CENTER FOR EDUCATION + RESEARCH IN CONSTRUCTION
DEPARTMENT OF CONSTRUCTION MANAGEMENT

DESIGN AND CONSTRUCTION INNOVATION THROUGH **COLLABORATION, LEAN CONSTRUCTION AND BUILDING INFORMATION MODELING**

A case study of Integrated Project Delivery in Healthcare

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EXECUTIVE SUMMARY

The construction industry has long tried to improve the efficiency of its outcomes and maximize the value to owners by improving the team integration and applying manufacturing-oriented production philosophies. We studied a successful example of the recent approach to project delivery in the industry and interviewed key project participants to understand their working processes. This is a healthcare project on the west coast of the US which included a tenant improvement in an existing core and shell tower. A architecture and general contractor team delivered this project.

This report is divided into two main themes. First, we describe the project team's integrative efforts as it relates to current Integrated Project Delivery industry trends. Then, we explain the value-adding activities in this project along with their applied tools and shows how collaboration facilitated maximization of the value to the client.

Finally, a summary of the key findings of this project are highlighted to be applied by the industry. Based on these findings, some of the key elements for establishing collaboration among the team members include the creation of an integrated team of project participants, the relationship development and open communication, and early involvement of all project parties (including users and subcontractors) into programming and design of the project. These principles resulted in the success of this project while combined with value-adding focus of the team through design optimization, pull-planning, and supply chain management.

1 BACKGROUND

We studied a healthcare project to build out tenant spaces in a core and shell tower at the heart of an urban campus in the Pacific Northwest region. The office of the architectural firm and the general construction company formed an integrated team on this project. This report describes their innovative approach in project delivery, which became possible through close and timely collaboration of all parties, standardized working processes, and implementation of technology (such as BIM).

Some general information about this project is shown in table 1.

SIZE (SF)	COST ($)	DESIGN DURATION	CONSTRUCTION DURATION
24,500	**16,500,000**	**4 months**	**~6 months**

Table 1. Project's general information

2 COLLABORATION AND INTEGRATION

2.1. Background and Literature

Much has been written in recent years on the subject of collaboration and integration in the AEC (Architecture, Engineering and Construction) sector (3xPT Strategy Group 2008; AIA California Council 2007). In "Rethinking Construction", Egan (1998) states that construction industry is suffering from the lack of efficiency and owner dissatisfaction. These problems are believed to be rooted in extreme fragmentation of specialties and processes in the industry (Mitropoulos and Tatum 2000, Baiden et al 2006). To overcome these challenges, Egan (1998) suggests that 'integration of processes and teams' should be applied in the industry along with 'focus on the customer', 'committed leadership', 'commitment to people' and 'quality-driven agenda' to change toward more efficient, less wasteful outcomes.

Integration and collaboration are often used interchangeably in the literature (NASFA et al., 2010). In the context of organization theory, Lawrence & Lorsch (1986) define integration as "the quality of the state of collaboration which exists among departments that are required to achieve unity of effort because of environmental demands". Baiden and Price (2011) define integration in the construction context as "where different disciplines or organizations with different goals, needs and cultures merge into a single cohesive and mutually supporting unit with collaborative alignment of processes and cultures". To achieve integration, knowledge and information should be exchanged between the interdependent subsystems (Mitropoulos and Tatum 2000).

Mitropoulos and Tatum (2000) believe that integration is critical in design of buildings for two reasons: to avoid problems that might arise in construction and post-construction phases and to select design alternatives that optimize overall project performance. The integration in design, as they suggest, addresses both design and construction phases of a project and implies the involvement of contractors and suppliers in information sharing and decision-makings (Mitopoulos & Tatum 2000).

The mechanisms for achieving integration are usually embedded in the framework of project delivery systems. Various project delivery systems allocate roles and responsibilities differently and implement different sequencing of project phases and activities. This results in different degrees of integrated project environments. In general, project delivery systems with less integrated project sequencing, such as Design-Bid-Build (DBB), tend to apply less integrated project team environments.

Some argue that less integrated project delivery methods, such as DBB, are prone to high levels of separation between project parties and the resultant great amount of claims, disputes and long delays associated with them (CMAA 2012). Moreover, more complex projects need more coordination which was not achievable through these types of project delivery methods (Beard et al. 2001; Cushman and Loulakis 2001). Construction Management (CM) and Design-Build (DB) project delivery systems were developed in response to these problems and needs.

A recent approach to project delivery is Integrated Project Delivery (IPD), introduced to deliver value to owners by increasing collaboration and integration among parties. In contrast to some project delivery systems, such as Design-Bid-Build (DBB), which offer low levels of integration, IPD provides the opportunity for higher levels of integration among project parties. This approach to project delivery is still new to the industry and is gaining popularity particularly in the health care sector.

Integrated Project Delivery (IPD) is an "approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction" (AIA California Council, 2007). It is, in fact, designed to overcome some of the main problems existing in construction industry such as high inefficiency, lack of innovation, adversarial relationships, and low productivity (CMAA 2009).

In IPD, the key participants of the project contribute their knowledge and expertise in the early phases of project, and the responsibilities that they take on are based on their abilities. Usually, a single contract binds the IPD team to the owner, where each primary team member takes on the full responsibility of all terms, conditions, and requirements of the shared contract (Matthews & Howell 2005).

According to the Construction Management Association of America (CMAA), the IPD projects usually integrate four aspects of project delivery (CMAA 2010):

- **Agreements:** The core team of the project is bound together through a multi-party contract that allows the team to pursue shared goals with incentives set for the entire team.
- **Leadership:** A project culture is generated in the team environment by leaders who focus on transparency, trust, mutual respect, and collaborative decision making.
- **Information:** Virtual environments and collaboration tools are used by the team to facilitate access and updating of information by the entire team.
- **Processes:** More ambitious objectives are defined, compared to traditional project delivery systems, and execution processes derived from theories such as Lean Production are applied to achieve those objectives (CMAA 2010).

Mutual respect, mutual benefit, early goal definition, improved communication, standards with clear definition, appropriate technology, and high performance are the main principles of the IPD (AIA California Council, 2007).

2.2. Collaboration and Integration – the case-study's story

In the healthcare project we studied, the owner, the architect and general contractor team applied a variety of collaboration principles, procurement systems, and tools to encourage and facilitate collaboration and integration among the parties. Some of the key collaboration strategies included 1) integrated A/E/C team, 2) lean-focused interview during subcontractors selection, 3) alignment of interests, 4) Shared contingency pool, 5) involvement of downstream stakeholders in upstream decision-making, and 6) communication in design and construction:

2.2.1. Integrated Team of Architect/General Contractor

The integration in design and delivery was a major integrative effort in this project. To respond to request for the project's proposal, the collaboration of the architect and the general contract's staff initiated even before being selected for the work. The focus for the architect was to explain to owner how the team intended to work with them and with each other. In this way, the project team could also collaborate in the programming phase of the project, in addition to design and construction phases, and all team members, including the owner, the architect, The general contractor, as well as key subconsultants and subcontractors could have a voice and play a collaborative role in setting the targets and defining the program requirements.

What we learned from this case is that the proposal development process itself established norms of collaboration that were vital, according to project participants, to the overall project success. Interviewing set the stage for and established the norms for the teamwork. A two-hour session was assigned to each team to present its approach to project. As one of the general contract's team member recalls:

"....they gave no framework structure to the interview. You had to engage them in. And, in that two hours, you had to engage them in the process, the process that you might use to deliver the project, and engage them in a way that they participate and learn more about the project doing it. And we had to come to a successful completion in that two hour period to show that we are able to deliver work in intended time frame. And you did it in an integrated way, architect and contractor together collaborating but also engaging them, pulling them in, and saying hey what are you looking for, what about this, have you thought about these issues...."

The architectural firm and the general contractor were the winning team of this process and were awarded the contract. In their interview session, they tried to show that they are capable of delivering to the owner the best value with respect to schedule, budget, quality, space area, and sustainability. To do that, they attempted to map a timeline for the project and demonstrated that they would make sufficient timely planning efforts which engaged.

the various project stakeholders. The architect-contractor team created a plan that communicated the decisions that need to be made and the timing of those decisions within the project timeline. They also addressed the construction aspects of the project and showed how they would develop the Building Information Models (BIM) of the project with the aid of relevant downstream parties so that everything could be prefabricated and that, in this way, the construction site would be turned into an assembly and installation site, a particular strength of the general contractor team on this project. Lean was a major focus of the architect-contractor team proposal. Not only did it match with the owner's lean efforts, but the architect-contractor team demonstrated how sustainability could also be achieved as a result of waste reduction in the construction process. A member of the architect team remembers:

"…they had all that information in the RFP that were responded to during the interview because what we did in our interview was to build chemistry and comfort level that they can work with you…"

The integration of architect and general contractor proved to be very helpful in facilitating collaboration among the parties, even beyond traditional limits of practice, in order to reduce the project uncertainties. The contractor's project manager believes this integration was the fundamental success factor in this project and states:

"I don't know if it was purposeful but that [collaboration of architect and contractor for proposal submission] was brilliant on [owner's] part because it forced us to be collaborative in order to win the job together. I don't know how much you've gone through pitching jobs so it can get to be quite interesting. I think…that was the second time I had pitched a job with a design firm and there was quite a spin … when you take a construction firm into your architecture firm, I have to tell you when they are pitching together they really do differently and I've had the opportunity to pitch a lot of work so I was really surprised. So, that really helped us align and bring the group together and I would say that was the fundamental factor in probably the success of the project because it tied us together and then we were tied to the client because a lot of time, you know, you think of three friends who can't walk on the sidewalk together. It is hard to have three friends because there is always one guy on the outside and that's why construction is really messed up on that where the owner pits the design and construction off each other or the owner and contractor get on against design and all the rest of it. That never happened here."

2.2.2. Lean-focused Interview for Selection of Subcontractors

Once the collaboration was established in the first tier, and the design partners worked closely together during program and design development with owner stakeholders, the builders needed to be brought in and integrated into the project. A culture of collaboration at this level is not the norm in construction, so the subcontractors who join the project had to make some adjustments to how they expected to participate.

One of the mechanisms for selecting subs reflected the A/GC selection process above – find those who are a "best fit" with the project. With an emphasis on prefabrication, the team was looking for subs who were innovative and had Lean Construction capacity. Selection of subcontractors was done after interviewing with respondents to a request for proposal. The interviews focused mainly on the philosophy of the subcontractors and their approach to providing their service in addition to the fees and rates. Implementation of lean was a key factor in the interview sessions and issues such as the capability to eliminate wastes such as time reduction for handling tools and to standardize repetitive processes were questioned and discussed.

2.2.3. Involvement of Downstream Stakeholders in Upstream Decision Makings

Decisions in a project should be founded on timely reliable information which is not always available to the owner or IPD team. And, since many of the key cost and performance driving decisions in a project are made in the early design process, early involvement of those project parties, such as contractor, subcontractors, and suppliers, which are traditionally not included in the design process, is a main often lauded for the IPD project success (AIA 2011). In this way, the access of the decision-makers in a project to the reliable information in a timely manner is guaranteed.

We previously talked about involvement of the general contractor in this project in the framework of an integrated architect-contractor team. A member of the architect's team stated:

"…in traditional mode, the designer works with the owner; they come up with the vision; they both agree upon with what it is; [and then] try to put it in graphical formula into the documents we hand to contractor in order to make it happen. But they go look at it and say why did you do that or if you just could show this doesn't mean we're gonna build that. We're gonna move it over here because it makes it easier for us. They [contractor] have now integrated into the process. They're now part of every decision. They understand why something is done that way, as opposed to, 'well that doesn't make any sense so we moved it here because it was cheaper'. So, that's where I think the difference is at. I think we get the benefit of integrated design. And, in that way, when we hand off the drawings we're not just translating the information."

The involvement was not limited to contractor but also engineers, subcontractors, and users. The contractor's project manager recalls:

"…The first thing we chose after we were hired was mechanical and electrical engineers and from there, we went right into the subs…"

"…We involved them [major specialty trades] in conceptual… [before GMP was set]. The GMP was set on 8/5 and we had chosen them in March…"

The early involvement of the downstream stakeholders provided the opportunity for collaboration in order to standardize the process and save money. A member of the drywall subcontractor, a project's subcontractor, states:

"Brought on in March (6 to 8 months before being on site), we held weekly meeting with the architect and it was very helpful. It was their first time in that branch to have them that early to help create a design that saves money using framing and hanging input."

2.2.4. Alignment of Commercial Interests

Different parties in a construction project usually have different interests and come to the table with different priorities. An important prerequisite to a full extent of collaboration is aligning the different parties' interests and getting them to follow the project interests rather than their own interests and to take the ownership of the project. In this project, a variety of contractual and organizational measures (such as shared contingency pool, integration, etc.) were taken to facilitate alignment of interests among the parties. As a member of the architect's team states:

"...the interesting thing about this process is, what's unique about IPD is, you manage the core team with three parties, manage the entire project not our component budgets so we're collaborating on the construction cost. All the other soft costs are owner's medical equipment costs.... so we're all on it together. We all succeed. If anyone of them fails we all fail. So, there is a lot of trust in the process and there is a lot of incentives to make sure each of us is successful, where if someone has difficulty we would need to help them overcome that difficulty so we can succeed as a team...

The general contractor's project manager points out the role of owner in aligning the interests and states:

"...There were a lot of talks about commercial interests. There's a lot of talk about getting everybody focused. You know, IPD came out of Lean Institute and...the owner follows the Toyota production system and the Toyota way and that's about harnessing this human energy, focusing it as to what's going on and so, they're focused on the patient experience and patient safety and that draws everybody in. So, they're incredibly aligned and they pull everybody else's alignment into that. So, they are able to get more out of their building because everybody is focused on that. There was focus and motivation... and the fact that we take as much money as we saved...."

There is also the discussion about alignment of interest with the subs. Many of the specialty trades were involved in conceptual design (in March) before setting GMP (in August). There was a design assist contract with mechanical and electrical subs, lump sum design build with fire protection sub, and a guaranteed maximum price, GMP with gypsum wallboard subcontractor."

In interviewing the drywall subcontractor we noted that there was about up to 2% of the contract amount of their GMP of shared savings. One of the main challenges was how to track their costs. It is different than traditionally done in their trade and there was a learning curve. In spite of this, the subcontractor felt that IPD is easier for everybody as compared to hard bidding. The shared monetary incentives were not that much important; but rather, the experience and opportunity and growth potential were the important thing for the drywall subcontractor. A lot of savings were not achieved because owner kept changing until last minute; so much of front work of planning of savings were not achieved because owner kept changing until last minute; so much of front work of planning was not fully utilized. However, working as a team with all subs allowed them to develop a collaborative culture and to be flexible to adapt to changes by owner.

The benefits of the early team building work and financial alignment, enabled the team to leverage resources across the project for the benefit of the project as a whole. Once the interests were aligned, the project parties could show more flexibility in, and even be open to, going beyond their traditional work scope for the benefit of the project. An example of this was the architect's positive response to contractor's request of providing elevation drawings for every interior wall in order to optimize the positioning of construction components (such as studs, etc.) which required additional work on architect's side but lowered the uncertainties of the work on contractor's side.

2.2.4.1. Shared Contingency Pool for Key Project Parties

The key project parties were not tied in this project by a standard AIA Integrated Form of Agreement (IFOA). However, the owner had its own contractual agreement that was used on that project. There was a shared contingency pool which incentivized performance of the core team in reducing the risks and uncertainties associated with the project and thus, encouraging on-time on-budget delivery of the project. The shared contingency pool addressed risks, mistakes, errors, etc., excluding the future changes by owner and its value was about 1%, which was available through the entire course of project from early design.

2.2.5. Communication in Design and Construction

Delivery of construction projects requires efficient exchange of a great deal of information among various professionals and stakeholders to support project decisions. Diversity and intensity of these information call for establishment of various communication platforms and tools in order to transfer information from one party to the other. Integrated events and construction site were two major platforms for communication in this project.

The owner held several integrated events during schematic design phase which brought together various project stakeholders including their clinical and support staff, design team, construction team, etc. In these day-long events, the architect set the vision and outlined a conceptual program for the project and then, project parties broken into several cross-functional teams which worked together and brainstormed in order to define the project scope and provide several alternatives to meet the project program. An architect's team member recalls:

"... [in integrated events,] they go through brainstorming where the staff could imagine anything they wanted, what would be the ideal state, what's the most benefit of it. "

"...we worked with clinical staff, they were part of these processes, you break them in the teams, the cross functional teams that not always are together. It is not that surgeons are on one table, nurses on one table, and designers on another table. You bring in cross-functional teams that represent each one of those areas. And different tables are needed to work on their own and you need to come back to compare those and vote on them and then you'll look at the principles and you continue to narrow it down....And, it was not also just the clinical user and us, the architect, we had also the general contractor that was there...So parts of it is that they are including IT vendor who was there. The clinical engineer who fixes the medical equipment is there. Pharmacist is there. The lab technician is there. Everybody is there. Because it's all about patients not about my role but just about patients so we went through all these different events."

Integrated events were an effective means for designers to collect information from all parties and achieve a democratic definition and design of the project. Traditionally, the outcome of design process is communicated to construction site through design and construction drawings. Construction site, however, works under a different culture and language from that of a designer's office which often requires interpretation of the information or frequent requests for clarification of designer's drawings. BIMs significantly helped project teams overcome this challenge and achieve a shared understanding of project. We describe later in section 3.4.1 in further detail how BIMs contributed to the success of this project. In addition to the BIMs, the leadership of project managers and foremen at site location and their availability to subcontractors and workers played a major role in facilitating communication on construction site. Project team members stated:

"...We look at probably, I would say, 10 years ago, you start to pull in, the larger the job, the foreman started to get away from the job over to a job office or a job shack. 20 years ago, he was at the field trying to get it done with the paper work and the procedures and policies. You put more and more pressure and more and more work on the admin side for your foreman that pulls him away from the field and puts him in a job site office. After, you know, 10 years of that, we're realizing that we need him back in the field, if we can figure out where is the happy medium so let's get rid of the paper let's go digital, let's get him on demand access to RFIs and let's get his awareness and the crew's awareness that he is right there around the corner working with them, you don't have to stop what you're doing to look for him or to go get him or walk here to get that, let's keep him there with the information at his fingertips and that's where we're moving towards..."

"…Paperwork and safety requirements and everything is so much more demanding. The only way to be successful, what we're seeing make you happier being successful, is to keep our leadership of foreman in the field and have that access around their boots so they can still be a part and lead the project instead of being pulled to so many different directions away from that, and having to have a foreman in the project but then have your lead have to leave the project to go to talk to him and print out something or go back to the crews. It takes ways from your leadership…"

"This seems like a simple one, I know almost everybody's name on this job. The single most important thing that I did was focus on talking to the guys [on construction site] by their name and communicating with them."

The tools and IPD contract framework was only meaningful when leaders throughout the organizations acted with and upon this framework.

3 VALUE-ADDING ACTIVITIES

Increasing the value to the client is at the center of most industries. This is a complex value proposition in construction where the client is a multitude of project stake holders from owner operators, to end users, to facilities managers, to tax payers, to pedestrians and they may have conflicting obligations and expectations for the project. Construction industry is therefore moving towards life-cycle thinking that encompasses end users, facilities and operations, as well as first costs.

Koskela (1992) is the first study focusing on value and value-adding in construction. In an attempt to describe lean philosophy, this study shows that there are two aspects to any production; a) a conversion aspect which deals with processing of materials/ information, and b) a flow aspect which is represented by inspecting, moving and waiting (Koskela 1992). While the activities associated with both aspects are cost- and time-consuming, this study indicates that only conversion activities, such as assembly and disassembly, are value-adding, with value defined as "fulfillment of customer requirements" (Koskela 1992). Therefore, the flow aspect should be improved to eliminate non value-adding, or waste, activities such as inventory storing, waiting, etc., that are not modeled in Critical Path Models or other models used for controlling of the activities (Koskela, 1992). Construction industry, too, is moving toward increasing design optimization and reducing the construction waste activities, which are caused by a) rework (as a result of the errors in design or construction), and b) non value-adding activities that occur in material and work flows, such as waiting and inspection (Koskela, 1992).

According to Graham and Smithers (1996), some of the construction waste that could occur during various stages of project development include:

- **Design (design changes, errors in drawings and details),**
- **Procurement and material handling (improper storage, shipping/ordering error, improper handling),**
- **Operation (human error, equipment error, labor, accidents and weather),**
- **Residual (leftover, etc.), and**
- **Other (theft, vandals, etc.)**

The project team took several measures in design and construction phases to ensure reduce/eliminate the waste (non value-adding) activities and maximize the value to the client.

3.1. Value-Adding in Design by Optimization

The single most important value to the owner in this project was to provide the best service to the patient. Also, it was important to generate maximum possible revenue from the spaces, without compromising the patient. The project team, therefore, tried to test various design iterations (Figure 1) in order to optimize the design with respect to service to the patient, flow of staff and patient movement, the floor area of revenue-generating spaces, and construction costs. A member of the design team recalled that the team was able to reduce the ratio of admit/recovery rooms from 3 to 1.5 per procedure room

A design team member stated:

"it was honestly one of the most difficult things was to determine how many admit/recovery rooms because there is limited spaces so there is a balance of procedure rooms that they make money for us. Recovery rooms are just to make it functional and so it took them months and months to figure out exactly that they could make half the normal amount of the typical recovery rooms to work and we were substantially good into the design before that decision was finally made that this is the number of rooms."

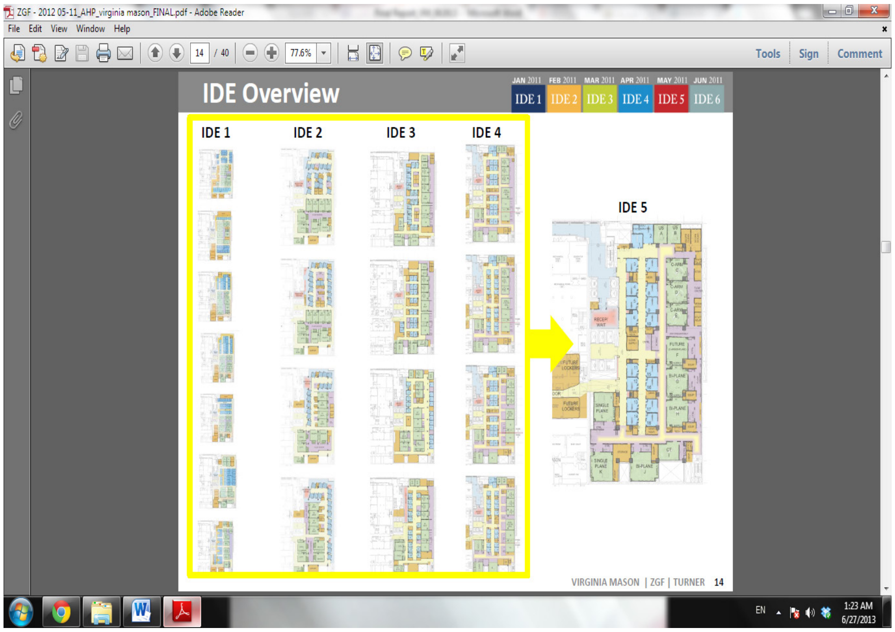

Figure 1. Various design iterations.

In the meanwhile that various design iterations were being generated and tested, a cost model for the entire floor was constructed by the project team in three 16-hour sessions. The cost model included detailed specification information for all spaces and their components (doors, frames, finishes, etc.) along with their associated costs.

The cost model provided helpful early information on how the costs changed with design iterations. The owner in this way was able to make decisions based on more tangible information.

Finally, various design iterations were ranked in order to select the final design alternative for the configurations of spaces:

"[Different iterations of plan] were ranked by clinical staff, not mostly us….So,…at this point, we were looking at the floor plan from the macro level, you know, the overall aggregation of procedural rooms and the recovery bases and the flows, movement between those but then also we were looking from more micro-level and carrying different options with different configurations of recovery bases and we were testing those different sets of configurations."

In this process they had one area that was not designed until the very end. They kept it blank worked around it developing more detailed designs in other areas. This meant that some areas were at DD where another area was still at earlier design stages. The team was enabled to think creatively about design development and did not feel pressured to develop the entire design to an equal level of detail throughout.

The outcome of this process was tested through a full-sized physical plywood mock-up, after which the design underwent major changes. The final design was a scheme with most of the spaces designed to be multi-functional. For example, some rooms were flexible to function as a recovery and preparation space, or procedural space could accommodate various types of procedures, depending on the time of the day and number of patients.

3.2. Value-Adding in Construction by Coordination Planning

As mentioned before, non value-adding activities in construction, such as inspection, waiting time for materials, etc., are major sources of waste. Reducing this type of waste primarily requires high level of coordination and planning of interdependent tasks that are inherent in the construction processes. Pull-planning sessions supply chain management, and visual controls are three great examples of maturity of coordination efforts in this project.

3.2.1. Pull-Planning

Pull techniques and team planning (i.e., interactive scheduling) are used to develop schedules for each phase of work, from design through turnover. The phase schedules thus produced are based on targets and milestones from the master project schedule and provide a basis for lookahead planning. A pull technique is based on working from a target completion date backwards, which causes tasks to be defined and sequenced so that their completion releases work. We found that the pull planning process contributed to not only generating reliable work flow but also to team collaboration. The general contractor held pull-planning sessions regularly throughout design and construction phases. These pull-planning sessions, which started in the early design phase with the involvement of the subcontractors, attempted to understand subcontractors' working processes and the critical elements in these processes and thus, to identify the type and timing of the decisions to be made by the owner as well as the team. Early pull-planning sessions provided the owner and the team with more time for making decisions.

During construction phase, pull-planning sessions were held weekly and outlined the tasks to be performed, responsible subcontractors, and the timings of the tasks. General contractor's project manager recalls:

"...We had it every week....It was 4.5 months so I had a master schedule and I kind of did a one piece flow. So, I made a master schedule of exactly what we were going to do and actually we turned over on April 13th so we were right in what we had initially done. So, I put together a master overall, because you gotta have some sort of framework on what you're gonna do and then the thing I like to do is to have everybody comes with the card already on....they do the initial one of what are the steps of the work that you're going to do so they come to that prepared, then we look at what the interaction is gonna be and from that we generate a one-week or three-week plan..."


Figure 2. Pull-Planning sessions were a platform for management and coordination of activities.

3.2.2. Supply Chain Management

Supply chain management is applied in construction to regulate the interactions of suppliers and the construction site and to ensure a reliable and timely supply of materials, equipment, etc., to the site. The general contractor's project manager in this project relied primarily on UPS and FedEx to manage the supply chain. Although potentially being more costly, UPS and FedEx gave the project manager the ability to monitor the flow of materials from supplier's facility to the construction site, track the delivery, and thus, coordinate future tasks accordingly in a more reliable way. In this way, the wastes in the process and the costs associated with them could be reduced.

After the purchased materials, equipment, etc. arrived on site, photographs of the delivered materials were taken for records and an email was sent to the relevant subcontractor with that regard so that subcontractors could coordinate their work based on that. The project manager describes his experience with this regard:

"...I had lights that were late, manufactured, taking four days to get from Ontario to Renton and another four days to get it from Renton to my site. This is absolutely unacceptable and that was something that happened all the time. And with UPS, we could track pieces coming from across the country and I could have an email half an hour after it hit the dock and know that it is actually here. So, we got to the point where a team member was taking a photo of everything that came down when they came in so I had a record of it. But the thing is that he sent me an email of who from it [the UPS delivery] came, and a video record of the time and the date stamped on that. And, that email actually went to subcontractor to signal them that there's stuff that are coming down and it's ready to be moved into the place. Because I'm trying to get to the point where everything is [like placing] concrete, two hour after it hits the job and it is in place. What's interesting about the his story was that there was one place that we used technology to help communication. The team member didn't feel like his voice is being heard, it was some of his frustrations, so I said it's ok you email me all the time, he was frustrated because the guy didn't show up with on the schedule deliveries. So, I said [he can] just type out on the schedule deliveries or whatever it is and send me the picture because I don't have time to go out there all the time but I have all the stuff, so I say ok [to the team member] thanks for the info. Immediately, his kind of emotional anxiety level dropped because he felt like he was heard. And I ended up having much better information."

3.2.3. Visual Controls

Visual control provides information to guide everyday actions. The general contractor utilized visual controls in a creative way to effectively and efficiently convey information and coordinate work. This was obvious in three examples. First, the GC created a visual room, where the subs used colors on the walls to show the drywallers that other trades (e.g. MEP trades) are done with their work and installations, so they can go ahead and install drywalls. This effective coordination and communication process minimized errors and rework.

Second, the GC was utilized xyz coordinates extracted from the BIM to support installation. E.g., as a means to convey the needed information, they used color coded paints on the ground to identify where steel sections should go on the ceiling.

Besides contractors need to be sensitive to the needs of their workforce. In this project, the GC used signs with larger font because of eye sight issues with some older laborers on site.

Figure 3. Using colors to show the work of a certain subcontractor was done.

3.3. Value Adding in Construction by Standardization

Standardization is defined as “the extensive use of processes and components with regularity, repetition and a background of successful practice”(Gibb et al, 1999). Egan (1998) identifies standardization as a way to improve construction processes and Gibb (2000) believes standardization brings efficiency, effectiveness and performance benefits. Lean theories in construction prescribe standardization of processes and components for increasing predictability and value-adding in construction through reduction of variability. Indeed, process and component standardization moves the construction industry towards manufacturing-oriented philosophies which tend to be more efficient than construction with respect to meeting costs, schedule and quality targets. Moreover, standardization increases the predictability and reduces the uncertainty that surrounds construction working processes.

'Repeatability', 'existence of pattern' and 'variability reduction' are major elements that the project parties highlight as examples of standardization:

General contractor's project manager: *"…I define standardization as taking a process flow chart, analyzing present state, looking at future state, and utilizing at standard process amongst a group of people and focus on improvement through perfect execution.…It has to be repeatable and that could be an object also. This is really about pattern. You know, I think building is about pattern recognition. Every object is implicit pattern of actions so if you figure out what the pattern is, you know, it is fractal based. I think that is the simplest way to look at.…"*

A subcontractor: *"…it would be scope of our work that is repetitive; repetitive in the sense that it is the same size, the same approach, the same SOP (standard operation procedures), the best way to identify standardized item is identical or very similar [in] nature and the best way to do it is the same over and over and over.…"*

The case-study's project team applied both process and component aspects of standardizations in various phases of project delivery. Process standardization was a characteristic hidden in the way the owner, architectural team and contractor or construction trades practiced their own work. When asked about how they applied standardization in their work, the architectural team members believed that standardization could not take place in the architect's work as each project has specific characteristics that does not allow repetition of a process.

An architectural team member: *"…For our design production,… we don't set that one thing fits all, we have very low standardization in what we do. We're very iterative.…There is actually no standard of work to the point where every element we cover is identical. We tailor our work around with client's functions…"*

Another member of architectural team, however, pointed out that architectural design is a standardized process in itself:

"…in the beginning our process is very globalized. Then you need these functions, you need these many rooms, how big the rooms are and how adjacent to each other. The next step is what is in the room, how's that room shaped, what do you think you need in the room and why do you need it to be in there and then we're going through how many outfits do you have, how do you like the lights switched, what would be here in the cabin, we're getting deeper and deeper into details so that process for us is somewhat typical for almost any job, no matter big or small. It is just within that that it'll expand or contract based on complexity of the job, whether it needs extra construction…and those kinds of things. So, we do have a degree of standardization in that perspective. But we're not restarting every time a new process. We just kind of adjust our process based on what our next project is. We don't build standard because every project is unique but our process is somewhat standardized and you have to adjust process to fit that unique project…"

Even though architectural design attempts to respond to unique characteristics of each project, it can still apply standardization. An example in the studied project was the standardization of room layouts so that working processes of clinical staff, such as care-givers, nurses, etc., could be standardized. A member of architectural team recalls:

"...we did an attempt to, in design side, to standardize so every room is basically the same layout, from the patient care perspective and operational perspective. A nurse care-giver can walk into any room that they knew it is always the same thing in every room, it is in the same location,...the mechanical gas has its own valve box and the electrical panel in the same location outside the door. Switches were always in the same location so it didn't matter where you work...We did a lot of that with them to allow them to do the standard work."

Similar to architectural practice, process standardization on the construction site can occur as a result of inherent standardized nature of the construction trades:

Contractor: *"...most of the stuff when you break it down to small enough, it's a repeatable task. We repeat them every time. If you think about taping, going back to drywall, the majority of the time, in the drywall you're repeating the same thing; you're laying out, putting a framing up, you're covering it with the rock, and you're taping it. And that doesn't change..."*

However, standardization of processes in this project happened in a more explicit intentional way as well, by standardizing and simplifying the working processes that involved several trades in order to deliver and install a component. Here are four examples:

- **Tagging and organizing studs for delivery and installation:** The quantity and dimensions of studs in this project were determined using the BIMs and were ordered pre-cut to length. Indeed, 95% of the studs used in this project were precut to length when delivered to construction site. Since studs and their bundles were in different sizes, a challenge was to identify which of the studs goes where. To overcome this challenge, the studs were grouped at vendor's facility by wall/room and packaged in bundles which had been designed to fit the dimensions of the special carts that carried them within the site. These bundles were tagged and labeled so that studs could readily be assigned to their right intended location on construction site. Finally, the studs were lined up in the intended room based on the direction to be installed in and the position of penetration holes and were placed evenly in previously marked locations.
- **Hanging and taping:** Taping drywalls is a process that costs more than hanging them. Therefore, taper's work should be reduced by optimizing hanging process. In the studied project, unlike traditional practice, the person responsible for hanging did not figure out the best way to do the hanging so that joints are minimized or to do the measurements for cutting and spacing the board. Instead all the information needed for his work was provided as written on the studs' flange and he could rely on the information for doing his job.

- **Elevation of the walls to optimize stud placement and drywall layout:** Despite variations of rooms in a building with respect to room size, room layout, position of the column, etc., the architect traditionally provides the general contractor with the elevation drawings of the walls for only a typical room as well as the plan of every space. These elevations are then used and interpreted by contractor to figure out the elevations for the other rooms and a way to construct them. In this project, the general contractor asked architect to provide them with the elevation drawings for every room so the contractor can optimize the stud placement and drywall installation. For example, while the typical board size to be used in drywalls is 40" by 8', in this project, pre-cut boards of 54" by 10' were applied for drywalling in order to reduce the needed seams and cuts. The wall elevations also helped the subcontractors with showing the position of electrical outlets, IT outlets, etc. These elevations were proved to help the construction team to have more controllability, reduce uncertainty and assemble faster as a result of elimination of some seams, cuts and jointing.
- **Labor Motion Minimization:** As contractor's project manager stated: *"They try to minimize unnecessary motion by labor. Every 240 ft is a $1 waste for laborer who costs $60/hr. So, they optimize locations even of water coolers".*

Component standardization, on the other hand, took place at both the macro and micro levels in this project. At the macro-level, as previously mentioned, rooms were standardized with respect to their layout, position of outlets, etc., so that the working processes for clinical staff and patients are improved and standardized. At the micro-level, the following elements were standardized:

- **Integrated ceiling assembly**: In this project, all operational components that are used in a typical room, such as ductwork for air diffusers, overhead lights and sensors, IT devices, etc., were assembled as a single integrated ceiling and installed at location. While an integrated ceiling assembly costs more, it resulted in coordination saving and reduced the installation time from 3 weeks to 2 days and in this way lead to cost saving as well. These cost saving could not have been identified if it was not for the close coordination between the design and construction teams.
- **Imaging equipment:** The imaging equipment is expensive and sensitive to deflection and movement. Inthis project, a universal suspended system was chosen to be used but its components were brought down a shaft and assembled and put it in place in 15 hours.

3.4. Tools Used for Value-Adding

Various tools were applied in this project in order to maximize the value to owner. These tools included application of BIMs, mock-ups, process flow charts, 3D laser scanner, mobile workstations and Quick Response (QR) code scanner.

3.4.1. BIM for Design/Construction Simulation

BIM has been around in the construction industry for nearly a decade to provide not only geometric 3D data about a construction project but also other information such as the quantity of materials, insulation values, etc., which can be used over the life-cycle of a project for various operational and maintenance purposes. Furthermore, BIM is being widely used to support effective coordination among trades in the pre-construction and construction phases.

In this project, a BIM for the project was prepared early on in the design phase. To prepare the BIM, engineers and architect relied on Revit while subcontractors worked in AutoCAD MEP. AutoCAD MEP, however, could operate in Navisworks used by the construction team but not in Revit. To tackle the interoperability issue, the contractor asked subcontractors to draw in Revit. The BIM was used for different purposes. Two examples of these purposes include the following:

- **Wall elevations plot:** The BIM was used to plot the walls in full scale needed for the mock-up construction as well as construction of the actual project. Wall elevations plot included details such as medical gas outlets.
- **Stud measurement:** The length of all studs was determined using the BIM. As previously mentioned, the studs were then ordered precut to length from vendor which were then brought to the site and placed in intended location (Figure 4).

Figure 4. The precut studs were stored in their intended locations.

Project team members believed the BIM contributed to the success of project by giving the team more controllability, reducing the risks, reducing the number of change orders, and making estimating more effective. The GC project manager states:

"...We use that [the BIM] to identify...the best way to do that so the guy in the field doesn't have to think. If we can use information upfront that we have available to us through the drawings or estimates or the BIM or the model....when you have the crew out there, if we can remove those hurtles and remove their questions so they show up and they go to the work, that's where everybody's most beneficial..."

3.4.2. Mock-up for User Behavior Simulation

After a conceptual design was completed for the project, the team decided to simulate the design by a rudimentary mock-up which was built in the 6th floor of the building. Indeed, every wall was plotted out in full scale using BIMs and every room and passage way of an entire floor were constructed out of plywood panels without complete details in just two days (Figure 5). Then, two teams consisting of users (clinical staff) and project team were walked through various spaces. In the space, nurses, physicians, and administrative staff, were asked to simulate behavior of the patients, family members and service providers. An architectural team member highlights the benefits of this:

"…So, what's the benefit for this? Healthcare construction is extremely expensive. Healthcare providers have a difficult time reading through 2-dimensional drawings and what we were driving here was, we were integrating them as three different departments. They're doing process improvement at the same time to reduce waste, reduce costs, to get value out for the patients and this process made them integrated as a team. They got an understanding as a whole about the right operational model, the right functional aspects of the relationships, and right processes and now, you know, one of the best things I have ever heard was when the scope processing manager walked into the scope cleaning room and said this is exactly what I wanted it built, what I asked to do. And, what you get in their buy-ins is the reduced amount of complaints that this is not what I wanted. Which means that you don't have to change it…"

The idea of simulation using a mock-up was very helpful. After the design was tested with the aid of users, it was decided that it should undergo major changes to be more efficient with respect to walking distances and the working processes of the users.

3.4.3. Process Flow Chart for Value Identification

The construction team used a process flow chart to categorize each activity into value-adding or non value-adding. Once an activity is identified as non-value adding activity, a collaborative effort was made to minimize or eliminate the activity. This was very similar to value stream mapping process in lean and contributed to standardization and waste-eliminating process.

3.4.4. 3D Laser Scanner

3D laser scanning was used to provide the BIM with information of the existing building including floor waves, vertical alignment, pipework layout, etc. This information was later used in the construction phase for various purposes such as preparation of the floor for imaging equipment installation and so forth. Using laser scanning, for instance, it was realized that the concrete floor level is inconsistent and varies in its finish floor level as much as 2”. Since the placement of the medical equipment needed to be precise, more accurate floor leveling with thicker topping slab was provided in needed spaces to support installation of the equipment. In less critical spaces, a thinner topping slab was used in order to save the costs.

3.4.5. Mobile Workstations

To facilitate the access of subcontractors to reliable and up to date information in the construction site, several mobile workstations were provided on site (which is called Turner Information Kiosk (TIK)) equipped with the BIM in Navisworks. These workstations were used by the trades and workers to get information such as dimensions, etc. Indeed, every effort was made not to leave any information missing or subject to interpretation.

General contractor’s project manager: “…One of the goals of this project was to provide perfect information at the point of attachment. Taking the analogy from the auto industry, when someone on the assembly line puts a component on the car, they have all of the information they need – the screw holes are predrilled, the piece fits and the holes show how it attaches. They do not need to measure. Same with the drywall tapers and concrete finishers – they have all of the information they need to do their job visible in the materials they are working with….”

3.4.6. Quick Response (QR) code Scanner

QR code scanners were used on the construction site to support supply chain management. More specifically, the QR code scanner contributed to track the flow of materials so that responsible subcontractors could have reliable information for taking their next steps.

Figure 5. QR code scanner was used for tracking the flow of materials’ information.

4 CHALLENGES

The path to IPD and standardization in this project was not without challenges. Some of the major challenges are discussed below.

4.1. IPD Challenges

Two particular challenges with IPD were found in this project. The first one deals with legal contract. In construction projects, participants and their attorneys naturally try to minimize the liability and, therefore, less integration is generated among the project parties. Serious efforts are needed to achieve a contract that is both satisfactory to all project parties and compliant with IPD principles. It took the parties in this project 2 years to finalize the legal contract, while the project itself lasted 6 months. This indicates that, since the IPD is in its relative infancy, participants should plan to invest significant amount of time and resources to draft a good contract. As IPD gets more and more common, future projects will have more ready-to-use templates to adopt.

The second challenge is a cultural issue and refers to the resistance of industry to the IPD and its associated changes in practice. The contractor's project manager states:

"When we sent out the RFP, we sent out a checklist on lean so we asked a set of questionnaires. When we did the interviews with the subcontractors, our partner contractors, we talked with them about lean and how do they work, how is gonna work this job, who is on the team, and what's the company's philosophy… there was one company that we didn't go after because the superintendent obviously wasn't interested in listening in anything that project manager was talking about during the interview…"

4.2. Standardization Challenges

When asked about the challenges to standardization, the project team members highlighted three major issues:

Mentality and resistance
General contractor's project manager: *"…Communicating the vision to change the behavior, that was the biggest one [i.e. the biggest challenge] because people don't see, once [you] go down this pathway, your role changes, your perspective changes. People think standardization is boring…"*

General contractor's project manager: *"…The problem is that they [workers and trades] create so much variation that you can never keep track of it and then their frustration level gets really high. If I let one guy get out of it [i.e. standardized process], then he starts to disrupt the whole process.…"*

Immaturity of the practice with respect to standardization
This issue refers to the negative impact of other stakeholders' working practices on a standardized process or components. An example, as raised by the general contractor's project manager, was the impact of inspection on stud assembly:

"….one time we actually talked about stud assembled either at electrical engineer's factory, or you know, shop or the stud contractor shop and the other trade would go to that shop and put their work in and then the question is how do we get the inspector to go out and see it to get approved? How to get that done? And so, in the end, they chose not to face the issue yet. At some point, we're gonna figure out how to make that work but we're not quite there yet. So, they chose to do it on the floor as opposed to a remote location."

The need to adaptat to new practices
An example of this need was brought up by the drywall subcontractor when referring to the need to adoption of new costing practices that are needed for optimization:

"That was one of our biggest, I would say, struggles but our learning curve was the approach of tracking the cost on job. We were not set up like in a typical MEP trades where we job cost everything or a general contractor job cost everything across the board and then they negotiate a fee. It is not how we operated in the past and it was a challenge for us to kind of set up that way. We did it and it was fine. It was just a learning curve for us."

5 FINDINGS

The key findings of this project, which either confirm the existing theories or develop new hypotheses to be tested, can be summarized as below:

- **Confirmation:** