-making structure of the project are also included in this section. The organization section covers the following measures:

- Choosing project delivery method
- Owner's goal
- Team selection
- Developing the agreement
- Project team structure
- Champions
- Decision-structure

4.1.3 Processes

Once the organizational setup process is studied, this section explains the project execution plan, if one is developed for the project. 'Process' also describes the training part of the project, in case the project participants were given specific training sessions or workshops to improve the coordination process. During the design and construction process, the medium of coordination and communication between the project participants was also analyzed to assess its effectiveness. This section investigates the processes employed in the project to achieve higher team integration and cooperation. This section specifically identifies innovative processes adopted in the project. The following sub-sections are covered in the processes:

- Execution plan
- Training/workshop
- Communication and workspace
- Collaboration
- Innovative practices

4.1.4 Technology Implemented

The selected projects for this research showcased a wide range of technology use to support the implementation of the IPD principles in the design and construction processes. This section identifies the level of BIM/VDC implementation on the project along with the specific tools used by various involved project participants during the design and construction processes. In addition, this section also identifies the various uses of adopted technologies/tools. The technology section consists of following sub-sections:

- Uses of technology
- Tools implemented
- Scope and level of modeling
- Information exchange

4.1.5 Project Outcomes

The project outcome essentially consists of the results achieved at the end of the project in terms of the owner's perception, cost, and schedule. Specifically, it compares the initial estimated cost and schedule to the actual project cost and duration. It also reveals the benefits of the adopted innovative approach in the project along with the challenges faced and the lessons learned. The project outcomes consist of the following sub-sections:

- Owner's requirements
- Cost and schedule
- Benefits
- Challenges
- Lessons learned

4.2 Case Study Selection

The selection of the case study projects was based on the selection criteria (mentioned in chapter 3). Ideally, all the case studies selected for this research should have adopted formal IPD delivery method and should be a housing project. However, the St. Jerome's University project is currently the only completed housing project in Canada that has been delivered through formal IPD contracting. As there was only one complete IPD housing project, another IPD office building project (Mosaic Centre) was selected in this study to get detailed knowledge about another formal IPD process. It was considered that office building construction is similar to housing construction and possesses less complexity. The research was aimed to develop detailed and comprehensive case studies identifying IPD-like collaborative strategies adopted and implemented in the project.

As mentioned earlier, the selected projects either followed a full IPD process with the multi-party agreement or implemented at least three of the following IPD principles:

- Early involvement of key participants
- Shared risk and reward based on project outcome
- Joint project control
- Reduced liability exposure
- Jointly developed and validated targets

Thus, based on the project's appropriateness for this research, the following 4 projects were selected, and their detailed case studies were developed:

1. priMED Mosaic Centre, Edmonton, Alberta
2. St. Jerome's University Student Residence and Academic Centre, Waterloo, Ontario
3. UBC Brock Commons, Vancouver, BC
4. Jacobson Hall, Trinity Western University, Aldergrove, BC

Table 4-2 identifies selected projects' type, delivery methods and implemented IPD principles.

Table 4-2 Implemented IPD principles in selected case studies

	Project type	Delivery method	Early involvement of key participants	Shared risk/ reward	Joint project control	Reduced liability exposure	Jointly developed / validated targets
priMED Mosaic Centre	Office	IPD	●	●	●	●	●
St. Jerome's University	Student housing	IPD	●	●	●	●	●
UBC Brock Commons	Student housing	CM+	●		●		●
Jacobson Hall, Trinity Western University	Student housing	Design-Build	●		●		●

4.3 Data Collection

A detailed case study of Brock Commons was developed in 2016 by the BIM TOPiCS research team at UBC and the same data was used to develop the case study for this research (Fallahi, 2017; Kasbar, 2017; Poirier et al., 2016; Francisco, 2018). For the priMED Mosaic Centre project, a case study was developed by Cheng et al. (2016) that was analyzed to identify the missing knowledge-gaps. St. Jerome's University Student Residence and Academic Centre project was featured in several news articles and some of the knowledge resources were available in the of formal presentations by project participants. The final case study, Jacobson Hall at Trinity Western University, was developed. For the Jacobson Hall project, an off-site manufacturing plant visit and a construction site visit were conducted near the end of the project. Table 4-3 shows the collected data source for each project.

Table 4-3 Data collection for each case study

Projects	Previous work by Others	Online resources (Project/ Participants' website/news articles)	Project Documents	Site/ Factory visit	Interviews	Interviewees' Role
priMED Mosaic Centre	•	•	•		•	-Owner -Architect -Construction Manager
St. Jerome's University project		•	•		•	-Owner -Architect
UBC Brock Commons	•	•	•			
Jacobson Hall, Trinity Western University		•	•	•	•	-Project Manager -Designer -Manufacturing Director -Director, Innovative Solution

The following chapters are the detailed analysis of each case studies project.

Chapter 5: priMED Mosaic Centre

5.1 Context

5.1.1 Project Description

The priMED Mosaic Centre is an approximately 3000 square-meter (32,300 sf) LEED Platinum certified multi-tenant office building located in Edmonton, Alberta. The project comprises a multi-tenant office space for 130 workers, a child-care centre and a restaurant (Figure 5-1). The vision behind the project was to prove that sustainable buildings can be both beautiful and affordable.

The project served as a “first of its kind” on many levels. It was the first LEED Platinum and Living Building Challenge Petal certified project for the City of Edmonton. It was the first net-zero commercial building in the province. It was the first integrated project delivery (IPD) project for all of the team members involved, although a few had experience with lean construction project.

The design charrettes started in April 2013; the construction started in April 2014 and the building was completed in March 2015. The target budget for this project was $11,355,667 (~$350/sf).

Figure 5-1 priMED Mosaic Centre (priMED Mosaic Centre, 2018)

5.1.2 Owner Identity

The owners, Dennis Cuku, was intimately involved in every aspect from conceptual design through to completion. Dennis is an engineer by training from the oil and gas industry who was already implementing lean principles within his engineering practice. However, when it came to building construction, Cuku's Nest Enterprise's previous experience had only been with small commercial renovations and the Mosaic Centre was by far the largest project they had taken on.

Initially, Dennis learned about IPD through his own personal research and from the general contractor, Chandos, who introduced him to the Dr. F. H. Wigmore Regional Hospital in Moose Jaw, Saskatchewan, which is one of the first IPD projects in Canada (Graham Construction, 2018).

5.2 Organization

5.2.1 Choosing Project Delivery Method

The owner had a strong belief that his goals of affordable, sustainable, and high-quality design and construction could only be achieved with a highly collaborative team culture that IPD can provide (Cheng et al., 2016). Although the owner had no previous experience with IPD, the main risk for them was not from within the terms of the IPD agreement but from finding the right people and develop the right team culture.

With prior experience with lean project practices in the oil industry, the owner, Dennis Cuku, encouraged whole-hearted adoption of lean practices from the very start of the project. He believed that lean and IPD would mutually support each other (Cheng et al., 2016), with IPD fostering the level of collaboration necessary to optimize the benefits afforded by lean practices. The owner believed that the best way to deliver an affordable high-performance innovative building was by changing the traditional way of operating construction projects (priMED Mosaic Centre, 2018), and IPD seemed the best option.

5.2.2 Owner's Goal

From the beginning, the owner wanted the project to be different. He wanted to build a net-zero building in Edmonton that could hold about 130 people with a child-care centre and a restaurant in it. Besides being an energy efficient and sustainable building, he wanted the building to be beautiful and affordable. Figure 5-2 shows the owner's ambitious goals for the project, which were developed collectively by the project team.

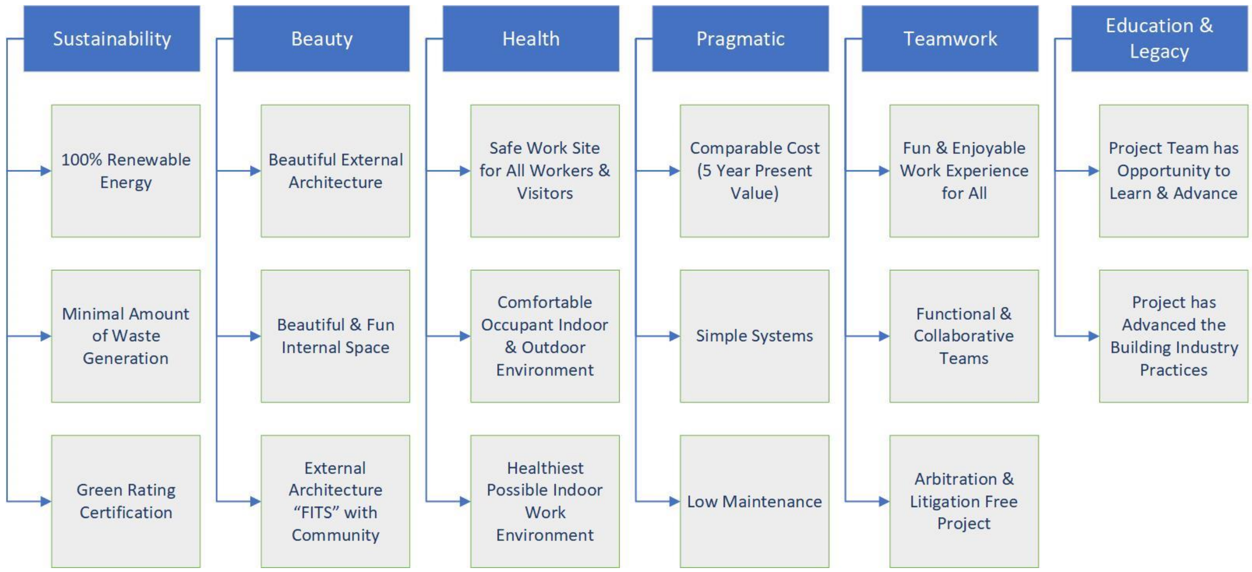


Figure 5-2 priMED Mosaic Centre owner’s goals (Image source: Chandos Construction)

Before selecting the project team, the owner initially wanted a fast-tracked LEED Platinum, 30,000 square-foot mixed-use office building for $9 million, which later was increased to $11,355,667 after discussing with the project team and considering the feasibility for a net-zero building (Cheng et al., 2016).

5.2.3 Team Selection

To select and retain the project team, the owner issued a “call to partners” memo instead of a traditional Request for Proposals (RFP) (Cheng et al., 2016). To assist with team recruitment, he also created a video: “The Mosaic Centre: Alberta’s first Living Building?”, which set out the goals and objectives of the project. While selecting the core project team, the owner mentioned that he didn’t look for the cheapest or the fanciest. He hired a team who actually understood his vision for the project and aligned themselves with the core values of the project. The general contractor, Chandos construction (an established local firm), was the first core team member to be hired based on existing relationships with the owner and they were the only one who expressed interest in IPD at that time. Hiring the contractor first for projects of this type is unusual. However, the owner wanted the contractor to bring key trades into the project as early as possible.

The owner selected Manasc Isaac Architects because the owner believed that they understood what is meant by beauty and sustainability, and how those two can work together. Manasc Isaacs Architects were retained by the owner in March 2013 to start work on the project design. With input from the architect, the general contractor was then responsible for assembling the rest of the project team. The rest of the team members were selected based on their sustainable design expertise, their ability to collaborate with each other and their willingness to think differently (Cheng et al., 2016).

During the team selection process, the contractor chose not to call for prior experience with lean or IPD because neither was widely adopted at the time. Instead, they shortlisted firms based on track record, hourly rates, overhead and profit, and experience with highly collaborative project delivery and/or with design-build projects. Project team selection interviews were conducted with the individuals who would be working on the project. The successful proponents were those who the owner and contractor considered would contribute the most to the collaborative culture they were hoping to create.

5.2.4 Developing the Contract

The IPD contract for this project was prepared by the US-based construction lawyer and IPD expert, Howard Ashcraft of Hanson Bridgett LLP, who made some minor modifications to "Canadianize" the Hanson Bridgett Standard IPD Agreement. About 90-95% contract stayed the same.

The multi-party agreement succinctly stated the IPD principles within a readable and logical agreement and was built on the key IPD concepts of early involvement of key participants, early validated target setting, joint sharing of risk and reward, joint project management and limitations on liability to increase creativity and reduce defensiveness (Gallo et al., n.d.). It followed the principles of the AIA / AIACC IPD Guide.

The primary contract signatories for the priMED Mosaic Centre comprised of the owner (Cuku's Nest Enterprise), architect (Manasc Isaac Architects), and general contractor (Chandos Construction). Then a series of parallel IPD subcontracts and IPD consulting agreements with trade contractors and consultants were established resulting in a total of 14 parties to the Agreement, all of which were involved in the pool of shared risk/reward.

Contract execution was delayed until three months after construction had started because the team wanted to wait for all the supplementary conditions and amendments to the project to be completed before they signed the base agreement. According to the contractor, this was not a major challenge to the project team because of the high level of trust. In retrospect, the agreement could have been signed and amendments added at a later date.

5.2.5 Project Team Structure

The project management structure was organized into a Senior Management Team (SMT), Project Management Team (PMT) and Project Implementation Team (PIT). This approach helped to compensate for the lack of prior experience with IPD and ensured that responsibilities were clearly defined and key decisions did not get missed.

The Senior Management Team members were required to monitor that the project was going well on a monthly basis, as they had less overall involvement in the project execution than the PMT.

The Project Management Team was responsible for managing and executing the project and they were responsible for making important project related decisions.

The Project Implementation Teams were usually cross-functional teams that were formed to take responsibility for specific technical deliverables (LEED/Living Building Challenge, commissioning, BIM plan, site work, structure, envelope, HVAC, plumbing, geothermal, power distribution, communication systems, interiors, etc.).

Table 5-1 identifies the SMT and PMT members and Figure 5-3 shows the project team structure.

Table 5-1 SMT & PMT – PriMED Mosaic Centre

Teams	Role
SMT	Owner
	Architect
	General Contractor
PMT	Owner
	Architect
	General Contractor

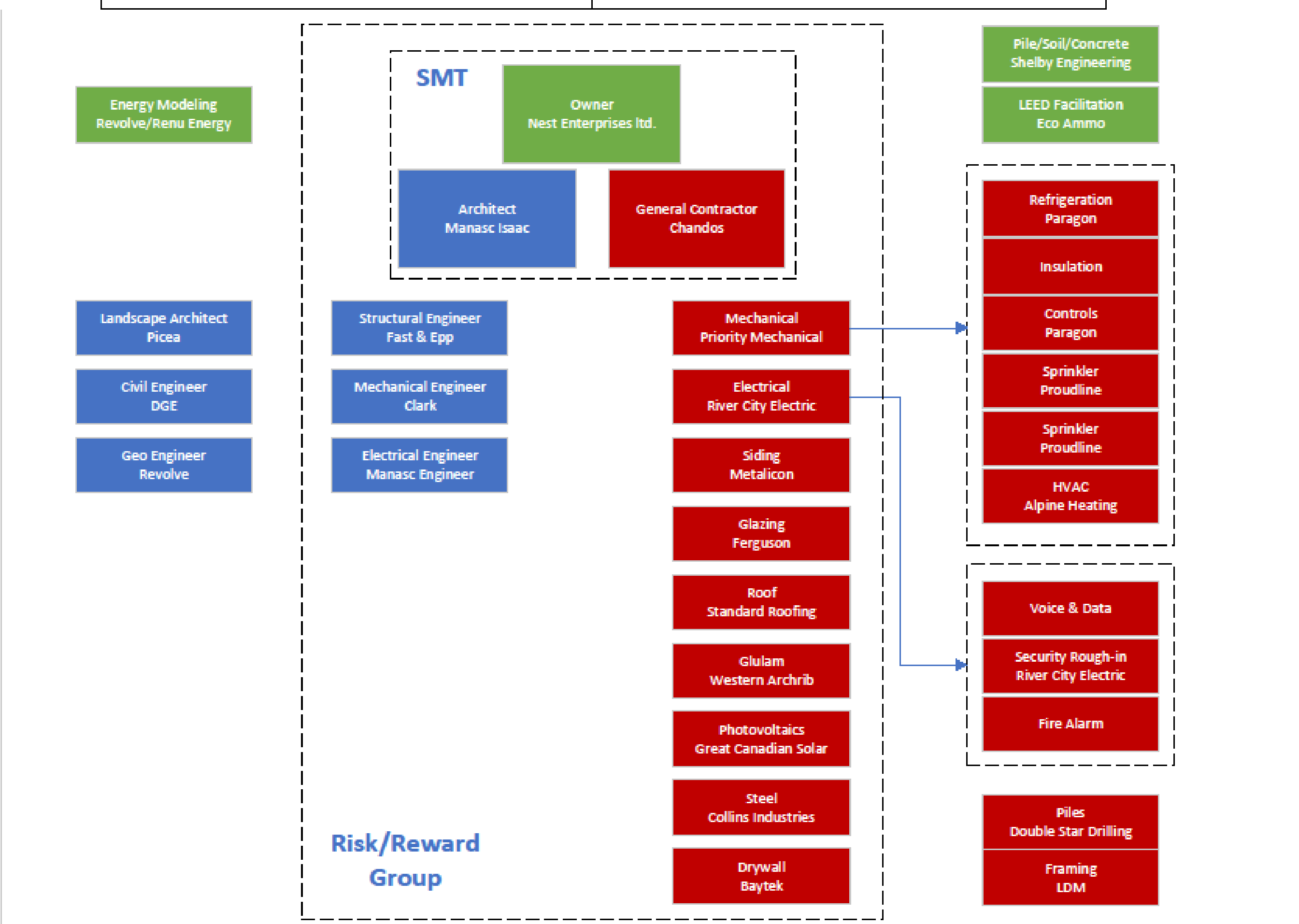


Figure 5-3 IPD and Non-IPD team of priMED Mosaic Centre (Image source: Chandos Construction)

5.2.6 Champions

The project was championed by a fully engaged owner supported by very experienced professionals (contractor and architect) who were able to function effectively in the face of uncertainty. During the first few months of the project, the owner invested considerable time in team building exercises and socials to create a "safe" collaborative team environment within which everybody could share ideas and opinions openly. He believed that as a result, people in the team got really engaged in the project and treated it as "their own" project and developed an "appetite for investigating better ways of doing things".

Working with a progressive contractor like Chandos was key to supporting the owner's vision. The value of involving a general contractor who is willing to champion the project cannot be overstated. At the time of the Mosaic project, senior staff at the contractor firm (Chandos) were actively learning about lean and IPD in order to implement it on their projects. The contractor team understood that lean champions can come from all levels of an organization and from business partners such as trade contractors. To enhance overall project performance, it was therefore essential to bring representatives from further down the supply chain into IPD meetings.

5.2.7 Decision Structure

Interviews with project designers and engineers identified three elements that supported good decision-making: the clarity of goals, the right team, and mutual trust within the team (Cheng et al., 2016). Once the team understood the owner's goals, the owner was open to letting team figure out how those could be achieved. Dennis Cuku is quoted as saying, “One of the reasons why this clicked is probably that I was too naive to know it could have gone off the rails. There is an element of ‘Hey, I trust you. Let’s do stuff.’” (Cheng et al., 2016)

To facilitate fast project decision-making, a project “Values Matrix” was developed during early “all-hands” meetings. The matrix synthesized the owner’s goals into several generic categories with associated metrics or key performance indicators. The Values Matrix (Figure 5-4) provided the PMT team with a well-structured way to make decisions quickly that were in the best interest of project and track progress.

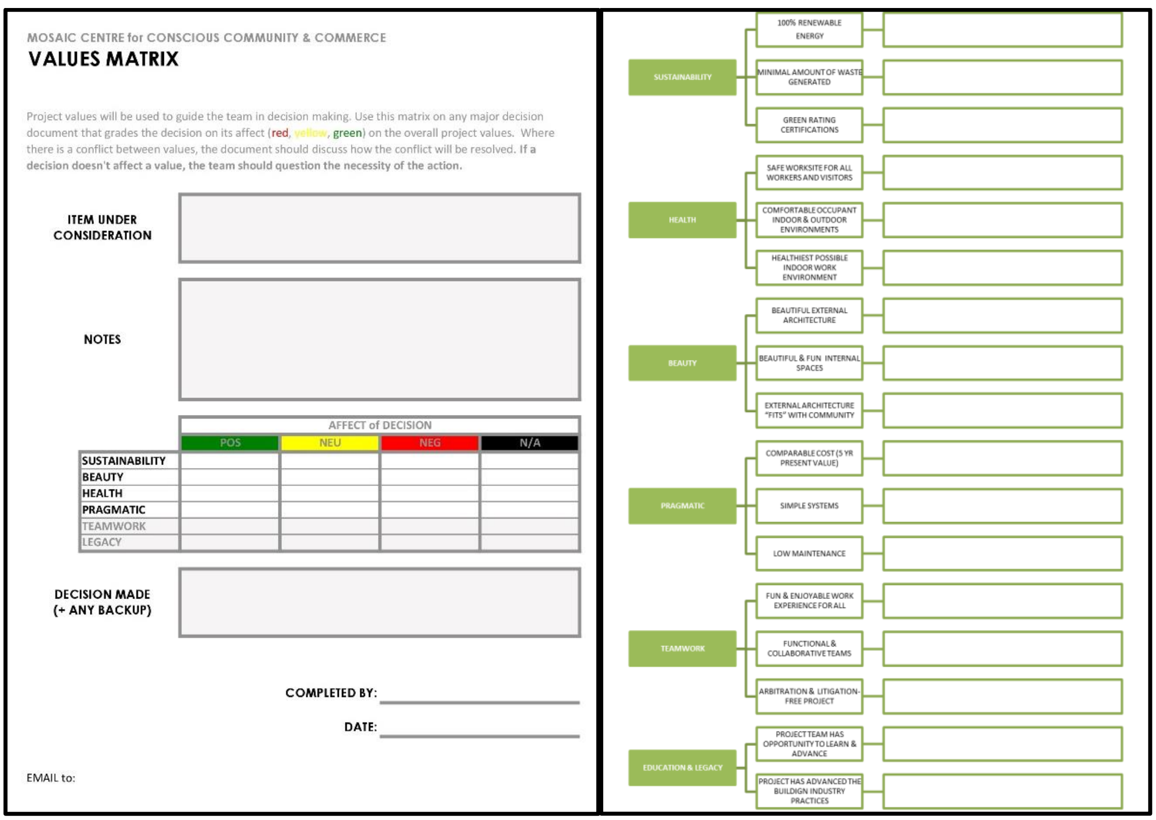


Figure 5-4 One-page Value Matrix for Fast Decision-Making (left) & Owner’s goals (right) (Image source: Chandos Construction)

When the PIT wanted to make any decision that had a cost related to it, then the PMT would review it against the Value Matrix to determine whether the decision should be accepted. If the decision did not impact the project budget, then the PIT was empowered to make logical decisions based on the best interest to the project and the PMT was informed of the decision subsequently.

The decisions were then recorded with a one-sentence description, the date, and a signature to track the content and timing of the change. This helped the team to work without constant oversight from the owner. The owner was updated about the decision at a convenient time and how it aligns with the project values (Cheng et al., 2016). The fact that the owner attended almost every meeting and held “office hours” for the project also expedited the decision-making process.

5.3 Processes

5.3.1 BIM Execution Plan

The communication and coordination strategy between the design consultants was defined in the early design stage. The project’s BIM execution plan defined the way that Revit models and CAD files would be exchanged within the project team. Consistent file naming conventions were established to keep track of various models and their versions. For example, each Revit file had to be named by project number, name, consultant discipline, and version (i.e. 10-000_MC4_ARCH_v14).

The architect provided the base Revit model with grids, levels, orientation, and shared internal coordinates set in place. The levels and grids were copied/monitored from architect's model and placed on consultants' designated work set for increased control of grids and levels visibility in each consultants' model.

During design coordination meetings, the consultants had to note meeting minutes of any changes needed in the model for a future update. The consultants had to exchange their models every week by Friday noon and run coordination and interference checks to address any clashes of linked model elements.

5.3.2 Training / Workshops

Initially, outside IPD and lean experts were brought in to facilitate an intensive 2-day IPD and lean training for the project team. The project team participated in lean pull planning and lean scheduling training workshops starting early in the project process. IPD "boot camp" training was provided by Hanson Bridgett (author of the construction contract) and DPR Construction, a US-based contractor with IPD expertise that had been providing advice to the project contractor, Chandos. Project team members could also voluntarily attend a weekly or bi-weekly webinar for extra coaching. The project contractor, Chandos, continued to offer regular informal coaching to team members after the initial training program and to trades as part of the onboarding process to help them get up to speed quickly (Cheng et al., 2016).

5.3.3 Communication and Workplace

The project team held regular "Big Room" meetings where they brought every player of the team to the table. In this setup, everybody had access to anybody in the Big Room. The Big Room meetings were very helpful in making the team gel as a collaborative group. In particular, the Big Room culture enabled the team to collaborate on finding cost efficiencies to the design. The "open book" approach allowed for a detailed review of labour and materials costs from the trades which generated opportunities to discuss how to decrease them. The first Big Room meeting was held over two days in Fall 2013 once the whole team was selected.

The team found that the level of trust that they established allowed them to collectively discuss everyone's work openly and constructively. This created opportunities for creative problem-solving, where "what seemed like a dumb question could turn into an 'Aha!' moment" (Cheng et al., 2016).

There was a great deal of learning through collaboration. As the construction progressed, the team communicated stories of innovation through a wide range of media (Cheng et al., 2016). By the end of the project, the contractor had made hundreds of short videos aimed to document continuous improvements to their site processes – in particular, how even the smallest tasks can be completed faster, more safely or more easily.

