Strategies for Collaborative Construction:

Integrated Project Delivery Case Studies

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SUPPORTING INFORMATION

PART 1

INTRODUCTION

1. **Overview of IPD**
2. **Case study project selection**

1. Overview of IPD

"Integrated Project Delivery (IPD) is a project delivery 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." [1]

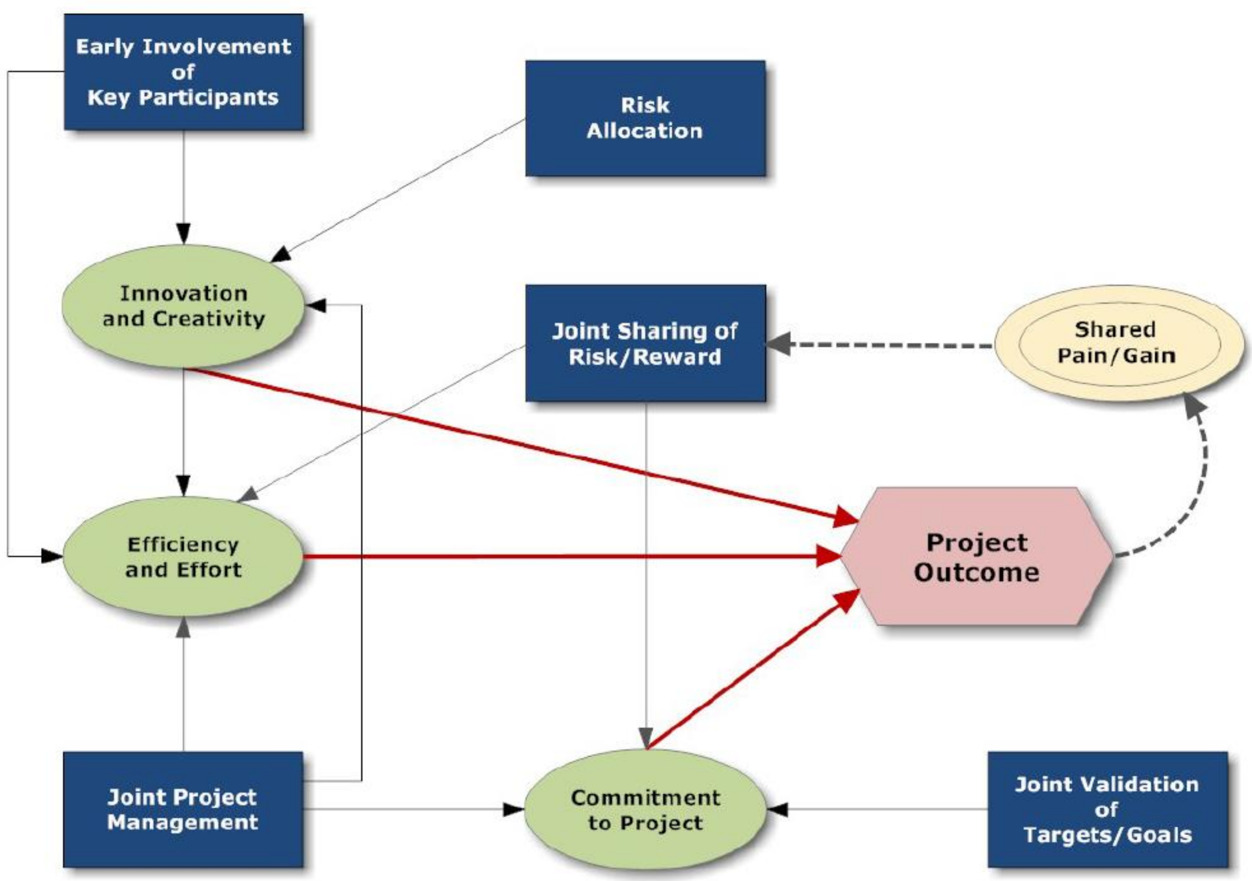
American Institute of Architect, California Council

Integrated Project Delivery (IPD) is a project delivery method which aligns the project team goals and provides effective collaboration mechanism among them to achieve overall project goals efficiently.

IPD is an innovative building project procurement strategy which 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[2] (Figure 1). In IPD, the stakeholders' success depends on the project's success.[3] IPD consists of the following five factors[4], which are discussed below:

1. **Early involvement of key participants**
2. **Shared risk and reward based on project outcome**
3. **Joint project control**
4. **Reduced liability exposure**
5. **Jointly developed and validated targets**

Figure 1- IPD elements and outcomes (©Hanson Bridgett)



1. Early involvement of key participants

Early involvement of key project participants (those who may have the highest influence on the project's success) is the most essential element of IPD. In addition to the owner, architect and contractor, other key participants may be mechanical and electrical design consultants, subcontractors that may provide critical knowledge and positively affect the design development. 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 project to project based on their capability to influence the design development. Usually the owner, architect and contractor collaborate from the inception of the project. The rest of the team may or may not be required until later. Key participants must be involved in the project at the time when their contribution would influence the project outcome.

2. Shared risk and reward based on project outcome

IPD projects are run "open book", where key participants know and accept the costs incurred by each party, including overhead and profit. 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.

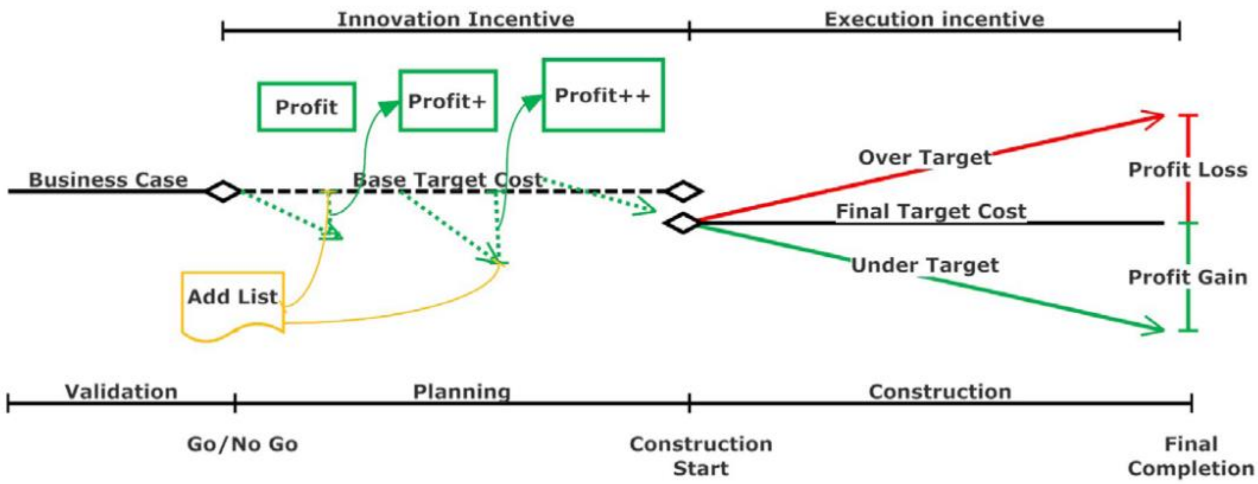
For those that do participate in the IPD multi-party contract, a fixed amount of their profits (based on their work or services) are "pooled" to serve as a means to managing risk and incentivizing performance. These project participants would be paid for time and materials, but some or all of their profit would be at risk depending upon the project outcome/success. The sum of the project participants' profits is usually referred to as the profit pool or risk/reward pool.

Shared risk and shared reward

The shared risk and reward compensation structure in IPD helps to the align the project participants' goals with the project goals. 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.

Together, the project participants agree to the target cost for the project separate from the profit pool. The project participants receive their initially agreed profit percentage if they achieve the project cost equal to target cost. 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 (Figure 2). Conversely, if the project costs more than the target cost, the project participants' profit is reduced – potentially to nothing[5].

Figure 2 - Risk and Reward sharing setup in IPD (© Howard Ashcraft, 2014)



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. Because participants accept the risks related to a 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) comprising, at a minimum, the owner, architect and contractor. The PMT is authorised to manage the project to achieve the jointly agreed objectives and to take decisions that are in the best interest of the project. If the project decisions are not unanimous at the PMT level, those decisions are elevated to the Senior Management Team (SMT). 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. The SMT is comprised of executive-level of members from every party that sign the IPD contract. The SMT generally handles and resolves disputes.[6]

4. Reduced liability exposure

Cross-discipline communication is important in all projects, and especially so where situations are complex and/or innovative approaches are being deployed. In traditional delivery methods, concerns about liability hinder the free exchange of information among project participants for fear of being found responsible for errors or omissions that might cause loss or damage to others. In IPD, a multi-party agreement facilitates contractual risk-sharing based on a shared profit pool, but the objective is for the project team to work closely together to fully understand the project and minimize the “unknowns”. A liability waiver is then established which promotes unfettered exchanges of ideas, incentivizes suggestions to be made that reach beyond disciplinary “boundaries” and encourages creativity. Liability waivers can also reduce litigation costs and project delays (especially at hand-over).

It is common in traditional procurement situations for bidders to add a contingency (or “padding”) to their prices. The intention is to cover (at least some of) their exposure to liability. By eliminating many of the risk factors for which contingencies are added through greater transparency, ability to inform project decisions and trust within the project team can therefore help to reduce project costs.

Concerns about liability serve to promote standard practice, complete with all the inherent inefficiencies and flaws. Reducing liability exposure can give team members the confidence to consider the types of innovative approaches necessary to improve productivity, efficiency and performance.

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 everyone. These targets serve as metrics for compensation adjustment and as goals for target value design in the later stages.

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

2. Case study project selection

1. PriMed Mosaic Centre

Edmonton, AB

2. St. Jerome's University campus renewal

Waterloo, ON

3. UBC Brock Commons Tallwood House

Vancouver, BC

4. Jacobson Hall, Trinity Western University (TWU)

Aldergrove, BC

Given that IPD is still at an early stage of adoption in BC, the five case study projects were not only selected to assess the outcomes of a full IPD delivery process but also to evaluate "IPD-like" projects that used other, more traditional methods of project delivery, to achieve the five IPD factors for success.

The purpose of this project is to research the adoptability of IPD to housing projects in BC. While, ideally, all of the case study projects would comprise some aspect of residential design, there is only one housing project (St. Jerome's University in Ontario) that has been completed using a full IPD process in Canada.

It was therefore considered important that the projects were complete, the project team was willing to share the results in order to provide complete data and that the projects were based in Canada. Thus, a small-scale largely timber office building (Mosaic Centre) that completed a full IPD process has been included because it possessed similar characteristics to housing projects along with three BC-based "IPD-like" residential projects, which captured many IPD factors of success (Figure 3). The research methodology is presented in Appendix A.

Figure 3 Innovative characteristics of selected case studies

	Project type	Delivery model	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, TWU	**Student housing**	Design-Build	●		●		●

3. Comparison of case study characteristics

	 **priMed Mosaic Centre**	 **St. Jerome's University**	 **UBC Brock Commons Tallwood House**	 **Jacobson Hall, Trinity Western University**
Location	Edmonton, AB	Waterloo, ON	Vancouver, BC	Aldergrove, BC
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
Contractual arrangement	Full IPD	Full IPD	CM+	Design-build
Owner's involvement	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	Contractor was involved from project inception before the consultants were brought on.	Contractor was involved from project inception.	CM was involved from the schematic design stage.	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 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 project team was collocated in one office

				
	priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
Use of digital tools	BIM used for: • Visualization • Design coordination and some clash detection	BIM used for: • Visualization • Design coordination • Clash detection • Construct-ability review • Quantity take-off • Digital fabrication to some extent • Minor facility management	BIM/VDC tools used for: • Visualization • Multi-disciplinary coordination • Clash detection • Construct-ability review • Quantity take-offs • Structural analysis • Sequencing • Digital fabrication	BIM was not used. Design development and coordination 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 counter tops	Entire timber structure was prefabricated (CLT panels and PSL columns, etc.)	Modular construction (units were 95% complete)

PART 2

FOUR CASE STUDIES

1. PriMed Mosaic Centre

Edmonton, AB

2. St. Jerome's University campus renewal

Waterloo, ON

3. UBC Brock Commons Tallwood House

Vancouver, BC

4. Jacobson Hall, Trinity Western University (TWU)

Aldergrove, BC

CASE STUDY 1: priMED Mosaic Centre

The Mosaic Centre[7] used a full IPD process complete with an "open book" multi-party construction contract structured on a "shared risk, shared reward" basis with 14 signatories. It was a technically demanding project comprising multi-tenant office space for 130 workers, a child-care centre and restaurant. The project was the first to be certified LEED Platinum and Living Building Challenge Petal in Edmonton and the first net-zero commercial building in Alberta.[8] The building was acquired by priMED Medical Products Inc. in 2017.

Location: Edmonton, Alberta

Gross floor area: 30,000m2 (32,300sf)

Design charrettes started: April 2013

Construction started: April 2014

Target completion: August 2015

Actual completion: March 2015

Target cost: $11,355,667 (~$350.sf)

Final cost: $11,355,667

Number of RFIs: 0

Number of Change Orders: 0

Estimated value added by IPD process: approximately $2,000 per week related to lean implementation

Owner: Cuku's Nest Enterprises Ltd

Architect: Manasc Isaacs Architects

Contractor: Chandos Construction

Mechanical Engineer: Clark Engineering

Electrical Engineer: Manasc Isaac

Structural Engineer: Fast & Epp

© Mosaic Centre

The Mosaic Centre's owner was intimately involved every step of the way. This passion and commitment contributed greatly to the success of the project.

Project owner Dennis Cuku set out to prove that sustainable buildings can be both beautiful and affordable. Even four years after completion, Dennis is an ardent evangelist for this project, and its success is in large part a result of his tireless efforts to inspire, educate and support the project team.

An engineer from the oil and gas industry, Dennis brought extensive experience implementing resource projects. However, when it came to building construction, Cuku's Nest Enterprise's previous experience had only been with small commercial renovations. The Mosaic Centre was by far the largest building project Dennis had taken on.

Initially, Dennis learnt about Integrated Project Delivery (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 one of the first IPD projects in Canada.[9] Dennis firmly believed that his goals of affordable, sustainable, and high-quality design and construction could only be achieved with a highly collaborative team culture and that IPD was key to success.[10] Although (and perhaps because) he had no prior experience with IPD, the main risk for Dennis was not from within the terms of the IPD agreement but from finding the right people and develop the team culture.

CONTEXT

Integrated Project Delivery (IPD) is an emerging construction project delivery system that collaboratively involves key participants very early in the project timeline, often before the design is started. It is distinguished by a multiparty contractual agreement that typically allows risks and rewards to be shared among project stakeholders.[11]

Lean Project Delivery (LPD) is a highly collaborative process that comprises the application of target value design and lean methods during construction.[12]

Lean Methods seek to develop and manage a project through relationships, shared knowledge and common goals. Traditional silos of knowledge, work and effort are broken down and reorganized for the betterment of the project rather than of individual participants. The objective is to deliver significant improvements in schedule with dramatically reduced waste, particularly on complex, uncertain and quick projects.

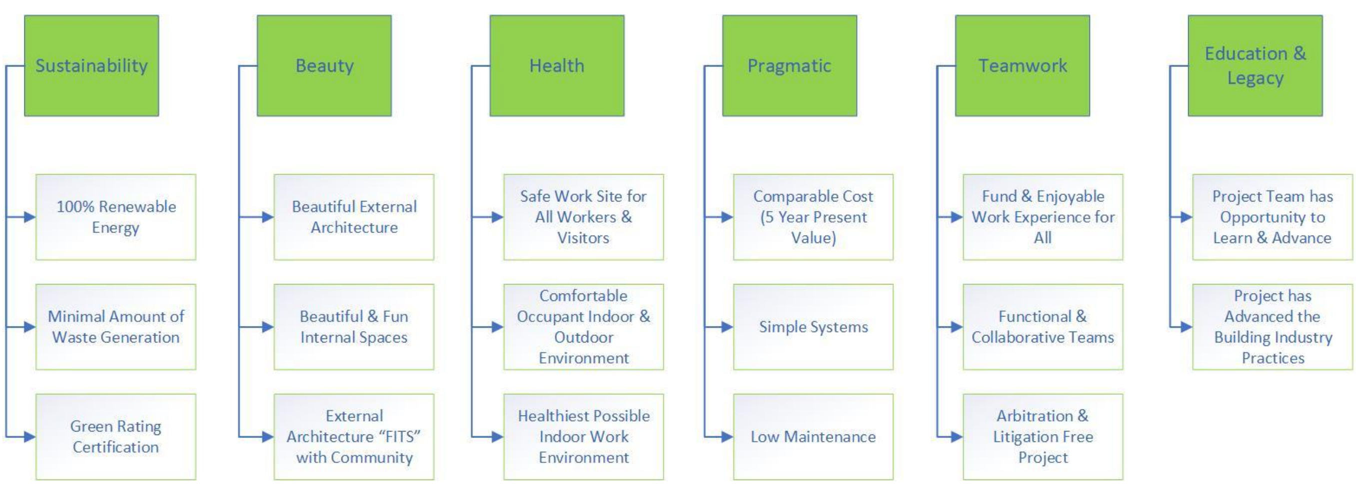
Building on his background in lean project delivery, the owner selected IPD as a way to promote the level of project team collaboration necessary to achieve a high performance, innovative project at an affordable price.

Dennis Cuku believed that the best way to deliver an affordable high-performance innovative building was by changing the traditional way of operating construction projects. With prior experience with lean project delivery in his oil and gas projects, Dennis encouraged whole-hearted adoption of lean practices from the very start of the project despite the fact that only a few members of the project team had any experience with lean methods. Dennis also believed that lean and IPD would mutually support each other, with IPD fostering the level of collaboration necessary to optimize the benefits afforded by lean practices.[13] The Mosaic Centre was the first IPD project for all involved.

The project goals inspired the team to collaborate intensively.

From the beginning, Dennis Cuku wanted the project to be different. Prior to hiring the project team, his initial vision was to fast-track the project while achieving LEED platinum-level performance – all for a construction budget of $9 million or about $278/sf, which was the average conventional office construction cost in Edmonton at that time. Once the project team were on board, they worked together to set highly ambitious goals for the project in the areas of building performance, business practices, design, and construction (Figure 4). To achieve these goals, the budget was subsequently increased to $11,355,667 (about $350/sf).

Figure 4 - Mosaic Centre project goals (© Chandos)



Learn more about the technical accomplishments of the Mosaic Centre

The building received LEED Platinum for New Construction certification in October 2017. For a summary of the environmental accomplishments, the Canada Green Building Council has developed an online case study (which also provides a complete list of the team members).[14]

Technical details of the project are available in a case study prepared by the Canadian Wood Council's Wood *WORKS*! Program.[15]

> "One thing they [the owners] knew for certain was that the Mosaic Centre couldn't easily be completed on budget if they took a traditional approach to building a commercial space. Often companies and contractors are focused on their own section of the project rather than the "big picture" final product; this can result in cost overruns, scope creep and an overall negative experience."
>
> **Mosaic Centre website**

The owner hired a team who understood his vision for the project and aligned themselves with the core values of the project.

To select and retain the project team, Dennis issued a "call to partners" memo instead of a traditional Request for Proposals (RFP). He was clear that he "didn't look for the cheapest or the fanciest". To assist with team recruitment, he also created a video "The Mosaic Centre: Alberta's first Living Building?" [16], which set out the goals and objectives of the project.

The general contractor, Chandos Construction[17] - an established local firm with a track record for being an early adopter of new ideas - was the first core team member to be hired. Dennis had a prior relationship with the Chandos team and Chandos were the only firm to express interest in IPD. Hiring the contractor first for projects of this type is unusual. However, Dennis wanted Chandos to bring key trades into the project as early as possible.

Dennis selected Manasc Isaacs Architects[18] - a well-known firm in Edmonton and nationally recognized for their expertise in sustainable design - because he believed that "they understood what he meant by beauty and sustainability, and how they can work together". Manasc Isaacs were brought on board in March 2013 to start work on the project design.

With input from Manasc Issacs, Chandos was then responsible for assembling the rest of the project team. Team members were selected based on their sustainable design expertise, their ability to collaborate with each other, their ability to communicate really well with each other and their willingness to "think differently". From the outset, this project was pitched as "an adventure".

Chandos' team selection process did 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, rates, 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 Chandos and the owner considered would contribute the most to the collaborative culture they were hoping to create.

IPD standards and contract documents

The Hanson Bridgett IPD Standard Agreement[19]

A multi-party agreement that seeks to succinctly state IPD principles within a readable and logical agreement, this document is 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.

According to Hanson Bridgett, "Key to this Agreement is the compensation system which is designed to spur creativity and align the parties' interests. Essentially, the owner guarantees the direct and indirect project costs. The architect and contractor place all, or a portion, of their profit into a risk pool ("incentive compensation layer or "ICL") that is augmented or decreased depending upon project outcome (time and cost) and project quality. In the base agreement, the incentive compensation layer is distributed to the architect, contractor, and cost-reimbursable consultants and subcontractors, although variants can be used that apply disbursements at milestones to overcome cash-flow and other issues." It follows the AIA IPD Guide.

AIA / AIACC IPD Guide[20]

A collaborative effort between the American Institute of Architects (AIA) National and AIA California Council, this Guide provides information and guidance on principles and techniques of integrated project delivery (IPD) and explains how to utilize IPD methodologies in designing and constructing projects.

The multi-party construction contract for the Mosaic Centre used an established US-based model with minor modifications.

The construction contract was prepared by US-based lawyer and IPD expert, Howard Ashcraft of Hanson Bridgett LLP[21], who made some minor modifications to "Canadianize" the Hanson Bridgett Standard IPD Agreement. About 95 per cent of the contract stayed the same.

The primary contract signatories for the 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.

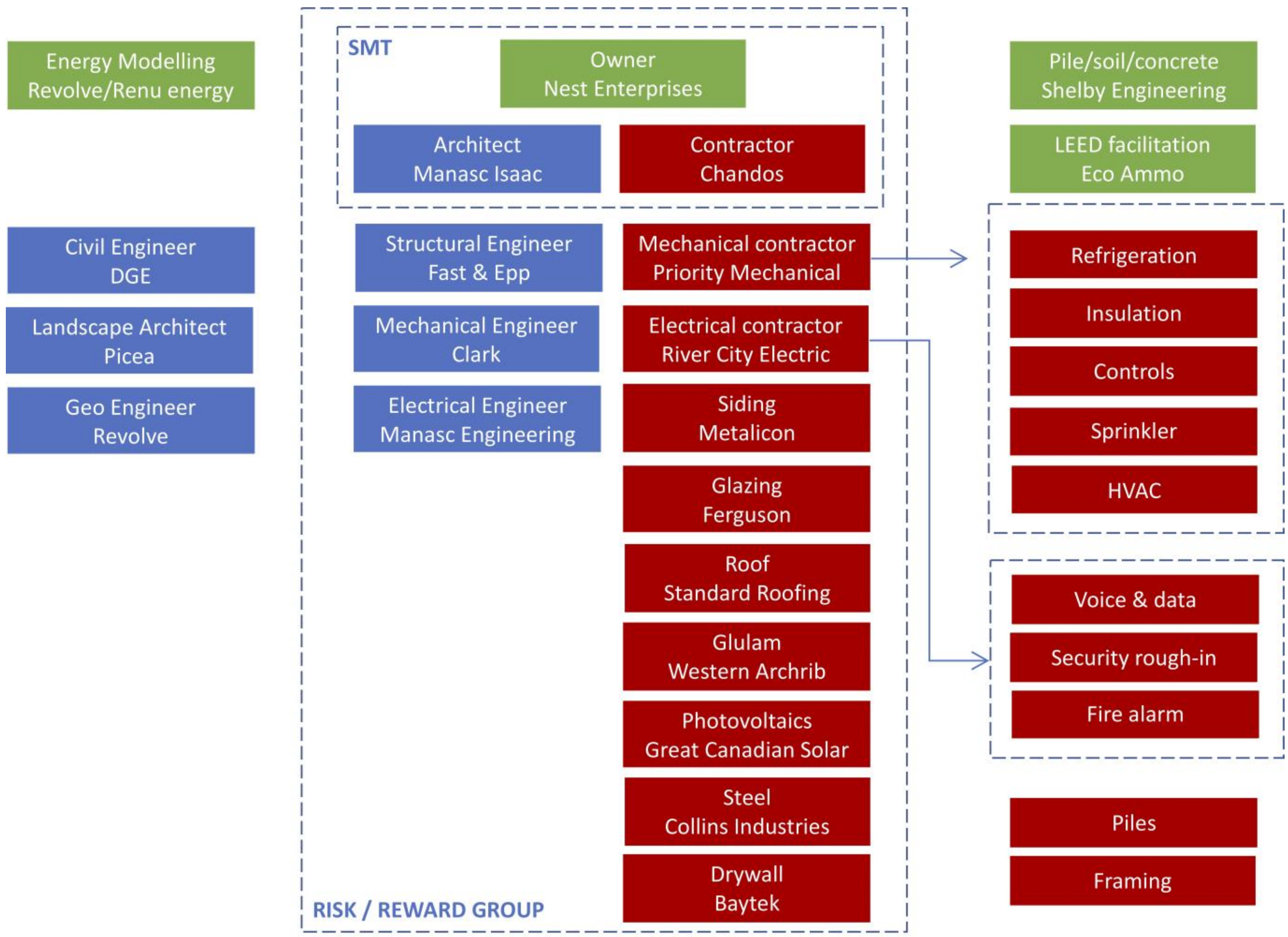
Contract execution was delayed until three months after construction had started. This was because the team wanted to wait for all the supplementary conditions and amendments (specific to the project) to be completed before they signed the base agreement. According to Chandos,[22] this was not a major 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.

The IPD project team was structured in three layers.

The project management structure was organized into a Senior Management Team (SMT), Project Management Team (PMT) and Project Implementation Team (PIT) (Figure 5). In part, this "belt and braces" approach was put in place to compensate for the lack of prior experience with IPD and ensure that responsibilities were clearly defined, and key decisions did not get missed.

> **The Senior Management Team** members were required to check and update that the project is going well on monthly basis and they had less overall involvement in the project execution as PMT, generally, executes the project, not SMT.
>
> **The Project Management Team** was responsible for managing and executing the project and 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.). Led by a team captain, PIT membership is "fluid". Core team members can be supplemented with technical members from the whole IPD team on an "as needed" basis.

Figure 5 - Mosaic Centre IPD team structure



The project was championed by a fully engaged owner supported by very experienced professionals who were able to function effectively in the face of uncertainty.

During the first few months of the project, Dennis 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. Dennis 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 Dennis's vision. Chandos is an employee-owned Canadian construction company with a mission to be the most innovative and progressive contractor in Canada.

Learning through collaboration

As the construction progressed, the team communicated stories of innovation through a wide range of media. By the end of the project, Chandos had made hundreds of short videos to document "continuous improvement" to their site processes – in particular, how even the smallest tasks can be completed faster, more safely or more easily.

> "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.' "
>
> **Dennis Cuku**

Today, Chandos employs over 400 field and office staff across offices in Edmonton, Calgary, Toronto, Red Deer and Vancouver and is the largest B-Corp certified contractor in North America. They specialize in complex projects where value can be delivered to the client through collaborative project delivery models, lean methodologies and building information modelling.

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 Chandos were actively learning about lean and IPD in order to implement it on projects. The Chandos 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.

The success of the Mosaic Centre is testament to the quality of the project team and the efforts that went into team building. However, at the end of the day, each team member had to buy into a process that was highly dynamic. The team had to learn to interpret what Dennis wanted and Dennis had to invest far more time with his team than might be considered normal by conventional building owners.

It is therefore fair to say that the risk profile of this project might not appeal to every design or construction firm. The strength of the Mosaic team meant that they were willing to work together despite the fact that, at the outset, many of the owner's conditions of satisfaction were largely subjective and/or qualitative.

Good decision making is predicated upon clarity of goals, the right team and mutual trust.

Once the team understood the owner's goals, Dennis was open to letting the team figure out how those could be achieved. To facilitate fast project decision-making, a project "Values Matrix" was developed during early "all-hands" meetings. The matrix synthesized the owner's goals (Figure 4 on page 14) into several generic categories with associated metrics or key performance indicators. The Values Matrix (Figure 7 next page) provided the PMT team with a well-structured way to track progress and to make decisions quickly that were in the best interest of the project.

Figure 7 - Mosaic Centre Values Matrix (source Chandos)

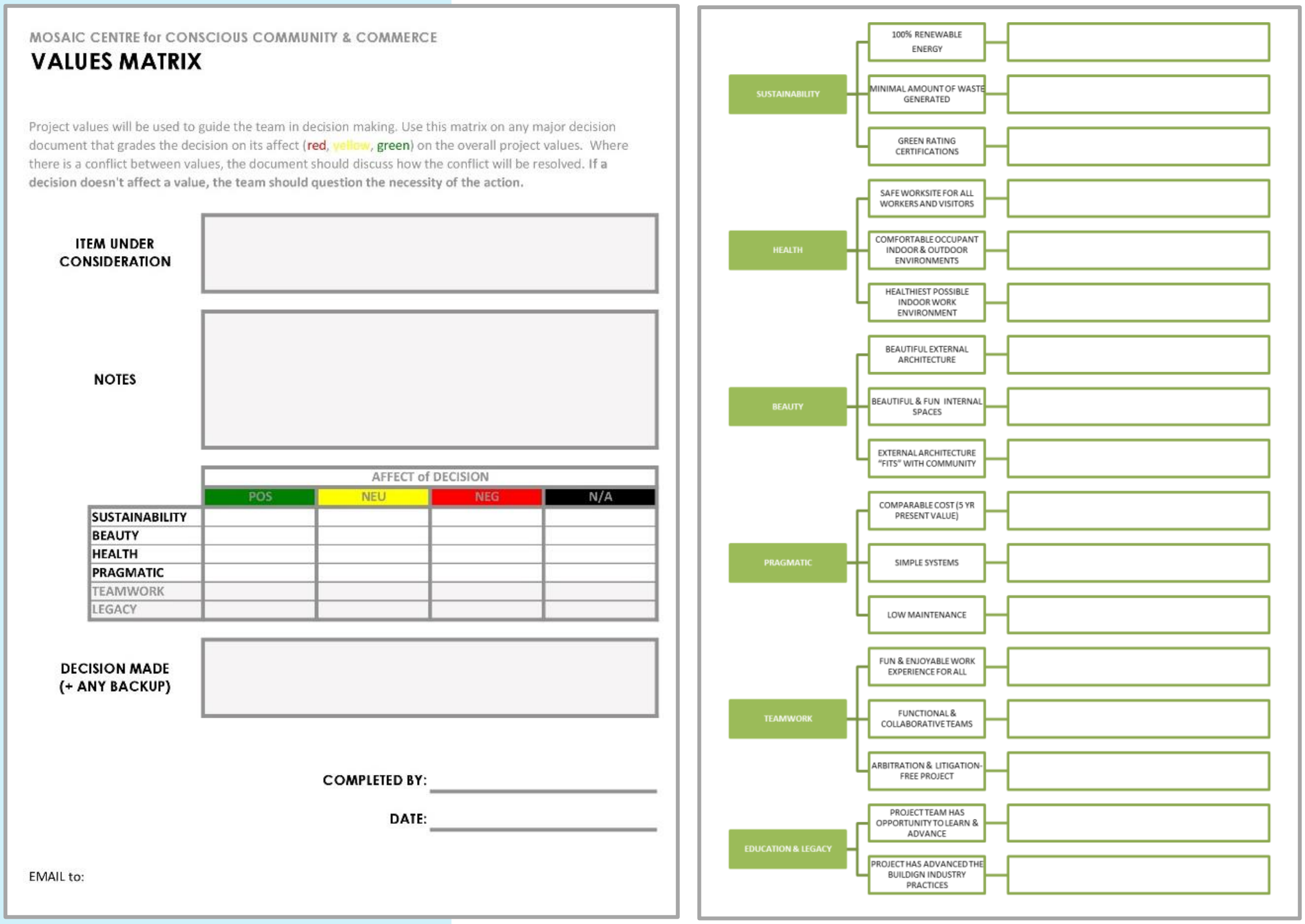
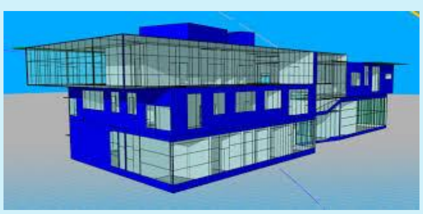


Figure 6 - BIM model of the Mosaic Centre (source Mosaic Centre website)



When a PIT wanted to make a decision that had a cost related to it, then the PMT would review it against the Values 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. The fact that the owner attended almost every meeting and held "office hours" for the project also expedited the decision-making process.

PROCESSES

Building Information Modelling (BIM): The use of BIM – 3D modelling of the design – can potentially provide IPD project teams with the opportunity to pursue a truly collaborative approach to design, construction and ongoing management of an asset.

Pull Planning: According to the Lean Construction Institute, Pull Planning involves "working from a target completion date (milestone) backward, tasks, which are defined and sequenced so that their completion releases work. Work tasks, information flow, and material deliveries are planned based on the request (or "pull") of downstream customers. Pull scheduling will often expose the need for smaller batches, just in time delivery, improved levelling of resources, and reduced lead times. Workflow becomes more reliable and efficient as the waste of waiting, redundancy, and over-processing are eliminated."[23]

The Big Room: According to the Lean Construction Institute, "An effective Big Room supports cross-functional team collaboration by advancing work and bringing the larger team up to speed on the activities of other groups or individuals. It allows teams to understand their impact across clusters or work groups. The Big Room also provides teams with the time to discuss project-wide concerns like budgets, hot topics, or global changes. The term Big Room refers more to the behaviours and actions of the team than the physical space. It is more than co-location of people; it is about collaborative behaviour and the work they are producing."

The communication and coordination strategy between the design consultants was defined in early design stage.

The project's BIM execution plan defined the way of 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 architects 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 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.

Outside IPD and lean experts were brought in to facilitate 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 Chandos. Project team members could also voluntarily attend a weekly or bi-weekly webinar for extra coaching. 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.

Regular "Big Room" meetings brought every player of the team to the table and everybody had access to anybody.

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.

TEAMWORK

Growing a culture of collaboration

Throughout the Mosaic Centre construction process, there were numerous examples of team members exhibiting project-first or team-first attitude in the face of changing project scope or unforeseen problems. This practice was founded in the fact that all the key team members were signatories to the contract and shared in a risk/reward pool.

Addressing major problems in an IPD environment

The following example illustrates the level of effectiveness that the Mosaic IPD team functioned at to mitigate unforeseen problems and achieve the project goals.

During the course of construction, the Mosaic 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 shear wall. An impromptu meeting was held with rest of the team and a solution found that reduced the cost to change the wall to $80,000 while meet the structural requirements. The team then found enough savings elsewhere in the project to cover the outstanding cost increase.

"I had a mandate that we would have the zero change orders and that then forced everybody to be hyper-hyper communication-involved all of the time."

Dennis Cuku

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.

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.[24]

Although the contract was signed three months after the start of construction, the 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." At the same time, they conceded that, in the absence of a signed contract, the legal relationships were quite "fragile" and, particularly at the outset, it took more work than would be usual by the owner and the SMT to keep the team moving forward.

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 unaccustomed to having their design questioned (especially by trades).

A major difference between IPD and traditional practice is the level of team resiliency. This is highlighted in the way the team functions in the face of a major problem.

In traditional contractual arrangements even with the most collaborative of team structures, problems that occur during the construction process generally cause 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 that is hard-wired into an IPD agreement, individual team members will tend to look after their own interests ahead of those of the project.

INNOVATIVE PRACTICES

> "We had 32 to 34 months [of schedule] and when we came out of the Big Room we were down to 18 months. but 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. That's when I realized we have stumbled onto something pretty amazing."
>
> **Dennis Cuku**

Lean methods underpinned the ability for the Mosaic Centre to complete on budget and ahead of schedule.

Target Value Design is a collaborative design process involving designers, builders, suppliers, estimators and owners co-located in one place to collaboratively produce a design that provides the best value for the Owner. Budget (the target value) is a design criterion. The team designs to the budget instead of the conventional process of estimating the cost of the design, and then re-designing to eliminate overruns.

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 8). 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. Chandos 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 set-up.

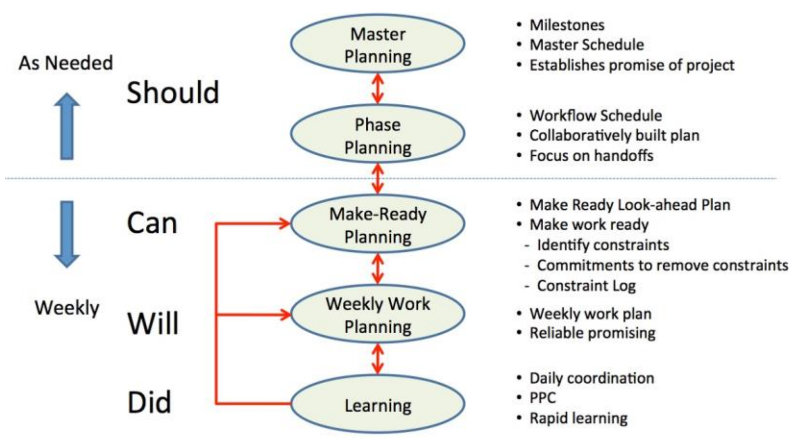


Figure 8 - Last Planner System (source Lean Construction Blog)

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.

The team also followed Paul Akers' "**2 Second Lean"** approach[25], which teaches team members to continuously improve and eliminate waste in small increments each and every day. The goal is to "turn every team member into a world class problem solver who seeks and destroys waste every day".

TECHNOLOGY

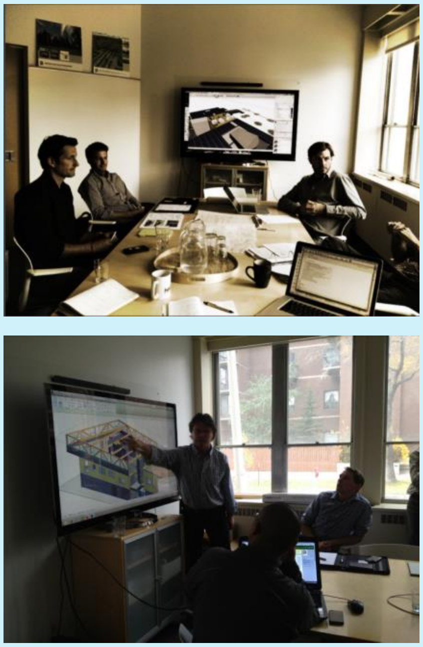


Figure 9 - Design coordination meeting (source Manasc Isaac Architects)

Figure 10 - Pre-fabricated elements such as large trusses were installed in the Mosaic Centre (image © Western Archrib, sourced from Wood *WORKS*! case study and Fast & Epp)

Although not specifically requested by the owner, the architects developed a 3D Building Information Model (BIM) of the project not only to understand the building geometry, but also to optimize communication and coordination processes during design and construction.

A 3D virtual model was developed early in the design phase to help the project team visualize and understand spatial geometries and relationships. The initial scope of modelling was only to develop discipline-specific designs of the building.

The model was continuously updated, which helped to coordinate the design process while providing a quick visual reference for ongoing design refinements (Figure 9). It also allowed for detailed models (e.g. the mechanical, electrical and plumbing (MEP) systems, and some of the exterior wall systems) and for clash-detection, which was particularly important for MEP system coordination.

The architects and the structural, mechanical, electrical engineers all accessed the Revit[26] model and imported and exported information from/to other disciplines and key trades using the IFC[27] format. For example, the structural steel and timber trades used the model for shop drawings and imported key elements of the model into their CAD/CAM systems for prefabrication of key structural elements (Figure 10).

During construction, the BIM model enabled improved understanding of the design and helped to streamline project coordination.

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 for why BIM was not utilized as fully 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 an advanced level.

OUTCOMES AND METRICS

Owners requirements met

All of the owner's requirements as described in the initial project goals framework (Figure 4 on page 14) were met.

On budget

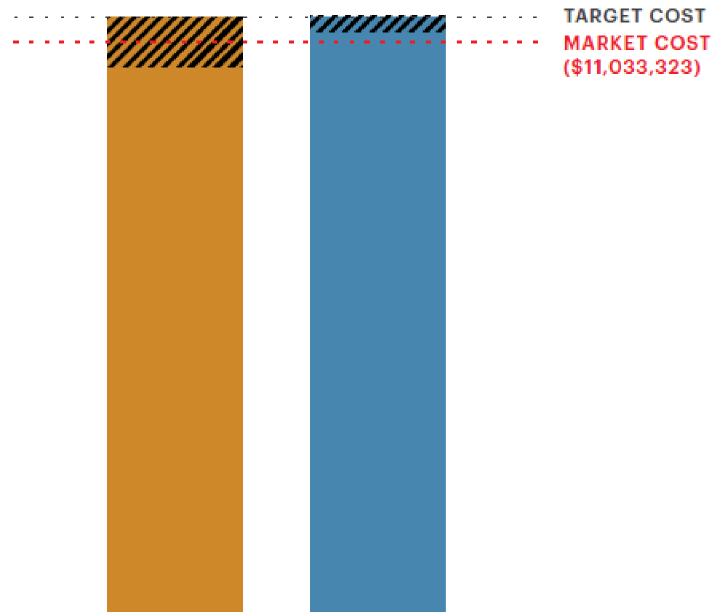
The project was delivered for the target cost. However, the project team believed that they did not perform quite as well as they had intended, resulting in a reduced profit pool of $316,865 – which was about 2.8 per cent of the Target Cost. Even though the team collectively only received 33 per cent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

4 months ahead of schedule

The project benefited from the up-front investment for extensive early planning and resulted in 4-months of saving in project schedule. The project was completed in 11 months which is 39 per cent faster than the original schedule of 15 months.

In this project, the contractor tracked savings directly related to Lean implementation; which, on average, were estimated to be approximately $2,000 per week.

Figure 11 - Comparison of target cost and final cost for the Mosaic Centre [28]



Allowable Cost	**N/A**
Target Cost	**$11,355,667 (100%)**
Final Cost	**$11,355,667** (100.00%)
Target Profit	**$960,366** (8.5% of Target Cost)
Final Profit	**$316,865** (2.8% of Final Cost)

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 team to condense the project schedule by 4-months.
- Development of the owner's "Values Matrix" clarified and sped up the decision-making processes. The Matrix, along with the Big Room collaborative format, eliminated RFIs and change orders.
- For those interviewed, the collaborative project 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).

CHALLENGES AND LESSONS LEARNT

Taking on one of the first IPD projects in Canada had the potential to magnify the challenges facing the owner and the project team.

- In 2013-14, IPD and lean methods 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. Getting to grips with all the new tools and processes added additional challenges 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 IPD contract signatories and therefore outside the profit pool.

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 feared 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.
- With hindsight, 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 learnt that lean champions can come from all levels of an organization, and that lean champions can change as the project progresses.
- 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, and interfer with the free exchange of information between project team members. The idea was that a certain level of informality encouraged ongoing interaction, which would lead to reduced administration. However, in retrospect, they felt that a more formal structure could have worked better during the 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, cost estimating is not a passive role. It happens in "real time" and the estimator needs to proactively participate as an integral member of the team.

CASE STUDY 2: St. Jerome's University residence and academic building

An independent university opts for a full IPD process complete with an "open book" multi-party construction contract structured on a "shared risk, shared reward" basis. IPD was selected as a means of managing the risks of a project that was of a scale and complexity that the owner was unaccustomed to dealing with.

Location: Waterloo, Ontario

Gross floor area: academic building 2,087m^2 (22,456sf), student residence 10,223m^2 (110,000ft^2)

Construction started: October 2013

Target completion: August 2016

Actual completion: May 2016

Target cost: $47 million

Final cost: $47 million

Estimated value added by IPD process: about $2M in value-add improvements through Target Value Design process

Number of RFIs: "few"

Number of Change Orders: 0

Owner: St. Jerome's University

Architect: Diamond Schmitt Architects

Contractor: Graham Construction

Mechanical & Electrical Engineer: The MCW Group

Structural Engineer: RJC Consulting Engineers

Civil Engineer: MTE Consultant

Electrical contractor: OZZ Electric Inc.

Mechanical contractor: Urban Mechanical Contracting Ltd.

IPD Consultant: Ghafari Associates

St. Jerome University's campus renewal project is the first example in Canada of Integrated Project Delivery (IPD) being used in an academic context.

Founded in 1865 and granted independent university status in 1959, St. Jerome's University is a public Roman Catholic university with about 1,000 mostly full-time students federated with the University of Waterloo in Ontario. In 2016, St. Jerome's University completed a $47 million campus renewal construction project, which included:

- A two storey academic building comprised of a variety of flexible classroom configurations and a 300-seat auditorium.
- 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 onsite accommodation. The ground floor has physical recreation amenities as well as study, games and music rooms.
- Significant site works including reconfigured roads, landscaping and new parking.

CONTEXT

Integrated Project Delivery (IPD) is an emerging construction project delivery system that collaboratively involves key participants very early in the project timeline, often before the design is started. It is distinguished by a multiparty contractual agreement that typically allows risks and rewards to be shared among project stakeholders.[29]

Lean Project Delivery (LPD) is a highly collaborative process that comprises the application of target value design and lean methods during construction.[30]

Lean Methods seek to develop and manage a project through relationships, shared knowledge and common goals. Traditional silos of knowledge, work and effort are broken down and reorganized for the betterment of the project rather than of individual participants. The objective is to deliver significant improvements in schedule with dramatically reduced waste, particularly on complex, uncertain and quick projects.

Understanding the owner's governance structures is critical to any capital project. 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.

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, Darren 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).

Darren initiated much of the exploratory research on IPD and its applicability to the university's redevelopment.[31] 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.[32] In his role as head of university operations, Darren became the project's lean champion who advocated for innovative ideas.

Figure 12 - Rendering showing the extent of the proposed campus renewal project [31]

"We wanted to find an innovative way that would allow us to be more collaborative, but also to manage the risks of undertaking a build of this size for an institution our size."

Darren Becks, St. Jerome's University

Figure 13 - Summary of St. Jerome's University's core IPD team selection criteria with weightage

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

"We gave them up front … a whole backgrounder. It was different because we were procuring a whole suite [of services]. This has not been done a whole lot in Canada in the full IPD way. We commenced the project with a cost, [and continued to work] until we got to validation."

Darren Becks, St. Jerome's University

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 and on budget.

St. Jerome's University'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 of IPD fit with the university's values of "Fostering Community, Inside & Out". Moreover, the St. Jerome's University is affiliated with the University of Waterloo which is considered as Canada's most innovative university. 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.

Team selection was based on a series of weighted criteria that were designed to promote IPD and innovation.

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 (Figure 13). 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 submission deadline (April 19, 2013). The owner received 10 full team bids for this project. The core IPD team of Graham Construction (general contractor) and Diamond Schmitt Architects (architect) was selected after conducting interviews with short listed teams.

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 Hanson Bridgett IPD Standard Agreement[33]: A multi-party agreement that seeks to succinctly state IPD principles within a readable and logical agreement, the Hanson Bridgett document is 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. According to Hanson Bridgett, "Key to this Agreement is the compensation system which is designed to spur creativity and align the parties' interests. Essentially, the owner guarantees the direct and indirect project costs. The architect and contractor place all, or a portion, of their profit into a risk pool ("incentive compensation layer or "ICL") that is augmented or decreased depending upon project outcome (time and cost) and project quality. In the base agreement, the incentive compensation layer is distributed to the architect, contractor, and cost-reimbursable consultants and subcontractors, although variants can be used that apply disbursements at milestones to overcome cash-flow and other issues."

"The more you put in, the more you get out [of the IPD process]. My energy going into this whole thing was [justified by the fact that], even if I committed all of my time for 3 years to the project, my salary relative to our gains on this project would be a minimal contribution to the outcome that we would get from having a building that we were happy with and that was well executed. Any cost overruns are easily going to eat up to my salary."

Darren Becks,
St. Jerome's University

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 which 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. The final IPD team structure comprised a Senior Management Team (SMT), Project Management Team (PMT) and Project Implementation Teams (PITs) (Figure 14, next page).

The Senior Management Team members were required to check and update that the project is going well on a monthly basis and they had very less overall involvement in the project execution as PMT, generally, executes the project, not SMT. 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 from each owner, contractor and architect, at many times, other people 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, and 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.

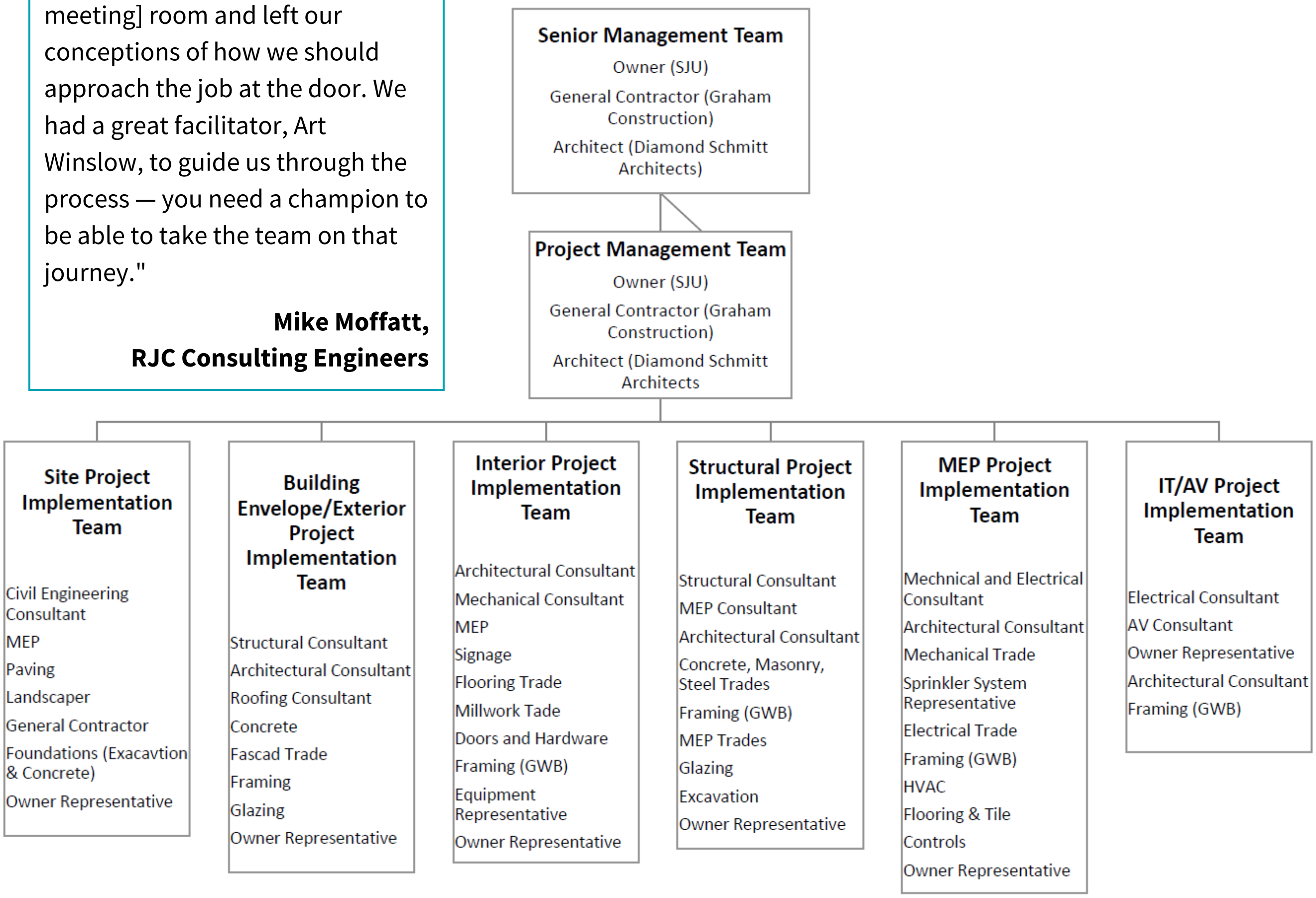
All three members of the SMT were lean and IPD champions. The contractor had prior experience with IPD and was already set up with the necessary project management systems. St. Jerome's SMT representative was critical to setting the tone for the project, both internally and with project partners.

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[34]), 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."

Mike Moffatt,
RJC Consulting Engineers

Figure 14 - IPD team structure (© St. Jerome's University)



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. 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 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.[35]

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 then, would be responsible for decision-making.

"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. ….. And within that agreement there are various clauses that limit quite significantly the times where we can apportion blame or sue each other effectively. So therefore, it's better for us to work together. It's a legal framework to help enforce the collaboration."

David Dow,
Diamond Schmitt Architects

"All this time we were spending on the front end… it's paying its dividends now [in construction]."

Darren Becks,
St. Jerome's University

PROCESSES

Building Information Modelling (BIM): The use of BIM – 3D virtual modelling of the design – can provide IPD project teams with the opportunity to pursue a truly collaborative approach to design, construction and ongoing management of an asset.

Pull Planning: According to the Lean Construction Institute, Pull Planning involves "working from a target completion date (milestone) backward, tasks, which are defined and sequenced so that their completion releases work. Work tasks, information flow, and material deliveries are planned based on the request (or "pull") of downstream customers. Pull scheduling will often expose the need for smaller batches, just in time delivery, improved levelling of resources, and reduced lead times. Workflow becomes more reliable and efficient as the waste of waiting, redundancy, and over-processing are eliminated." [36]

Figure 15 - Big Room meetings at Mississauga (source, St. Jerome's University)

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 included 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.[37]

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.

Because this project was the university's first experience with IPD, full IPD consulting, coaching, and management services was included and the team made sure to celebrate early wins.

Ghafari Associates (a US-based construction engineering company)[38] guided the IPD team in project planning and information flow management. Ghafari provided Last Planner coaching services through to project hand-over to facilitate collaboration, sequenced decision-making, and informed, timely feedback.

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.

TEAMWORK

The Big Room: According to the Lean Construction Institute, “An effective Big Room supports cross-functional team collaboration by advancing work and bringing the larger team up to speed on the activities of other groups or individuals. It allows teams to understand their impact across clusters or work groups. The Big Room also provides teams with the time to discuss project-wide concerns like budgets, hot topics, or global changes. The term Big Room refers more to the behaviours and actions of the team than the physical space. The Big Room is more than co-location of people; it is about collaborative behaviour and the work they are producing.” [39]

"Every detail of this project was available to every team member."

Darren Becks,
St. Jerome’s University

"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."

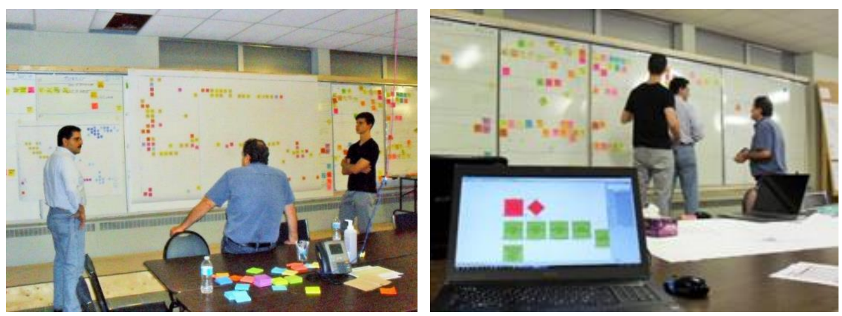
Art Winslow,
Graham Construction[40]

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.

As most of the IPD team was from Greater Toronto Area (GTA), the Big Room was set up at Graham’s office in Mississauga right after award of RFP. During the design stage, the consultants meet regularly every week and the owner’s team participated every other week to ensure the workflow was progressing satisfactorily (Figure 15 and Figure 16).

Each design detail (with its corresponding completion time) was logged into a flowchart of tasks generated by vPlanner and projected on one wall of the Big Room. 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 to make it more efficient.

Figure 16 - Big Room meetings showing the detailed schedule on wall[31]



St. Jerome’s University team members noted that key to making the IDP process work was early involvement of key participants, shared risks and rewards, jointly shared project control, collaborative decision making, trust, lean principles and the use of BIM. [41]

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, overhead and profits of each discipline which were continuously monitored by everyone. The structural engineer noted that IPD is very different from the traditional practice because it requires trust between all of the partners. [42] 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.[43]

INNOVATIVE PRACTICES

“I spent a much larger amount of my time working on this project than I [normally] would for a project of the same size. And perhaps, that’s true for most people on the team because they are not only performing their everyday role, but they are also getting involved in a lot of stuff that normally they might not be. With a Big Room there are 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 more work.”

David Dow,
Diamond Schmitt Architects

"When you are able to embark on a project in that manner, I was amazed at how it changed what I thought was collaborative behavior in the past to true collaboration."

Mike Moffatt,
RJC Consulting Engineers[44]

"We end up getting changed behaviours, 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."

“We are working backward from outcomes. In other words, we have milestones and then we have things we need to get done to deliver these milestones.”

Art Winslow,
Graham Construction[45]

Lean methods and “true collaboration” underpinned the ability for St. Jerome’s University campus renewal to complete on budget and ahead of schedule while including about $2m in “value-added” improvements to the project.

Target Value Design is a collaborative design process involving designers, builders, suppliers, estimators and owners co-located in one place to collaboratively produce a design that provides the best value for the Owner. Budget (the target value) is a design criterion which, for St. Jerome’s University campus renewal project, was $47 million. The team designs 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.

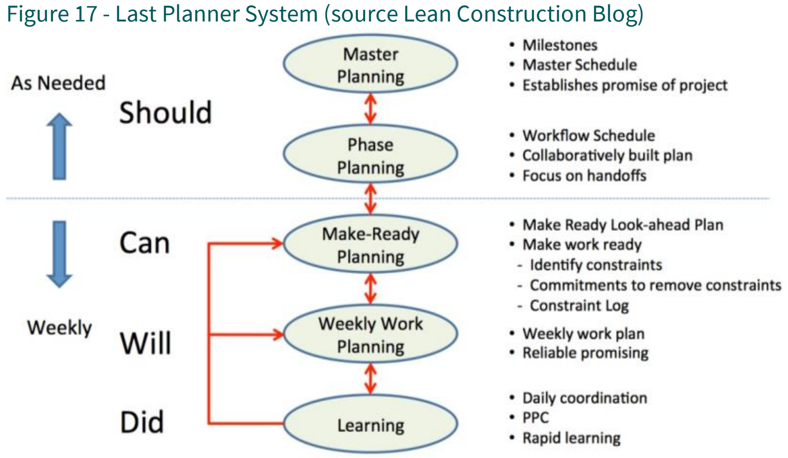
“These kinds of things happen all day long in IPD, the price can fluctuate dramatically week-to-week. One of the team’s main challenges was controlling those cost fluctuations. So, we had moments when we were half a million above multiple times.”

“If it’s a traditional bid-build, the contractor would be sitting on all those fluctuations and you never get to know about them.”

David Dow,
Diamond Schmitt Architects

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 17). 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.

Figure 17 - Last Planner System (source Lean Construction Blog)



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

Task management: Using vPlanner (a graphical Last Planner® System software solution developed by Ghafari), tasks were checked out to the active user when they need to be edited and checked back in when edits are complete. This eliminated the possibility that one user may accidentally override changes made by another and improved communication, because users were able to see who was working on checked-out tasks.

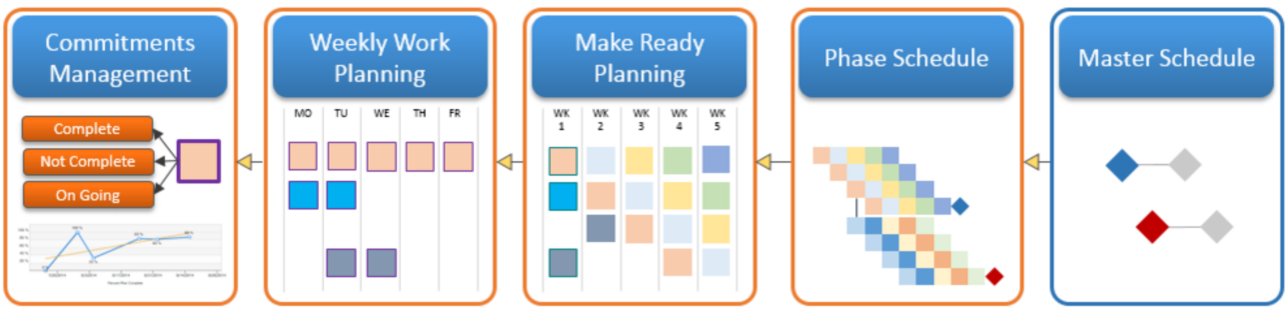


Figure 19 The Last Planner system phases supported by vPlanner

Figure 18 - Mock-up tests for finalizing room size and furniture (© Diamond Schmitt)

Prefabrication: All of the HVAC, heating and cooling piping systems were prefabricated and connected on site (Figure 20). The student residence had the same piping layout floor to floor and therefore, it ended up being cost effective. Although time saving was key, the decision to go with prefabrication was driven by labour and materials savings. The team also decided to go with the 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.

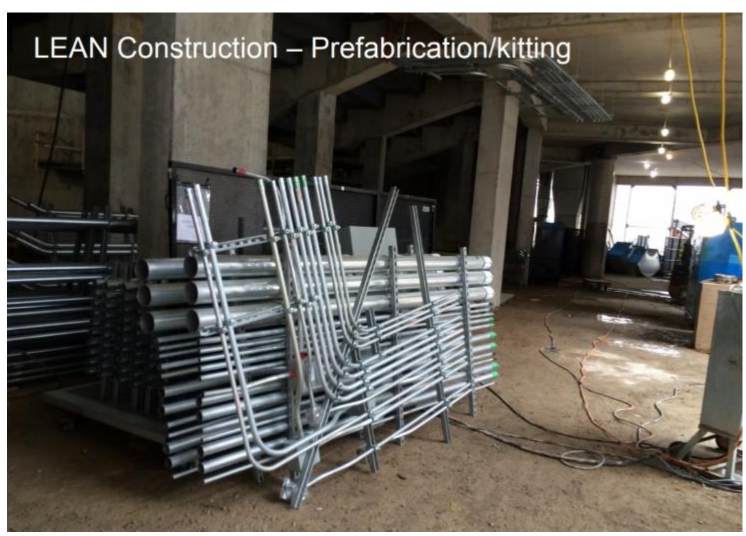
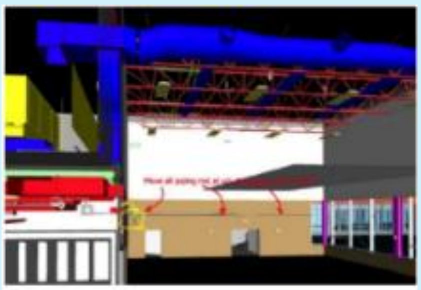


Figure 20 - Prefabricated piping system (© Diamond Schmitt)

TOOLS TO AID COLLABORATION

Design coordination: All of the design consultants developed their discipline-specific 3D models which were used in the design coordination meetings. In addition, each consultant was given a live access of other discipline's models for reference and coordination purposes (Figure 21).

Figure 21 - Coordination of 3D virtual models (© Diamond Schmitt)



Clash detection: Once the design was sufficiently developed, the team had clash detection meetings where they used Navisworks to identify clashes between their models.

Quantity take-off: The contractor, outside of mechanical and electrical, used the model for cost estimation.

Digital fabrication: The 3D model was not widely used for fabrication. For example, the mechanical sub-contractor recreated their own model from the engineer's information to fabricate the mechanical systems.

On-site: the 3D model was used in the field for layout and coordination.

Facility management (FM): While the 3D model was not specifically used for FM, much of the data such as rooms areas, room counts, etc. was pulled from BIM and was used to plug into the university's FM systems. However, information relating to mechanical or electrical equipment was not included.

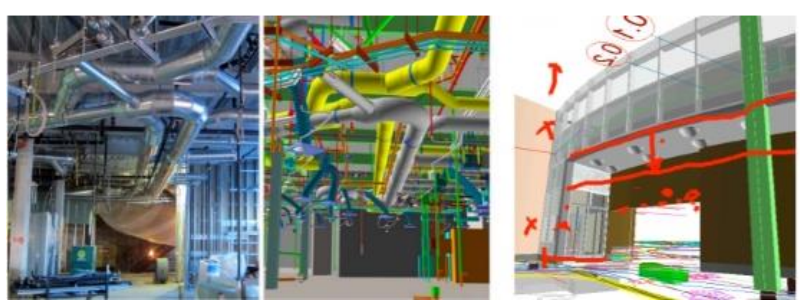
BIM was widely implemented in this project as a means to improve efficiency and support collaboration.

Visualization: The design team developed a detailed 3D model so the client and contractor could better visualize the project (Figure 22). This 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.

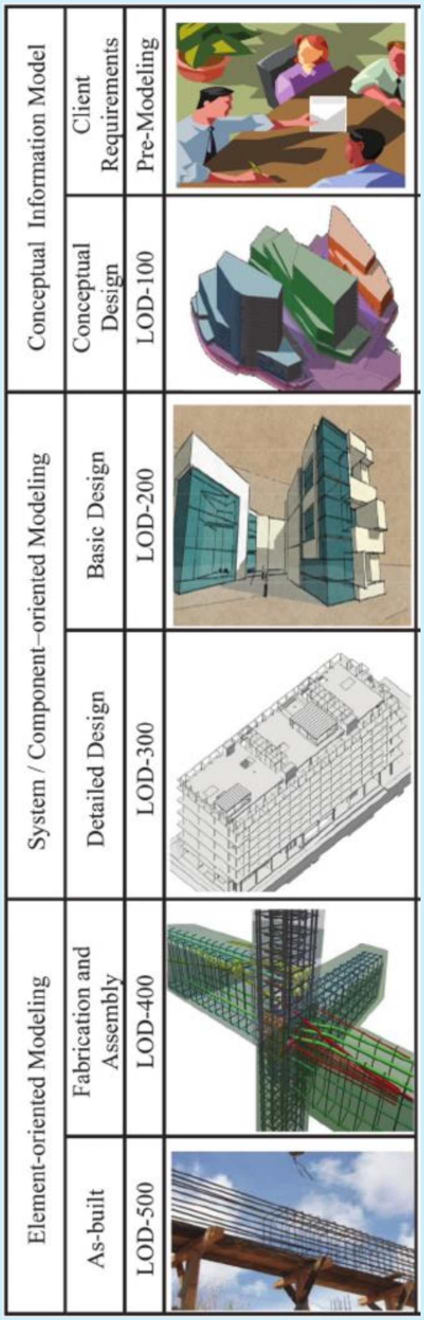
Figure 22 - 3D model of the academic building used to assist client visualization (© Diamond Schmitt)

Constructability review: There was a mandate to hand the consultants' models over to the trades for construction. The use of BIM for constructability review was particularly important for mechanical and electrical systems given that there were some locations with limited room for services (Figure 23). In addition to rationalizing layout and configuration, the teams also discussed the sequence of work in those areas to optimize buildability.

Figure 23 - 3D modelling of complex mechanical and electrical systems (© Diamond Schmitt)



BIM Levels of Detail (LoD) simplified



Adapted from AIA Document E202, 2008.

The BIM level of detail (LoD) applied on the St. Jerome's University campus development project varied between 300 to 400.

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.

The mechanical and electrical design models were developed to the level of 400, and certain architectural details were also close to 400.

To share design information with rest of the team, a proprietary project management and collaboration platform was used.

Using the project management platform, the entire project team including the owner were able to collaborate on drawings and construction information. They all had access to up to date compiled information of the project from design files to construction documents.

The platform also contained clash detection reports, meeting minutes, Requests For Information (RFIs), site instruction, current set of drawings, etc. There were zero change orders on the project. Then number of RFIs was minimized by proactively highlighting issues that were resolved within the PITs.

The architect was responsible for controlling information flow.

Though the team used very collaborative methods of information exchange, the architect was responsible for controlling the information flow. All design revisions would go through the architect's office. After collecting new documents from electrical, mechanical and structural consultants, the architect would post revised drawings, paperwork etc. onto the project management platform, archive and distribute to the team at the same time.

While much of this process follows traditional practice, a key difference is the speed of information transfer because as soon as information was issued and posted to the project management platform, it was immediately in the hands of trades. So, the latest information would be on site within 24 hours of being updated.

OUTCOMES AND METRICS

Owners requirements met: The owner's requirements of completing the project at the target cost were met. An additional $2 million in "value added" improvements were included.

On budget: The project was delivered for the target cost. The overall project cost was 20% less than projections developed using a P3 model. Contingency was reduced to less than 4% due to improved processes. The consultants' fees were budgeted at $1.48 million but only $1.07 million was spent. The savings (27% of the total fee) were due to reduced labour requirements gained through efficient processes and avoided duplication.

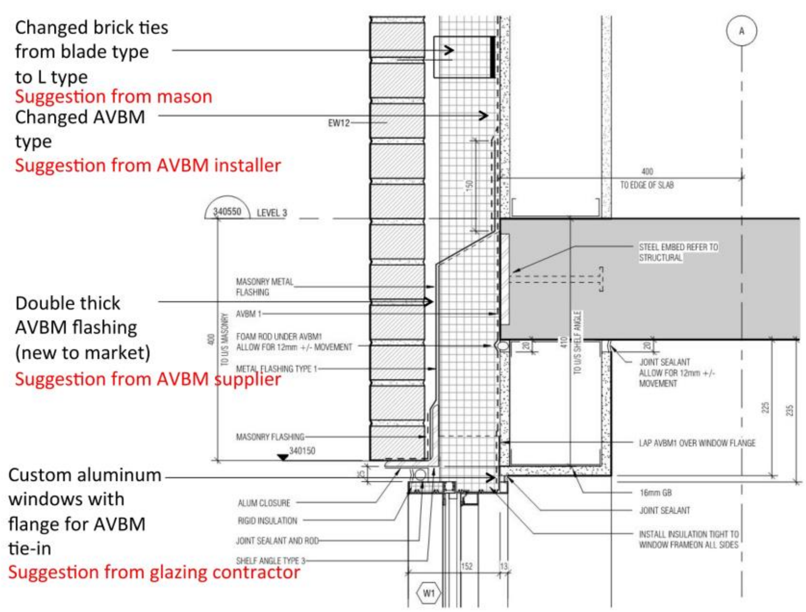
However, the team did receive only about half of their profit because of execution errors which they put down to the fact that the project was their first experience of IPD. Some team members considered this as a gain in terms of the unprecedented learning opportunity, while others saw it as a loss.

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

The project team realized the benefits of a more integrated approach through minimizing unnecessary rework and delays.

- 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 three 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 which created more savings.[46]
- 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. For example, each PIT team played a design-assist role (Figure 24).
- 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.
- The project was highly responsive to the client's specific needs.

Figure 24 - Detail illustrating sub-trade involvement in optimizing the building design (© Diamond Schmitt)



CHALLENGES AND LESSONS LEARNT

Sustained leadership from beginning to end is critical in realising the full potential of IPD.

- The main challenge was the culture shift and changing the team's attitude.
- With hindsight, the owner believed that the project could have been saved a further two months (i.e. be delivered a total of five 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 IDP 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.
- Team members need to be made to feel comfortable about "rocking the boat".

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 on each other.
- Celebrating small wins helps building collaborative culture in the team.
- Early involvement of trades 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 onboarding for new members is 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. via key clauses describing when blame can be applied) helps in embracing more open dialogue with the rest of team.

CASE STUDY 3: Brock Commons Tallwood House

The project team for UBC's Brock Common Tallwood House[47] undertook a highly collaborative approach that was driven by a dedicated and sophisticated virtual design and construction coordination within a conventional construction management (CM) contract to deliver an innovative 18 storey high-rise student residence that was, at the time of construction, the tallest wood structure in the world.

Location: Vancouver, BC

Gross floor area: 15,120m^2 (162,750sf)

Design started: January 2015

Construction started: October 2015

Target completion: August 2017

Actual completion: July 2017

Design cost: $2.41 million

Final construction cost: $41.23 million

Owner: University of British Columbia

Structural Engineer: Fast & Epp (prime)

Architect: Acton Ostry Architects

Advisory Architect: Architekten Hermann Kaufmann ZT GmbH

Contractor: Urban One Builders

Mechanical, electrical and fire protection engineer: Stantec

Building Code: GHL Consultants Ltd.

Building envelope and building science: RDH Building Science

Civil engineer: Kamps Engineering Ltd.

Landscape Architect: Hapa Collaborative

Energy Modelling: EnerSys Analytics

VDC Integrator: CadMakers Inc

Source: University of British Columbia

Brock Commons benefitted from a public owner for whom the pursuit of excellence in research, learning and engagement was a foundational institutional purpose and who sought to entrench these goals in all capital projects.

Brock Commons is an innovative 18 storey, 54.37 meter-high, hybrid timber-concrete structure providing 305 housing units (272 studios and 33 quads). 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 (provided by others).[48]

UBC Student Housing and Hospitality Services is the client and operator of this student housing project, which was part of the 2010 UBC Vancouver Campus Plan.[49] UBC Infrastructure Development performing 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.

> "At UBC, we view our entire campus as a living laboratory, a kind of giant sandbox in which there is the freedom to explore—creatively and collaboratively—the technological, environmental, economic and societal aspects of sustainability."
>
> **UBC website**

CONTEXT

Lean Project Delivery (LPD) is a highly collaborative process that comprises the application of target value design and lean methods during construction.[50]

Lean Methods seek to develop and manage a project through relationships, shared knowledge and common goals. Traditional silos of knowledge, work and effort are broken down and reorganized for the betterment of the project rather than of individual participants. The objective is to deliver significant improvements in schedule with dramatically reduced waste, particularly on complex, uncertain and quick projects.

Site-specific Regulation: In BC it is possible to create "custom" versions of the BC Building Code bound to a Legal Description (Property). The provincial government can utilize a Ministerial Order to issue a unique Building Code (known as a Site-specific Regulation) that must be backed up by consultation and testing by experts for all modifications in the Order. The reviewing / approving process is led by the Provincial Ministry responsible for Building Code, and related departments such as the fire commission.

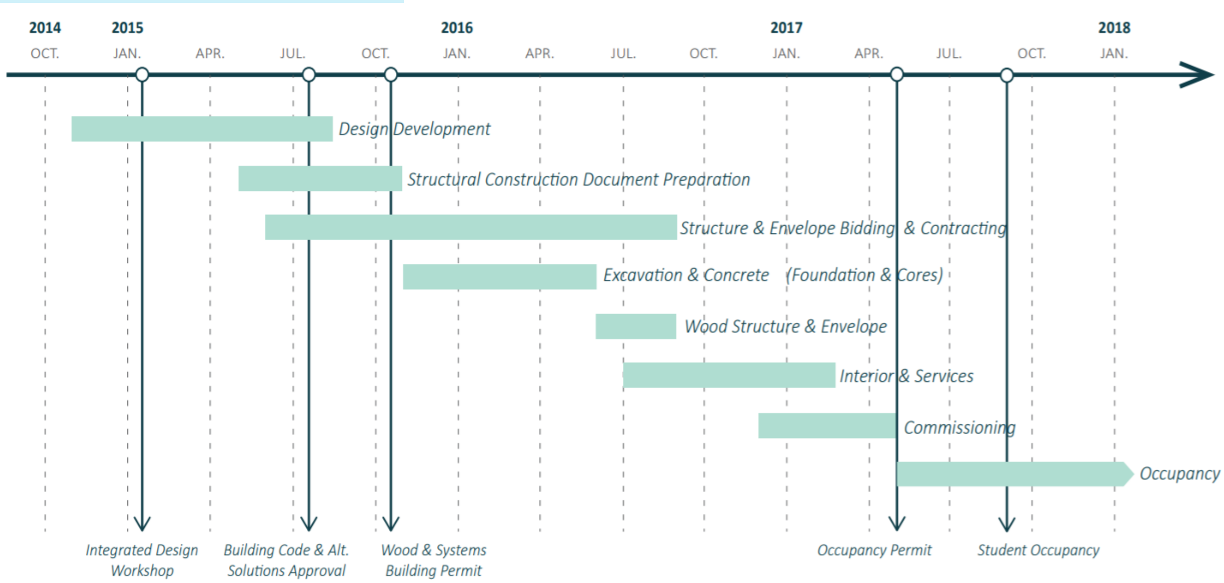
The owner's team was very experienced in the delivery of a wide range of innovative high performance and sophisticated projects from research labs to residential towers.

This project involved prefabrication in the form of cross-laminated timber (CLT) panels, glued-laminated timber columns, parallel strand lumber (PSL) columns, and on-site constructed on-site built 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 two elevator shafts were constructed with cast-in situ concrete.

At the beginning of the project, a Request For Proposals (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 pre-construction services was issued in October 2014. By November 2014, the owner had assembled the core team comprised of architect, structural, mechanical, electrical, and fire protection engineer, construction manager and building code consultant.

Figure 25 - Brock Commons project schedule (©Laura Gilmore[51])



The project was procured under CCDC 5A Construction Management at Risk (CM+) – an accepted form of agreement commonly used by public sector organizations in BC.

Using this model, 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, except for the Hermann Kaufmann Architects, who served as an "advisory architect". Hermann Kaufmann Architects was contractually bound to Acton Ostry Architects, the architect of record for Brock Commons. 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.

Building Information Modelling (BIM): The use of BIM – 3D modelling of the design – can potentially provide IPD project teams with the opportunity to pursue a truly collaborative approach to design, construction and ongoing management of an asset.

The owner hired a team with world class expertise in innovative wood design, building code and fire protection.

At full strength, the project team comprised a substantial team of experts in mass timber design and construction, building regulations, building science and project management, supported by a range of UBC's research and technical capabilities - particularly in sustainability and modern methods of construction (Figure 27).

The owner received more than 20 architectural submissions from local and international firms, from which three companies were invited to present their proposals in front of a selection committee. The successful team was led by Acton Ostry (a local architectural firm) in partnership with by Hermann Kaufmann Architects (an Austrian firm with experience building tall mass timber buildings in Europe).

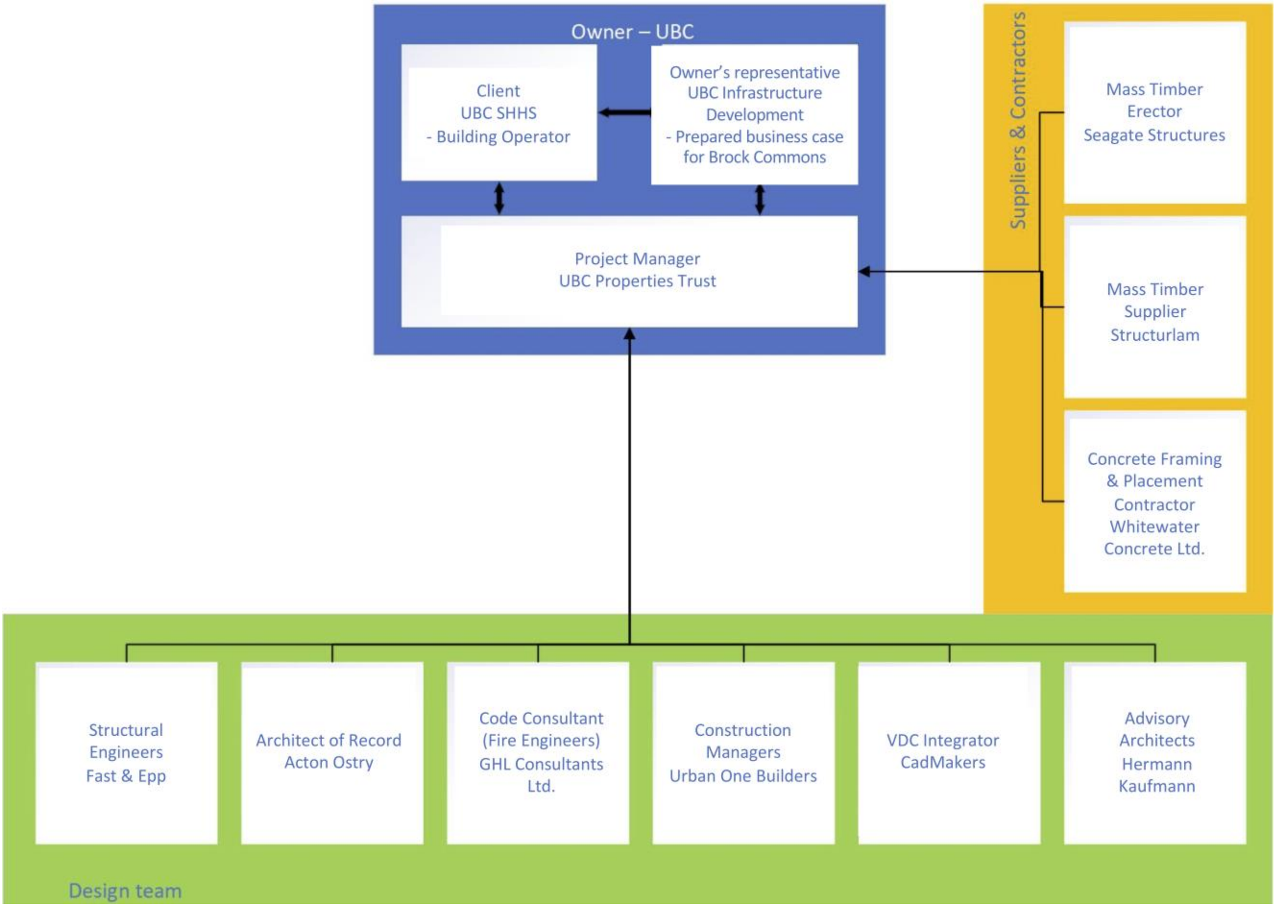
The mechanical, electrical, and fire protection engineers and the Building Code consultant were selected based on their previous positive experiences in collaborating with UBC. Also based on previous experience, CADMakers, a local specialist in virtual design and construction (VDC) integration was also brought on board at the very beginning of the project. At the time, the role of an independent third-party project coordinator was unusual in traditional practice but was considered valuable given the technical complexity of the project.

GHL Consultants Ltd, the Code consultant, was hired early to work with the BC Building Safety and Standards Branch (BSSB) on the project's Site-specific Regulation[52], which was a unique Building Code bound to the property to allow a wood structure above 6 storeys 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 made through a public RFP process in accordance with 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.

Figure 26 - Summary of measures to promote innovation (© Acton Ostry Architects)

Figure 27 - Brock Commons project team structure
(© Francisco Calderon Cifuentes)



BIM Modelling dimensions[53]

3D BIM is the process of creating graphical and non-graphical information and sharing this information in a Common Data Environment (CDE).

4D BIM (Construction sequencing) adds an extra dimension of information to a project information model in the form of scheduling data and time-related information.

5D BIM (Cost) Drawing on the components of the information model, accurate cost information can be extracted. Considerations might include capital cost of an element, its associated running costs and the cost of renewal/ replacement down the line.

The dedicated VDC support was the key driver of team-wide collaboration and project coordination. Established BIM capacity across the project team led to numerous instances of the BIM model being used to add value through efficiency.

Vancouver-based VDC consulting company, CadMakers[54], had extensive experience in providing a range of virtual design and construction services. For this project, in addition to providing 3D and 4D modelling and construction sequencing, CadMakers were also responsible for coordinating the design development process between the consultants.

Although project team members were not required to develop a Building Information Model (BIM) for this project, many had previous experiences working in BIM environments. This familiarity with BIM and its advantages led to some of the team members (notably the structural engineer and mass-timber supplier) developing their own 3D models for internal use (e.g. for structural analysis).

Decision-making for design development and refinement was made collaboratively using the 3D model for reference and coordination.

All design and construction related decisions were made in project meetings with involvement of relevant team members. The VDC integrator was given a responsibility of coordinating interdisciplinary design development and played an important role in managing the collaborative meetings.

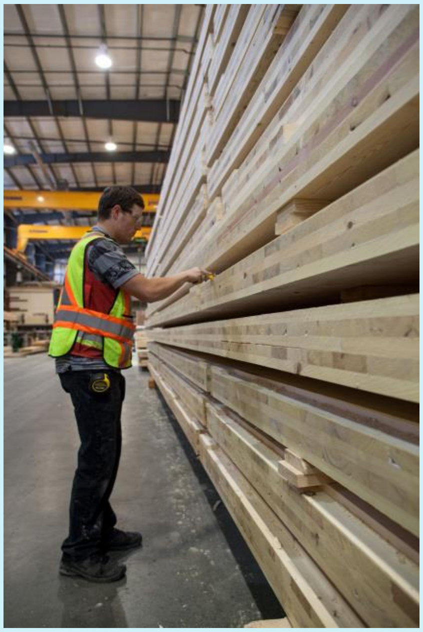
This also included interdisciplinary clash detection and issues identification such as the connection details between columns and slabs, or connections between slabs and concrete cores etc. Full-size mock-ups of key structural elements were built to test design assumptions and constructability (Figure 28).

Figure 28 - Full-size construction mock up (©Urban One Builders)

The construction manager, mass timber supplier (Structurlam), installer (Seagate Structures), 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 pre-fabricated which improved on-site productivity.

Structurlam championed BIM for digital fabrication of mass timber elements.



Structurlam, the mass-timber supplier for Brock Commons, is an industry leader in the application of comprehensive 3D modelling with digital fabrication of innovative structural solutions. Leveraging their established BIM capabilities, they were able to take advantage of available models for digital fabrication of the mass timber elements (Image source Wood Innovates BC[55]).

Mass timber acronyms

The mass timber elements installed in Brock Commons were fabricated from **cross-laminated timber** (CLT), **glued- laminated timber** (glulam) and **parallel strand lumber** (PSL).

PROCESSES

The Brock Commons 4D sequencing model underpins on-site collaboration.

For the development of 4D sequencing video, the mass-timber installer, Seagate, held one-to-one meetings with the VDC integrator (Image source: CadMakers).

Brock Commons represented a rare opportunity for researchers 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.

A three 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 29) to establish the major constraints related to material selection, production, installation, and shipping of the prefabricated components.

Although the project team was not co-located in one place (i.e. there was no “Big Room”), they held regular weekly or bi-weekly coordination meetings starting 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 like construction manager, installer, and construction trades started to get involved in coordination meetings towards the end of the design stage.

Figure 29 - The three-day design workshop (©Acton Ostry Architects)

INNOVATIVE PRACTICES

The sophisticated virtual modelling was a vital factor in the efficient delivery and placement of the prefabricated elements.

Prefabrication: The highly detailed and coordinated 3D model allowed the prefabrication of CLT panels, as well as the 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 30 and Figure 32). 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 30 - CLT panels in production (©Azadeh Fallahi).

Figure 32 - Glulam columns (left), and envelope panels (right) at off-site manufacturing facility (images courtesy Azadeh Fallahi and Acton Ostry Architects)

Figure 31 - Full scale mock-up testing of the building envelope panels (©Azadeh Fallahi)

Full-scale mock-ups were constructed of various sections of the building 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 (Figure 28 and Figure 31).

Given that so much of the building systems were new, mock-ups were important for practicing construction methods, as well as optimizing the on-site sequencing. The lessons learnt during the construction of the mock-up were incorporated into the 4D model, which then helped the project team to develop construction strategy documents including safety plans, transportation and loading schedules, as well as installation sequencing.

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.

Prefabrication on Brock Commons involved more than the wood structure and envelope.

The mechanical room was fully prefabricated and assembled on-site, shaving 2-3 months of on-site work.

Just-In-Time delivery (JIT) is a methodology aimed primarily at reducing times within a production system as well as response times from suppliers and to customers. In the construction context it reduces on-site materials inventory and can provide a significant improvement of project cost and time management.

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.

Implementing JIT 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.[56]

All CLT panels on each building floor were given a unique number to identify their position (Figure 33). The loading of the 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 34).

Figure 33 - CLT panel identity number and installation sequence (source: Seagate Structures)

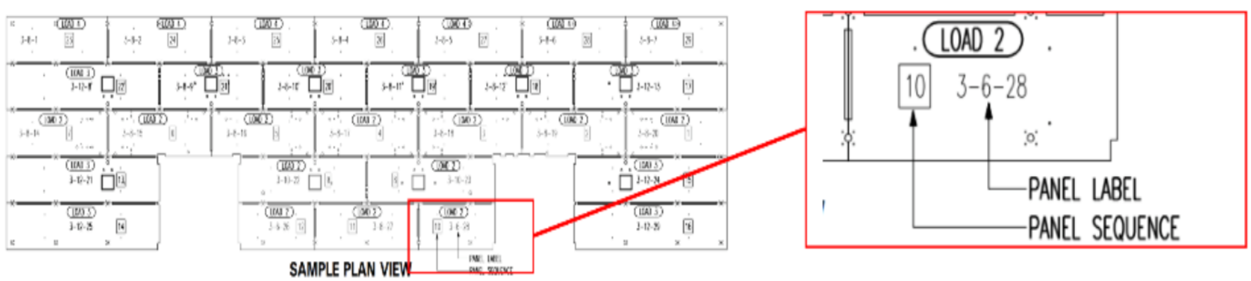
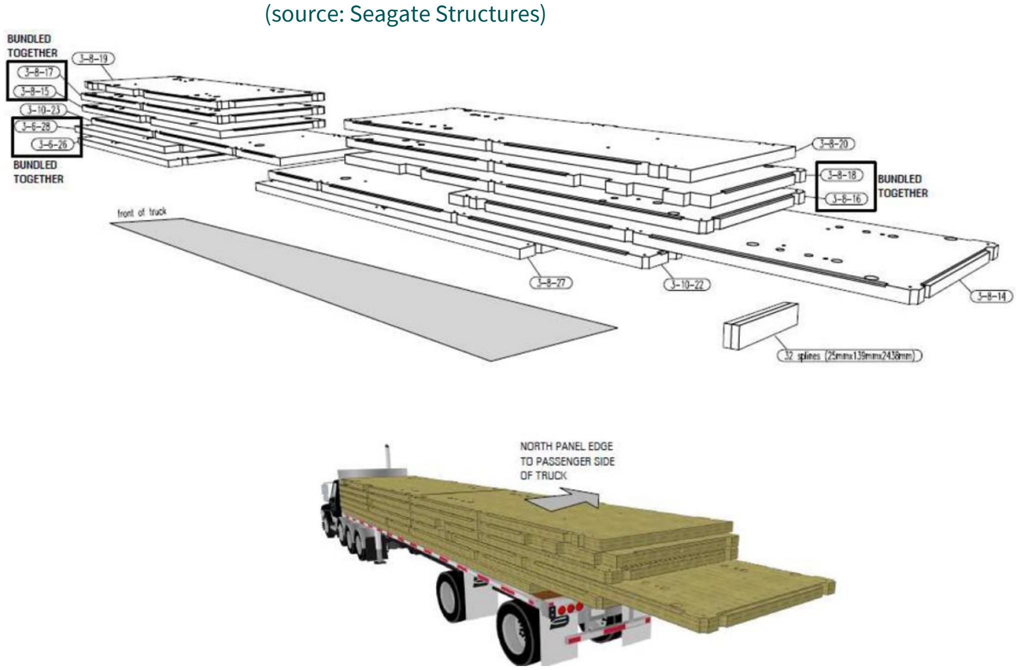


Figure 34 - Detailed modelling of loading and unloading cycles (source: Seagate Structures)



TOOLS TO AID COLLABORATION

Figure 35 - Integrated multidisciplinary coordination meeting (image ©Azadeh Fallahi)

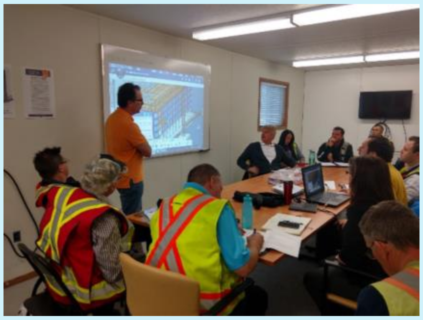


Figure 36 - Identified constructability issue - example (©CadMakers Inc.)

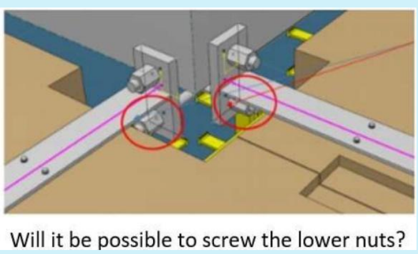


Figure 37 - VDC sample quantity take-off (source Diamond Schmitt Architects)

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.

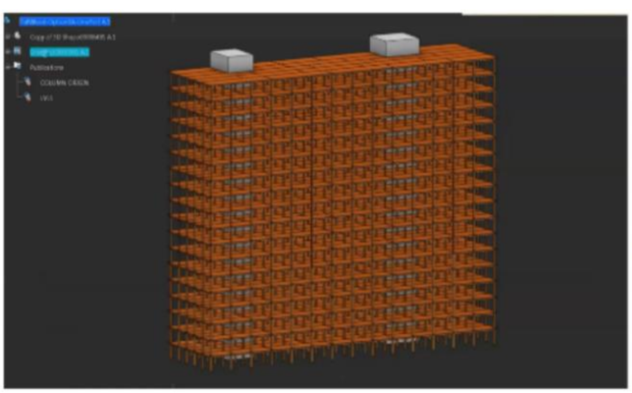
Visualization: 3D visualization of the latest design status and the changes applied to it was a great asset to entire project team as a way to ease the comprehension of the project's practical challenges and to communicate different scopes of work, as well as their interconnections. In this project, 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 more effective decision-making.

Clash detection: During the design phase, the design team regularly performed clash detection tests. Once identified, these clashes – if required – were communicated to the relevant 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.

Constructability review: The 3D model was sufficiently detailed to allow fabricators, manufacturers and installers to assess the design from the constructability perspective at the early stages of the project. This helped to identify whether some critical design solutions would result in impractical construction conditions (Figure 36).

Quantity take-offs: 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 37). The construction manager could directly extract the basic quantities from the model and develop detailed excel spreadsheets for cost estimation purposes.



	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		

Scope of modelling requirements

Architect: To generate discipline-specific 2D and 3D drawings containing architectural information of the building.

Structural engineer: To generate discipline-specific 2D CAD drawings and hand sketches containing details and information related to the structure of the building.

Mechanical, electrical, and fire protection engineer: To generate discipline-specific 2D CAD drawings containing details and information related to the MEP systems of the building.

VDC integrator: To develop a highly detailed holistic 3D model by incorporating and coordinating the information received from the project participants of the design team. Also, to develop a 4D sequencing videos showing step by step procedures of construction and installation processes.

Mass-Timber supplier: To develop fabrication-level model of the mass timber elements to support their manufacturing process.

The virtual models developed for Brock Commons were highly sophisticated in order to foster an integrated project delivery approach through technology as opposed to contractually.

Structural analysis: Due to lack of familiarity with the BIM platform used by CadMakers, the structural engineer did not extract data from the 3D model, but instead built their own model from scratch on specialized engineering software to conduct the structural analysis.

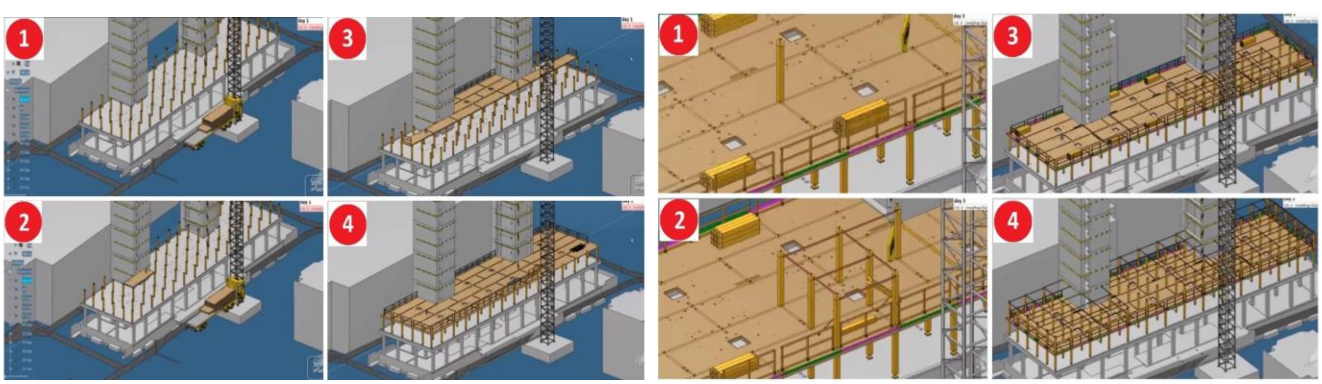
4D Planning and sequencing: The VDC integrator also developed a 4D plan including the on-site activity sequences and produced a video to help the team in organization of the on-site logistics as well as identifying the most effective installation sequence to gain higher on-site productivity (Figure 38).

Digital fabrication: The fabrication-level model was developed by the mass-timber manufacturer in CAD software who then added information related 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. The data thus generated 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.

The fabrication-level model was also used by the mass timber manufacturer to generate detailed installation and shop drawings.

Figure 38 - Installation of CLT panels and mass-timber columns - snapshots from sequencing video



OUTCOMES AND METRICS

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.

On budget

An initial "stretch" target cost of $30 million or $191 per square foot was proposed by UBC based on the actual built cost for a comparable UBC student housing completed just prior to the start of the design of Brock Commons. This stretch target would have been lower than actual market construction cost for a similar concrete building at the time of consultant selection.

In 2017, the construction cost for a comparable scale of building with a concrete structure would be $230 per square foot. 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).

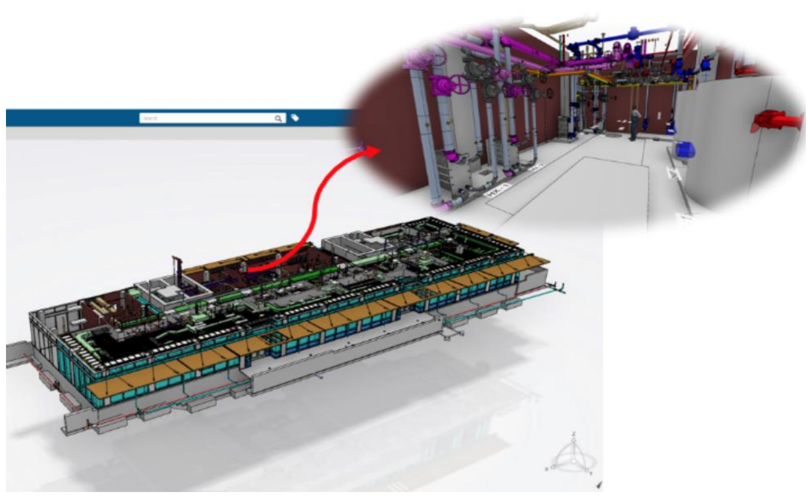
Two months ahead of schedule

The speed of the wood structure construction meant that the project was completed two months faster than a comparable concrete building.

Brock Commons demonstrates that it is possible to achieve the benefits of an integrated project delivery environment through early involvement of the full project team and the use of advanced collaborative technology.

- Having the full team (including the construction manager and key trades) together at the very beginning of the design helped to achieve aggressive schedule.
- Comprehensive use of VDC visualization with the construction trades helped in identifying the constructability issues and avoiding associated costs which also reduced number of on-site surprises and changes.
- Prefabrication of components increased the accuracy and productivity of the construction. It also helped in reducing activities and related waste. Prefabrication allowed performing concurrent off-site and on-site work.
- Detailed modelling of building including MEP systems (Figure 39) helped in determining the exact location of penetrations through CLT panels so the CLT floor panel manufacturer could pre-cut them accurately

Figure 39 - Detailed model of the mechanical room



> Paraphrasing Olund: From a project developer's perspective, the running cost of construction is very high: approximately $5,000/day or $150,000/month (or up to $10,000/day on a high-end project). We spent six months longer in the design stages (14 versus the typical eight months) to save three months of construction time – resulting in savings of $450,000 in running construction costs. At an approximate profit of $500,000/month renting out the 404 beds over those three months saved, results in a huge net benefit.
>
> **Brent Olund, Urban One Builders**[57]

CHALLENGES AND LESSONS LEARNT

There were insufficient situations of adversity that truly tested the team and the contractual arrangement they were working under.

- Although the construction team was informed well in advance of the speed that the structure would go up, the mechanical and electrical trades were still caught off-guard by the speed of erection of each floor.[58]
- 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 was addressed through a Just-In-Time delivery approach to avoid the need for on-site storage (and potential damage) of materials.
- The tolerances of prefabricated components were significant higher and meeting those constraints was a challenge – particularly with the concrete elevator shafts.
- Coordinate all CLT panel penetrations to the VDC integrator and the manufacturer before panel manufacturing start to cut out openings using CNC machines.
- The VDC sequencing model did not account for the weather impacts (especially wind) when the prefabricated panels were being lifted into place.

The Brock Commons project showed that higher levels of project team integration than might normally be achieved under a standard Construction Management arrangement is possible through the use of advanced multi-dimensional modelling technology.[59]

- The fact that Brock Commons was breaking new ground on so many levels meant that the team was very invested in the project and pre-disposed to working together.
- Extensive and integrative pre-planning led to direct benefits in the field.
- The presence of the VDC integrator made the process of project coordination tangible. It came with a direct cost to the owner and so its value in terms of risk management and project performance could be assessed. Coordination is often an “invisible” role that is under-resourced, and its value not made explicit to the owner.
- Continuous and consistent communications amongst project team ensured tighter project control.
- The integrative design and construction strategy encouraged the entire project team of design consultant, construction manager, and trades, 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 their “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.

CASE STUDY 4: Jacobson Hall student residence, Trinity Western University

An independent university chose a fully integrated project delivery process within a conventional design-build arrangement to complete a five storey student residence project within an accelerated schedule.

Location: Langley, BC

Gross floor area: 5,500m^2 (60,000ft^2)

Contract award: December 2017

Construction started: March 2018

Target completion: 1st September 2018

Actual completion: 1st September 2018

Target cost: $13.1 million

Final cost: $13.1 million ($218.33/sf)

Estimated value added by IPD process: housing for 218 students delivered on budget in nine months from the contract date.

Number of Change Orders: 7

Owner: Trinity Western University

Architect: BR2 Architecture

Contractor: Metric Modular

Structural Engineer: CanStruct Engineering Group

Wood supplier: Structurlam

© Metric Modular

At five storeys, the Trinity Western University (TWU) student housing project in Langley, BC, is currently the tallest wood frame modular building in BC and took just seven months from ground breaking to completion.

Enrolment has been steadily growing at TWU, a private Christian liberal arts university in Langley, but they only had on-campus housing available for less than 25 per cent of their 4,000 students. In the fall of 2017, the university faced a sudden and urgent need for student accommodation, ideally before the start of the following academic year. Through a highly integrated project delivery process that leveraged a tightly managed team led by a modular manufacturing company, Jacobson Hall is one of the fastest built projects in BC.

The TWU 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 the design process from the very beginning so that they could influence the conceptual and detailed design efficiently. Whenever the owner was contacted for any additional clarifications, they knew about what the rest of the project team is asking and responded very quickly.

CONTEXT

Modular construction is, according to the Modular Housing Institute, "a process in which a building is constructed off-site, under controlled plant conditions, using the same materials and designing to the same codes and standards as conventionally built facilities – but in about half the time. Buildings are produced in "modules" that when put together on site, reflect the identical design intent and specifications of the most sophisticated site-built facility – without compromise." [60]

Lean Project Delivery (LPD) is a highly collaborative process that comprises the application of target value design and lean methods during construction.[61]

Lean Methods seek to develop and manage a project through relationships, shared knowledge and common goals. Traditional silos of knowledge, work and effort are broken down and reorganized for the betterment of the project rather than of individual participants. The objective is to deliver significant improvements in schedule with dramatically reduced waste, particularly on complex, uncertain and quick projects.

"They [TWU] didn't go into every single detail or [keep asking] 'why this, why that?' They told us what they wanted, and we executed on that."

Tim Epp,
Manufacturing Director,
Metric Modular

TWU imposed two major constraints on the project team – a very narrow time window for construction and high cost predictability. This, along with a previous (and positive) experience with modular, led to the decision to choose modular construction and to seek a manufacturer ahead of hiring any other project team members.

In addition to ensuring that the project would be delivered for no more than $13.1 million, TWU needed to maintain a fully functioning campus during term time, so disruption had to be kept to a minimum. In the end, the only available time to assemble and complete the building was during the summer break (beginning of May to end of August).

TWU also placed a high value on getting an attractive, comfortable, and affordable building for student housing (Figure 40). Given prior experience with the modular construction in a previous three storey student housing project, TWU were familiar with the processes involved and the quality and predictability of a modular construction project.

There is no question that these very challenging goals energized the project team, led by Metric Modular. Given the tight timeframe, the team had to gel quickly. Metric imposed the necessary discipline and control via their established manufacturing management processes and very specific quality control measures in order to create the conditions for optimal team performance.

After choosing Metric Modular as the module 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.

Figure 40 - The interior of a student residence at Jacobson Hall (Source NaturallyWood)

"In modular construction, we are building the building while the foundation is also being poured. From my point of view, the TWU timeline would have been impossible to achieve using traditional construction methods."

Calvin Benson,
Senior Manager,
Design and Estimating,
Metric Modular

"It was a 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

"One of our goals is to provide attractive, comfortable and affordable housing that will foster an environment to promote the success of our students. This new residence helps to accomplish that."[62]

Scott Fehrenbacher,
Senior Vice President,
External Relations,
Trinity Western University

The tight timeframe was a major risk to this project. The project team selection – consultants, trades and suppliers - relied heavily on positive prior working relationships, familiarity with the modular construction process and proven track record.

Given the project's time and budget constraints, Metric worked with their own in-house mechanical engineer. However, 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 the related processes. The strength of these prior relationships is illustrated by the fact that both the structural and electrical engineers came on board to complete schematic design before Metric Modular was awarded the project.

Although Metric designed most of the building details in-house during the schematic design stage, they retained BR2 Architecture once they were awarded the project by TWU (again, based largely upon the success of previous working relationships), to conduct a full code-review, develop the design further, and coordinate the design development with other project consultants.

The same criteria were applied to the selection of most (though not all) of the on-site subcontractors and trades. Due to the project's rural location far from a major urban centre, the tight time frame and a busy time for the industry as a whole, Metric did have to hire some subcontractors without having previous experience with them. In these cases, it was imperative to Metric that they chose sophisticated and reliable firms with a sufficiently large labour force that they were able to work on-site 7 days a week.

Metric Modular supported by the selected project team (Figure 41) and internal resources (Figure 43) was awarded the Design-Build contract (CCDC 14) of the Jacobson Hall project in December 2017.

Figure 41 - Project team structure of Jacobson Hall project

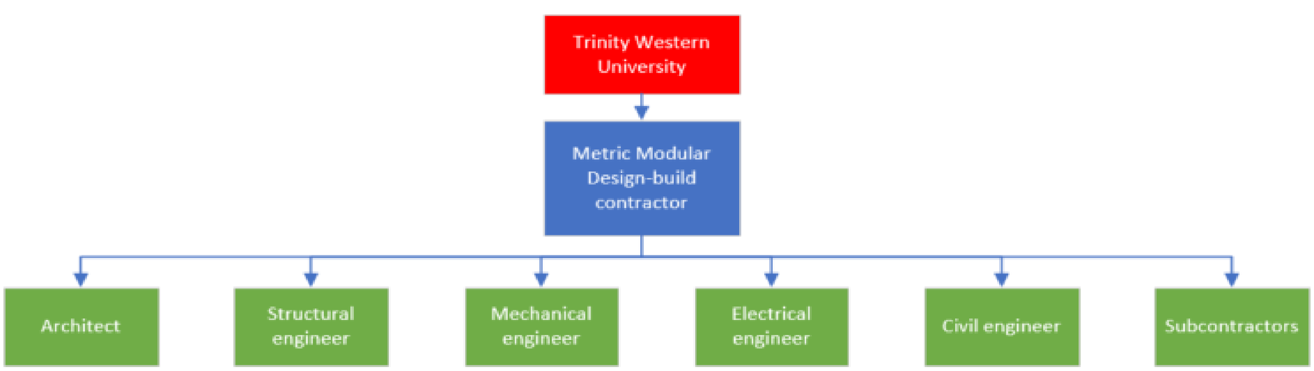
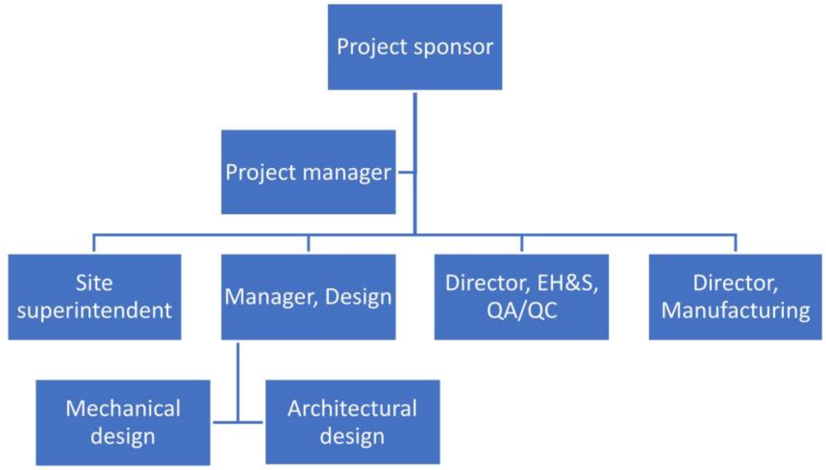


Figure 43 - Metric Modular's internal project team

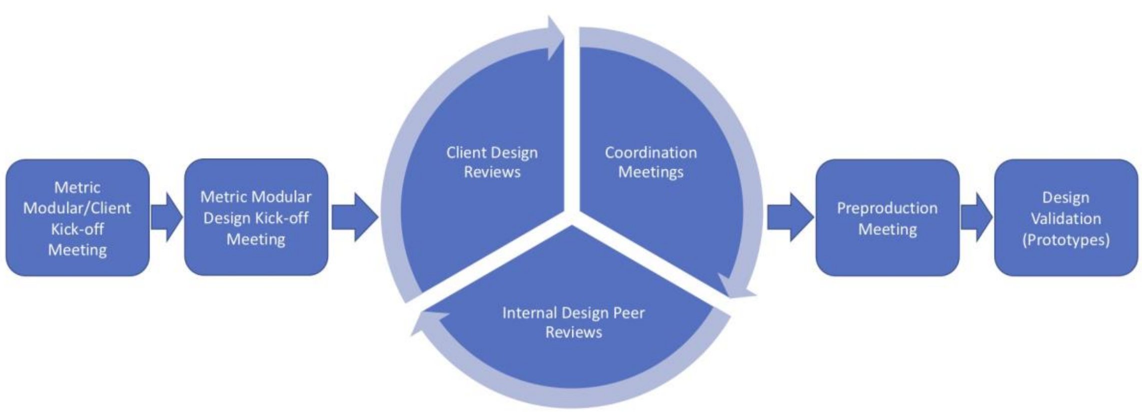


On a project that was to proceed at the speed of TWU, exceptionally close collaboration between the project participants needs to be sustained for the duration of the project.

Metric Modular is a vertically integrated firm. With over 40 years of experience in modular construction, they have developed very efficient policies and approaches when it comes to project execution (Figure 42), team collaboration and delineating the responsibilities for project team members.

During the design phase, all the decisions were made with the involvement of owner's representatives to expedite the turnaround time. Changes proposed by external consultants were assessed by Metric's internal team for potential impacts on constructability and module design. Team members felt that the decision-making process was highly collaborative, synergistic and fast. Once the design was developed, it was reviewed by the manufacturer, project manager and the client before locking in the design and starting module production.

Figure 42 - General project execution plan (© Metric Modular)



PROCESSES

Site preparation can be the riskiest phase of a construction process. It is a time-consuming process, rife with unknowns and can be the cause of significant delays.

To maintain the project timeline, site preparation and off-site modular unit production were performed simultaneously. Excavation, relocation of sewer and electrical services, and pouring the foundations took approximately two months (Figure 45).

Figure 45 - Site preparation work in Jacobson Hall project © Metric Modular

All the modules were manufactured at Metric's plant in Agassiz, BC (Figure 44). All modules were 3.7 metres wide, but lengths varied from 9.8 to 18.9 metres. The finished modules included interior partitions, plumbing, electrical, painting, tiling, fixtures, appliances, windows, millwork (Figure 46). After each module was prepared, they were shipped to the site and craned into position. This process was very efficient, and the first three 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 44 - Factory production (©Metric Modular)

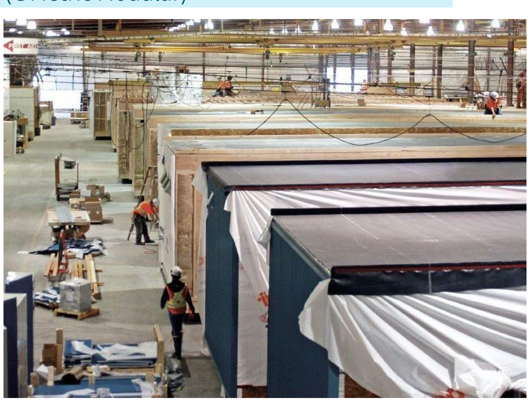


Figure 46 - When they are craned into place, the modules for TWU were about 95% complete. (© Metric Modular)

TEAMWORK

Characteristics of high-performing teams

Successful integrated project delivery is highly reliant on how well the project team functions. There has been extensive research into what makes a team work well. In essence, a high performing team is a group of people who share a common vision, goals, metrics and who collaborate, challenge and hold each other accountable to achieve outstanding results. The members of a high performing team have a clear vision of where they are headed and what they want to accomplish. Common approaches to building team performance include: [63]

- Establish urgency and direction.
- Select members based on skill and skill potential, not personalities.
- Pay particular attention to first meetings and actions.
- Set some clear rules of behaviour.
- Set and seize upon a few immediate performance-oriented tasks and goals.
- Challenge the group regularly with fresh facts and information.
- Spend lots of time together.
- Exploit the power of positive feedback, recognition, and reward.

> "We felt that Metric Modular was really responsive to student needs."
>
> **Richard Taylor, Vice-president of Student Life, TWU**

A high-performing team was vital in delivering the project to the client's satisfaction in such a short timeframe.

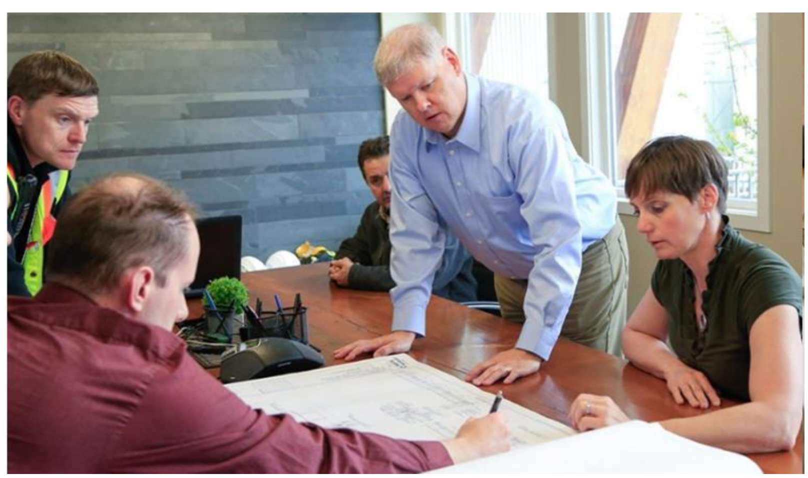
Metric made every effort to select a team that were experienced with modular construction and so there was no requirement for training and little formal onboarding. However, the subcontractors with no prior experience with prefabrication processes were invited to tour Metric's manufacturing facility and see the production process up close. Metric offers a very sophisticated orientation session which covers all the technical, logistical, procedural, QA/QC measures.

On the strength of prior relationships and a rigorous orientation program, there was a high level of trust and good will within the project team (as illustrated by the amount of time was invested by both the Metric team and the external consultants on advancing the schematic design before Metric was awarded the contract).

The project team was also highly integrated. From design development onward, the design team was in constant communication with the in-house mechanical division as well as with the external architectural and electrical consultants and from the earliest stages, Metric's senior estimating manager, project manager and manufacturing director were all proactively involved to keep track of constructability, logistics and the budget as the design developed. Communication was usually through in-person meetings (Figure 47), conference calls, and emails, and the design review was mainly based on digital or hard-copy 2D drawings.

Once production of the modules commenced, coordination between manufacturing workers and the design team was managed through regular daily meetings that was moderated by Metric's manufacturing director before every work shift. On-site activities were managed by Metric's project manager.

Figure 47 - Design coordination meeting (©Metric Modular)



COLLABORATION

"... 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 that leads to much easier planning."

Tim Epp, Manufacturing Director, Metric Modular

"We would set up a very open relationship with the client which is very important. Right from the beginning, they are on board with making decisions quickly, understanding and being involved with our process.

We built a mock-up for the bathroom area so the end users and the maintenance staff from TWU could tell us what would work and what would not. We could also ask if there is anything they would need us to change. [That way] end users can actually have input into the design, [which was important] because these guys were going to be maintaining and servicing the building. [Right from the start], they know how this building [is] going to work."

Tim Epp, Manufacturing Director, Metric Modular

The value of establishing a robust line of communication between designers and owner is well known. Less usual, though equally important, is meaningful engagement with end users.

Metric put a great deal of effort into collaborate with the client (TWU). To identify the requirements of the new building, TWU conducted a student survey to understand the strengths and shortcomings of the current housing and expectations of the new building. The survey results were provided to Metric's architectural group to inform the new building design.[64] For example, one issue that surfaced from the survey was the need for a dedicated study and social area within the new building. Once Metric had been awarded the project, the TWU student representatives, along with TWU's Vice-President of Student Life, worked very closely with Metric's design team to influence the design development according to their requirements.

"We had them [the owner and the future occupants] coming [to our factory] and we 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. [that way], they had a better understanding of why we are asking those questions and why we say no to certain things."

Tim Epp, Manufacturing Director, Metric Modular

Effective collaboration between the owner and Metric from the very beginning resulted in a highly efficient design and construction process. The continuous involvement of the owner with Metric Modular led to quicker decision makings throughout the project.

Besides collaborating with the owner's representatives, Metric's design team consulted also with TWU's maintenance department to identify regularly replaceable items of these type of building and matched those items in the new construction with the commonly used items. So that, the university does not require to buy specific different items for this new building.[1]

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, involvement of manufacturing director and project manager during the design development stage resulted in better manufacturable and constructible design of the building.

Figure 48 - Modules stored at Metric's factory ready for transportation (©Metric Modular)

Figure 49 - On-site installation of a typical module (© Metric Modular)

> "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."
>
> **Tim Epp, Manufacturing Director, Metric Modular**

Coordination during the construction phase:

Metric's project manager was responsible for the coordination between the off- and on-site work. The rate of off-site production was 2 modules per day, whereas the on-site installation rate was between 3 to 4 modules per day (Figure 48). Although the plant was only operational Monday to Friday, on-site installation continued 7 days a week (Figure 49). Metric therefore planned for the production of approximately 30 modules prior to starting on-site installation and a laydown area for up to 12 modules was established near the construction site to avoid interruptions. Modules were stockpiled on site every Friday so operations could continue on Saturdays, Sundays and Mondays. The required modules for Tuesdays were delivered on Mondays when factory re-opens and the weekly cycle of stockpiling modules started again.

Because the modules were installed at a faster rate than they were being manufactured in the plant, there was a pause in the installation process at the 3 stories while production caught up. At this point, work started on the inter-module connections (Figure 50). Installation of the 4th and 5th floors resumed once the modules were ready, such that once the last module was manufactured in the plant, it was directly delivered to the site and immediately installed.

Requiring 15 to 20 workers on site for craning at any given time, Jacobson Hall took just 11 days to construct the first three floors.

Figure 50 - Inter-module connection process (© Metric Modular)

INNOVATIVE PRACTICES

Figure 51 - Barcode scanner machine to track labour time

Figure 52 - Safety gear is available from a self-serve machine on the shop floor

The Jacobson Hall project is Canada's tallest wooden modular building to date and includes a variety of innovative construction processes, that helped to overcome different challenges faced during the planning, design, and execution of the project and push the boundaries of manufactured building in Canada.

Complex structural design. The height of the building meant that the project team had to deal with a series of atypical and complicated structural challenges. For example:

- The modules that were installed in the lowest 2 stories were constructed of 2x12 floor joists, spaced 16-inches on centre, for the floors of the bottom modules to accommodate thicker insulation (R40) against the slab. Floors on the upper modules used 2x10 dimension lumber, some were doubled for loading.
- Cross-laminated timber (CLT) was used to frame the elevator shaft; modules then connected to either side of the CLT structure.
- For seismic design purposes, it was necessary to include a significant amount of Anchor Tiedown System (ATS) rods and shear connections.

Labour time tracking: To manage and optimize workforce productivity, time tracking data allows for accurate "real time" labour performance analysis and productivity monitoring. For such purposes, Metric Modular has developed and established a labour time tracking system in their off-site manufacturing facility.

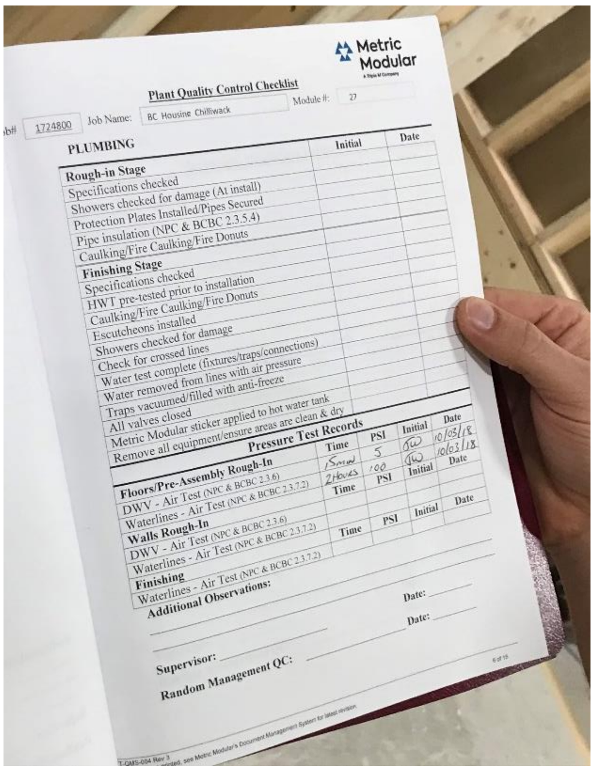
In this system, there is a specific barcode defined for each worker, each on going project, as well as each related task. In this way, every day when workers come to the factory and before beginning the work, they must scan their own barcode, then scan the specific project, and then the specific task they would perform on that day. Same process is being followed when the workers switch from a particular task or project to another task or project (Figure 51). Through this process, the manufacturing director is able to track the exact amount of labour-time for each task in each project.

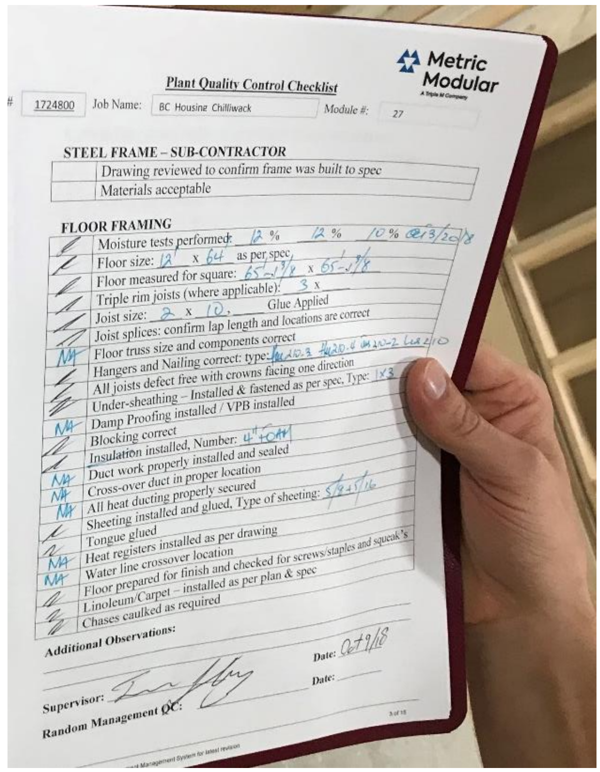
Performance monitoring is also being used to track the accuracy of project estimates and helps the manufacturer to quickly identify specific inefficiencies in the manufacturing process. From the data, it is possible to identify time-saving solutions, such as a readily accessible safety gear "dispenser" on the shop floor (Figure 52).

Figure 53 - Controlled construction environment at manufacturing plant ©Metric Modular

Quality Control (QC): Having a controlled manufacturing environment provides opportunities to apply quality control measures, that can be difficult to achieve in the field. QC measures are conducted at each of the 24 "stations" in Metric's plant. In addition, each module unit has its own "logbook" attached to it as the unit travels through the assembly line. When an activity is completed at a station, the results are inspected, rechecked and then written down into the logbook (Figure 54). The QC process also includes testing the installed appliances, fixtures, electrical, sprinklers, and plumbing before sending the modules to the construction site.

Figure 54 - Sample quality control checklist from logbook





Sound Insulation: In this project, each module unit had its own complete roof and floor, with its framing and insulation. When these modules were stacked on top of each other 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.

> "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**

TOOLS TO AID COLLABORATION

Metric's SaaS-based production management system: Scheduling and managing the manufacturing activities is run from a Software-as-a-Service (SasS) system which allows the production team to define the various off-site activities and assigns them to different trades. Once a task is assigned to a worker, s/he will get an automatic notification and can access the schedule to get further details of the task.

The key to an efficient modular construction project is a comprehensive and highly rigorous suite of management and technical procedures that are fully understood and acted upon by all staff and project team members. A highly integrated supply chain is central to success.

Metric's supply production processes (backstopped by an internal document management system and a well-established SaaS-based production management system) established the methods and terms of collaboration between management and the shop floor, reaching deep into their supply chain. For example, Structurlam, the supplier of wood products for Jacobson Hall, had to mesh their delivery schedules with Metric's pace of production.

For Jacobson Hall, there was no time to learn new systems. Outside of the use of advanced wood processing "kit" for pre-cutting, drilling, routering, etc. (Figure 55). Indeed, Metric's application of high-powered technology can afford to be quite low because the elements are highly standardized and the management processes so well established. Thus, Metric's team could get away with using very simple and conventional 2D drafting software and a free sketching and rendering tool (to create a conceptual 3D model at the early stages for visualization purposes). These systems were well understood and easy to share with external consultants. The project was carried out without the utilization of any Building Information Modelling (BIM) tools, and there were no specific efforts regarding parametric modelling, computational design, or specific simulations. Nevertheless, in the conducted interviews, the stakeholders emphasized the necessity of using BIM tools as a lesson learnt from this project and aim to incorporate such tools in their future projects.

Figure 55 - A selection of Metric's advanced wood processing equipment

OUTCOMES AND METRICS

Owners requirements met

All the owner's requirements were met and high-level of owner's satisfaction was achieved in the project.

> "The new housing offers a radical improvement in our ability to compete with other schools because it's so well-designed." [65]
>
> **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."[66]
>
> **Bob Nice, SVP Business Administration and CFO, TWU**

On budget

Jacobson Hall was delivered fully fitted out for $13.1 million ($218.33/sf) as stipulated in the Design-Build contract.

9 months construction schedule

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.[67]

There was a total of 7 changes to the Jacobson Hall design-build contract, all of which amounted to $995k and were accommodated in the total budget of $13.1 million.

- Excavation and foundation changes for raft slab due to poor site condition and seismic requirement. It was treated as a cash allowance at contract signing due to existence of unknowns.
- Site services in terms of relocating main electrical trunk and main water line to campus. Because TWU did not have layouts of established underground services, it was also treated as a cash allowance at contract signing.
- Plumbing fixtures related changes
- Flooring changes
- Additional pantry requirement
- White boards in corridor
- 5lb fire extinguishers in all suites

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

- The TWU campus only has one entry point. For the Jacobson Hall project, the off-site construction process diverted hundreds of delivery vehicles which reduced noise, pollution and disruption while improving campus safety.
- Modular construction allowed to complete the work within a restricted site area where space for materials storage and lay-down is limited.
- Construction noise was minimized not only from less on-site work and equipment use, but also due to the need for fewer power generators on-site.
- A conventional wood building would have required extensive weather protection and phased fire protection as work progresses. With the modules arriving already complete, these measures are far less invasive.

CHALLENGES AND LESSONS LEARNT

The main challenge for this project was extremely tight schedule. Trinity Western University had only nine months from contract signing to student 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 five-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 established underground services.
- The manufacturing team faced a big challenge in getting the mechanical equipment and fire dampers installed. As a result, they had to send them direct to site for the 1st and 2nd floors which was more expensive and time consuming.

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 five-storey wood frame building.

Figure 56 - Typical student accommodation of Jacobson Hall on completion ©Metric Modular

PART 3

APPLICABILITY TO HOUSING IN BC

Challenging industry norms

Because IPD is new to Canada's construction industry, knowledge gaps exist. Traditional approaches to project delivery have ked to industry fragmentation and many professionals are familiar with (and thus prefer) working in silos. There are challenges such as a real or perceived shift in the balance of power within the project team, issue with group decision-making and 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.

Changing the norms of the industry and breaking the silos is challenging. Research suggests that the key lessons for success of IPD implementation may be summarized as follows: [68]

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

Lessons learnt and applicability of IPD to housing projects in BC

The following section summarizes the key features and lessons learnt from the four case studies that would be relevant to multi-family housing projects in BC. It also offers actions that public owners may wish to consider for future construction projects.

There is a growing body of evidence[69] that demonstrates how and to what extent IPD can provide an efficient and effective project delivery method for achieving cost, time, quality, sustainable goals. It delivers value by promoting collaboration (even potentially forcing teams to work together in times of adversity), facilitating the sharing of ideas, and enabling the adoption of new technologies and processes (such as BIM and Lean planning methods).

Given that BC still only has a few companies with direct experience of IPD the question arises as to what extent these benefits can be delivered through traditional procurement methods. This is important to public owners in particular because they strive to deliver best value by ensuring the procurement process is as fair, open and transparent as possible. Established procurement pathways struggle to capture the benefits from hiring a fully integrated team (including key trades) at the outset, continuous improvement from learning together and fostering a culture of creativity.

After several years of development, CCDC30 is a Canadian standard form of the multi-party agreement that was released in early 2019.[70] Indeed, there are a variety of form contracts available, all of which are very similar. In addition to CCDC30, other options are the AIA C-191 (from the American institute of Architects) and ConsensusDocs 300[71]. According to the IPD Alliance, all of these can be good starting points, but all will require completion and modification before use on a specific project. In addition, there are proprietary forms that have been used widely, such as the Hanson Bridgett LLP form (used with modifications by the Mosaic Centre and St. Jerome's University). One advantage of the proprietary forms is that they continuously embed lessons learnt from real projects.[72]

In IPD, there is considerable up-front commitment and effort by the IPD team before the owner formalizes the design and construction scope.

While only two of the projects implemented full IPD, this report identified housing projects in BC that employed "IPD-like" principles with some success. It is possible to reliably deliver high performance projects – even in remote locations – to the satisfaction of owners. However, it is probably more difficult to do so on a consistent basis without the legal frameworks that truly motivate all key project team members to put the interests of the project ahead of their own.

All of the projects brought the full team on early and adopted lean planning methods which, particularly in the absence of a multi-party agreement, was key to success. Also, in all cases, the owner invested far more time in managing the project than might be normal for public agencies today. Because IPD is still new, many public owners may lack the in-house expertise and, indeed the time, to adopt, manage and operate a formal IPD project at this time.

1. SETTING CLEAR PROJECT GOALS AND OBJECTIVES

It is very important for the owner to set clear project goals and objectives, which can be related to 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. Project goals can also be set up as Key Performance Indicators (KPIs) to measure whether the team has achieved the goals or not. Project KPIs can be quantifiable, or quality based, or a combination of both, and are used to define "Condition of Satisfaction" for the project, i.e. whether (and to what extent) the project has been success.

Setting clear project goals and objectives			
priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
The project team developed an "Owner's Value Matrix" which documented the owner's goals for the project and guided project decision-making.	The owner's goal to complete the project on time and on budget was made clear to the project team. The project design and objectives were developed collectively by the core project team including the owner.	The owner's goals were to finish the project before Sept 2017, to build more sustainable and energy efficient building and to explore the potential for tall mass timber.	The owner's goals were focussed on cost and a very tight time constraint but also emphasised the need for an attractive and comfortable building.

Big Room setting

Owner representatives (and indeed key project team members) need to be available in the room to make decisions quickly and participate when needed but it does not mean they are required to devote all their time to the project. They can be working on other projects while sitting in the Big Room.

2. OWNER'S INVOLVEMENT

The owner's continuous, direct engagement with the project team communicates the owner's intent the best and allow quicker far and more decisive decision-making when the owner is present to answer questions or provide direction immediately. In addition, the end-user representation that often comes with continuous, direct owner representation serves to reduce change orders and misunderstandings that can impact cost or schedule.

Owner's involvement			
priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
The Owner spent considerable time from the outset on selecting the right project team and setting his expectations, which sped up decision-making processes.	The Owner's representative invested time upfront developing a collaborative working environment and team alignment, which resulted in a much smoother construction phase.	The Owner's in-house department acted as project manager to procure and develop a collaborative team and set clear expectations. Continuous ongoing involvement improved project process efficiency.	The Owner group conducted a student survey to identify their requirements and also connected student representatives and building maintenance staff with the design team to identify issues.

Validating the target cost

Ideally, the entire project team participates in establishing the Target Cost for an IPD project. However, this can be a challenging process. There an emerging number of IPD projects currently underway where owners have taken to hiring third party experts to review and validate the Target Costs.[73]

3. EARLY PROJECT TEAM INVOLVEMENT AND EFFECTIVE COLLABORATION

The key project participants should be retained early in the process to develop efficient design. These multi-disciplinary core team are needed for solving design and construction issues as early as possible. The downstream project participants like manufacturers and subcontractors should also be involved before finalizing 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.

It is largely on account of the structural silos created by traditional adversarial project structures that lead to large numbers of change orders, RFI's, mis-interpretations, litigation problems, and so on. A highly collaborative team leveraging their collective knowledge plan for and can solve problems early while also giving the team a sense of ownership to the project. From designer to installer, the team has contributed, agreed and set the scope under the owner's goals and objectives.

Communication is critical. Actors who join IPD projects with a traditional adversarial mentality can impede transparent communication and sharing of timely and accurate information.[74]

Early project team involvement and effective collaboration			
priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
The IPD contract required early project team involvement and aligned the team's goals with the project goals. When a major problem on site arose, it was addressed collaboratively thereby reducing the cost impact significantly.	The IPD contractual setup required early on-boarding of key project participants. Effective team collaboration was achieved through shared the risk/reward mechanism, Big Room setup, joint project control and reducing information liability exposure.	The innovative nature of the project required an integrated team led by the structural engineer to be brought together early to solve regulatory and technical challenges (SSR code process).	The owner hired vertically integrated modular builder first and leveraged their internal team set-up by getting various internal expertise on the table even before a contract was signed.

Getting the right people on the team

At a high level, the team selection processes for IPD projects can be broken down into 3-parts:

1. **Pre-qualification bid:** who can do this?
2. **Technical bid:** How will they do it?
3. **Interview/presentation:** Scenario-based testing to understand the team dynamics and to make sure they can work together well.

4. EFFICIENT PROJECT TEAM SETUP

To select the right project team for the project and enable them to work openly, collaboratively and 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. Team selection processes for the case study teams used scenario-based interview questions to give the owner a chance to assess the character of the people (do they work well together? Are they open to new ideas?) and to "test" how they might work in cross-functional teams.

Finding trade partners and consultants who are willing to join multi-party agreements can be difficult. Reluctance to join an IPD project may be due to the fear of partnership and risk and reward sharing structure, uncertainty about IPD implications and the risks embodied in IPD adoption, and the need for holding new and unfamiliar responsibilities under IPD model (e.g. early engagement of trade partners and contribution in developing the design).[75]

Efficient project team setup			
priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
The owner invested a significant amount of time in the team selection process. The IPD structure (SMT, PMT, PITs) was implemented successfully, and cross-functional teams were formed which efficiently achieved their deliverables.	The owner clearly defined the team selection criteria in an RFP for the core IPD team. The IPD structure (SMT, PMT, PITs) was implemented successfully, and cross-functional teams were formed which efficiently achieved their deliverables.	The project team was selected through a public RFP process relying on qualitative bids rather than considering only cost. Some of the design consultants were selected based on previous (and positive) experience. The architect was selected via RFP followed by a proposal presentation process.	The owner did not have a sophisticated selection process for the design-builder. However, after winning the design-build award, Metric Modular achieved efficiency through mostly working with the same project team regularly and leveraged their established relationships.

Insurance & bonding

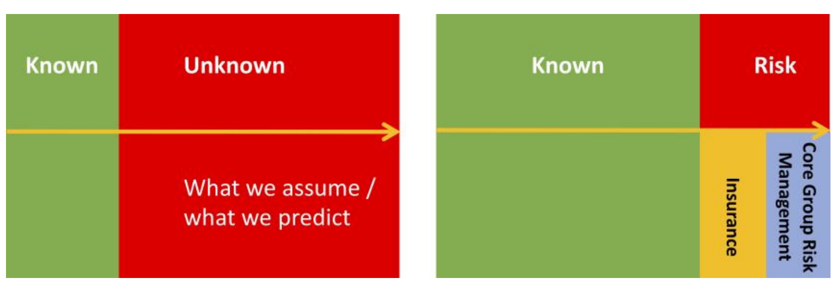
There is no difference between how insurance and bonding works in the IPD domain compared to traditional business practice. There is no single insurance solution available for IPD depending on project-specific priorities and many traditional insurance approaches are possible such as:

- The project team carrying their standard coverages and insurances as usual.
- The project team purchasing project specific policies to cover entire team and all of its dimensions.
- An owner-controlled insurance policy where the owner provides all the insurance to project team.

5. BE OPEN ABOUT RISKS – AND MANAGE 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, some 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".[76] However, these fears may not be founded. IPD. Experiences described in the case studies suggest that IPD evolves the understanding of risk from "fear of the unknown" to proactively enable the team to quantify, allocate and then manage either via insurance or through IPD tools such as risk registers (Figure 57).

Figure 57 - IPD evolves the understanding of risk from "fear of the unknown" (left) to quantification, allocation and management (right) (source Lean Construction Institute).[77]



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, the case studies make it clear that it is a team-based approach that is most effective at managing risk and solving problems.

Managing risks as a team			
priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
The IPD contract imposed a shared risk and reward mechanism on the project team to align project participants' goals and collaborate effectively. Project cost risk was managed collectively by the whole team.	The IPD contract helped the owner to manage risk through the shared risk/reward pool. This encouraged the project team to innovate and reduce waste to achieve target cost.	The CM+ arrangement led to a relatively traditional approach to addressing risks without incentivizing the project team for their better performance.	There was no sophisticated risk management. The owner assumed all the unknown risks.

The JCT-CE risk register

The Joint Contracts Tribunal – Constructing Excellence (JCT-CE) contract from the UK requires the parties to identify potential risks and record them in a risk allocation schedule. The parties must agree how the financial and time consequences of each risk are to be allocated between them. The risk allocation cannot be amended.

There is also a separate document which is prepared and updated from time to time (risk register) which is intended to be a project management tool. [78]

6. SET THE DECISION-MAKING STRUCTURE

Continuous involvement in the project can be demanding on the owner's time but there are two different ways to potentially alleviate the burden, both of which can lead to effective decision-making:

- Owner Representation: All levels, teams and sections important to the owner has 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.

- A decision matrix that clearly defines what decisions can be made inter-dependently, and what needs to be passed up the chain of command 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 decisions can be made with greatest benefit to the project. Also, an owner's commitment to be available for decision-making does not have to prevent the opportunity of working on other projects.[79]
- A full IPD structure ensures that the right team members form effective, cross-functional teams, which are optimised to make informed decisions and execute them successfully.

Set the decision-making structure			
priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
The owner's value-matrix established the structure for decision-making and allowed lower-level team members to make some of the decisions. Decision-making power was assigned to each IPD level (SMT, PMT, PITs).	The Owner's representative worked closely with the team making quick decisions on-behalf of owner. Decision-making power was distributed across SMT, PMT and PITs based on the decision impact on the project.	No formal decision-making structure. Involvement of owner's PM accelerated the design and construction process. All decisions were made collaboratively with the assistance of virtual 3D model PM.	No formal decision-making structure established. All the design-related decisions were made collaboratively by external consultant with the builder having final veto. The owner's team were consulted before making any major decision.

Is everybody happy?

"Off-the-record" conversations with project team members in IPD projects suggest that not every team member enjoys the IDP process. This may be for reasons of lack of familiarity, poor project team organization, inadequate communication, lack of team compatibility, etc. Nevertheless, some designers felt their designs were diluted or "overshadowed" in the quest to control costs. There can be a real or perceived "powershift" from traditional project delivery methods resulted in a loss of control for some consultants. Others (notably sub-trades) may believe they were not fairly treated when it came to the dispersion of the profit pool.

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 a couple of other case studies, there were clear penalties for failure to perform but no corresponding incentive for exceeding expectations.

Align team incentives with project goals			
priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
The shared risk/reward pool embedded in the IPD contract helped to align the project team's incentives with the project goals.	The shared risk/reward pool embedded in the IPD contract helped to align the project team's incentives with the project goals.	There was no mechanism of incentivizing the project team based on project performance.	There was no mechanism of incentivizing the project team based on project performance.

8. MAXIMISE DIGITAL TOOLS, PROCESS AIDS AND INNOVATIVE TECHNOLOGY

There is increasing evidence that the use of BIM can aid project team collaboration, irrespective of project size or type. [82] For example, level 1 BIM (a mixture of 3D CAD for concept work, and 2D for drafting of statutory approval documentation and production information) is commonly used in BC for multi-family residential and non-residential projects. As more design and construction firms gain familiarity with the systems and become increasingly "digitally literate", BIM will penetrate the construction process (i.e. Level 2 BIM), enable industrialization and thereby improve overall productivity.

Therefore, project teams should be encouraged to use digital tools and technology like BIM, Lean tools etc. to support "better" (faster, cheaper or better quality) outcomes. The case studies showed that, when it was used, technology generally helped with collaborative design and construction. It also helps those unfamiliar with building documents to visualize the project, add useful input from owners and end users, and minimizing revisions and re-work. In particular, BIM helps to reduce modeling 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.

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. Nevertheless, the state of technology adoption in BC's construction industry is still low (especially in rural/remote locations). For those projects with a tight time frame, access to limited skilled labour and no time to learn new systems, tried and tested paper-based information management systems and proven building typologies (i.e. modular units) are very much the norm.

The value of BIM in resolving unfamiliar situations (e.g. mass timber projects)

When dealing with relatively uncommon design or construction technologies (such as mass timber), unfamiliarity can result in increased premiums due to higher perceived risks. Yet, research shows that in cases where BIM has been employed, contractors are able to clearly visualize their scope of work and working conditions, resulting in more competitive bids. Indeed, BIM can also help to facilitate approvals and regulatory procedures as it allows the AHJ to more clearly visualize the proposed solutions.[80]

A key driver of BIM uptake into the construction process (i.e. Level 2 BIM) will be the extent to which digitization will reduce reliance on potentially wasteful, manual/slow or ad hoc decision-making on site. So, those activities that may not, at first glance, lend themselves to digitization (e.g. on-site boarding of light-frame residential buildings[81]) are likely to be improved through BIM-enabled panelization and prefabrication if these activities are slowing down the project process or generating large amounts of waste.

Use of digital tools, process aids and innovative technology			
priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
BIM implementation was minimal It was used primarily for 3D visualization, design coordination and clash-detection only.	Sophisticated BIM implementation All consultants used BIM for design development and design coordination, clash-detection, constructability review. Several contractors used BIM for quantity take-off as well. Minimal data extracted from the model for the facility management use. ProjectWise: Efficient information management and distribution (reports, meeting minutes, RFIs, site instructions, current set of drawings) to the whole project team (within 24 hours). VPlanner: Efficient task management tool to support the Last Planner® System workflow by aligning short-term plans with the long-term project plans, assigning tasks to various users that could be checked back when complete.	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.	No BIM implemented Barcode scanning system: Innovative way of tracking each labour-hour going into the project at off-site facility. Smartsheet: Used at the off-site facility to help the various subcontractors and suppliers collaborate. They used it 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.

9. PREFABRICATION

The case studies demonstrate prefabrication encourages teams to make rational decision prior to construction and increases on-site productivity while addressing labour shortage. Prefabrication can also provide high-quality products within shorter time period. Therefore, prefabrication often leverages IPD or IPD-like focus on preplanning, early collaboration and coordination prior to construction – where mistakes, risks and rework are far more expensive.

Additional skills in designing for prefabrication, just-in-time delivery and site and labour sequencing (to name a few) are often needed beforehand, but the superior outcomes can offset these commitments.

Prefabrication			
priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
The large wood roof trusses were prefabricated.	Prefabrication used for HVAC, heating and cooling piping system; Integrated sinks with counter tops used to save cost on-site.	Prefabrication implemented in form of CLT panels, glulam and PSL columns.	Modular construction – 90% completed modules at well-organized off-site manufacturing plant at Agassiz; modular construction helped completing project in 9-months form the award of contract to handover with higher off-site quality.

Definition of lean construction

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".[83]

10. LEAN EVERYTHING

Many of the successes delivered by IPD are predicated upon the successful implementation of Lean principles and planning methods. Lean construction methods evolved from the adoption of lean principles that are well-established within the manufacturing industry. Lean construction refers to the "Toyota way" which identifies and removes "waste": 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. A summary of lean principles and planning methods are provided in Appendix B.

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.

Teams that ventured into full IPD projects generally did so on the strength of extensive experience with Lean. Indeed, it is Lean design and construction that delivers the efficiencies in productivity and performance.

Lean construction planning methods can yield significant savings (material, labour, avoiding rework, etc.) because the project is seen as a single endeavour (similar to IPD), with all participants collaborating to maximise efficiency, reduce excess cost and increase safety.

- Develop metrics for every aspect of the project; including time, cost, material, progress, schedule to measure and improve continuously on the project.
- Sharing a "Big Room" to encourage broad team collaboration, problem solving and to allow the team to constantly "plan-deliver-check & adjust" (PLCA, next point).
- Implement Lean Planner® System (Pull planning), focusing on detailed planning time intervals that guarantee work that is required to keep the project process moving as efficiently as possible is complete "releasing" work for the next interval.
- Remove information liabilities by sharing information and resources among various team during design and construction.
- Employ online document management platform so the team is constantly aware of progress: what has been completed, what is needed from whom and what is still outstanding.

Lean practices			
priMed Mosaic Centre	**St. Jerome's University**	**UBC Brock Commons Tallwood House**	**Jacobson Hall, Trinity Western University**
Big Room with Last Planner® System. Snake diagrams to visually track milestones comparing with planned schedule. "2 Second Lean".	Big Room with Last Planner® System. Pull Planning. Mock-up for room dimensions and furniture.	Mock-up constructability tests. Extensive pre-planning. Just-In-Time delivery of prefab components.	Builder is a vertically integrated firm in which most of the project participants were collocated. Just-In-Time delivery of prefab components.

Supporting information

1. **Glossary**
2. **Appendices**
3. **References**

Glossary

Building Information Modeling (BIM): "Building Information Modelling (BIM) is a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space."[84]

BIM Level of Development (LoD) is a BIM metric to identify the amount of detail included in a BIM model. The LOD specifications are defined as following five levels.[85]

> **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 element 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.

BIM Modelling dimensions:[86]

> **3D BIM** is the process of creating graphical and non-graphical information and sharing this information in a Common Data Environment (CDE).

4D BIM (Construction sequencing) adds an extra dimension of information to a project information model in the form of scheduling data and time-related information.

5D BIM (Cost) Drawing on the components of the information model, accurate cost information can be extracted. Considerations might include capital cost of an element, its associated running costs and the cost of renewal/ replacement down the line.

Integrated Project Delivery (IPD) is an emerging construction project delivery system that collaboratively involves key participants very early in the project timeline, often before the design is started. It is distinguished by a multiparty contractual agreement that typically allows risks and rewards to be shared among project stakeholders.[87]

Just-In-Time delivery (JIT) is a methodology aimed primarily at reducing times within a production system as well as response times from suppliers and to customers. In the construction context it reduces on-site materials inventory and can provide a significant improvement of project cost and time management.

Life-cycle cost analysis (LCCA) is a method for assessing the total cost of facility ownership. It considers all costs of acquiring, owning, and disposing of a building or building system. LCCA is especially useful when project alternatives that fulfill the same performance requirements but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes net savings.[88]

Last Planner System (LPS) "is a technique for construction planning and control, that is focused on the people that make decisions at the site (called last planners); these last planners are committed to the project through the initial pull session that establishes the master plan with the key tasks and milestones. The site manager, with the help of the last planners, looks forward to remove constraints through the look-ahead plan and to improve the production flow." [89]

Lean methods seek to develop and manage a project through relationships, shared knowledge and common goals. Traditional silos of knowledge, work and effort are broken down and reorganized for the betterment of the project rather than of individual participants. The objective is to deliver significant improvements in schedule with dramatically reduced waste, particularly on complex, uncertain and quick projects.

Lean Project Delivery (LPD) is a highly collaborative process that comprises the application of target value design and lean methods during construction.[90] A summary is provide in Appendix B.

Modular construction is, "a process in which a building is constructed off-site, under controlled plant conditions, using the same materials and designing to the same codes and standards as conventionally built facilities – but in about half the time. Buildings are produced in "modules" that when put together on site, reflect the identical design intent and specifications of the most sophisticated site-built facility – without compromise." [91]

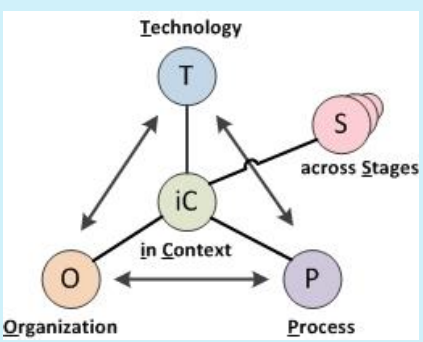
Pull Planning: According to the Lean Construction Institute, Pull Planning involves "working from a target completion date (milestone) backward, tasks, which are defined and sequenced so that their completion releases work. Work tasks, information flow, and material deliveries are planned based on the request (or "pull") of downstream customers. Pull scheduling will often expose the need for smaller batches, just in time delivery, improved levelling of resources, and reduced lead times. Workflow becomes more reliable and efficient as the waste of waiting, redundancy, and over-processing are eliminated." [92]

Target Value Delivery: "A disciplined management practice to be used throughout the project to assure that the facility meets the operational needs and values of the users, is delivered within the allowable budget, and promotes innovation throughout the process to increase value and eliminate waste (time, money, human effort.)" [93]

The Big Room According to the Lean Construction Institute, "An effective Big Room supports cross-functional team collaboration by advancing work and bringing the larger team up to speed on the activities of other groups or individuals. It allows teams to understand their impact across clusters or work groups. The Big Room also provides teams with the time to discuss project-wide concerns like budgets, hot topics, or global changes. The term Big Room refers more to the behaviours and actions of the team than the physical space. The Big Room is more than co-location of people; it is about collaborative behaviour and the work they are producing." [94]

Appendix A: Research methodology

Figure 58 - The TOPCS assessment framework (source: Dr. Sheryl Staub-French and the UBC BIM TOPICS Lab)[95]



Case study project selection

To research the applicability of IPD to housing projects in BC, the research team prepared a "long-list" of IPD projects. Criteria for project selection included:

1. The project is residential in use or incorporated structural and/or design elements that are transferable to or resonate with housing design and construction practices in BC. For example, the project is small to mid-rise in scale, built out of wood, etc.
2. The project followed a full IPD process, complete with multi-party agreement or implemented at least three of the following IPD principles:
    i. Early Involvement of Key Participants
    ii. Shared Risk and Reward based on Project Outcome
    iii. Joint Project Control
    iv. Reduced Liability Exposure
    v. Jointly Developed and Validated Targets
3. The project is located in Canada and, if possible, in BC.
4. The final five case studies should be different in scope, size, structural typology (mass timber, wood frame, concrete, steel, or some combination), location (urban or rural/remote) and climate zones.
5. The project is complete, and the project team is willing to share data.

Research assessment framework

Once five projects were identified that met the above criteria, the information as collected in a structured way. To analyse each project thoroughly and holistically, the research team used a modified version of the TOPICS framework to investigate/explore every aspect of the project (Figure 68). The TOPiCs categories help to identify key considerations from construction case studies across different stages of projects (from design to construction). This framework can be utilized to narrow in on important priorities and issues. The research also explored project context and the pre-planning efforts went in to assembling right team before start of a project.

Figure 59 - Project assessment methodology

Organization	Process	Technology	Outcome and Metrics
• Owner's goals • Choosing appropriate delivery method • Team selection process and rationales • Agreement/contract development • Project team structure • Decision structure of the project	• Execution plan • Training/workshop provided to team • Communication strategies implemented • Collaboration between project participants • Innovative practices implemented	• Different uses of digital technologies • Supporting tools used	• Owner's satisfaction • Traditional project outcomes in terms of cost and time • Other benefits and positive results achieved • Challenges and lessons learnt from the project

Data collection

The research team collected existing available information about each selected project through online resources including project participants' website, project websites, non-associated resources that feature the project, news articles, previously developed case-studies by others etc.

After analysing available information, the research team contacted key project team members and conducted 1hr interviews through structured open-ended question to fill the gaps of available information and investigate each project in detail. Follow-up calls were made for fact checking purposes.

The targeted role of project participants for an interview were owner, project manager, architect, and contractor/construction manager. These interviewees were also requested to provide supporting project documents for an analysis.

Case study review

To validate findings and content of the case studies, the interviewees/project participants/owners received draft copies of their case study project for review, comment and feedback.

It should be noted that while this report presents the findings from four case studies, a fifth case study of a remote modular housing project was also completed. However, despite the owner's representative, designer, construction manager and modular builder participating in interviews, the owner's organization subsequently decided that it was not possible to publish the findings.

Appendix B: Summary of lean construction methods

Lean construction is a new way to define design and construct that can be applied to any project and in any project delivery model.[96]

Implementing lean principles in design and construction processes (Figure 70) can help the project team to uncover and eliminate waste (Figure 71) and enhance project value by enabling the team to fully understand the owner's goals and pursue them throughout the project life-cycle.[97]

Figure 60 - Lean principles in design and construction (source LCI Canada)

Figure 61 - Types of wastes in construction (© Shift2Lean)

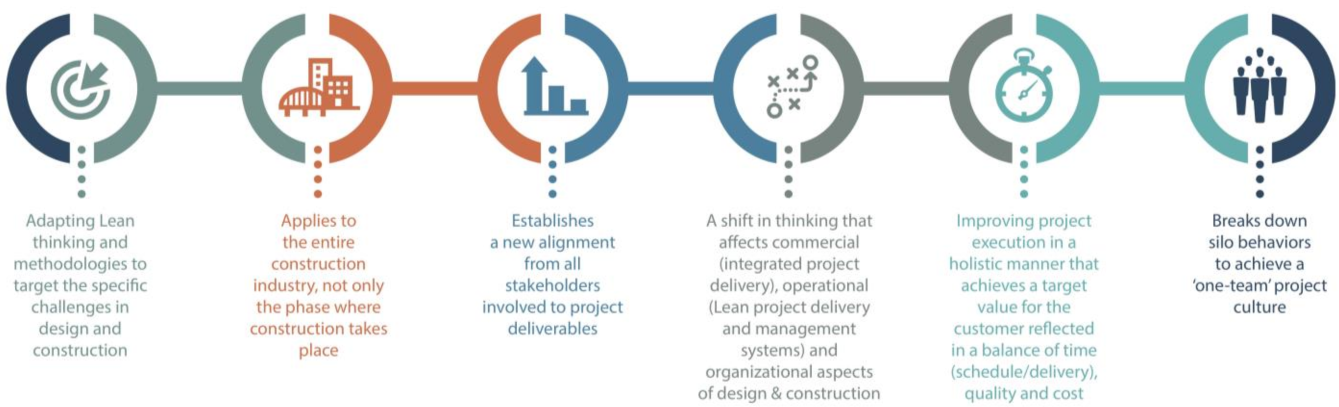
Waste	Definition	Impact
Defects	Producing goods/information not meeting requirements and require rework	Diverts workers from value add work, increases material cost and inspection requirements
Over Production	Producing more than is required or sooner than required	Unnecessarily increases staff, storage 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 between processes	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 materials/tools or wasted time walking to undertake work
Extra Processing	Processing beyond the standard required or inefficient processing	Adds cost and/or time that the customer has not defined as value add

Lean design and construction processes 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.

Lean methods are designed to improve the project management process by breaking down traditional silos and facilitating 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.[99] 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. Lean differ from traditional practice in following way:

- 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 decentralizing decision making through transparency by empowering project participants to take action by providing them with information on the state of production systems.

Figure 62 - Characteristics of Lean (source LCI Canada)[98]



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PART 3: APPLICABILITY TO HOUSING PROJECTS IN BC

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