5.3.4 Collaboration

Overall, the team members interviewed agreed that IPD had a positive impact on their decision-making process and encouraged collaboration in routine team interactions. For example, the structural steel contractor believed that the IPD approach and the shared risk/reward really helped in fostering far greater collaboration (Cheng et al., 2016).

Although the contract was signed 3 months after the start of construction, the interviewed SMT members did not believe there was an adverse effect on the project or on team relationships. They noted how “the owner was very big on promoting culture and really worked with the team on that.” As a result, “Everybody was really quite engaged and committed to the job.” (Cheng et al., 2016)

While not explicitly raised by interviewees, the forcefulness of key personalities appears to have played an important role in establishing the team dynamic. SMT members were strong supporters of the process. However, questions remain about whether there was a truly equitable balance of power across the entire project team and if, indeed, this is to be desired. For Mosaic, the consultants had to make decisions that would be the best for the whole group (not necessarily best for them). Managing this situation effectively requires great skill. This approach could lead to perceptions of loss of control and a feeling of being “bulldozed” – especially for those that are unused to having their design questioned (especially by trades).

A key differentiator between IPD and traditional practice is when the team is faced with a problem. In traditional contractual arrangements, even with the most collaborative arrangements, problems that occur during a construction process generally causes team members to take a position of self-preservation in order to minimize risk exposure, potentially at the expense of the project. In other words, without the motivation of the shared risk / shared reward structure, individual team members will tend to look after their own interests ahead of those of the project. During the construction stage of Mosaic, the project team discovered that due to a misunderstanding between the structural engineer and the contractor, there was an unexpected cost of $270,000 related to the design of a structural wall. In response, an impromptu meeting was held with rest of the team and a solution was found that reduced the cost to change the wall to $80,000 while meeting the structural requirements. The team then found enough savings elsewhere in the project to cover the outstanding cost increase (Cheng et al., 2016).

5.3.5 Innovative Practices

Target Value Design: The project team used a Target Value Design process which is a collaborative design process involving designers, builders, suppliers, estimators and owners co-located in one place to collaboratively produce a design that provided the best value for the owner. The project budget (the target value) was a considered as a design criterion through which the team designed to the budget instead of the conventional process of estimating the cost of the design, and then re-designing to eliminate overruns.

Last Planner® System: The project team adopted the last planner system which is a tool developed by the lean Construction Institute to control the pull planning process and, therefore, production (Figure 5-5). Production control is necessary on projects to support working toward planned accomplishments, doing what can be done to move along a planned path, and when that becomes impossible, determine alternative paths that accomplish desired goals. The contractor communicated progress to the entire team through weekly reports, describing the lean "wins" and the resulting net progress gained. The architects believed that the pull planning process worked well in this collaborative project setup.

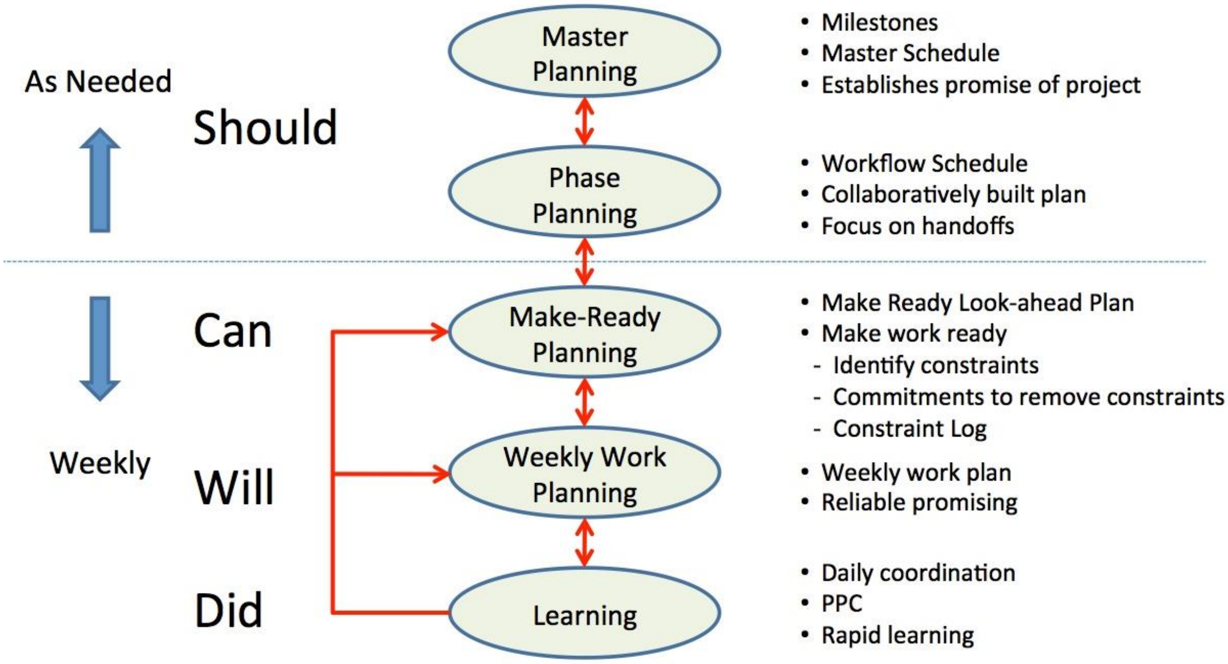


Figure 5-5 Last Planner System (Richert, 2017)

Snake Diagram: The team developed "snake diagrams" to visually track milestones and to know whether they are above or below milestone in terms of time. In the developed system, red-light alarms would be triggered if people were two weeks or more behind schedule. The architect was responsible for maintaining the snake diagrams.

2 Second Lean: The team also followed Paul Akers (2011) 2 Second Lean approach, which teaches team members to continuously improve and eliminate waste in small increments each and every day (Cheng et al., 2016). The goal is to turn every team member into a world class problem solver who seeks and destroys waste every day.

5.4 Technology Implemented

5.4.1 Use of Technology

The architects developed a 3D Building Information Model (BIM) of the Mosaic Center project, although this was not specifically requested by the owner. The model was used for the following applications:

Understand Building Geometry: The architect developed a 3D model of the building during the design phase in order to provide the project team with a better way to visualize and understand spatial geometry. The model was continuously updated, which helped to coordinate the design process while providing a quick visual reference for ongoing design refinements.

Communicating Design Intent: All the main design consultants were using Revit and they were exchanging the design models in IFC format with others for communicating their design with other disciplines.

Even the Revit model was shared with steel and wood trades in IFC format so that they could import it in the appropriate software that can communicate with the CNC machines and they used it for the shop drawing development as well.

Design Coordination and Clash Detection: The project team modeled the structural steel and wood elements, the mechanical, electrical and plumbing (MEP) systems, and some of the exterior wall systems in 3D, which was useful to communicate and coordinate the design to the various consultants. Clash-detection was particularly important for MEP system coordination (Cheng et al., 2016).

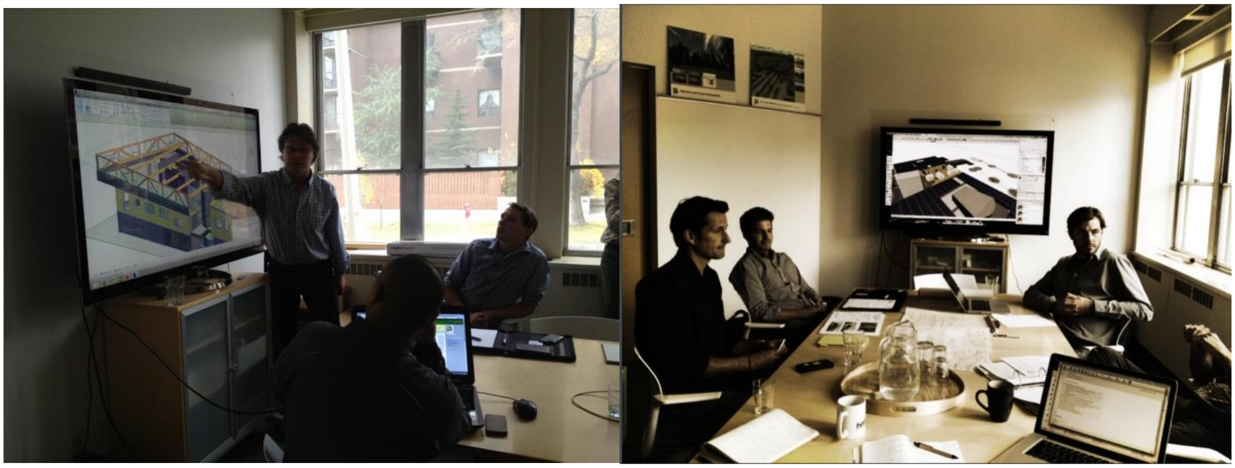


Figure 5-6 Design coordination meeting (Image source: Manasc Isaac Architects)

On-site meeting coordination: During construction, the major construction trades used the BIM model to communicate and coordinate effectively. The 3D model was used in the meetings for better understanding, along with 2D drawings to show the general orientation of design in 3D.

Despite the fact that BIM was used, most team members believed they missed some key opportunities to use it even more effectively. For example, the model could have been used more substantively for fabrication processes and was not used at all for quantity take-offs (for pricing or cost control), or for on-site coordination through 4D (i.e. time-based) simulation and sequencing. Some of the reasons why BIM was not as fully implemented as it could have been were that the owner did not specifically require BIM (e.g. for facility management purposes once the project was complete), and training would have been required for some project team members to be able to engage with the model at and advanced level.

5.4.2 Tools Implemented

All the major consultants – architect, structural, mechanical, and electrical engineers – used Revit for 3D modeling and coordination. There were some sub-trades who used other software suitable for their scope of work.

5.4.3 Scope and Level of Modeling

The initial scope of modeling was only to develop discipline-specific designs of the building for the main consultants. The owner did not mandate the use of BIM on this project. The modeling was done only for design development and coordination between design consultants and it wasn't used for quantity take-off or 4D simulation showing on-site activity sequencing. The final BIM model was between LOD 300 and 400.

5.4.4 Information Exchange

As mentioned above, the main consultants exchanged the Revit models with others in IFC format and the architect was coordinating the consistent 3D design development.

5.5 Project Outcomes

5.5.1 Owners Requirements Met

All of the owner's requirements as described in the initial owner's goals framework (Figure 5-2) were met. The initial owner's goal of building affordable net-zero building was achieved and Mosaic Centre received LEED Platinum rating and Living Building Challenge Petal

Certification. The owner's requirements in terms of budget and schedule were effectively met and discussed in the following section.

5.5.2 Cost and Schedule

The project was delivered for the target cost. However, the project team believed that they did not perform quite as well as they had hoped, which resulted in a reduced profit pool of $316,865 which was 2.8% of the Target Cost. Even though the team collectively only received 33% of the potential profit, all of those interviewed considered it a success, especially as it was their first IPD project.

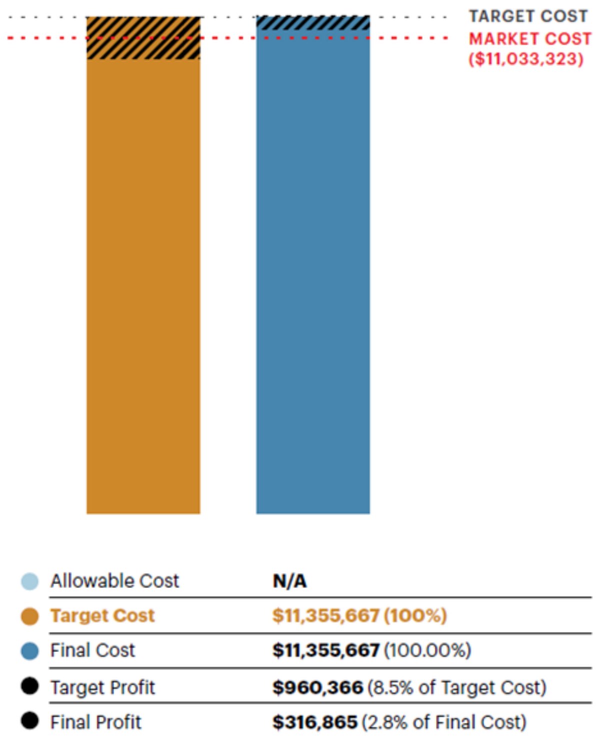


Figure 5-7 Targeted and final cost comparison (Cheng et al., 2016)

The project was completed four months ahead of schedule and within the target cost. The project benefited from the up-front investment for extensive early planning and resulted in 4-months of savings in project schedule. The project was completed in 11 months which is 39% faster than the original schedule of 18-months. The owner was quoted as saying -

> *"We had 32-34 months [of schedule initially but] when we came out of the Big Room we were down to 18 months. It was suggested that we could actually get it down to a year. So, we did the whole pull planning event in the Big Room, and that was pretty amazing. That's when I realized we have stumbled onto something pretty amazing."*
>
> – Dennis Cuku, Owner, priMED Mosaic Centre

In this project, the contractor tracked savings directly related to lean implementation, which, on average, was estimated to be approximately $2,000 per week (Cheng et al., 2016).

5.5.3 Benefits

The IPD process resulted in several key benefits and positive outcomes.

- The lean methods and, particularly, the extensive pre-planning and focus on continuous improvement helped the team to condense the project schedule by 4-months.
- Development of the owner's "Values Matrix" not only clarified but also sped up decision-making processes. Also, along with the Big Room collaborative format, helped to reduce RFIs and change orders.
- For those interviewed, the collaborative process resulted in a significantly improved overall experience compared to traditional practice.

- The IPD process provides a level of resiliency to team relationships through the principle of "putting the best interests of the project first" as was evident when the team was faced with a significant and potentially expensive unforeseen problem (the shear wall design) (Cheng et al., 2016).

5.5.4 Challenges

- In 2013-2014, IPD and lean were such novel concepts that the operating systems (such as Last Planner System®) were largely untested in Canada and had to be adapted from the US. Coming to grips with all the new tools and processes was challenging for the team on top of what was a very technically demanding project.
- Breaking down cultural barriers and getting buy-in across the team took considerable and sustained effort – especially from the owner. Even then, many firms (especially trade partners) still found it easier to follow traditional processes. Some needed specific assistance to buy into the project goals and get to grips with how IPD works.
- The IPD team members found that there was a feeling of separation on-site for some of the trade partners who were not the part of the signatory group or the shared risk/reward group.

5.5.5 Lessons Learned

The Mosaic Centre project delivery process was very intense with significant learning opportunities for all team members. The pace may not have been sustainable for an owner or for firms that had more than one project that was as time consuming as Mosaic.

- Team-wide openness, honesty and trust are essential in IPD. It requires concerted and sustained effort to build a collaborative culture – especially within those team members that may not be party to the profit pool.
- As it was their first IPD project, the team thought that everything would be different and were pleasantly surprised by the fact that, in reality, construction/site management activities proceeded no differently to traditional practice.
- The IPD multi-party agreement and the shared risk/reward pool helped to shift entrenched cultural drivers. "We over me!" and "Project first, not company first!" became powerful motivators that were reinforced within the team throughout the project.
- In retrospect, the project team recognized that they could have completed the base construction contract and then amended it to include all the supplementary conditions later instead of waiting three months for everything to be complete before they signed the contract.
- The contractor learned that lean champions can come from all levels of an organization and the lean champion may change as the project progress (Cheng et al., 2016).
- Having a formal contract with a shared risk/reward structure drives team-wide collaboration and sustains it in the face of adversity.
- The owner did not want to be overly bureaucratic in the way the inter-team exchanges were conducted. The idea was that a certain level informality encouraged ongoing interaction which would lead to reduced administration. However, in retrospect, they felt that more structure could have imposed to project documentation processes.

- The BIM model was not used to the fullest extent (e.g. for quantity take-offs, construction sequencing, facility management, etc.). Major components such as the glulam trusses were manufactured from shop drawings.
- Project forecasting is crucial. The project manager needs to have strong project and schedule control abilities.
- In IPD, the cost estimating role is not a passive one. Cost estimation should happen in real time and the estimator needs to proactively participate as an integral member of the team.

Chapter 6: St. Jerome's University Student Residence and Academic Centre

6.1 Context

6.1.1 Project Description

Figure 6-1 St. Jerome University's campus renewal project (Image source: Light Imagine Creative Photography)

In 2016, St. Jerome's completed a $47 million campus renewal construction project (Canadian Interiors, 2014), which included –

1. A two storey 2,087m^2 (22,456ft^2) academic building comprised of a variety of flexible classroom configurations and a 300-seat auditorium.
2. A seven-storey student residence that is organized around twelve "houses" of thirty students in a mixture of single and double rooms plus two dorm rooms on each of the upper six floors, which provided a total of 360 student beds for the university's on-site accommodation. The ground floor has physical recreation amenities as well as study, games and music rooms.
3. Significant site works including reconfigured roads, landscaping and new parking.

The project was the first example in Canada of Integrated Project Delivery (IPD) being used in the academic building sector where the architect, contractor, and client entered into an agreement to operate as a truly integrated team through all phases of design, fabrication, and construction (Becks et al., 2015).

Figure 6-2 Rendering showing the extent of the proposed campus renewal project (Becks & Dow, 2017)

6.1.2 Owner Identity

Understanding the owner's governance structures is critical to any capital project. Darren Becks was the Vice-President, Administration at St. Jerome's University and the owner's representative for the campus renewal project. Having served the university for over 20 years when he started the project, Mr. Becks had amassed increasingly senior-level experience and connections in a wide range of administrative areas including finance, human resources, facility management, IT, and ancillary operations (residence, food services, conference services, and parking). The owner's representative brought extensive senior-level experience with a wide range of university functions to the project and was able to effectively navigate university administration to achieve overall owner buy-in and speedy decision-making. Mr. Becks initiated much of the exploratory research on IPD and its applicability to the university's redevelopment (Dixon, 2014). During his research, he connected with the lean Construction Institute (LCI) and was introduced to IPD by US-based construction lawyer and IPD expert, Howard Ashcraft of Hanson Bridgett LLP. In his role as head of university operations, Mr. Becks became the project's lean champion who advocated for innovative ideas.

6.2 Organization

6.2.1 Choosing Project Delivery Method

St. Jerome's $47 million campus renewal project was the university's largest capital investment since the early 1960s. The decision to adopt an IPD strategy was made because it afforded the best way to manage the risks associated with the project size and scope (which was considerably larger than they were accustomed to), the tight budget and a fast-track schedule. The owner felt that because it was predicated upon "shared values, shared management, shared outcomes" and on complete transparency and inclusiveness, IPD would best suit the institutional context where decision-making across many different departments can be challenging.

They also believed that the emphasis on collaboration in IPD fit with the university's values of "Fostering Community, Inside & Out". Moreover, St. Jerome's University is affiliated with the University of Waterloo, which is considered one of Canada's most innovative universities. As a result, they were interested in exploring innovative and sustainable solutions to support a mandate of "educating the whole person". A major advantage to choosing IPD was that the university could include faculty, students, and other interested parties in the planning process.

6.2.2 Owner's Goals

As the project represented the university's largest capital investment for more than 50 years, the owner's most important goal was to complete the project on time, on budget and also to minimize its exposure to financial risk – something they felt IPD could provide.

6.2.3 Team Selection

Being the first IPD project for the university, the owner did not go out for a full public RFP. Instead, the university worked with Hanson Bridgett to develop a Canada-appropriate Request for Proposals (RFP) process in which IPD specific selection criteria were clearly set out and weighted (Table 6-1). The IPD team selection criteria were: firm's capacity, knowledge of lean, previous experiences, experience in delivering post-secondary educational campus projects, experience in collaborative project delivery, experience in BIM, financial capacity, and ability to deliver value.

Table 6-1 Summary of St. Jerome's University's core IPD team selection criteria with weightage (Source: St. Jerome's University)

Criteria	Points
Expertise, experience and qualifications with regards to post-secondary education campus projects.	20
Expertise, experience and qualification with regards to collaborative project delivery approach and BIM.	20
Financial health.	20
Appropriateness of multipliers, rates, overhead, and profit percentages to current market (Not a lowest price selection).	20
Proposed project strategy.	10
Strength of references.	10

6.2.4 Developing the Contract

The RFP was issued in March 8, 2013 and the owner arranged pre-submittal meetings with each of the proponent teams to answer any questions before the submission deadline (April 19, 2013). The owner received 10 full team bids for this project. Based on the above-mentioned criteria, the core IPD team of Graham Construction (general contractor) and Diamond Schmitt Architects (architect) was selected after conducting interviews with short listed teams.

> *"We received 10 full submissions. Each team had to assemble what they felt it [the project] needed. There were varying degrees of understanding [of the IPD model]," "We gave them up front…a whole backgrounder. It was just different because we were procuring a whole suite. This has not been done a whole lot in Canada in the full IPD*

way. We commenced the project with a cost until we got to validation." (Daily Commercial News, 2014)

– Darren Becks, St. Jerome’s University

After the general contractor and the architect were selected, the owner expected them to assemble the necessary expertise within their own firms and retain the rest of the team.
The multi-party construction contract for the St. Jerome’s University campus renewal project used an established US-based model with minor modifications. The IPD construction contract was signed after the validation phase and resulted in a detailed plan outlining what the project will entail. Consultants’ sub-agreements were organized under the architect and sub-agreements for trades were held with the contractor.

"In this arrangement, the three of us – the contractor, the architect and the client – are all signing one mutual contract. All three of us are legally bound together. So that's a very strong distinction."

"And within that agreement, there are various clauses that limit quite significantly the times where we can apportion blame or sue each other effectively. For lots of things on a typical project, I might end up suing, or he might end up suing me. Those are taken off the table,"

"So, therefore, it's better for us to work together. It's a legal framework to help enforce the collaboration." (Dixon, 2014)

– David Dow, Diamond Schmitt Architects

6.2.5 Project Team Structure

The final IPD team structure comprised a Senior Management Team (SMT), Project Management Team (PMT) and Project Implementation Teams (PITs). Figure 6-3 shows the project team structure and identifies members involved in each team.

The Senior Management Team members were required to monitor the project on a monthly basis and they had much less overall involvement in the project execution than the PMT. There were no issues significant enough that needed to be elevated to SMT level.

The Project Management Team was responsible for managing and executing the project closely and was involved in directing work. Although the PMT only consisted of 3 members—one each from the owner, contractor and architect—other people often moved into or out of the group to address particular issues when they came up.

The Project Implementation Teams were usually cross- functional teams that were formed to take responsibility for specific technical issues. The role of each PIT was to solve challenges, resolve issues, improve processes, reduce wastes and labour costs, eliminate duplication of effort, etc. Each PIT was responsible for their own budget and scope of work, creating and updating their portion of schedule, developing design details and specifications, means and method, and to report their work to the overall team at Big Room meetings, etc.

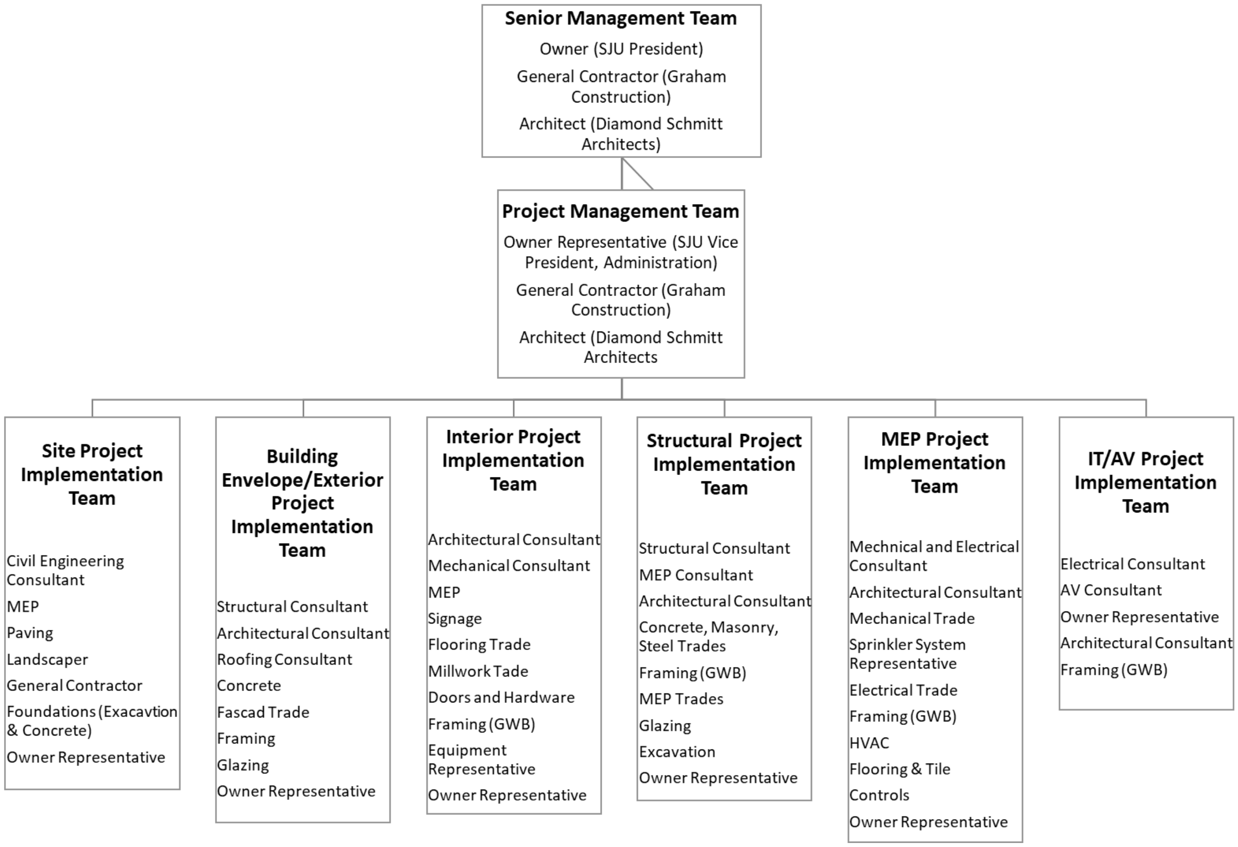


Figure 6-3 IPD Team Structure (Image source: St. Jerome's University)

6.2.6 Champions

All three members of the SMT were lean and IPD champions. The contractor had prior experience with IPD and was already set up with the necessary project management systems. St. Jerome’s SMT representative was critical to setting the tone for the project, both internally and with project partners. St. Jerome’s was Graham’s second major IPD project in Canada. Through their first IPD project (the Dr. F. H. Wigmore Hospital in Moose Jaw, Saskatchewan), Graham’s team (led by Art Winslow) had already developed many of the project management processes and standard practices for delivering IPD.

"We went into the [first project meeting] room and left our conceptions of how we should approach the job at the door. We had a great facilitator, Art Winslow, to guide us through the process — you need a champion to be able to take the team on that journey." (Wall, 2017)

– Mike Moffatt, RJC Consulting Engineers

6.2.7 Decision Structure

Throughout the project, the core team along with the specialty trades made decisions openly and collaboratively during the project meetings. The university's administration had a hand in the plans of new St. Jerome's buildings from the start, from the size and configuration of the raked lecture halls in the academic building to the smallest furniture details in the student residence (Dixon, 2014). All of the design choices were mapped out so that all parties were included in the decision-making process. While this may sound time-consuming, typically it meant that all of the options were modeled into 3D computer renderings, and then all the choices were agreed upon by the main parties and by other building specialists. The intention was to proactively and properly plan at the start to reduce the potential for possibly expensive and time-consuming changes later (Dixon, 2014).

"All this time we were spending on the front end… it's paying its dividends now [in construction]." (Daily Commercial News, 2014)

– Darren Becks, St Jerome's University

The PITs were empowered to make changes to the design and make decisions which could save time or cost if it's a small one. However, if the PIT would encounter an issue, it would be elevated to PMT, which would then be responsible for decision-making.

6.3 Processes

6.3.1 BIM Execution Plan

At the start of the project, a BIM Assessment Report was prepared to gauge each team member's level of expertise with BIM and the extent to which a "BIM culture" had been adopted within their firm. The BIM assessment report helped the project team in facilitating discussions for the development of a BIM project execution plan and BIM protocols. The BIM project execution plan was developed in the beginning of the project and agreed by everyone. It described what the consultants could and could not do in the model, and how all the different models would come together. There were also clearly defined model editing protocols. For instance, the architects could move structural slab edges up to 100mm and were allowed to create and edit slab depressions for floor finishes up to 25mm. Beyond that, they were required to communicate with the structural engineer (Becks and Dow, 2017). To avoid redundancies, all of the consultants' models were hosted locally on each consultant's server and were linked to others through a VPN connection so that all consultants would have live access to others' models. These models were also shared with trades for use as the basis for fabrication model.

6.3.2 Training / Workshops

Because this project was the university's first experience with IPD, Graham engaged Ghafari Associates (a US-based construction engineering company) to provide full IPD consulting, coaching, and management services (Ghafari, 2016). Ghafari guided the IPD team in project planning and information flow management. The project team chose to use vPlanner, a graphic Last Planner® System software solution, to plan the design, construction, and commissioning activities and Ghafari provided vPlanner coaching services through to project hand-over to facilitate collaboration, sequenced decision-making, and informed, timely feedback (Ghafari, 2016).

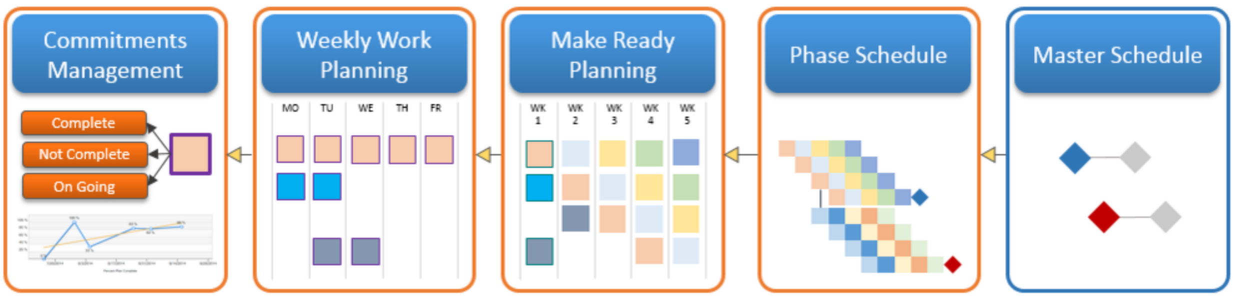


Figure 6-4 The Last Planner System Phases Supported by vPlanner (vPlanner, 2017)

Building rapport and trust with the project team took time and the team also made sure to celebrate early wins no matter how small. For example, gift cards were given to individual trade workers who went above and beyond what was required of them.

6.3.3 Communication and Workplace

The "Big Room" was where a lot of the initial action took place. In some cases, the Big Room meetings involved up to 50 people.

> *"Something comes up in this Big Room setting, we talk about it and deal with it right there. It's instant. It's not done in silos."*

"We deal with problems more often, but they are smaller problems." (Daily Commercial News, 2014)

– Art Winslow, Graham Construction

As most of the IPD team was from Greater Toronto Area (GTA), the Big Room was set up at Graham's office in Mississauga for cost effectiveness. The Big Room was set up right after award of RFP for approximately 4 months.

During the design stage, the consultants were meeting regularly every week. The owner's team used to travel to Mississauga every other week to attend these meetings to make sure the workflow between with the team is happening and progressing satisfactorily (Figure 6-5).

Figure 6-5 Big Room meeting at Mississauga (Left: Becks et al., 2014; right: Becks & Dow, 2017)

The team projected a flowchart of tasks generated by vPlanner for everyone to see on one wall of the Big Room. Each design detail was charted, and each task was given a completion time and inserted into the flowchart. Even small tasks taking only 30 minutes still needed to be checked off. On another wall, all of the significant construction costs were printed on spreadsheets and posted. This level of detail and transparency was key to the team's adoption of lean practices and the team continued to find ways to streamline the design process making it more efficient (Dixon, 2014).

Once the construction started, the Big Room was set up on-site where they had some offices adjacent to it with setup of work tables for trades. As they wanted everybody to work under the same place, there were no office-trailers on-site and they continued the weekly Big Room meetings on-site.

6.3.4 Collaboration

IPD encouraged close collaboration to optimize efficiency and mitigate risk through all phases of the project. The BIM model brought transparency to the forecasted costs, overheads, and profits of each discipline which were continuously monitored by everyone.

> *"I spent a much larger amount of my time working on the project than I would for a project of that scale. So, it took a lot of my time than it's typical. And perhaps, that's true for most people on the team because they are not only performing their everyday role, but they are being involved in a lot of stuff that in normally they might not be which is such as going to a Big Room, a lot more meetings, a lot more coordination sessions. So, there are a lot more things that definitely impact the team and this means that everybody has to do a bit more work."*
>
> – David Dow, Diamond Schmitt Architects

The structural engineer noted that the IPD is very different from the traditional practice because it requires trust between all of the partners. As a result, even the University's senior leadership accepted that the collaborative approach mitigated risk because they could see what the project would look like before a shovel went into the ground (Dixon, 2014). The structural engineer also believed that the keys to making the process work are early involvement of key participants, shared risks and rewards, jointly shared project control, collaborative decision making, trust, lean principles and BIM (Wall, 2017).

The contractor noticed the change in the team members' behavior as their profits were at risk. He also saw a change in culture.

> *"We end up getting changed behaviors, where contractors aren't hungry for extras and changeovers. We have architects that aren't building monuments to themselves… and we have owners who are willing to give and take."* (Daily Commercial News, 2014)
> – Art Winslow, Graham Construction

The owner noted that building rapport and trust, especially with the project architect took time, but was invaluable going forward. The team also made sure to celebrate early wins. The team also celebrated small wins, giving gift cards to individual trades workers who went above and beyond what was required of them (Hixson, 2016).

At the end of validation, the projected budget was $47 million. There were many instances when the actual cost was about to overcome budget. The numbers fluctuated rapidly all the time and that was one of the biggest challenges, to monitor and control the budget.

> *"These kinds of things happen all day long in IPD, the price can fluctuate dramatically week-to-week. One of the team's primary challenge is controlling those cost fluctuations. So, we had moments when we were half a million above multiple times. And in multiple occasions took all kind of actions to bring things back on course. So, I don't remember specifics that I could point to, but certainly, it did happen more than once."*
>
> *"If it's a traditional bid-build, the contractor would be sitting on all those fluctuations and you never go about them."*
>
> – David Dow, Diamond Schmitt Architects.

The architect also mentioned that having the whole team from the very beginning helped to make design development more efficient. A lot of the trades were involved in a way that they wouldn't have been involved in the past. For instance, the sprinkler trade modeled all the sprinkler lines and integrated with the consultants' model. So, they had a lot more trade immigration into the model just trying to resolve things in the design process. The PITs had a lot of collaborations and coordination where they had conversations in the Big Room and could collaborate digitally.

The downstream project participants helped and contributed to the design by giving their input to cost savings and potential efficiencies. The trades' inputs were also sought to make sound decisions in terms of design.

6.3.5 Innovative Practices

Target Value Design: Adopting Target Value Design involving designers, builders, suppliers, estimators and owners in one place to collaboratively produce a design that provided the best value for the owner. Budget (the target value) is a design criterion that, for St. Jerome's University campus renewal project, was $47 million. The team designed to the budget instead of the conventional process of estimating the cost of the design, and then re-designing to eliminate overruns. For this project, there were many instances when the actual cost was about to go over budget. One of the biggest challenges was to control a budget that tended to jump around a lot.

Last Planner® system: The project team used "Last Planner" scheduling, which enabled the team to plan the project in such a way that produces predictable workflows and rapid learning, all of which saved time. The Last Planner system allowed the team to plan and then fine tune, to find the champions and encourage them, and to keep design ahead of construction. Weekly calls were conducted with the design team and PIT leaders, and planning huddles were done daily. The use of pull planning encouraged the team to be outcome-based thinkers – essentially, planning the building process from back to front. To manage the process, the project schedule was managed on v-Planner which helped the project team to measure percent-planned completed, team accountability, and to identify potential constraints.

Figure 6-6 Weekly meetings with designers, PIT leaders (left: Becks & Dow, 2017) & Daily planning huddles (right: Becks et al., 2014)

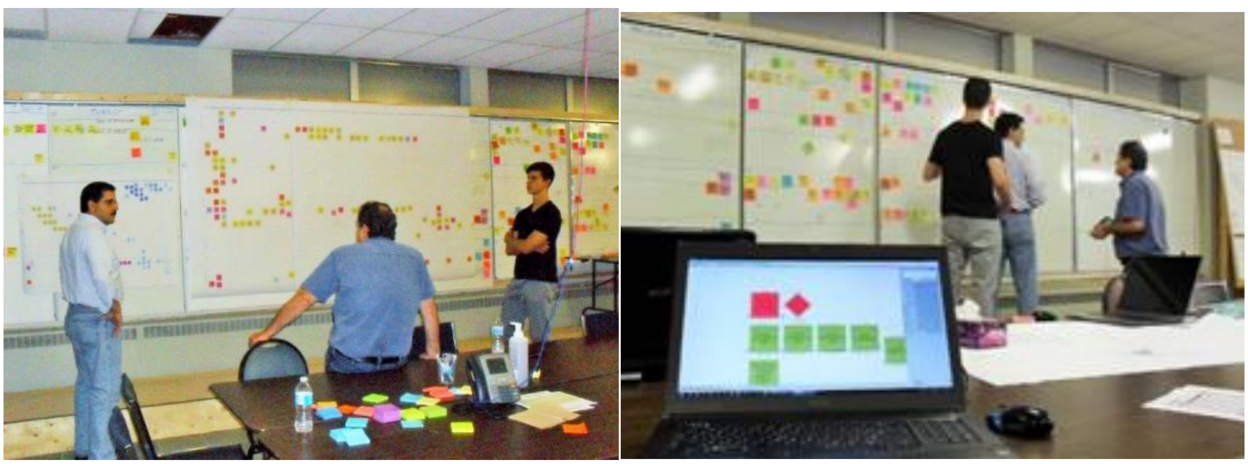


Figure 6-7 Big Room setup showing a detailed schedule on the wall (Becks et al., 2014)

Mock-ups: The team conducted a mock-up test to review precedents, to review furniture in terms of durability and flexibility, and to test room dimensions (Figure 6-8).

Figure 6-8 Mock-up test for finalizing room size and furniture (Becks & Dow, 2017)

Task Management: Using vPlanner, tasks were checked out to the active user when they needed to be edited and checked back in when edits were complete. This eliminated the possibility that one user could accidentally override changes made by another user and improved communication, as users will be able to view who was working on checked-out tasks.

Prefabrication: All the HVAC, heating and cooling piping systems were prefabricated in the end shop. So, when they came in, they were brought to the place and connected on-site (Figure 6-9). The student residential building had the same piping layout floor to floor and therefore, it ended up being cost-effective. Although the time-saving was key, the decision to go with prefabrication was driven by material and labour savings. The team also decided to go with integrated sinks with counter tops which resulted in significant cost savings from having separate trades connect the plumbing, install the cabinets and then the counter tops, drop the sink in, etc.

Figure 6-9 Prefabricated piping system (Dow, 2016)

6.4 Technology Implemented

6.4.1 Uses of Technology

BIM was widely implemented in this project as a means to improve efficiency and support collaboration. The following describes the different uses of BIM:

Visualization: The design team developed a detailed 3D model so that the client and contractor could better visualize the project (Figure 6-10), which was particularly important for the university given the large number of stakeholders involved. Even during construction, the model was continuously updated and shared with trades to help them identify their scope of work.

Figure 6-10 3D model for client visualization (Dow, 2016)

Design Coordination: All the design consultants developed their discipline-specific BIM that was used in the design coordination meetings. In addition, each consultant was given live access to other discipline's BIMs so that they could use them as a reference for their modeling purpose and coordinate accordingly (Figure 6-11).

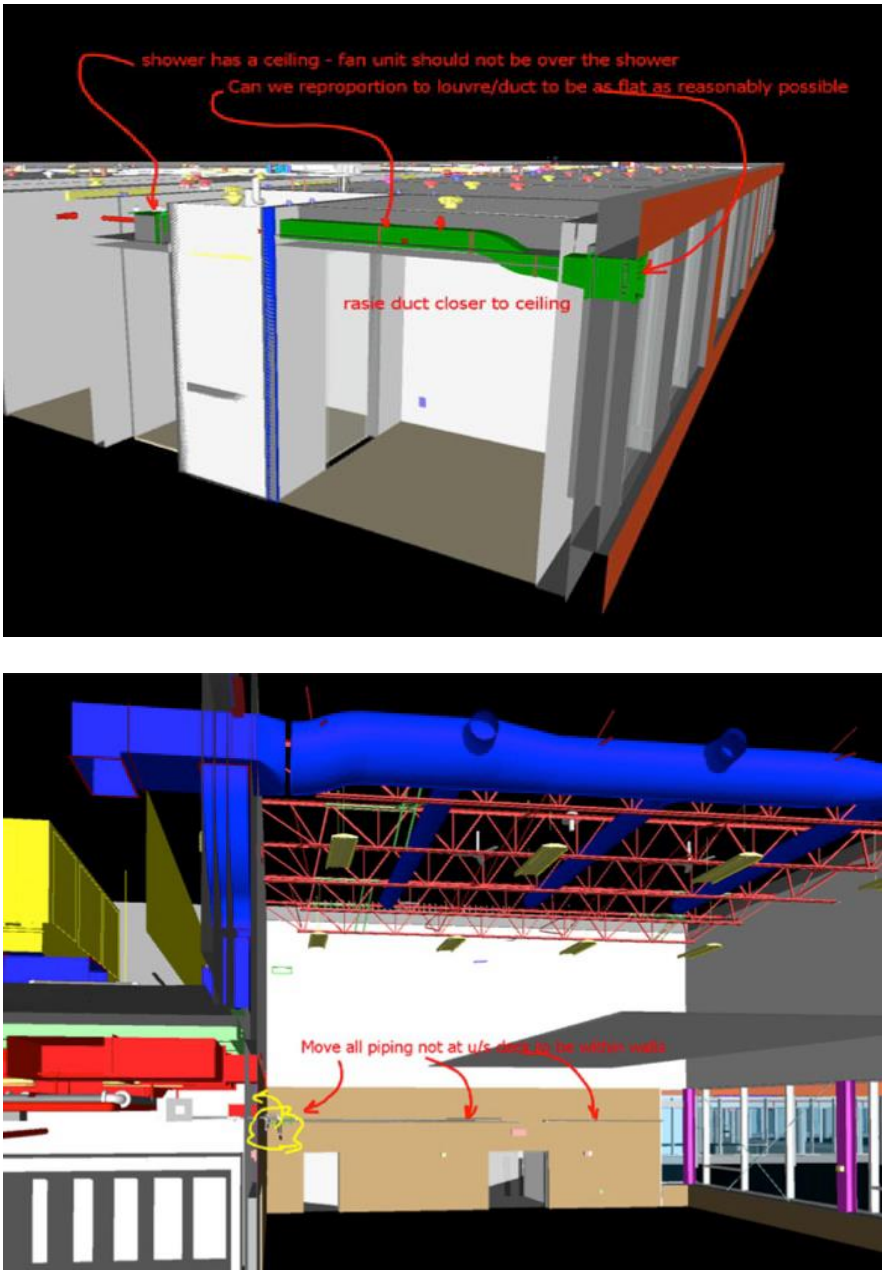


Figure 6-11 Coordination of design models in Revit (Dow, 2016)

Clash Detection: Once the design was sufficiently developed, the team had clash detection meetings where they used Navisworks to identify clashes between their models. The identified clashes were addressed during these meetings and resolved.

Constructability Review: The project team used BIM for constructability review particularly for mechanical and electrical systems. They had a few areas where they did not have much room to fit mechanical and electrical services (Figure 6-12). So, they went through the combined model and tried to make things buildable, rational, and reconciled the locations of services. They also discussed the sequence of work in those areas, such as whether the ductwork or conduits should go first, and they inspected the efficiency of the construction sequence using the models.

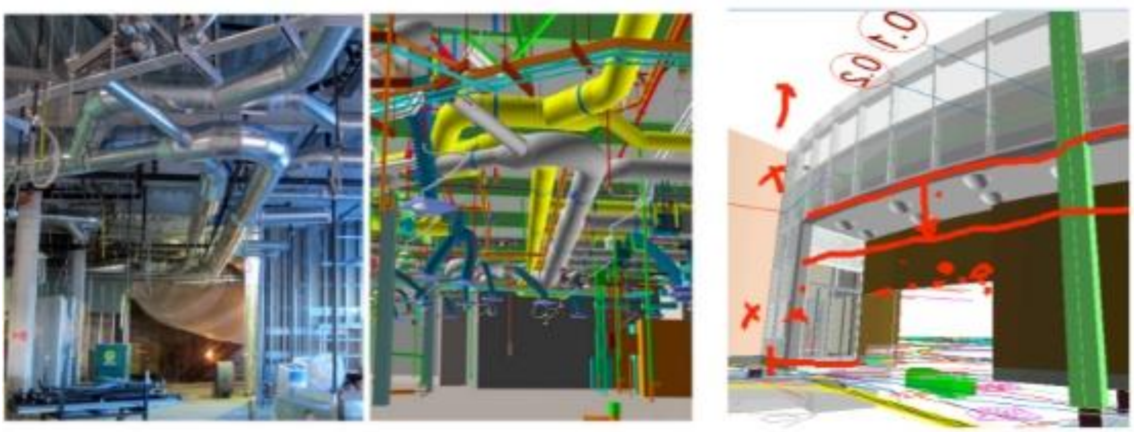


Figure 6-12 Complex mechanical and electrical systems modeled in Revit (Dow, 2016)

Quantity Take-off: The contractor used the BIM for quantity take offs (other than mechanical and electrical).

Digital Fabrication: The 3D model was not widely used for digital fabrication. For example, the mechanical trades remodeled the mechanical systems by using the mechanical consultant's model as a reference and then used their own model to fabricate the mechanical systems.

Facility Management: The BIM in this project was not specifically used for facility management. Some of the data, such as room areas, counts, and names, was pulled from BIM and used to plug into the university's facilities management systems. However, information relating to mechanical or electrical equipment was not included.

6.4.2 Tools Implemented

A variety of different tools were used for various purposes by different disciplines in the project are shown in Table 6-2.

Table 6-2 Tools used by various participants for various purposes

Project role	Software used	Purpose
Architect	Revit Navisworks	3D modeling Clash detection
Mechanical consultant	Revit	3D modeling
Structural engineer	Revit	3D modeling
Electrical consultant	Revit	3D modeling
Landscape and Civil	AutoCAD	For their scope of work
Steel trade	Tekla	Steel modeling

6.4.3 Scope and Level of Modeling

Scope of Modeling

The initial scope of modeling in this project was to visualize and coordinate the consultants' design and to avoid duplication of the scope of work in modeling between consultants and trades. There was a mandate to take the BIMs from the consultants and handover to the trades for their uses. For the size of the project and the available expertise for the trades, it was intended that this would apply to every trade, including with the mechanical and electrical as well. There was also a mandate to perform clash detection to make sure design development was clash-free.

Level of Modeling

According to the architect, the BIM level of detail applied on this project varied between 300 to 400. It depended on the scope of work in a particular area. The mechanical and electrical design models were developed to the level of 400, and certain aspects of the model part were also close to 400. However, the rest of the building design was modeled at 300 to 350 level of detail. The decision as to what level of BIM to develop the model to was decided based on cost benefit analysis. The model was developed to the level of detail where the amount of extra labour time required to maintain the model was never more than the benefits the teams received from the level of modelling.

6.4.4 Information Exchange

All the consultants' offices were setup with a Revit server which was connected by live VPN between design offices. As a result, architectural, structural, electrical, and mechanical had live access to each other's BIM, but nobody else had live access to these BIMs. To share design information with the rest of the team, they used the "ProjectWise" platform. Thus, the larger project team, including the owner, had access to compiled information of the project from design documents to current construction documents. The architect replaced the current BIMs on ProjectWise regularly if there was any progress or changes. The ProjectWise site also contained current Navisworks files and clash detection reports, meeting minutes, RFIs, site instructions, the current set of drawings, other types of project documentation.

Though the team used very collaborative and efficient information exchange methods, they still followed very traditional roles of information dissemination throughout the project where all the information exchanges between the design consultants flowed through the architect. If there was any design revisions, they would go through the architect's office and, after collecting new documents from electrical, mechanical and structural, the architect would post revised drawings, documents, etc. on to ProjectWise site, archiving and distributing these to the team at the same time. The untraditional aspect of this was that it was very immediate since it was distributed and in the hands of trades on the site very quickly. In this way, all document revisions were fully distributed within 24 hours of information being updated.

6.5 Project Outcomes

6.5.1 Owner's Requirements Met

The owner's requirements of building classrooms, 300-seat auditorium, 360 students accommodations along with study, games, and music rooms were fulfilled at the target cost and time were met. An additional $2 million in "value added" improvements were included. The owner also wanted to minimize their financial risks that were effectively addressed by IPD's risk and reward sharing mechanism.

6.5.2 Cost and Schedule

The project was delivered for the target cost. The overall project cost was 20% less than projections developed using a P3 model (Becks et al., 2015). Contingency was reduced to less than 4% due to improved processes (Becks et al., 2015). The consultants' fees were budgeted at $1.48 million but only $1.07 million was spent (Dixon, 2014). The savings (27% of the total fee) were due to reduced labour requirements gained through efficient processes and avoided duplication. However, the team did receive only about half of their profit because of execution errors that they attributed to this project being their first experience of IPD. Some team members considered this as a gain in terms of the unprecedented learning opportunity, while others saw it as a loss.

The project benefited from the up-front investment for extensive early planning and resulted in 3-months of saving in the project schedule. The project was completed in 32 months, which is 9% faster than the original schedule of 35 months.

6.5.3 Benefits

- The lean methods enforced by the IPD arrangement and, particularly, the extensive pre-planning and focus on continuous improvement helped to condense the schedule by 3-months.
- Many advantages came in the first five months of the project during the Big Room planning. For example, minor adjustments to room sizes saved $1 million and early planning allowed for advanced furniture purchase that created more savings.

- For those interviewed, the collaborative process resulted in an improved overall experience compared to traditional practice.
- The use of BIM and a virtual project management platform encouraged collaboration and improved the efficiency with which information flowed through to workers in the field.
- Adoption of a full IPD approach, complete with multi-party agreement enabled St. Jerome's to mitigate risks, explore and realize continuous cost savings, achieve milestones on time and on budget, enhance active management and project transparency, and improve the project's final design. Also, the involvement of subcontractors helped in optimizing the building design as shown in (Figure 6-13).
- The team-based review with real-time feedback reduced resubmissions and shortened the approval time.
- The client received better value for money and had a better understanding of the building facility earlier in the process (Dow, 2016).
- The project was highly responsive to the client's specific needs (Dow, 2016).

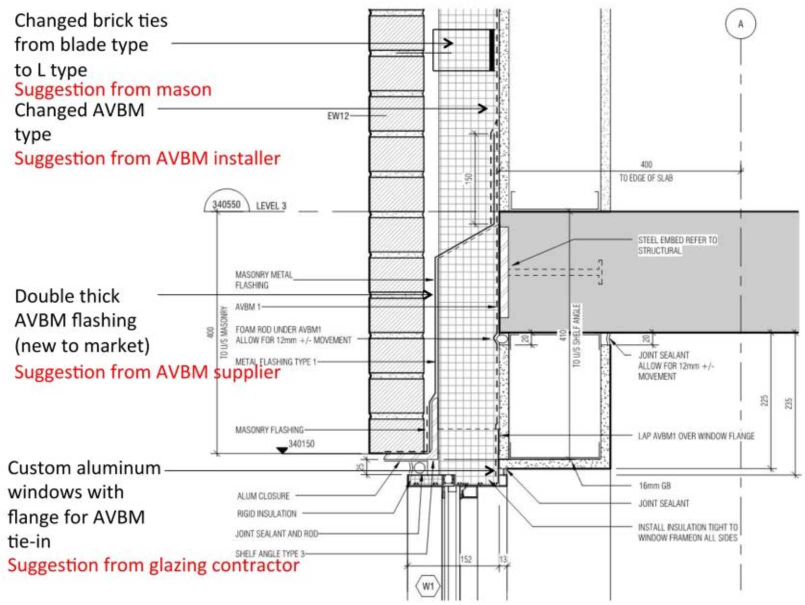


Figure 6-13 Detail illustrating sub-trade involvement in optimizing the building design (Becks & Dow, 2017)

6.5.4 Challenges

- The main challenge was the culture shift required in the IPD setting and changing the team's attitude.
- With hindsight, the owner believed that the project could have saved a further two months (i.e. be delivered a total of 5 months faster than scheduled), but in the last 10-15% of the project, some key people left when their part of work was complete.
- To reap the full potential of IPD requires team members to take on leadership roles that extend beyond traditional disciplines. The fragmented nature of the construction industry does not encourage this type of leadership.
- Speaking up in a Big Room meeting in front of 50 people can be intimidating and the project would have benefitted from coaching and support for those who are not comfortable with public speaking.

6.5.5 Lessons Learned

The St. Jerome's university campus renewal was a complex project that was delivered on budget and ahead of schedule with significant added value but, with hindsight, there were further opportunities for improvement left on the table.

- The initial BIM assessment report was important in gauging team members' comfort level with the technology and ensuring there was a level playing field from the outset.
- Team-wide openness, honesty and trust are essential in IPD. It requires concerted and sustained effort to build a collaborative culture – especially within those team members that may not be party to the profit pool.
- It would have been beneficial to have had the journeymen, foremen and superintendents from the various trades at the table earlier.
- Training, early onboarding, and educating team members worked well in building rapport and trust in each other.
- Celebrating small wins helps to build a collaborative culture in the team.
- Early involvement of on-site trade leads to design improvements and process innovation.
- The team did not collocate in a Big Room space on an ongoing basis, although they had a dedicated space in which they met regularly. In retrospect, they believed that collocation would have resulted in a more efficient coordination process.
- Ongoing training and management of new members' onboarding are essential in collaborative team building.
- Project teams can deliver a better project simply by being open to changing workflow processes and being open to adjusting the way they collaborate.

- Making sure that the contract addresses the liabilities and limits the opportunities for inter-term member confrontation (i.e. through key clauses describing when blame can be applied) helps in embracing more open dialogue with the rest of team.

Chapter 7: UBC Brock Commons

7.1 Context

7.1.1 Project Description

Brock Commons is an innovative 18 story, 54.37 meter-high, hybrid timber-concrete residential high-rise located at the University of British Columbia (UBC) on the Vancouver campus, which is the tallest hybrid timber building in the world (Figure 7-1). It is a student housing facility providing 305 housing units (272 studios and 33 quads) for students, with public amenity spaces on the ground floor and a lounge on the top floor. The total project budget $51.5 million, with $47.07 million financed by UBC and a premium for the mass timber innovation of $4.5 million (external funding shown in Table 7-1).

Figure 7-1 Brock Commons under construction (left image source: Naturally Wood) and after construction (right image source: University of British Columbia)

Table 7-1 External funding for Brock Commons (Poirier et al., 2016)

Funding Source	Amount
Natural Resources Canada (NRCan)	$2,335,000
Binational Softwood Lumber Council (BSLC)	$467,000
Forest Innovation Investment (FII)	$650,000
Further Government Targeted Fundraising	$1,000,000
Total 3rd party funding provided	$4,452,000

This project involved prefabrication in the form of Cross-laminated timber (CLT) panels, Glued-laminated timber (GLT) columns, Parallel strand lumber (PSL) columns, and on-site constructed elevator shafts with reinforced concrete. Prefabricated timber elements are used in the building from level 2 to level 18 in the form of slabs and glulam columns. The structural system of the building—including the foundation, ground level, first level, and 2 elevator shafts—were constructed with cast-in-situ concrete.

The project was initiated in November 2014 and the design began in January 2015. The construction of Brock Commons started in October 2015 and it was completed in July 2017. Figure 7-2 shows timeline of the project schedule.

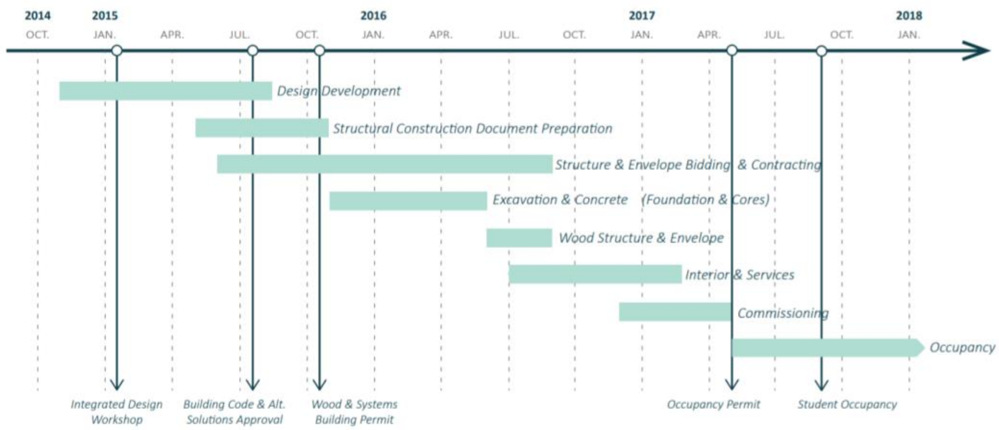


Figure 7-2 Brock Commons project schedule (Pilon et al., 2017)

7.1.2 Owner Identity

UBC is a public owner of this project who is always in the pursuit of excellence in research, learning and engagement. UBC Student Housing and Hospitality Services is the client and operator of this student housing project. UBC Infrastructure Development acted as owner's representative, managed the project business case development, Board approval process, project governance committees and external funding agency relationship/reporting. UBC Properties Trust, which is UBC's Property Management subsidiary, was responsible for assembling the project team and served as the owner's project manager during design and construction phase. The owner's team was very experienced in the delivery of a wide range of innovative high performance and sophisticated projects from research labs to residential towers.

7.2 Organizational Setup

7.2.1 Choosing Project Delivery Method

The Brock Commons project was procured under Canadian Construction Documents Committee (CCDC) 5A Construction Management at Risk (CM+) contract, which is an accepted form of agreement commonly used by public sector organizations. Every member of the project team has a direct contract with the owner in a CM+ setup and it allows the owner to retain more control over the project, which was the rationale behind selecting the CM+ delivery method.

7.2.2 Owner's Goal

This project was part of the 2010 UBC Vancouver Campus Plan to address the growing demand for student housing on Campus. Therefore, the main goal of the owner was to minimize the design and construction duration by adopting prefabrication and fast-tracking techniques. As UBC is a public entity, the cost of the construction was also one of the concerns. Therefore, the owner's goal was to get a complete building at a competitive price compared with campus's standard concrete buildings (Fallahi, 2017). The reason behind using the timber solution for the project was the availability of nearly $4.5M worth of innovation grants from various funding sources as mentioned earlier (Table 7-1) (Fallahi, 2017).

After deciding to go with a mass timber structure for this project, the goal was to design, build, and evaluate a 18-storey building and demonstrate the applicability of advanced wood-based building systems in the tall building market (Poirier et al., 2016). In addition, UBC mandated to achieve LEED Gold certification for all the buildings delivered since 2008. Therefore, one of the owner's goal for Brock Commons was to build a sustainable building aiming to achieve LEED Gold certification (Poirier, 2016).

Considering the novel nature of high-rise mass-timber building, the most important concern for UBC was fire and life safety of the building occupants (Poirier et al., 2016). Therefore, any real or perceived risks to safety were required to be addressed to ensure safety during construction as well as operation of the building (Fallahi, 2017).

7.2.3 Team Selection

UBC Properties Trust, performing as an owner's project manager, led and managed the project. At the beginning of the project, a Request For Proposal (RFP) for design and pre-construction services was issued by the owner in late 2013. Given the innovative nature of the mass timber structural systems and the fact that a site-specific regulation would need to be developed and approved by the BC government, the owner and the project manager selected the structural engineer as the prime consultant from a small group of local firms with expertise in mass timber design. Later, the owner issued separate RFPs for design consultants in the summer of 2014 and finally, the RFP for preconstruction services was issued in October 2014. By November 2014, the owner had assembled the core team comprised of the architect, structural, mechanical, electrical, and fire protection engineer, construction manager and building code consultant. The team selection process relied on qualitative bids.

The Owner received more than 20 initial architectural submissions from local and international firms, from which three companies were selected and invited to present their proposals in front of a selection committee. A team formed by Acton Ostry (a local architectural firm) and by Hermann Kaufmann Architects (an Austrian firm with previous experience with tall mass timber buildings in Europe) considering the limited level of expertise in tall wood construction in Canada (Poirier et al., 2016).

The Mechanical, Electrical, and Fire Protection Engineer and the Building Code Consultant were selected based on their previous positive experiences in collaborating with UBC. Also, based on experience with CadMakers (VDC integrator) on a previous project, UBC Properties Trust appreciated the value of Virtual Design and Construction (VDC) modeling. Therefore, CadMakers was brought on board at the very beginning of the project. GHL Consultants Ltd, the Code consultant, was hired early to work with the BC Building Safety and Standards Branch on the project's site-specific regulation (Fallahi, 2017), which was a unique building code bound to the property to allow a wood structure above 6 stories and, at the time, a new regulatory tool that had only been used once before.

The selection of Urban One Builders as the Construction Manager (CM) was through a public RFP process in accordance with the public procurement regulations in BC. The construction manager was involved early in the project to provide design-assist services, including cost estimation, constructability, and planning services (Poirier et al., 2016).

7.2.4 Developing the Contract

As mentioned earlier, the project used a CCDC 5A Construction Management at Risk (CM+) agreement, so every member of the project team (consultants, construction manager, trades and sub-trades) had a direct contract with UBC Properties Trust. Each member of the consultant team was contractually bound to UBC Properties Trust, except for Hermann Kaufmann Architects who served as an "advisory architect" and was contractually bound to Acton Ostry Architects, who were the architect of record for the project. The specialty trades were invited to provide design-assistance (without formal contractual binding) to help with the design development and then the trade contracts were let by tender.

7.2.5 Project Team Structure

The key project participants are identified in Table 7-2 with their respective roles and Figure 7-3 shows the project team structure of the Brock Commons project.

Table 7-2 Brock Commons project team (Poirier et al., 2016)

Role	Company
Client & operator	University of British Columbia, Student Housing and Hospitality Services
Owner's Representative	UBC Infrastructure Development
Owner's Project Manager	UBC Properties Trust
Architect of Record	Acton + Ostry Architects
Advisory Architect	Architekten Hermann Kaufmann ZT GmbH
Structural Engineer	Fast + Epp
Mechanical, Electrical, and Fire Protection Engineer	Stantec Ltd.
Building Code Consultant	GHL Consultants Ltd.
Building Envelope & Building Sciences	RDH Building Science Inc.
Acoustical Engineer	RWDI AIR Inc
Civil Engineer	Kamps Engineering Ltd
Landscape Architect	Hapa Collaborative
Building Energy Modelling	EnerSys Analytics Inc.
Virtual Design & Construction Integrator	CadMakers Inc
Construction Manager	Urban One Builders
Mass Timber Supplier	Structurlam Products Ltd
Mass Timber Erector	Seagate Structures
Concrete Forming and Placement Contractor	Whitewater Concrete Ltd.

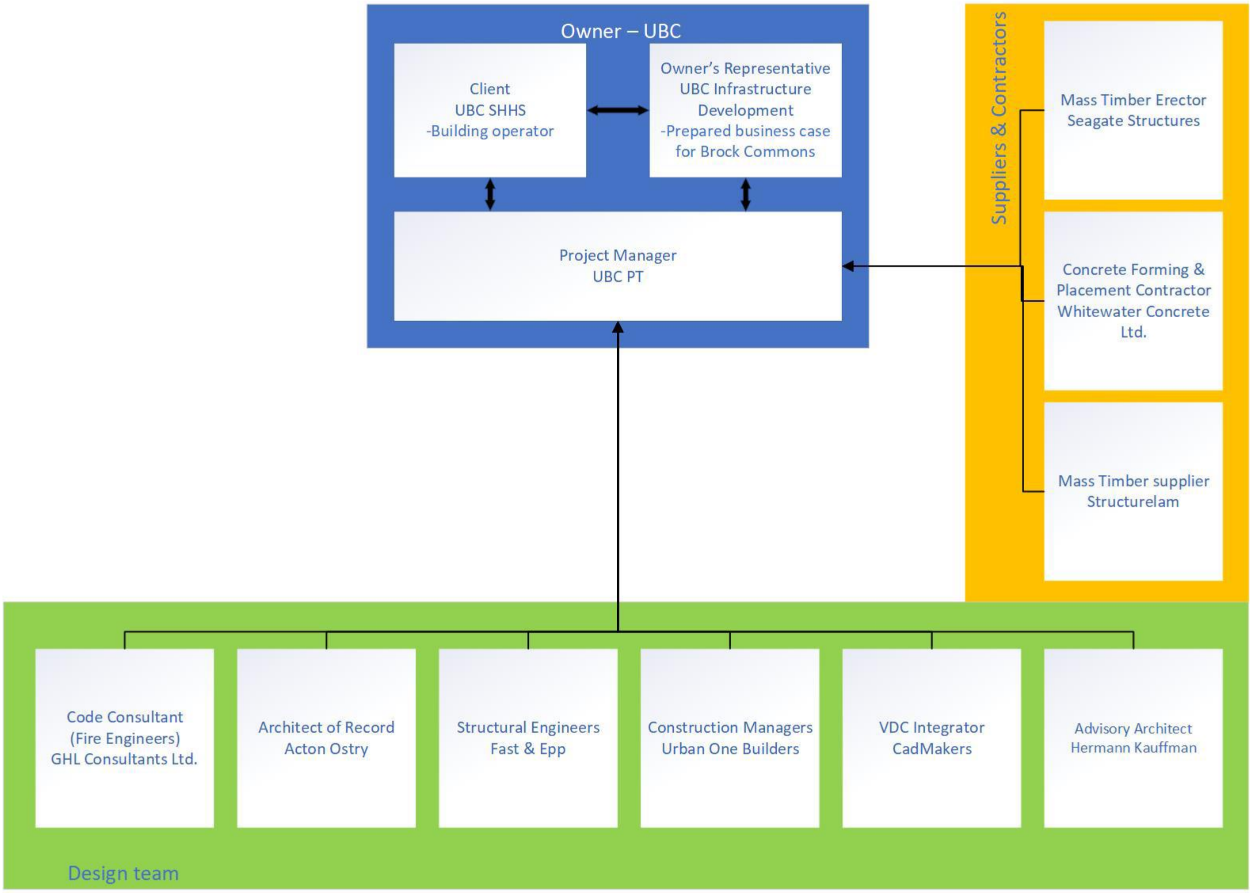


Figure 7-3 Brock Commons project team structure (Poirier et al., 2016)

7.2.6 Champions

The owner's project manager, UBC Properties Trust, championed the collaborative project delivery process in this project. Considering the innovative nature of the project, UBC Properties Trust assembled the core project team of architects, VDC integrator, structural, mechanical and electrical engineers, construction manager and Building Code and Fire engineer early in project and invited other team members to participate as needed (Poirier, 2016). UBC Properties Trust also hired specialty trades (mass timber supplier, erector and concrete forming and placement trade) that deemed critical to the project as a design-assist role to provide their pre-construction services (Poirier, 2016).

Vancouver-based Acton Ostry Architects in collaboration with Hermann Kaufman from Austria, acting in a advisory role for the tall wood component of the project, were champions for the tall mass timber building. The code consultant, GHL Consultants Ltd., also acted as an expert with mass wood structures (Poirier et al., 2016). In this project, having the VDC expertise was the key for collaborating and coordinating process for the owners. They were responsible for coordinating the design development process between the design consultants.

The selected mass-timber supplier, Structurlam, was one of the local industry leaders in combining comprehensive 3D modeling with the digital fabrication of mass timber solutions. The mass-timber supplier took advantage of available models through leveraging their capabilities in developing and using comprehensive 3D models for digital fabrication of mass timber.

7.2.7 Decision Structure

After owner decided to go with the innovative approach for this project, UBC Properties Trust hired the core project team for Brock Commons. Decision-making for design development and refinement was made collaboratively in coordination meetings with the involvement of all key project members. According to Poirier et al. (2016), the project team relied on following strategies for design-related decision:

- Using Ponderosa Commons Phase II as a design precedent

- Well defined project constraints during initial 3-days workshop
- Conducting integrated design workshops
- Using a design approach akin to set-based design
- Heavy involvement of the VDC integrator for planning and constructability review
- Building full-scale mock-up
- Involving Authority Having Jurisdictions throughout the design process

Poirier et al. mentioned that the project team used a design approach akin to set-based design, through which all project stakeholders shared a range of acceptable solutions for a particular scope of work and looked for an overlap. They also mentioned that the project team selected structural solution of the building at the end of the workshop through mutual consensus. The construction manager developed comprehensive cost model through which the project team was able to rapidly estimate alternative design solutions (Poirier et al., 2016). This helped in making key design-related decisions. All the further design and construction-related decisions were made in project meetings with involvement of relevant team members. UBC Properties Trust also funded full-size mock-up to test and validate the viability and constructability of design solutions, key structural elements, prefabricated envelope panels (Figure 7-4) (Poirier et al., 2016).

Figure 7-4 Full-size construction mock-up (Poirier et al., 2016)

7.3 Processes

Brock Commons represented a rare opportunity to test new technologies in a real project setting, which posed significant pressure of scope creep on the project team. An intense collaborative effort by all team members was required to keep the project on budget and on schedule.

7.3.1 VDC Execution Plan

As mentioned earlier, UBC Properties Trust retained the service of VDC integrator to develop a single comprehensive 3D model for design coordination use throughout the lifecycle of the project. One of the key reasons for this was to remove any burden on the design consultants to produce a 3D model that could be used throughout the project's lifecycle and each consultant could focus on design, using the tools that they were most comfortable with (Poirier et al., 2016). The requirement of having only a single 3D model was made to avoid interoperability issues and to avoid redundancy issues occurring from information transfer from one software to another. The VDC integrator was tasked with collecting all relevant project information and 2D plans from the different team members and to create a singular model of the building that would be developed to a very high level of detail (Poirier et al., 2016).

7.3.2 Training / Workshops

To ensure the uniqueness of the building be contained to a manageable scope and to discuss various structural strategies effectively, a 3-day workshop was held early in 2015 involving the owner, architect, structural engineer, code consultant, construction manager, VDC integrator, and wood erection and concrete trades (Figure 7-5). A key outcome of this workshop was the identification of the major constraints related to the material selection, production, installation, and shipping of the prefabricated components (Fallahi, 2017).

Figure 7-5 3-day design workshop (Image source: Acton Ostry Architects)

7.3.3 Communication and Workplace

Although the project team was not co-located at one place (i.e. there was no “Big Room”), they held regular weekly or bi-weekly coordination meetings starting with the design development stage. The VDC integrator worked closely with the architect, structural engineer, and MEP engineer to develop and coordinate the virtual model.

The primary means of communicating the discipline-specific designs with the VDC integrator was via 2D drawings or PDFs, as well as weekly/bi-weekly coordination meetings. In coordination meetings, the interdisciplinary design clashes were identified and resolved.
To assess the constructability of the design and to identify the coordination issues early before construction commenced, the downstream project participants (construction manager, installer, and construction trades, etc.) started to get involved in coordination meetings towards the end of the design stage.

For the development of a 4D sequencing video, the mass-timber installer, Seagate, had one-to-one meetings with the VDC integrator.

7.3.4 Collaboration

The scope of the design team (in terms of their deliverables) was clear and they were required to collaborate effectively with each other and with the VDC integrator. As mentioned previously, team collaboration was achieved through regular meetings during the design development stage. The VDC integrator was given responsibility of coordinating interdisciplinary design developments and played an important role in collaborative meetings.

The construction manager, manufacturer, installer, and key construction trades provided design assistance early in the design stage and attended meetings regularly.

This highly collaborative environment resulted in comprehensive and constructible design development and it also helped the construction team to understand their scope of work. Intensive early planning before the construction phase in this project resulted in many elements being prefabricated, which improved on-site productivity.

7.3.5 Innovative practices

Prefabrication: The highly detailed and coordinated 3D model allowed the accurate prefabrication of CLT panels, as well as glulam and PSL columns with manufacturing tolerances of +/- 2 mm along the length and width, and +/- 1.2 mm for the thickness of prefabricated components (Figure 7-6). As the model contained details of MEP systems and component connections with accurate positions, it allowed for holes in mass-timber elements to be pre-cut in the manufacturing facility. The envelope panels of the building were divided into 13 different types and were fabricated off-site.

Figure 7-6 CLT panels, GLT columns, and envelop panel at off-site manufacturing facility (Image source: Fallahi (2017) & Acton Ostry Architects)

Full-scale Mock-up: As shown in Figure 7-7, a mock-up was composed of a section of the ground and second floor, spanning 3 bays by 3 bays. It included the primary elements and connections that should be used in the building. The full-scale mock-up test was performed to validate decisions such as connection details with column and slab, connection with the slab and concrete core and confirm the choice of steel assembly for the structural columns.

Another purpose of building a mock-up was to practice construction methods, as well as checking and optimizing the on-site sequencing. The result of the sequencing during the construction of the mock-up was incorporated in the model, which helped the project team to develop construction strategy documents including safety plans, transportation, and loading schedules, as well as installation sequencing.

Figure 7-7 Mock-up testing (Image source: Fallahi (2017) & RDH Building Science)

The availability of the structural assembly mock-up allowed the project team to evaluate companies that had been shortlisted for the building envelope contract more effectively than might normally be the case. Each proponent was invited to provide sample panels to demonstrate the precision, performance and ease of installation before being awarded the job.

The mechanical room was also prefabricated and assembled on-site which reduced 2-3 months of on-site work.

Just-In-Time Delivery: Implementing Just-In-Time delivery of the prefabricated mass-timber elements involved intensive pre-construction planning but was able to speed up construction to the point that Brock Commons was completed in 18 months, whereas a comparable concrete building would have taken roughly 22 months to build (Haden, 2017). As shown in Figure 7-8, all CLT panels on each building floors were given a unique number to identify their positions. The loading of these CLT panels on the truck at the manufacturing workshop was also arranged in a way that the installation sequence of the panels on-site was maintained from the truck itself (Figure 7-9).

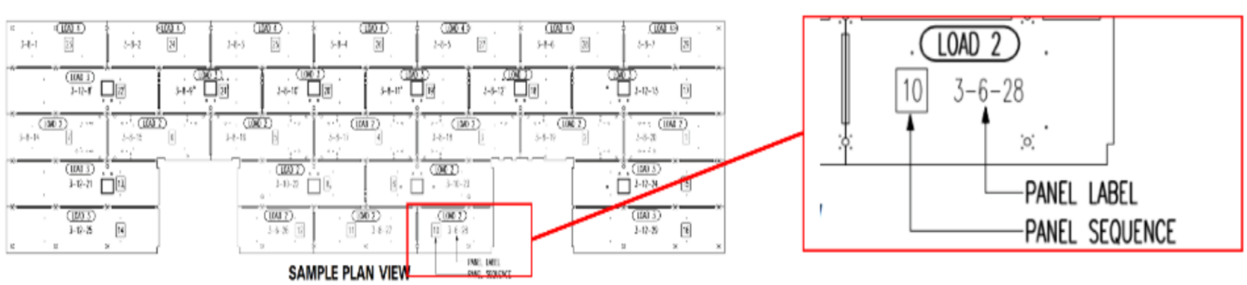


Figure 7-8 CLT panel identity number and installation sequence (Fallahi, 2017)

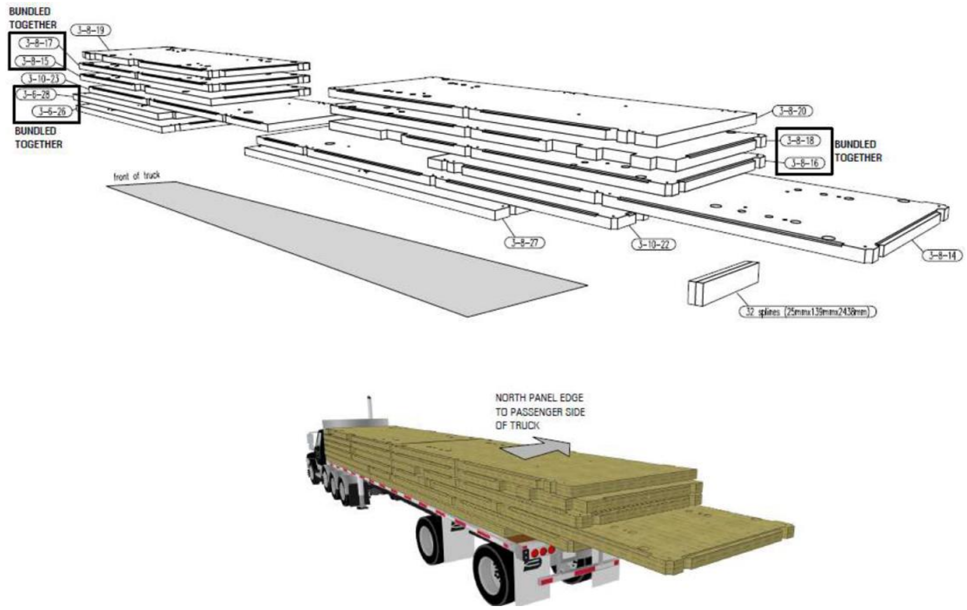


Figure 7-9 Detailed modeling of loading and unloading cycles (Fallahi, 2017)

A highly integrated team was able to pre-plan the construction sequencing and delivery of prefabricated elements so that the speed of assembly reached the point at which two levels of mass timber structure and prefabricated façade were installed each week.

7.4 Technology Implemented

7.4.1 Uses of Technology

The 3D and 4D models in the Brock Commons project were used extensively during the design, manufacturing, and construction stages for a wide range of different purposes. The main uses are described below:

Visualization: 3D visualization of the latest design status and the changes applied to it was a great asset to the entire project team. Particularly, the 3D visualization was an effective method to ease the comprehension of the project practical challenges and to communicate different scopes of work, as well as their interconnections. In this project, the 3D model was continuously updated by the VDC integrator, who was also in charge of providing suitable visualizations in the coordination meetings.

Multidisciplinary Coordination: The 3D model was used in coordination meetings and workshops for issue identification and resolution purposes. Consequently, having a unified 3D model helped different participants to better understand and communicate interdisciplinary systems, which led to a more effective decision-making.

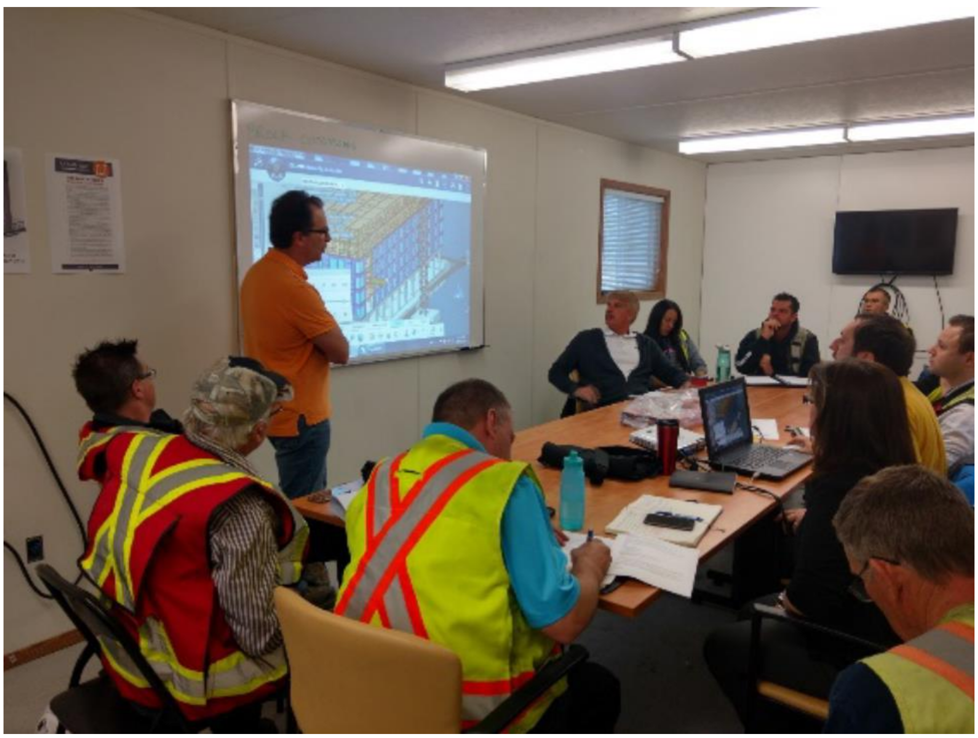


Figure 7-10 Integrated multidisciplinary coordination meeting (Fallahi, 2017)

Clash Detection: During the design phase, the design team regularly performed clash detection tests. Once identified, these clashes – if required – were communicated with the other project team members, either through open discussions during the multidisciplinary meetings or through formal and informal emails, which included snapshots of the identified clashes, their descriptions, and the proposed solutions, if any. Figure 7-11 shows the snapshots of some clashes with proposed solution options.

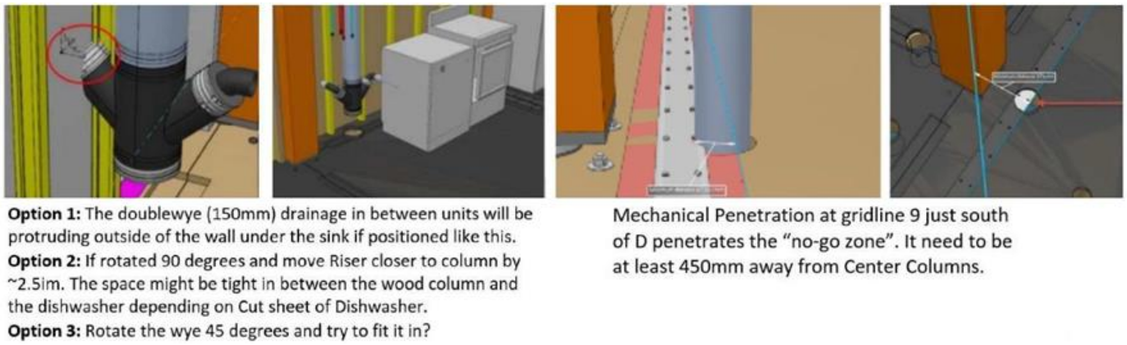


Figure 7-11 Sample of clash detection in design development phase (Image source: CadMakers Inc.)

Constructability Review: The 3D model was sufficiently detailed to allow fabricators, manufacturers and installers to assess the design from the constructability perspective in the early stages of the project. This helped to identify whether some critical design solutions would result in impractical construction conditions. The constructability review was conducted by the practitioners visually and, when an issue was spotted, then these issues were shared with the relevant project team for issue resolution (Figure 7-12).

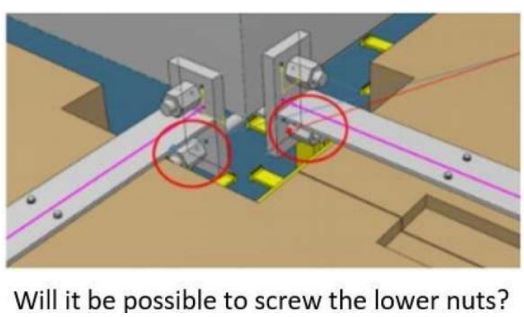
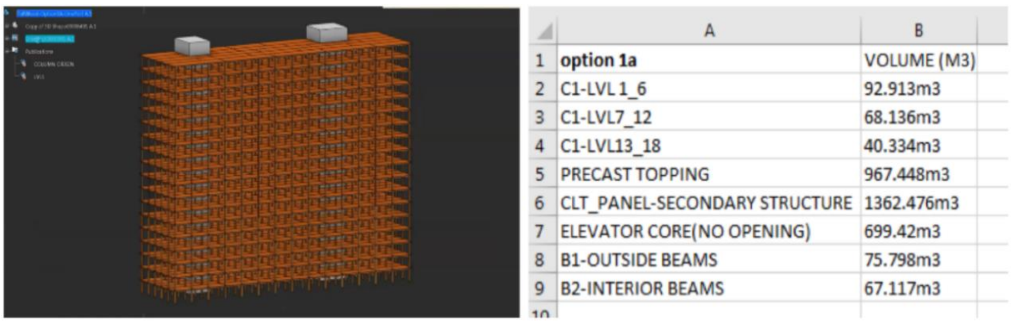


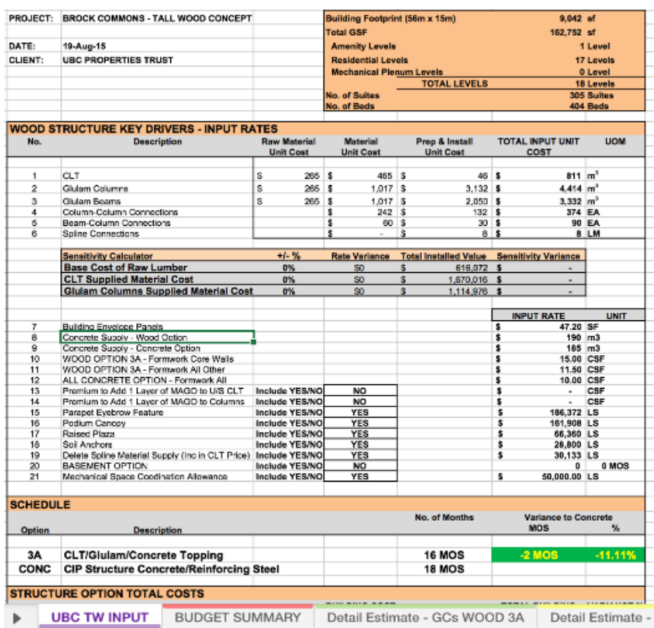
Figure 7-12 Identified constructability issue sample (Image source: CadMakers Inc.)

Quantity Takeoffs: Since there was a commitment by the project participants to keep the model up to date, the 3D model could also be used for extracting volumetric and numeric information of the building elements (Figure 7-13). The construction manager could directly extract the basic quantities from the model and develop detailed excel spreadsheets for cost estimation purposes (Figure 7-14).



	A	B
1	option 1a	VOLUME (M3)
2	C1-LVL 1_6	92.913m3
3	C1-LVL7_12	68.136m3
4	C1-LVL13_18	40.334m3
5	PRECAST TOPPING	967.448m3
6	CLT_PANEL-SECONDARY STRUCTURE	1362.476m3
7	ELEVATOR CORE(NO OPENING)	699.42m3
8	B1-OUTSIDE BEAMS	75.798m3
9	B2-INTERIOR BEAMS	67.117m3
10		

Figure 7-13 VDC sample quantity take-off (Fallahi, 2017)



PROJECT:	BROCK COMMONS - TALL WOOD CONCEPT
DATE:	19-Aug-15
CLIENT:	UBC PROPERTIES TRUST

Building Footprint (56m x 15m)	9,042	sf
Total GSF	162,752	sf
Amenity Levels	1	Level
Residential Levels	17	Levels
Mechanical Plenum Levels	0	Level
TOTAL LEVELS	18	Levels
No. of Suites	305	Suites
No. of Beds	404	Beds

WOOD STRUCTURE KEY DRIVERS - INPUT RATES

No.	Description	Raw Material Unit Cost	Material Unit Cost	Prep & Install Unit Cost	TOTAL INPUT UNIT COST	UOM
1	CLT	$ 265	$ 465	$ 46	$ 811	m³
2	Glulam Columns	$ 265	$ 1,017	$ 3,132	$ 4,414	m³
3	Glulam Beams	$ 265	$ 1,017	$ 2,050	$ 3,332	m³
4	Column-Column Connections		$ 242	$ 132	$ 374	EA
5	Beam-Column Connections		$ 60	$ 30	$ 90	EA
6	Spline Connections		$ -	$ 8	$ 8	LM

Sensitivity Calculator	+/- %	Rate Variance	Total Installed Value	Sensitivity Variance
Base Cost of Raw Lumber	0%	$0	$ 616,072	$ -
CLT Supplied Material Cost	0%	$0	$ 1,670,016	$ -
Glulam Columns Supplied Material Cost	0%	$0	$ 1,114,976	$ -

No.	Description			INPUT RATE	UNIT
7	Building Envelope Panels			$ 47.20	SF
8	Concrete Supply - Wood Option			$ 190	m3
9	Concrete Supply - Concrete Option			$ 185	m3
10	WOOD OPTION 3A - Formwork Core Walls			$ 15.00	CSF
11	WOOD OPTION 3A - Formwork All Other			$ 11.50	CSF
12	ALL CONCRETE OPTION - Formwork All			$ 10.00	CSF
13	Premium to Add 1 Layer of MAGO to U/S CLT	Include YES/NO	NO	$ -	CSF
14	Premium to Add 1 Layer of MAGO to Columns	Include YES/NO	NO	$ -	CSF
15	Parapet Eyebrow Feature	Include YES/NO	YES	$ 186,372	LS
16	Podium Canopy	Include YES/NO	YES	$ 161,908	LS
17	Raised Plaza	Include YES/NO	YES	$ 66,360	LS
18	Soil Anchors	Include YES/NO	YES	$ 28,800	LS
19	Delete Spline Material Supply (Inc in CLT Price)	Include YES/NO	YES	$ 30,133	LS
20	BASEMENT OPTION	Include YES/NO	NO	0	0 MOS
21	Mechanical Space Coodination Allowance	Include YES/NO	YES	$ 50,000.00	LS

SCHEDULE

Option	Description	No. of Months	Variance to Concrete MOS	%
3A	CLT/Glulam/Concrete Topping	16 MOS	-2 MOS	-11.11%
CONC	CIP Structure Concrete/Reinforcing Steel	18 MOS		

STRUCTURE OPTION TOTAL COSTS

UBC TW INPUT | BUDGET SUMMARY | Detail Estimate - GCs WOOD 3A | Detail Estimate -

Figure 7-14 Detailed Excel spreadsheet developed by the construction manager (Image source: UrbanOne Builders)

4D Planning and Sequencing: The VDC integrator also developed a 4D plan, including the on-site activity sequences, and produced a video to help the team in the organization of the on-site logistics as well as in identifying the most effective installation sequence to gain higher on-site productivity. Figure 7-15 shows the snapshot of the 4D sequencing video.

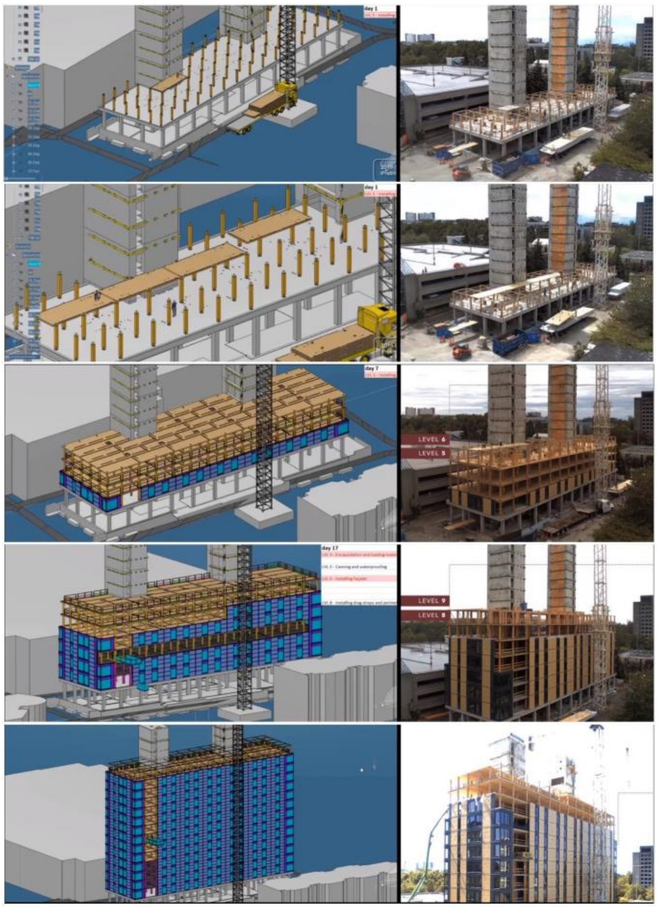


Figure 7-15 4D sequencing vs actual construction of Brock Commons (Left image source: CadMakers & right image source: Dr. Thomas Froese)

Digital Fabrication: The fabrication-level model was developed by the mass-timber manufacturer in CAD software, Cadwork. The mass-timber manufacturer added information related to manufacturing tolerances and to the precise location of bolts and screws that were part of the connections in the model. These details are needed for fabrication, since the mass-timber elements typically require some form of detail to make these connections feasible.

The fabrication-level model also had the precise location of all holes on the CLT panels for utilities. Thus, the generated data was then used to generate CNC codes that were fed to the CNC machines. In this way, the mass-timber manufacturer was able to fabricate the CLT panels with all the necessary cuts and details to accommodate the MEP systems.

Generation of Installation and Shop Drawings: The Cadwork model, which had a fabrication-level of detail, was also used by the mass timber manufacturer to generate detailed installation and shop drawings, as shown in Figure 7-16 and Figure 7-17.

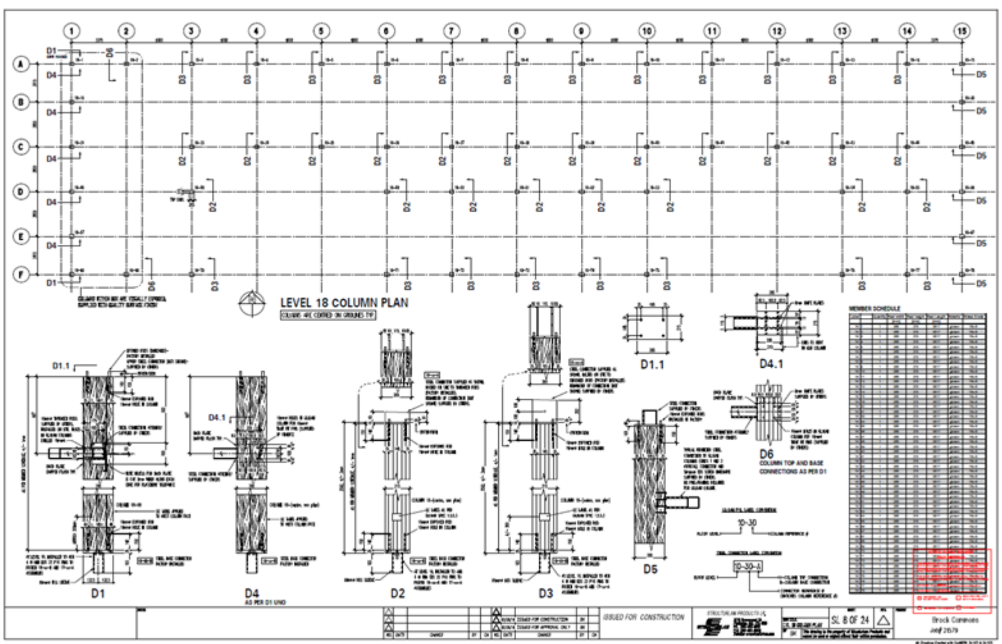


Figure 7-16 Columns installation drawings generated from the Cadwork model (Image source: Structurlam Products Ltd.)

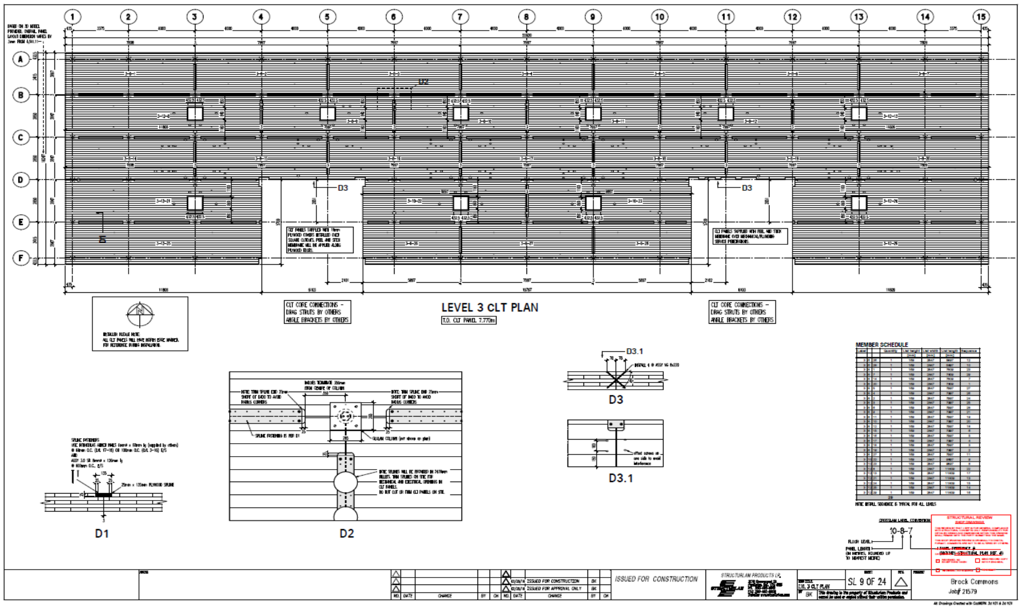


Figure 7-17 CLT panels installation drawings generated form Cadwork model (Image source: Structurlam Products Ltd.)

7.4.2 Tools Implemented

A variety of different tools were used for different purposes by different disciplines in the Brock Commons project. These tools are summarized and categorized based on the associated users in the following Table 7-3.

Table 7-3 Tools used by various project participants for specific purposes

Project role	Software used	Purpose
VDC integrator	Catia Delmia (3D Experience platform)	3D modeling 4D simulation video development
Architect	SketchUp	Conceptual design development
Structural engineer	AutoCAD ETABS RFEM	Design development Structural Analysis (Concrete part) Structural Analysis (Timber part)
MEP trade	AutoCAD	Design development
Manufacturer	Cadwork Canbium Lignocam	Fabrication-level modeling To generate CNC codes for panels manufacturing To generate CNC codes for GLT columns

7.4.3 Scope and Level of Modeling

Scope of Modeling

The involvement of the VDC integrator eliminated the requirement of discipline-specific BIM development by the other project participants. However, the project participants were still required to produce their discipline-related information in a 2D format and share it with VDC integrator. The scope of the model for each discipline is described below:

Architect (Acton Ostry Architects): The architect's scope was to generate discipline-specific 2D and 3D drawings containing architectural information of the building (Figure 7-18).

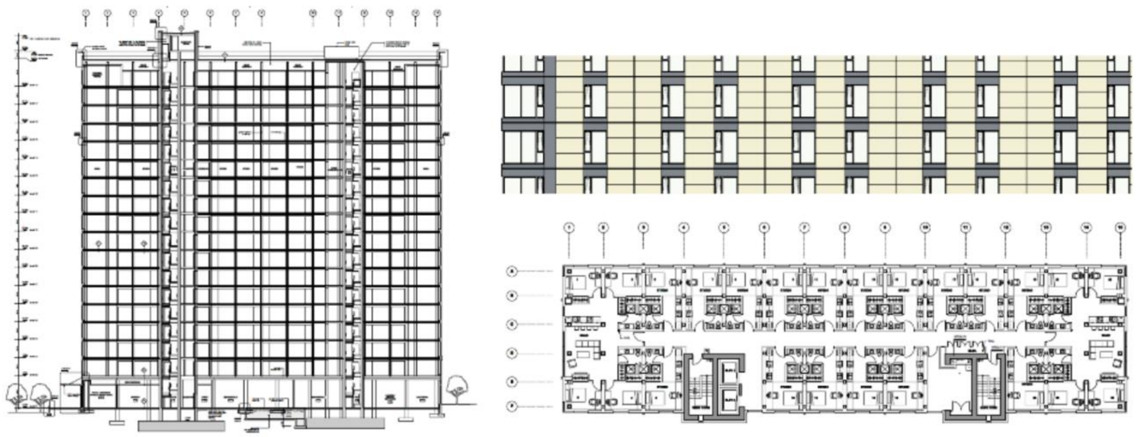


Figure 7-18 Architecture design development drawings used as input for the VDC model (Fallahi, 2017)

Structural Engineer (Fast + Epp): The scope of structural engineer was to generate discipline-specific 2D CAD drawings and hand sketches containing details and information related to the structure of the building. The Structural Engineer also used ETABS and RFEM to run a structural analysis of the building (Figure 7-19 & Figure 7-20).

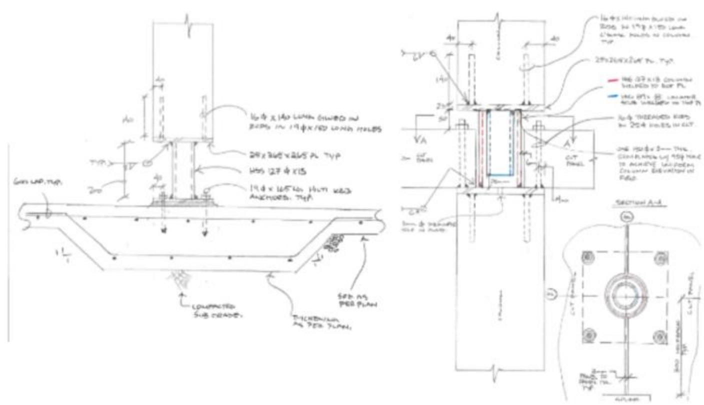


Figure 7-19 Preliminary structural design hand sketch (Image source: Fast and Epp)

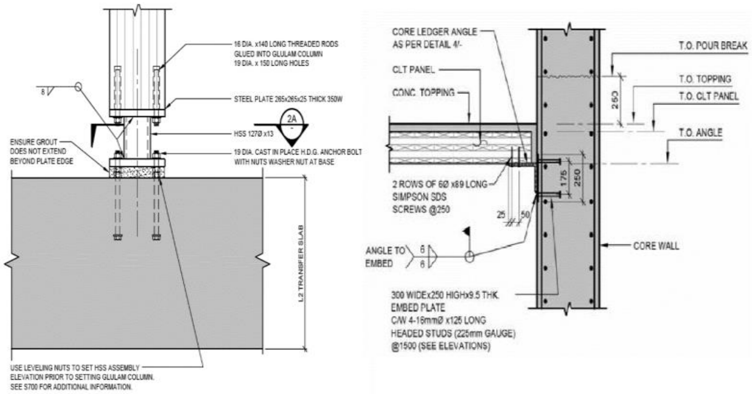


Figure 7-20 Sample Structural CAD Drawings Used as Input for the CATIA 3D Model (Image source: UrbanOne Builders)

Mechanical, Electrical, and Fire Protection Engineer (Stantec Ltd.): The scope of MEP engineer was to generate discipline-specific 2D CAD drawings containing details and information related to the MEP systems of the building (Figure 7-21).

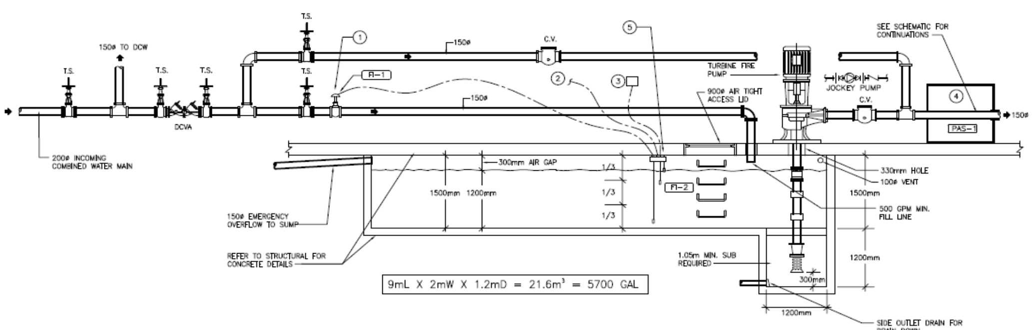


Figure 7-21 Sample MEP CAD Drawings Used as Input for the CATIA 3D Model (Image source: UrbanOne Builders)

VDC Integrator (CadMakers Inc.): The modeling scope of VDC integrator was to develop a highly detailed holistic 3D model by incorporating and coordinating the information received from the project participants of the design team (Figure 7-22). Also, to develop a 4D sequencing videos showing step by step procedures of construction and installation processes (Figure 7-23).

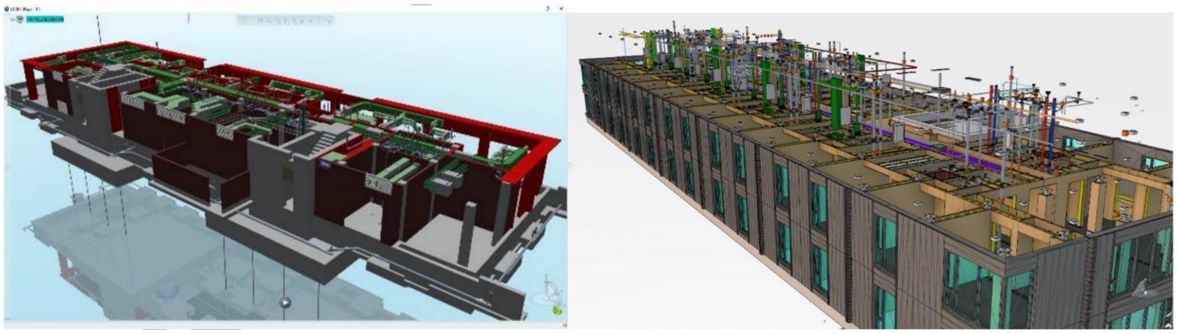


Figure 7-22 Snapshot of CATIA 3D model (Image source: CadMakers Inc.)

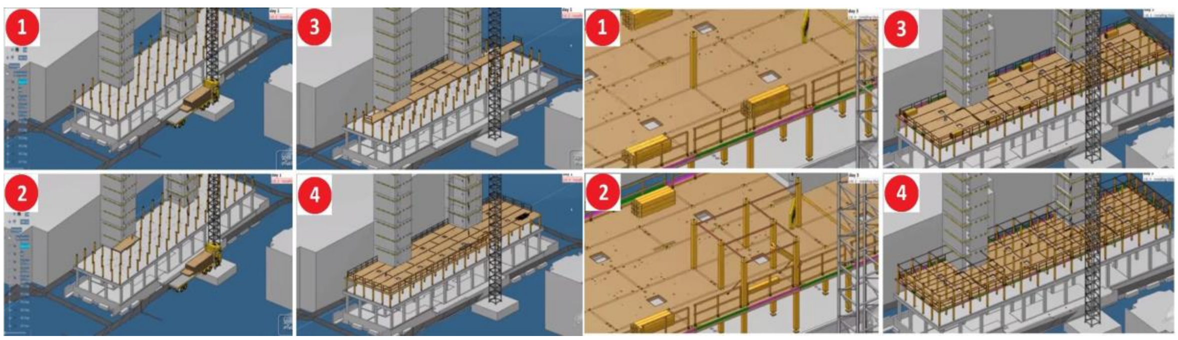


Figure 7-23 Installation of CLT panels and mass-timber columns - snapshots from sequencing video (Image source: CadMakers Inc.)

Mass-Timber supplier (Structurlam Products Ltd.): The scope of mass-timber supplier was to develop a fabrication-level model of the mass timber elements to support their manufacturing process.

Level of modeling

When evaluated, the Brock Commons project model would largely be considered LOD 400. The model included the architectural, structural, and MEP systems with a high level of details (Figure 7-24), which facilitated direct quantity take-off and generating bills of material for MEP elements, allowing prefabrication to take place (Figure 7-25). The VDC integrator also developed a 4D sequencing video showcasing virtual construction activities.

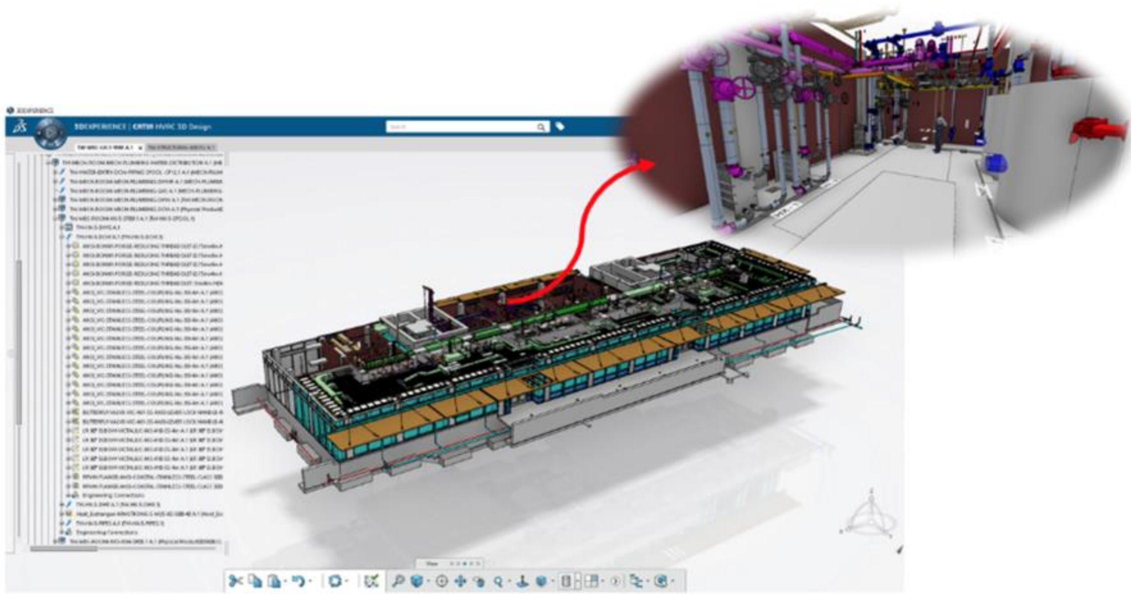


Figure 7-24 Detailed modeling of the mechanical room - snapshot from CATIA 3D model (Fallahi,, 2017)

The model was also used in the integrated design meetings to get inputs and constructability reviews as well as interdisciplinary coordination purposes. Also, the model was used for quantity take-off and for costs estimation. In addition, the mass-timber supplier developed a fabrication-level model that allowed the prefabrication of all CLT panels with the necessary holes for utilities. Not even one additional hole had to be made on-site, with all MEP elements being installed exactly as modeled. The fabrication-level model was used to generate installation and shop drawings.

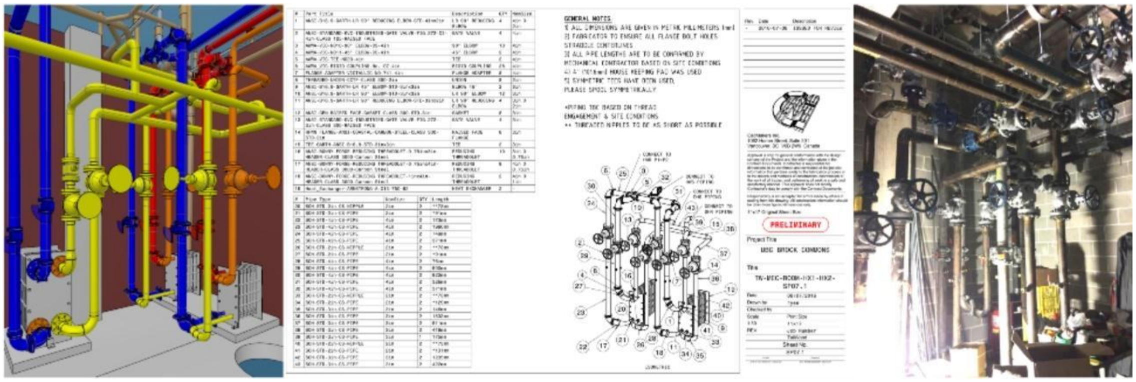


Figure 7-25 MEP bill of materials and as-built condition (Image source: CadMakers Inc. and UrbanOne Builders)

7.4.4 Information Exchange

During the design development stage, the design team shared their discipline-specific designs in the form of 2D drawings or PDFs with the VDC coordinator. The project downstream participants, such as the construction manager, installer, construction trades, etc., were also invited to attend weekly/bi-weekly coordination meeting to provide their inputs near the end design stage. Once the design was complete, the coordinated 3D model (in STEP file format) was shared with the manufacturer for the further detailing to enable digital fabrication.

7.5 Project Outcomes

7.5.1 Owners Requirements Met

The owner achieved approval of the site-specific regulation, and then received a record-setting mass-timber structure that has garnered worldwide attention. The owner’s concern for fire and life safety of the mass timber building was addressed by encapsulating all structural elements to offer fire-resistance rating of 2-hours. Brock Commons effectively demonstrated the applicability of advance wood-based building systems in tall building market and gathered world-wide media attention for its innovations.

7.5.2 Cost and Schedule

The construction manager believed that the project team's extra design and preconstruction time was valuable and helped to save construction time.

> *"From a project developer's perspective, the running cost is of construction is very high (approximately $5,000/ day or $150,000/ month [and can be] $10,000/day in a higher project). The profit made by renting out 404 beds is approximately $0.5M/ month. We spent [6] months longer in the design stages (14 months as opposed to a typical 8 month) to save 3 months of the construction time … [resulting in] a huge benefit".*
>
> – Brent Olund, Urban One, 2016 (Fallahi, 2017)

In 2017, the construction cost for a comparable scale of building with a concrete structure would be $230 per square foot (Poirier et al., 2016). Brock Commons was completed for $253 per square foot, which was well in alignment with current market costs for this building type. Being the first of its kind, it entailed an initial innovation cost and received funding from Natural Resources Canada ($2.34 million), the Province of B.C. ($1.65 million), and the Binational Softwood Lumber Council ($467,000) (Poirier et al., 2016). The project was scheduled for the August 2017 completion, but the construction speed of prefabricated mass-timber components allowed completion of the project in July 2017, which was approximately 2-months ahead of schedule.

7.5.3 Benefits

- Having the full team together at the very beginning of the design by having design professionals and construction professionals (like construction managers and key trades) helped to achieve an aggressive schedule.
- Comprehensive use of VDC visualization with the construction trades helped in identifying the constructability issues and avoiding associated costs, which also reduced a number of on-site surprises and changes.
- Prefabrication of components increased the accuracy and productivity of the construction. It also helped in reducing activity-related waste. Prefabrication allowed performing concurrent off-site and on-site work.
- Detailed modeling of the building including MEP systems helped to determine the exact location of penetrations through CLT panels and enabled to pre-cut them accurately. Also, the ducts, pipes, and other MEP systems were pre-cut off-site accurately. As a result, no single cut was done on-site.

7.5.4 Challenges

- The main challenge for Brock Commons at the time of construction was a regulatory concern as the British Columbia Building Code only allowed 6 stories for residential timber-construction with a maximum height of 18 m (Poirier et al., 2016).
- The use of mass timber products in the structure makes it a significantly lighter building than a comparable concrete building.

- Limited space available at the construction site making it more congested, which was addressed through just-in-time delivery approach.
- The tolerances of prefabricated components were significantly higher and meeting those constraints was a challenge.
- The prefabricated panels (specifically envelop panels) were very sensitive to wind while being lifted.

7.5.5 Lessons Learned

The Brock Commons project showed a higher level of collaboration and the importance of early involvement of project participants, demonstrating innovation in using VDC technologies. Fallahi (2017) identified the following lessons learned from the project.

- The fact that Brock Commons was breaking new ground on so many levels meant that the team was very invested in the project and predisposed to working together.
- Extensive and integrative pre-planning led to direct benefits in the field.
- Continuous and consistent communications amongst the project team ensured tighter project control.
- The integrative design and construction strategy encouraged the entire project team of the design consultant, construction manager, and trades to actively contribute to the successful implementation of many innovations.
- Prefabrication was the key to achieve project targets and aggressive timelines.
- Repetitive floor layout supports prefabrication and a rapid learning curve of trades.

- The VDC integrator acting on behalf of the owner allowed for better communication between the team.
- Obtaining buy-in from the trades increases ownership of the project. On Brock Commons, strategies to encourage trades to invest in the project included early and sustained engagement with the 3D model, emphasis on prefabrication and the use of mock-ups as a means to assess the compatibility of trade contractors' products and approaches.

Chapter 8: Jacobson Hall: Trinity Western University Student Housing Project

8.1 Context

8.1.1 Project Description

The Trinity Western University (TWU) student housing project in Langley, BC, is a 5 story modular building with 218 beds providing housing and study area to students (Figure 8-1). This modular building contains 90 volumetric prefabricated modules in total and is currently the tallest modular wooden building in Canada.

Figure 8-1 Jacobson Hall at Trinity Western University, Langley (Image source: Metric Modular)

8.1.2 Owner Identity

Trinity Western University is the owner in this project and the representatives of the owner team consisted of the Senior Vice-president of the TWU External Relations, the Vice-president of the TWU Student Life, the Senior Vice-president of the TWU Business Administration, and the TWU Chief Financial Officer. The owner team was very clear about the project requirements from the outset and was actively involved in the planning and design processes from the very beginning so that they could influence the conceptual and detailed design effectively.

The owner team had previous experience with modular construction in another student housing construction project. Therefore, they were familiar with the construction processes and knew what worked well and what can be a challenge in such projects. They were able to work proactively in the Jacobson Hall project, as the Manufacturing Director emphasized in the interview:

> *"They told us what they wanted, and they would let us [perform] as experts. [And we could say-] 'okay. This is what you wanted this is what we are going to give you.' And they didn't go into every single detail or 'why this, why that?'. They trusted us as experts, but they were very clear about what they wanted! They told us what they wanted, and we executed on that."*
>
> – Tim Epp, Manufacturing Director, Metric Modular

8.2 Organization

8.2.1 Choosing Project Delivery Method and Owner's Goals

Since the owner had experience with modular construction in a previous 3-story student housing project, they were familiar with the involved processes and the value from a modular construction project in terms of quality and time. In the Jacobson Hall project, the owner placed a high value on getting an attractive, comfortable, and affordable building for student housing, which explained the owner's eagerness to have specific quality control measures. Considering the students' constant presence on the TWU campus, it was essential to the owner to ask for the minimum site impact and limits to simultaneous work activities on the site. Therefore, the available time window for this project was very short and limited to the summer break when there weren't many students on the university campus.

Another significant project goal for the owner was achieving higher predictability of the construction costs. These two major project constraints, i.e., the narrow time window and the cost factor, led to the decision to choose modular construction and to seek a module manufacturer. These considerations led to the decision to choose modular construction and to seek a manufacturer ahead of hiring any other project team members. The owner procured Metric Modular which is a vertically integrated firm through Design-Build contract (CCDC 14).

8.2.2 Team Selection

After Metric Modular was chosen to be the manufacturer and installer by the owner, the rest of the project team was assembled by Metric Modular as the design-builder. For this project, Metric Modular decided not to take any chances of working with new consultants:

"It was very intensely defined schedule and we didn't have any room to play with [the] training and [integration] of [the] new consultant."

– Steve Ashcroft, Senior Designer, Metric Modular

Given the project's time and budget constraints, Metric Modular worked with their own in-house mechanical engineer but for structural and electrical consulting services, they opted to build on "tried and tested" relationships and selected consultants with whom they already had a proven and positive track record and who would come to the project with a sufficient understanding about modular construction and related processes. The strength of these prior relationships is illustrated by the fact that both the structural and electrical engineers came on board to provide their service early in schematic design stage before Metric Modular was awarded the project. These services were limited to schematic designs and the consultants did not have any formal contract with Metric Modular at that point; assuming once Metric Modular wins the project tender, they would be hired for the rest of the project. In the same way, the selection of the architect, BR2 Architecture, was largely based upon the success of previous working relationships with the Metric Modular.

According to Metric Modular's manufacturing director, the risk potential in this project was quite high considering the aggressive project timeline. Therefore, the selection of the subcontractors for the manufacturing process was also primarily based on the previous experience of the manufacturer in working together. However, due to the project location and the tight time frame, they ended up having to hire some subcontractors without having previous experience working with them. An essential factor was choosing sophisticated and reliable subcontractors with a large labour force availability to be able to work on-site 7 days a week without any major issues in staying on schedule.

8.2.3 Development the Contract

Metric Modular—supported by the selected project team (Figure 8-2) and internal resources (Figure 8-3) —was awarded the Design-Build contract (CCDC 14) of the Jacobson Hall project in December 2017.

As mentioned previously, the external structural and electrical consultants helped Metric Modular with preliminary design development without any formal contract before Metric Modular was awarded this project. However, all the external consultants and subcontractors made formal contractual bindings with Metric Modular after they won the project tender.
As for the architect, Metric Modular designed in-house most of the building details in the schematic design stage. After winning the project tender, they hired an external architect, BR2 Architecture, to conduct a full code-review, and develop the design further, including coordinating the design development with other project consultants.

8.2.4 Project Team Structure

Figure 8-2 shows the project team for Jacobson Hall project where the mechanical engineering was done in-house Metric Modular. Metric Modular's internal team setup is shown in Figure 8-3.

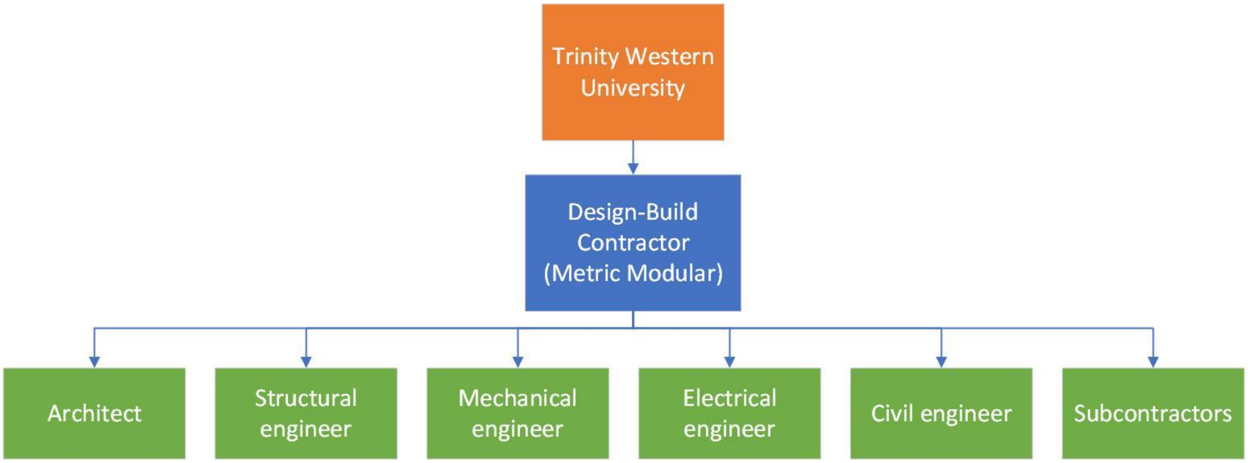


Figure 8-2 Project team structure of Jacobson Hall project (Image source: Metric Modular)

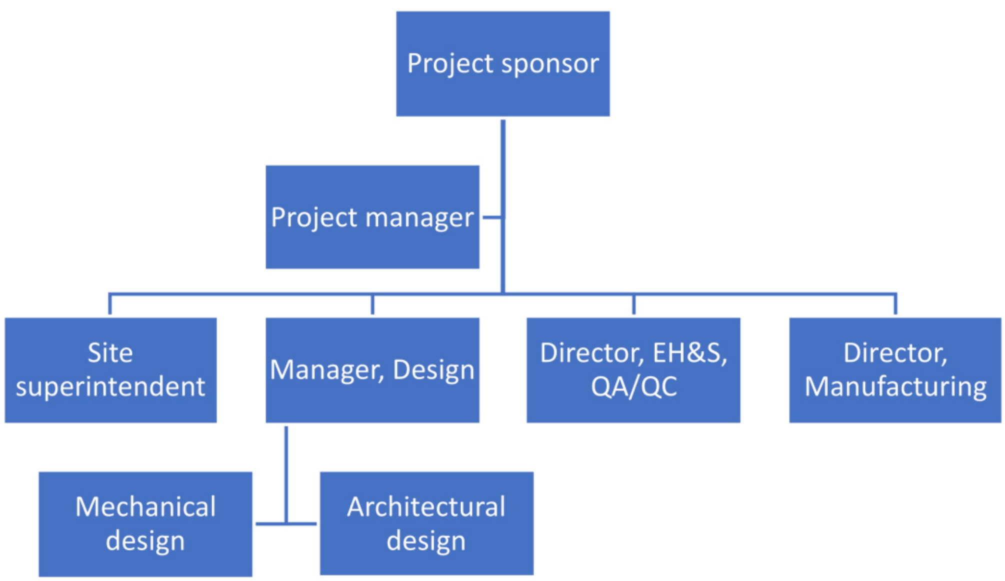


Figure 8-3 Metric Modular's internal project team (Image source: Metric Modular)

8.2.5 Champions

Metric Modular, as a vertically integrated firm, was the modular champion in this project. Since Metric Modular has over 40 years of experience in modular construction, they knew the exact responsibility of each of their affiliates. Besides that, most of the consultants and subcontractors on this project had extensive previous experience in working with Metric Modular on previous modular construction projects. This resulted in exceptional collaboration between the project participants.

Metric Modular also hired a few subcontractors in this project with whom they did not have any working experience previously. Therefore, Metric Modular took the extra effort to integrate them in the early stage of the project by clarifying their respective scope of work and performance expectations. This led to efficient collaboration and coordination among the entire project team.

8.2.6 Decision Structure

In the design phase, all the design related decisions were made with the involvement of the owner's representatives to expedite the turnaround time. During the design development phase, all the decisions were made in the coordination meetings involving all consultants while the external consultants had the final authority to decide about their respective scopes. In particular, the decision-making process in the coordination meetings followed generally the approach in which whenever the external consultants suggested any changes to the design, and then that suggestion was brought to Metric Modular's internal team for assessing the constructability and other impacts on the modules. These impacts were then coordinated with the external consultants who suggested those design changes, along with some recommendations based on the Metric

Modular's process for modular construction. However, the final decisions were made by the consultants, which usually was a synergy of the original suggestions and Metric Modular's feedback. It should be mentioned that the client was continuously involved in the design process to make the decision-making process quicker. Once the design was developed, it was reviewed by the manufacturer, project manager, and the client for their input before finalizing the design and starting with the production of the modules.

8.3 Processes

8.3.1 Project Execution Plan

With over 40 years of experience in modular construction, Metric Modular have developed very efficient policies and approaches when it comes to project execution, team collaboration and delineating the responsibilities for project team members. The overview of execution planning is shown in Figure 8-4 which represents the general execution planning of Metric Modular for all of their projects.

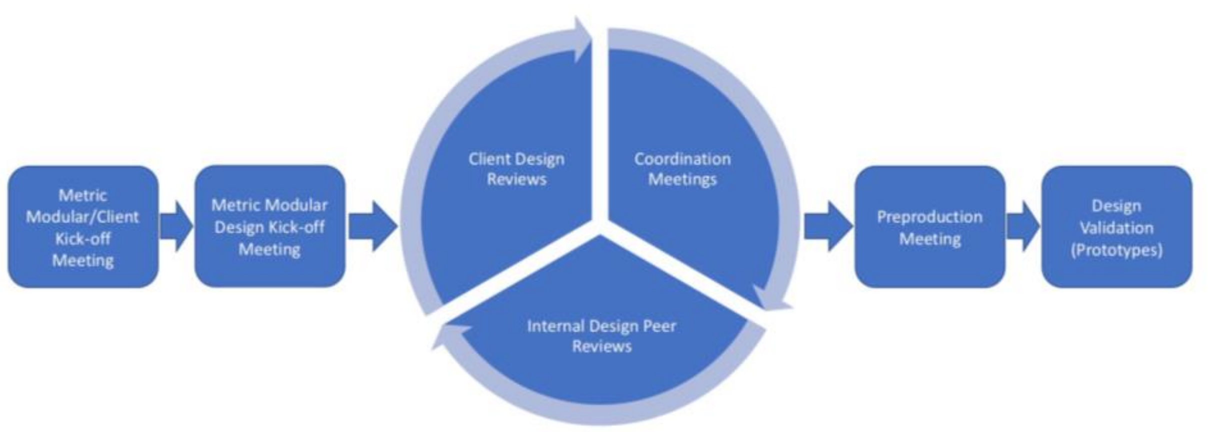


Figure 8-4 General project execution plan (Image source: Metric Modular)

In the Jacobson Hall project, the site preparation was critical, since it is a time-consuming process and could have delayed the rest of the construction. To keep up with the challenging timeline of the project, the on-site foundation work (Figure 8-5) and the off-site housing units manufacturing process were performed simultaneously.

Figure 8-5 Site preparation work in Jacobson Hall project (Image source: Metric Modular)

The site preparation work in the Jacobson Hall project took approximately 2 months including the site excavation, relocation of sewer and electrical services, and pouring the foundation for the new building. At the same time, all the modules were being built off-site at Metric Modular's manufacturing facility in Agassiz, BC (Figure 8-6). All modules were 3.7 meters wide, but lengths varied from 9.8 to 18.9 meters. The finished modules included interior partitions, plumbing, electrical, painting, tiling, fixtures, appliances, windows, millwork. After each module was prepared, they were shipped to the site and craned into position. This process was very efficient, and the first 3 floors were assembled in only 11 days. Cross-laminated timber (CLT) was used to frame the elevator shaft and modules then connected to either side of the CLT structure.

Figure 8-6 Finished module at the factory (Image source: Metric Modular)

8.3.2 Training / Workshops

In the Jacobson Hall project, there were no official training or workshops conducted. However, Metric Modular invited their subcontractors, who had no previous experience working with modular construction or with the prefabrication processes at Metric Modular, to their manufacturing facility and explained their processes to establish a better collaborative understanding between them and Metric Modular.

> *"…We had to bring them [subcontractors] in [to our factory] to show them our process, show them the modules and [discuss] 'how is this going to work for you guys? do you rather prefer this or this? Because we can do either. You just tell us what is going to be easier [for you]?"*
>
> – Tim Epp, Manufacturing director, Metric Modular

8.3.3 Communication and Workplace

A key communication priority in every construction project is the communication between the designers and the client, as well as the ultimate occupants, to address their requirements. To identify the requirements of the new housing building, TWU had conducted a student survey asking them about their points of criticism regarding the current housing facility and their expectations of the new housing building. Then the results of this survey were provided to Metric Modular's architectural group to be considered while designing the new building (Metric Modular, 2018). For example, one identified issue through the conducted survey was that the currently available study area for students was located outside of the current housing building. As a result, the architects dedicated a study and social area inside the new housing building.

Another communication, priority in this project was to connect Metric Modular's architectural design team and the owner representative to develop the schematic design of the new housing building, addressing the owner's requirements and fitting it into the surrounding housing buildings (Metric Modular, 2018). Considering the owner's requirements and the TWU students' feedback, the architectural team decided to design the new student housing building with 90 prefabricated modules. The communications regarding the schematic design were carried out before Metric Modular was awarded the contract.

After winning the project tender, the TWU student representatives, along with the Vice-President of Student Life at TWU, worked very closely with Metric Modular's design team to influence the design development according to their requirements. At this stage, the early communications between Metric Modular and the TWU representatives included also the senior estimating manager of Metric Modular to keep track of the project budget as it was getting more detailed. During the design development phase, the design team was also in constant communication with the in-house mechanical division as well as with the external architectural and electrical consultants. These communications were usually through in-person meetings, conference calls, and emails, and the design review was mainly based on the 2D drawings on paper or PDFs (Figure 8-7).

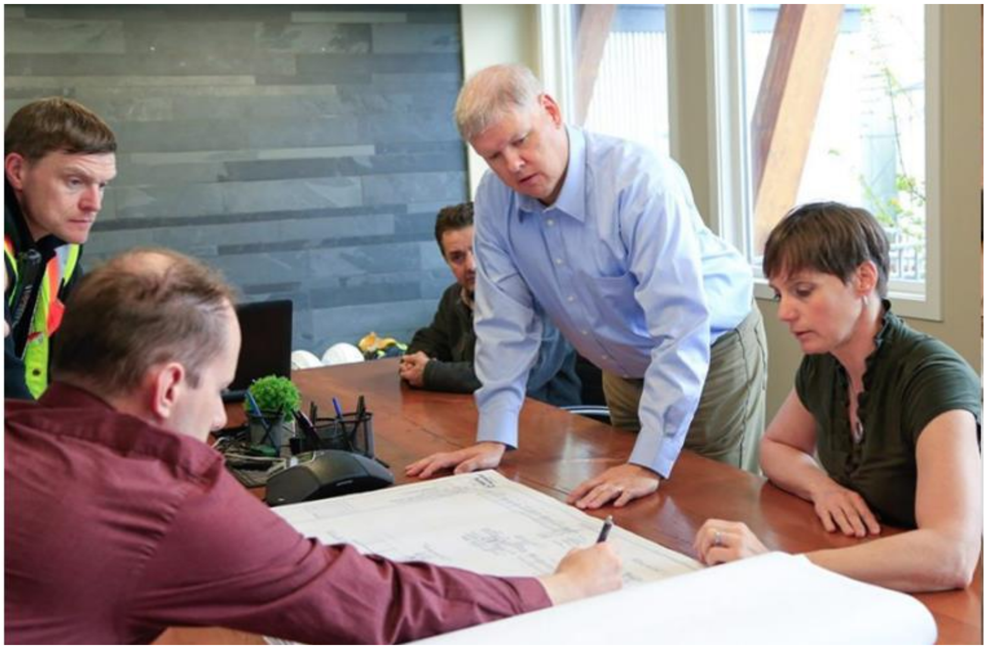


Figure 8-7 Design coordination meeting (Image source: Metric Modular)

During the design-development stage, the project Manager and Manufacturing Director from Metric Modular were also in constant communication with the designers, reviewing the design and providing suggestions, which was critical for finalizing the design.

During the construction phase the communication regarding the off-site activities between Metric Modular and their own manufacturing workers, as well as with external subcontractors, was mainly based on regular daily meeting before every work shift and was moderated by Metric Modular's manufacturing Director. At the same time, the communication regarding the on-site activities was managed by Metric Modular's project Manager.

"... There is a lot of time and energy spent making sure that there was very clear communication. So, they [subcontractors] were not surprised. So, when they got into the site, they knew what they are getting, they knew how they [modules] are going to look, they knew their job whereas they didn't have to spend a lot of time [thinking] 'what's this or how do they do this?'."

"It's all that upfront collaboration leads to much easier planning."

– Tim Epp, Manufacturing Director, Metric Modular

8.3.4 Collaboration

The effective collaboration between the owner and Metric Modular from the very beginning resulted in efficient design and construction of the project. The continuous involvement of the owner with Metric Modular led to quicker decision making throughout the project. Metric Modular's design team also consulted with TWU's maintenance department to identify regularly replaceable items in this type of building that could be matched with commonly used items. As a result, the university did not have to buy different items specifically for this new building (Metric Modular, 2018).

As Metric Modular was working with the same external design consultants and subcontractors, and they knew their responsibilities and deliverables, they were able to effectively collaborate with each other to streamline the execution of design, manufacturing and construction processes. Also, the involvement of Manufacturing Director and Project Manager during the design development stage resulted in a more manufacturable and constructible building design.

Metric modular put extra effort into collaborating with the client (TWU), to get their inputs in the design.

> *"We would set very open relationship with the client which is very important. Right from the beginning, they are on board with – making decisions quickly, understanding our process, and being involved in the process. So, we did the mock-up for the bathroom area for example, and we had the end users, the maintenance staff from TWU actually came and toured the factory, toured the bathroom mock-up and say, 'hey, this is what we want to do, this won't work' [and we would ask] 'is there anything that you like us to change?' So, you [are] having the end users actually having input into the design. That was also great, because either these guys were going to be maintaining and servicing the building. So, they know how this building [is] going to work. They know how students [are] going to use each part. So, having them involved in the upfront process is just as important as having me involved. So, we gave them a product that's going to work for them."*
> – Tim Epp, Manufacturing director, Metric Modular

Coordination During the Construction Phase

The project Manager was responsible for the coordination between the off-site and on-site work. According to the Project Manager, the rate of the off-site module production was 2 modules per day, whereas the on-site module installation rate was between 3 to 4 modules per day. Moreover, the on-site work was carried out 7 days a week, while the off-site factory was open 5 days a week. Therefore, a significant number of modules had to be manufactured in the factory before they started stacking them on-site. According to the project Manager, approximately 30 modules were completed before starting the installation process on-site to avoid interruptions in module installation (Figure 8-8).

Figure 8-8 Modules stored at the factory and ready for transportation (Image source: Metric Modular)

They also had a laydown area near the construction site to store up to 12 modules. Because they were working 7 days per week on-site, they stockpiled 12 modules on-site every Friday so that they could continue to operate on weekends and Mondays (4 modules installed on Saturday, Sunday, Monday = 12 modules). The required modules for Tuesdays were delivered on Mondays when the factory opened again and the cycle of stockpiling 12 modules on-site by Fridays was achieved every week.

Figure 8-9 On-site installation of module (Image source: Metric Modular)

The Project Manager also mentioned that as they were installing at a much faster rate than the manufacturing plant production rate, they ran out of modules after installing 3 stories (Figure 8-9). At this point, they started working on inter-module connections and interior connections on-site (Figure 8-10) until the manufacturing plant produced sufficient modules that would be enough to carry out the rest of the installation work without running out of modules. Then, they continued the installation of the 4^{th} and 5^{th} floors, such that as the last module was manufactured in the plant and delivered directly to the site and installed immediately.

Figure 8-10 Inter-module connection process (Image source: Metric Modular)

8.3.5 Innovative Practices

The Jacobson Hall project is Canada’s tallest wooden modular building to date, which makes it a highly innovative construction product. Moreover, this project included a variety of innovative construction processes that helped to overcome different challenges faced during the planning, design, and execution of the project. These processes are described below.

Modular Construction: Since there was a very short time window of only 9 months available for this project, the stakeholders decided to go with modular construction as an innovative process allowing them to carry out the on-site and off-site construction simultaneously. This decision was made despite the fact that this was the first 5 storey wood-based modular construction, which was a great contribution to pushing the boundaries of modular construction in Canada.

Complex Structural Design: As Jacobson Hall project was the first 5 stories Canadian wooden modular building, the project team had to deal with a series of atypical and complicated structural challenges. To meet the structural requirement of the building, it was necessary to consider the excess amount of structural lumber in the design of the first 2 stories, which included considering double studs as well as intense framing. Furthermore, it was necessary to include a significant amount of Anchor Tiedown System (ATS) rods to address high seismic risk in the construction area. For the same reason, there were much more shear connections required between modules compared to similar projects in areas with lower seismic risk, such as in Alberta or Saskatchewan.

Labour Time Tracking: In fast track projects, it is significant to control the productivity of the workforce. This is especially efficient in modular construction where a significant amount of construction activity takes place in a controlled off-site environment. In this regard, innovative processes such as labour time tracking have a great impact on labour performance analysis and productivity monitoring. For such purposes, Metric Modular developed and established a labour time tracking system in their off-site manufacturing facility.

In this system, there is a specific barcode defined for each worker, each ongoing project, as well as each related task. In this way, every day when workers come to the factory and before beginning the work, they must scan their own barcode, then scan the specific project, and then the specific task they would perform on that day. The same process is being followed when the workers switch from a particular task or project to another task or project (Figure 8-11). Through this process, the Manufacturing Director was able to track the exact amount of labour-time for each task in each project. This performance monitoring is also being used to track the accuracy of project estimates and to help the manufacturer quickly identify inefficiencies in the manufacturing process.

Figure 8-11 Barcode scanner machine to track labour time tracking

Integrative Planning, Design and Construction: As described earlier, Metric Modular worked closely with the owner and future occupants of the building during the planning and design development stage. Their involvement from the early stages of the project was important to understand and accommodate the project requirements and expectations. Metric Modular also invited the owner to manufacturing facility and explained why information from the owner is so critical from them.

> *"Being as transparent as possible right from the beginning [is important]. That's when projects usually are successful; when they [the owner and the future occupants] want to get involved and we have their involvement from step 1 all the way to step 10 instead of starting just at step 9. …*
> *We had them [the owner and the future occupants] coming [into our factory] and we had a tour and went over our process and explained, why certain pieces of information are so critical. Why, in our process, we don't like changes at the last minute. And when we start production, why changes are very expensive. So, they had a better understanding of why we are asking those questions and why we had to say no to certain things."*
> – Tim Epp, Manufacturing director, Metric Modular

Quality Control: Having a controlled manufacturing environment in modular construction provides opportunities to establish certain quality control measures that ultimately lead to owner and building user satisfaction (Figure 8-12). These innovative measures were also established in the manufacturing process of Metric Modular.

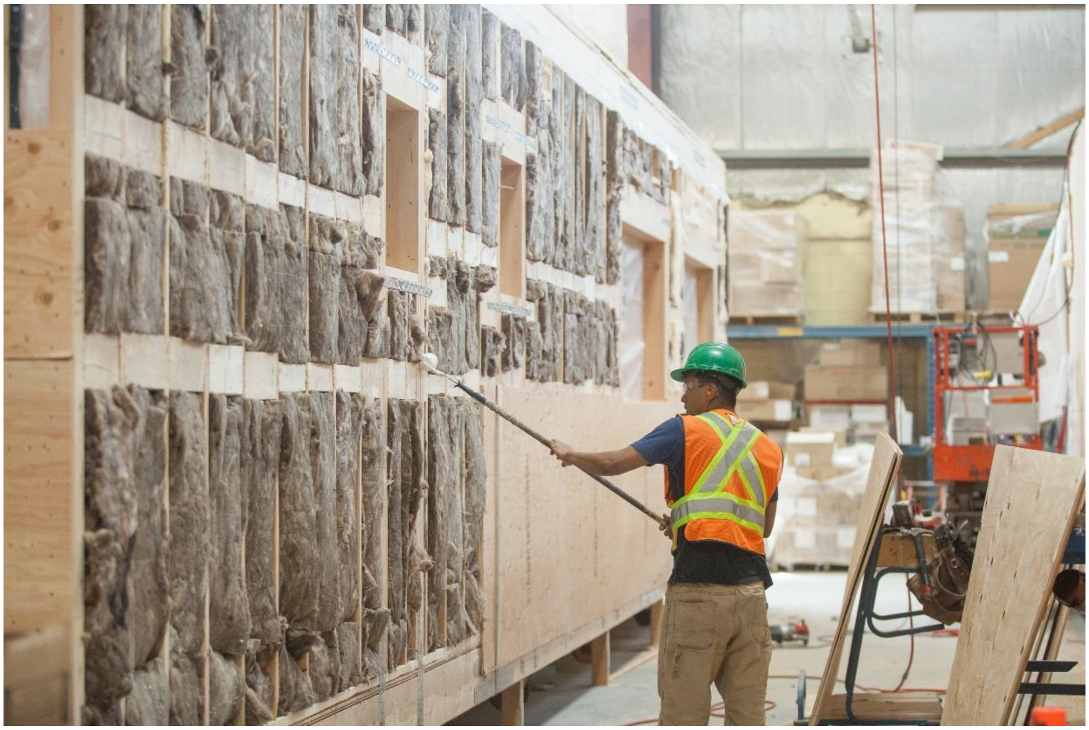


Figure 8-12 Controlled construction environment at manufacturing plant (Image source: Metric Modular)

Metric Modular has 24 stations in their off-site plant. Quality control measures are conducted at each of those stations for different purposes. Each module unit has its own "logbook" attached to it as the unit travels through the assembly line (Figure 8-13). At each station when an activity is completed, the results are inspected, rechecked and then written down into the logbook. This is how the logbook shows the progress of the module manufacturing at every stage. This quality control process also includes testing the installed appliances, fixtures, electrical, sprinklers, and plumbing before sending the modules to the construction site.

> *"Everything gets checked [in the factory] …. In a conventional building, they can't test anything until all the work is done. We can discover and fix problems as we go."*
> – Tim Epp, Manufacturing director, Metric Modular

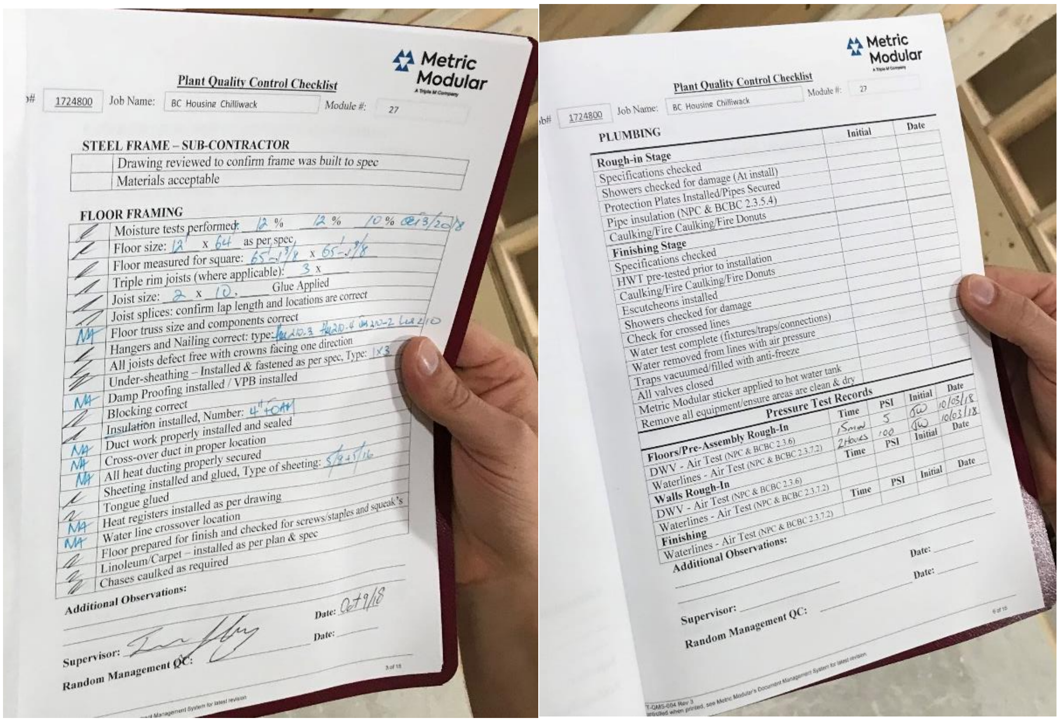


Figure 8-13 Sample quality control checklist from the logbook

Sound Insulation: In this project, each module unit had its own complete roof and floor, with a layer of framing and insulation. When these modules were stacked on one another with an air barrier in-between, it became an extra layer of framing and insulation between each floor. As a result, the living spaces of the building became much quieter and sound insulated compared to traditional construction.

8.4 Technology Implemented

The following section identifies the different uses of technology in Jacobson Hall project.

8.4.1 Uses of Technology

Space Planning: The technology used was quite traditional, with the design team using AutoCAD, Autodesk's commercial computer-aided design and drafting software application for the building space planning.

3D Visualizations: The visualization process, which was conducted by the architectural designer from Metric Modular, was mainly done using SketchUp in combination with other third-party rendering programs. These 3D visualizations were primarily used in the early design stage for presentation purposes and did not contain any detailed information.

Design Development and Coordination: In the design development phase, all design consultants used AutoCAD as the basis for their work. Furthermore, they mainly shared PDF files containing 2D drawings of their design to exchange information and coordinate the design. In particular, these digital 2D drawings were used as a basis to mark-up the issues on the drawings and provide comments.

Design Detailing and Shop Drawings: The digital 2D drawings developed during the design development and coordination stage were primarily used for inserting manufacturing detailing and generating shop drawings by the design team and the structural consultant. This process was similar to the design development conducted using AutoCAD. Metric Modular has a library of standard details in AutoCAD that has been developed over their previous projects that could be used accordingly while developing the shop drawings.

Off-Site Schedule Coordination: The Manufacturing Director used Smartsheet, which is a software as a service application for collaboration and work management, to develop a schedule and manage the manufacturing activities. Smartsheet was used to define various off-site activities and assign them to different trades. Once a task is assigned to a trade in Smartsheet, they will get an automatic notification and can access the schedule to get further details of the task.

Document Management: Metric Modular uses a customized version of Microsoft SharePoint, called "Metric Central," for document management of their projects. Metric Central works as a data repository and most of the exchanged information is being shared in this system. In this way, it is possible to keep track of the information provided by different project participants and facilitate collaboration.

8.4.2 Tools Implemented

The various tools used on this project are summarized and categorized based on the associated users in Table 8-1.

Table 8-1 Tools used by various participants for various purposes

Project Role	Purpose	Primary Utilized Technology
Design Team (Metric Modular)	Space planning	AutoCAD
	Design development & Coordination	
	Design detailing and shop drawings	
	Rendering	SketchUp
	Document management	MS SharePoint
Manufacturing Team (Metric Modular)	Off-site scheduling coordination	Smartsheet
	Document management	MS SharePoint
Project Manager (Metric Modular)	Document management	MS SharePoint
	On-site scheduling & management	Microsoft Project
Architect (BR2 Architecture)	Design development & coordination	AutoCAD
Structural Engineer (Canstruct Engineering Group)	Design development & coordination	AutoCAD
Electrical Engineer	Design development & coordination	AutoCAD

8.4.3 Scope and Level of Modeling

The Owner did not require any modeling for this project. The Jacobson Hall project was executed without the utilization of BIM tools, and thus there were no efforts regarding parametric modeling, computational design, or specific simulations. A 3D model was developed at the early stages for visualization purposes but was not developed further in the following stages of the project. In the interviews, however, the stakeholders emphasized the necessity of using BIM tools as a lesson learned from this project and they aim to incorporate such tools in their future projects.

8.4.4 Information Exchange

As mentioned above, the information exchange between project participants was based on traditional practice using 2D drawings and plans. Metric Modular eliminated potential inefficiencies by working with the same consultants' team with whom they had previous experience. To share essential information with the off-site subcontractors efficiently, Metric Modular used Smartsheet and MS SharePoint, to embed their schedule to the manufacturing plant's schedule and to provide access to up-to-date construction documents and drawings to the project team.

8.5 Project Outcomes

8.5.1 Owner's Requirements Met

All the owner's requirements were met and a high-level of owner satisfaction was achieved in the project. The owner's representatives were quoted saying -

> *"The new housing offers a radical improvement in our ability to compete with other schools because it's so well-designed."* (Metric Modular, 2018)
>
> – Scott Fehrenbacher, SVP – External Relations, TWU
>
> *"These guys [Metric Modular] are builders. They built trust with us because they say what they're going to do and then they do it. I would be happy to work with them again on a future project."* (Metric Modular, 2018)
>
> – Bob Nice, SVP Business Administration, and CFO, TWU

The owner's main goal was to get an attractive, comfortable, and affordable building for student housing with higher-level of quality. Another requirement of owner was to construct the building in very short-time (9-months) before September 2018. These goals were effectively achieved through modular construction approach. In addition, modular construction also allowed to reduce on-site impact and reduced the building footprint.

8.5.2 Cost and Schedule

Jacobson Hall was delivered fully fitted out for $13.1 million ($218.33/sf) as stipulated in the Design-Build contract. The project was completed in just 9 months and handed over to TWU to accommodate students from September 1, 2018. The Metric team estimate that the process was 50% faster than conventional construction.

8.5.3 Benefits

Integrative project delivery is at the root of modular construction, the benefits of which are speed, quality, and reliability.

- The TWU campus only has one entry point. For the Jacobson Hall project, the off-site construction process diverted hundreds of delivery vehicles, which was critical for campus safety.
- Modular construction allowed the completion of the work within a restricted site area where space for materials storage and lay-down was limited.
- As most of the building was constructed off-site, modular construction enabled the project to be completed quietly with no hammering and pounding from the workers for

months in the student residence area. Also, it required very few power generators on-site, which are usually the main source of noise for building sites.

- A conventional wood building would have required extensive weather protection and phased fire protection as work progresses. With the modules arriving already complete, requirements of these measures were far less.

8.5.4 Challenges

- The main challenge for this project was the extremely tight schedule, with only 9 months from contract signing to students moving in.
- The building's tight location made fire truck access, garbage and recycling collection difficult. To address that problem, the designers adjusted the building angle several times.
- The 1st and 2nd storey of the building needed extra structural requirements (e.g. the large number of tie-downs) to meet the requirements of the 5-storey wood frame design.
- There was a lot of site work in this project compared to what Metric Modular typically performs. Also, TWU did not have layouts of existing underground services.
- The manufacturing team faced a big challenge in getting the mechanical equipment and fire dampers initially. As a result, they had to send them directly to the site for the 1st and 2nd floors, which was more expensive and time-consuming.

8.5.5 Lessons Learned

The means and methods to drive collaboration does not have to rely on technology. With clearly understood, rigorous processes the team can afford to deploy low levels of proven systems to support the design, production and delivery processes.

- While shorter time frame for designing, manufacturing and construction can cost more money on a comparative unit price basis, the savings / benefits for an owner to begin operating the building early can be significant. For example, the cost to TWU for not getting students into residence for the first day of the new semester would be significantly greater than the potential savings from a longer construction schedule. A total life-cycle based business case for a project based on “best value” is essential.
- From a structural framing point of view, the Metric team learnt about the requirements and considerations for a 5 storey wood frame building.

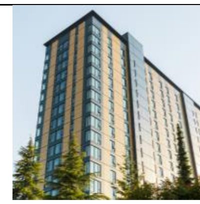
Chapter 9: Discussion and Conclusion

The following section contains the cross-project analysis of case studies' outcomes, focusing on the IPD-like characteristics adopted and innovative practices implemented (Section 9.1). From the cross-project analysis, the collaborative characteristics and innovations have been identified that enabled the analyzed projects to achieve their goals efficiently. These characteristics and innovative practices are presented in Section 9.2. The interviews with the industrial personnel also helped in identifying some of the challenges for IPD adoption in the housing sector, which is presented in Section 9.3.

9.1 Cross-Project Analysis

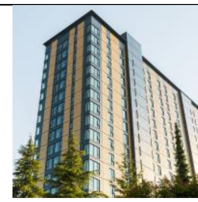
Table 9-1 shows the cross-project comparison of the project outcomes.

Table 9-1 Cross-project comparison of project outcomes

				
	priMED Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons**	**Jacobson Hall, Trinity Western University**
Location	Edmonton, Alberta	Waterloo, Ontario	Vancouver, BC	Langley, BC
Contractual arrangement	Full IPD	Full IPD	CM+	Design-build
Owner's expectation met	Yes	Yes	Yes	Yes
On time	4-months ahead of schedule	3-months ahead of schedule	2-months ahead of schedule	Met schedule
On budget	Yes	Yes	Within market expectations for a comparable concrete building.	Yes

To efficiently implement IPD principles and achieve project goals, owner's continuous involvement with the project team and early involvement of key participants were essential. In addition, innovative technologies and process aids, including lean, BIM/VDC, and prefabrication, were valuable drivers to achieve project goals efficiently. Table 9-2 compares the IPD-like innovative and collaborative practices adopted on the analyzed projects.

Table 9-2 Cross-project analysis of project delivery characteristics

	 **priMED Mosaic Centre**	 **St. Jerome's University**	 **UBC Brock Commons**	 **Jacobson Hall, Trinity Western University**
Owner's involvement	The owner was continuously and intensively involved throughout design and construction.	Owner's representative was involved continuously and led the IPD process.	Owner's project manager was involved continuously from project inception	Owner and end users were involved in the design development process.
Early contractor involvement	The contractor was involved from project inception before the consultants were brought on.	The contractor was involved from project inception.	CM was involved from the schematic design stage.	The modular builder was a vertically integrated firm and involved from the beginning of the project.
Lean planning methods	• Integrated design approach • Last Planner® • Snake diagrams to keep track of the schedule • 2 Second Lean • Big Room	• Integrated design approach • Last Planner® • Effective Pull Planning using vPlanner • Mock-up of rooms size • Big Room	• Integrated design approach • Mock-up and testing • Extensive Pre-planning • Just-In-Time delivery of mass-timber elements	• Integrated design approach • Integrated design and construction firm meant that the project team was collocated in one office
Use of digital tools	BIM used for: • Visualization • Design coordination and some clash detection	BIM used for: • Visualization • Design coordination • Clash detection	BIM/VDC tools used for: • Visualization • Multi-disciplinary coordination	BIM was not used. • Design development and coordination

		• Construct-ability review • Quantity take-off • Digital fabrication to some extent • Minor facility management	• Clash detection • Construct-ability review • Quantity take-offs • Structural analysis • Sequencing • Digital fabrication	were done in 2D • Document management systems • Off-site scheduling software • Barcode scanning to track labour time
Use of prefab/ modular elements	Pre-fabricated roof trusses	Prefabricated HVAC, and pipework, Integrated sinks with countertops	Entire timber structure was prefabricated (CLT panels and PSL columns, etc.)	Modular construction (units were 95% complete)

9.2 Lessons Learned and Recommendations

The following section summarizes the key features and lessons learned from the four case studies that would be relevant to housing projects. It offers actions that can be considered for implementation in future housing projects to obtain better outcomes. While only two out of four projects implemented full IPD, this research identified housing projects in BC that employed "IPD-like" principles with some success. It is possible to reliably deliver high-performance projects to the satisfaction of owners without formally implementing IPD. However, it is more difficult to do so on a consistent basis without the legal IPD framework that truly motivates all key project team members to put the interests of the project ahead of their own.

All the analyzed projects brought the full team together during the early stages of the project and adopted innovative approaches, which were the key to success. Also, in all cases, the owners invested far more time in managing the projects. The following are the lessons learned from the research that were categorized into innovative collaborative strategies of IPD. Collaborative strategies represent the action items that can be implemented by the owner to establish effective collaboration among project team members and strategies that represent recent innovative construction approaches to enable and leverage higher team collaboration.

9.2.1 Collaborative Strategies

1. **Setting Clear Owner's Goals and Objectives**

   As shown in Table 9-3, the owners of all the analyzed projects had set clear goals and effectively communicated with the project team. It is very important for the owner to set clear owner's goals and objectives, which can be cost, time, energy performance, quality, capacity, sustainability, etc. Goals and objectives clearly communicate the owner's desired outcome for the building and help to define the priorities that the project team needs to address through the design and construction process. The project goals can also be set up as Key Performance Indicators (KPIs) to measure whether the team has achieved the goals or not, determining the project's success or failure. These indicators can be quantifiable, or quality based, or a combination of both, and are used to define "Conditions of Satisfaction" for the project.

Table 9-3 Setting clear owner's goals and objectives

Mosaic Centre	The project team developed an owner's value matrix document, identifying the owner's goals and objectives for the project that guided the team in decision-making.
St. Jerome's Student Housing project	The owner's most important goal was to complete the project on time and on a budget, which was made clear to the whole project team. The project design and objectives were developed collectively by the core project team including the owner.
Brock Commons	The owner's main goal was to finish the project before Sept 2017 to reside students. To build a more sustainable and energy efficient building were also primary goals. Considering the innovative nature of the project, the owner procured key project participants early for further goals and objectives setting.
Jacobson Hall	Setting cost and time constraints and emphasizing an attractive, comfortable and affordable building, the owner worked closely with Metric Modular for the design and construction related decision-making.

2. Owner's Involvement

All the analyzed projects were seen to leverage higher up-front time commitment of the owner in the procurement and design stage, as shown in Table 9-4. The owner's continuous and direct engagement with the project team helped to communicate the owner's intent effectively. It also allowed quicker and more decisive decision-making when the owner was present to answer questions or provide direction immediately.

In addition, the end-user representation that often comes with continuous owner representation serves to reduce change orders and misunderstandings that can impact cost or schedule.

Table 9-4 Owner's involvement

Mosaic Centre	The early time commitment by the owner helped them assemble the right project team and set the expectations, speeding up decision-making processes that benefitted the later design and construction process.
St. Jerome's Student Housing project	The Owner's representative invested time upfront developing a collaborative environment and team alignment that resulted in a much smoother construction phase.
Brock Commons	The owner had an in-house department acting as project manager to procure and develop the collaborative team and set clear expectation from them. Continuous involvement of UBC Properties Trust also helped in controlling and speeding up the processes.
Jacobson Hall	The owner group conducted a student survey to identify their requirements in the new housing building. The owner group also connected student representatives and building maintenance staff with the design team to identify issues.

3. Early Project Team Involvement and Effective Collaboration

One of the key elements of IPD requires the early involvement of project participants. Although two of analyzed projects were not delivered through formal IPD method, they had adopted different way to get the downstream participants' input early in the design stage (Table 9-5).

The key project participants should be retained early in the project to develop the efficient design. These multi-disciplinary core teams are needed for solving design and construction issues as early as possible. The downstream project participants, such as the manufacturer and subcontractors, should also be involved before finalizing the design. Their knowledge can also be leveraged by consulting them or hiring them in a "design-assist" role without awarding the actual contract. In the four project case studies, procurement of these downstream participants was often done on an ongoing basis.

A highly collaborative team leveraging their collective knowledge plan can solve problems early while also giving the team a sense of ownership to the project. In the case studies, it was seen that the project team (from designer to installer) contributed, agreed and set the scope under the owner's goals and objectives.

Table 9-5 Early project team involvement and effective collaboration

Mosaic Centre	The IPD contract facilitated early project team involvement and aligned the project team's goals with the project goals through the various mechanism (such as shared risk and reward, joint project control, jointly validated goals etc.).
St. Jerome's Student Housing project	The IPD contractual setup required on-boarding of key project participants from project inception. Effective team collaboration was achieved through a shared risk/reward mechanism, a Big Room arrangement, joint project control and reduced information liability exposure.
Brock Commons	Brock Commons innovative nature required an integrated team to make mass-timber possible, bringing consultants, builders, and the owner together much earlier to solve regulatory and technical challenges.
Jacobson Hall	The owner hired a vertically integrated firm (Metric Modular) and leveraged their internal team setup by getting various internal expertise at the table early in the project, even before a contract was signed.

4. **Efficient Project Team Setup**

To select the right team for the project and enable them to work openly, collaboratively and to be focused on the owner's goals, the owner needs to clearly and rigorously define the selection criteria. The selection process should be value-based as opposed to solely based on lowest bid. Each applicant should be assessed by key criteria (may vary based on project requirements) and should always be followed up with interviews by the key contractual parties: owner, contractor and architect.

The team selection processes for the IPD project teams used scenario-based interview questions to give the owner a chance to assess the character of the people involved (do they work well together? Are they open to new ideas?) and to "test" how they might work in cross-functional teams (Table 9-6).

Usually, the main team selection processes for IPD projects can be broken down into 3-parts:

a. **Pre-qualification bid:** Identifying firms who can perform and are eligible.
b. **Technical bid:** Assessing how those firms will perform to meet the goals.
c. **Interview/presentation**: Implementing scenario-based testing to understand the team dynamics and to make sure they can work well together.

Table 9-6 Efficient project team setup

Mosaic Centre	The owner invested a significant amount of his time to select the right team for the project. The IPD hierarchical structure (SMT, PMT, PITs) was implemented successfully, and cross-functional teams were formed that were able to efficiently achieve their deliverables.
St. Jerome's Student Housing project	The owner clearly defined the selection criteria in an RFP for the key IPD team members. The IPD hierarchical structure (SMT, PMT, PITs) was implemented successfully, and cross-functional teams were formed that efficiently achieved their deliverables.
Brock Commons	The project team was selected through an official RFP process relying on qualitative bids rather than considering only the cost. Few of the design consultants were selected based on positive previous experience. The architect was selected after a thorough RFP analysis followed by a proposal presentation process.
Jacobson Hall	After initial consultation with the design-builder about the project, the owner awarded the design-build contract to Metric Modular. After winning the design-build award, Metric Modular achieved efficiency through leveraging their established relationships and worked with usual project team with whom they had previous experience.

5. Be Open About Risks and Manage Them as a Team

To avoid "risk paralysis" and encourage a "solutions-oriented attitude", project risks need to be managed by the team as a whole. An IPD multi-party agreement facilitates contractual risk-sharing based on a shared profit pool. However, a recent study by Ghazal et al. (2018) presented that the consultants and trades are reluctant to participate in IPD because of the belief that it embeds new and unfamiliar risks on them through a perceived redistribution of the 'balance of power'. However, the experiences described in the case studies suggest that IPD evolves the understanding of risk from "fear of the unknown" to proactively enabling the team to quantify, allocate and then manage risks either via insurance or through tools, such as risk registers (Figure 9-1 IPD evolves the understanding of risk from “fear of the unknown” (left) to quantification, allocation and management (right) (Bayer, 2015)Figure 9-1).

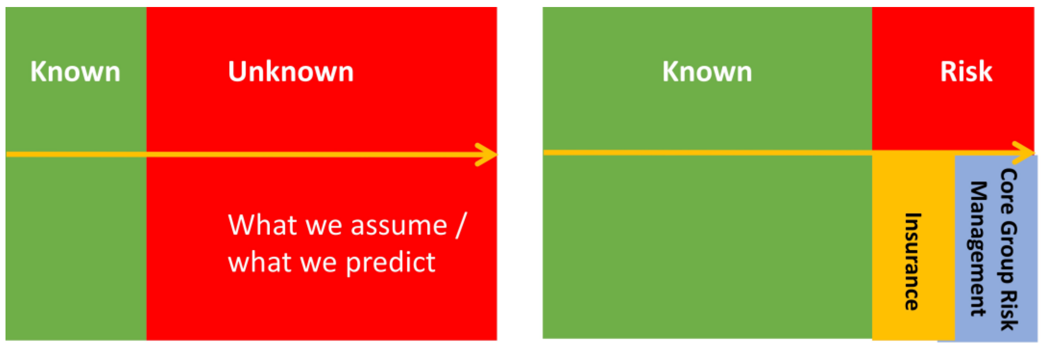


Figure 9-1 IPD evolves the understanding of risk from “fear of the unknown” (left) to quantification, allocation and management (right) (Bayer, 2015)

Project risks need to be communicated frequently and openly. As with traditional projects, the case study team members continued to take on specified responsibilities based on their expertise. However, even though some types of risks may be similar for all the case studies (financial, technical, environmental, etc.) others can be very project specific (team experience, local market dynamics, etc.). In addition, the level of risk tolerance can differ significantly between a private owner / developer and a large institutional organization. Nevertheless, even though each of the projects handled risk in a different way (Table 9-7), the case studies make it clear that a team-based approach was effective at managing risk and solving problems.

Table 9-7 Managing risks as a team

Mosaic Centre	The IPD setup enabled a shared risk and reward mechanism on the project team to align project participants' goals and collaborate effectively. Risks related to project cost were managed collectively by the whole team.
St. Jerome's Student Housing project	The IPD contract helped the owner to manage unknown risks effectively through creating a shared risk/reward pool where the project team assumed costs associated with the unknown risks; this mechanism encouraged the project team to innovate and reduce waste in design and construction processes to achieve target costs.
Brock Commons	The owner adopted a fairly traditional approach to addressing risks without incentivizing the project team for their better performance. All the cost and construction-related risks were transferred to construction manager after accepting the bids.
Jacobson Hall	The owner used traditional Design-Build approach that allowed design-builder to efficiently manage design and construction risks collaboratively with design consultants. In addition, as the design-builder was vertically integrated firm, which allowed early engagement of downstream participants. This resulted in discovering unknown risks and addressing them efficiently.

6. Set Decision-Making Structure

The owner's continuous involvement in the project may be required to make quick design and construction related decisions. There are two different ways to potentially accelerate the design and construction processes, both of which can lead to effective decision-making:

- **Owner Representation:** All levels, teams, and sections important to the owner have representation to directly answer or make decisions.
- **Delegation:** The owner specifically appoints team member(s) to make decisions on behalf of the owner.

The case study projects had different ways to achieve this (Table 9-8).

- A decision matrix clearly defines what decisions can be made independently, and what requires consultation of the higher management level, which allowed the owner to delegate some decision-making responsibilities.
- The degree of owner involvement required at the start of the project does not necessarily have to be maintained throughout. Involvement is typically “front-end” loaded, where a decision can be made with the greatest benefit to the project.
- A full IPD structure ensures that the right team members form effective cross-functional teams are optimized to make informed decisions and execute them successfully.

Table 9-8 Set decision-making structure

Mosaic Centre	The project team developed the owner's value-matrix from the very beginning to speed up the decision-making process and allow lower-level participants to take some of the decisions without asking the higher-management level. Decision-making power was assigned to each IPD level (SMT, PMT, PITs).
St. Jerome's Student Housing project	The owner's representative worked closely with the project team throughout the project, making quick decisions on behalf of the owner. Decision-making power was distributed across the SMT, PMT, and PITs based on the impact of the decision on the project.
Brock Commons	Continuous involvement of the owner's project manager accelerated the decision-making in design and construction process. Design and construction-related decisions were made collaboratively by the project team with the assistance of a virtual 3D model.
Jacobson Hall	Design-Builder made design related decisions and changes collaboratively by consulting an external consultant by giving them final power. The owner's team were consulted before making any major decision related to design and construction.

7. Align Team Incentives with Project Goals

The project team should be incentivized and rewarded for achieving or exceeding project outcomes set by the owners. IPD achieves this through a shared risk/reward pool that places the consultants and contractor's profits "at risk". The two case studies that undertook full IPD demonstrate similar principles although, in other case studies, there were clear penalties for failure to perform but no corresponding incentive for exceeding expectations (Table 9-9).

Table 9-9 Align team incentives with project goals

Mosaic Centre	IPD contract's key characteristic – Shared risk/reward, helped aligning project team's incentives with the project goal.
St. Jerome's Student Housing project	IPD contract's key characteristic – Shared risk/reward, helped aligning project team's incentives with the project goal.
Brock Commons	There was no mechanism of incentivizing the project team based on project performance used.
Jacobson Hall	There was no mechanism of incentivizing the project team based on project performance used.

9.2.2 Innovative Strategies

1. **Maximize Digital Tools, Process Aids, and Innovative Technology**

The project team should be encouraged to use digital tools and technologies, such as BIM, lean tools, etc. to support "better" outcomes. The researched case studies showed that, when it was used, technology generally helped the project team with collaborative design and construction processes. It also helps to visualize the project with owners who usually are unfamiliar with building documents and to get useful input from owners and their end users, minimizing revisions and re-work.

BIM/VDC helps to reduce waste and speeds up the design development with better coordination between design consultants. The digital visualization also supports better schedule development, identifying constraints, coordinating issues and helping with detailed planning. In addition to BIM/VDC, the researched case studies also showcased that adoption of lean tools (such as vPlanner) and project documentation tools help to better and faster communicate project information allowing access of up-to-date documents to project participants.

Interviews with case study project team members revealed that, in most cases, their use of digital tools has increased on subsequent projects and the degree to which BIM is deployed is driven primarily by the owner. Table 9-10 identifies innovative technologies that were implemented in the analyzed projects.

Table 9-10 Use of digital tools, process aids, and innovative technology

Mosaic Centre	**BIM implementation** was minimal: For 3D visualization, design coordination and clash-detection only.
St. Jerome's Student Housing project	Sophisticated **BIM implementation**: All consultants used BIM tools for their design development and used it for design coordination, clash-detection, constructability review. Quite a few contractors used the BIM for quantity take-off as well. Minimal data extracted from the model for facility management use. **ProjectWise:** Efficient and fast (updated) information and documents distribution to the whole project team (within 24 hours); Efficiently managed clash detection reports, meeting minutes, RFIs, site instructions, the current set of drawings on the cloud-based platform. **VPlanner:** Efficient schedule and task management tool; Supported the Last Planner® System workflow aligning short-term plans with the long-term project plans; Supported tasks assignment to various users and checked back when complete.
Brock Commons	**Sophisticated and well executed BIM/VDC tools:** • Visualization, Multidisciplinary coordination' • Clash-detection, • Constructability review, • Quantity take-off, • Structural analysis, • 4D planning and sequencing, • Digital fabrication, • Shop drawings and installation document generation.
Jacobson Hall	No BIM implemented. **Barcode scanning system:** Innovative way of tracking each labour-hour going into the project at the off-site facility. **Smartsheet:** Implemented at off-site facility to achieve collaboration between various subcontractors and suppliers: Used to assign tasks with specific due dates, track project progress, share documents, etc. **SharePoint:** Used to manage design and construction documents with the whole on-site and off-site project participants.

2. Prefabrication

The analyzed case studies demonstrate how prefabrication encourages teams to make a rational decision prior to construction and increases on-site productivity while addressing labour shortage. Prefabrication can also provide high-quality products within a shorter time period. Therefore, prefabrication often leverages IPD-like focus on preplanning, early collaboration and coordination prior to construction – where mistakes, risks, and rework are far more expensive. In addition, prefabrication also often leverages just-in-time delivery and efficient site and labour sequencing on-site. Table 9-11 shows different level of prefabrication adopted in analyzed projects.

Table 9-11 Prefabrication

Mosaic Centre	The large wood roof trusses were prefabricated.
St. Jerome's Student Housing project	HVAC, heating and cooling piping systems were prefabricated. The project team also used integrated sinks with countertops to save cost on-site.
Brock Commons	Prefabrication was implemented in form of CLT panels, Glulam and PSL columns. All the MEP systems were also prefabricated and installed on-site.
Jacobson Hall	Modular construction – 90% modules were completed at the off-site manufacturing plant at Agassiz. Modular construction helped to complete the project in 9-months form the award of a contract to handover with higher off-site quality.

3. Lean Everything

Many of the successes delivered by IPD are predicated upon the successful implementation of lean principles and planning methods. Lean principle identifies and removes "waste", such as labour waste, material waste, wasteful activities, and focuses on concentrating effort on value-add activities that contribute to the owner's goals and objectives through continuous process improvement.

Lean can be effectively delivered within traditional forms of project delivery, offering a good starting point for project teams looking to get started with lean. On the strength of this experience, they can move easily into IPD which creates the legal structure within which the potential benefits of lean can be fully realized.

Lean construction planning methods can yield significant savings (material, labour, avoiding rework, etc.) because the project is seen as a single endeavor (similar to IPD), with all participants collaborating to maximize efficiency, reduce excess cost and increase safety. Some key takeaways from the case studies were:

- Develop metrics for every aspect of the project; time, cost, material, progress, schedule to measure and improve continuously on the project.
- Utilize a "Big Room" to encourage broad team collaboration, problem-solving and to allow the team to constantly "plan-deliver-check & adjust".
- Implement Last Planner® System (pull planning), focusing on detailed planning time intervals and engaging site personnel for their inputs in the schedule development.
- Remove information liabilities to some extent to facilitate free exchange of information and resources among various team during design and construction.
- Employ online document management platforms so the team is constantly aware of progress.

Table 9-12 identifies various lean practices adopted in four analyzed projects.

Table 9-12 Lean practices

Mosaic Centre	• Big Room with Last Planne® System, • Snake diagrams to visually track milestones comparing with planned schedule, • 2 Second Lean.
St. Jerome's Student Housing project	• Big Room with the Last Planner® System, • Pull Planning, • Mock-up for room dimensions and furniture.
Brock Commons	• Mock-up constructability test, • Extensive pre-planning, • Just-In-Time delivery of prefab components.
Jacobson Hall	• The builder is a vertically integrated firm in which most of the project participants were collocated. • Just-In-Time delivery of prefab components

9.3 Challenges for IPD Adoption

From the projects researched in this study and the interviews conducted with the industry experts, it was clear that IPD provides significant benefits to enable project success. However, the adoption of IPD in the housing sector has been low. This is because it is a relatively new delivery method in North America, particularly in Canada. In addition, interviews identified one of the barriers to IPD adoption as companies are reluctant to share their profit with other participants and they do not want to depend on others for their profit. The biggest barrier for IPD adoption identified in interviews is that it requires and asks for exceptional transparency in each company's business practice and cost structure which they do not want to share.

Since IPD is new to Canada's construction industry, a knowledge gaps exist. Traditional approaches to project delivery have led to industry fragmentation and many professionals are familiar with (and in some cases prefer) working in silos. There are challenges, such as a real or perceived shift in the balance of power within the project team, the issue with group decision-making, the discomfort with over-stepping the lines between work areas, and in establishing mutual respect and trust. IPD requires project participants to enter each other's area of work crossing the lines of traditionally defined disciplines. This may feel restrictive to those who are used to taking the lead on certain aspects of the project.

Ebrahimi and Dowlatabadi (2018) have identified several perceived challenges in implementing IPD from the stakeholders' viewpoint and suggests the following the key lessons for the success of IPD implementation, which are consistent with what was found in the case studies and expert interviews:

- Focus on partnership capability in IPD selection
- Establish a balance between efficient resource allocation and collaboration
- Empower IPD members to establish a flatter organizational structure
- Bridge the knowledge gap on IPD concepts and their implementation.

9.4 Limitations and Suggestions for Future Work

The purpose of this research was to identify the key innovative and collaborative strategies of IPD to achieve owner's goals in housing projects. However, the results rely on a limited number of case studies in which only two of the projects implemented full IPD. As there are few IPD housing projects currently under construction in Canada, a follow-up study should be conducted with a larger number of IPD projects to examine the influence of IPD characteristics on the project outcomes.

This research identified the innovative and collaborative strategies of IPD based on cross-project analysis, but it does not assess the impact of each strategy on the project outcomes. Therefore, follow-up research is recommended to quantify the impact of these strategies on the project outcomes.

Even though there are proven benefits of formal IPD implementation, there are very few housing projects that have been delivered through an IPD contract. Therefore, a follow-up study should be conducted to investigate the reasons for the lower IPD adoption rate in the housing industry and identify the major barriers to its use.

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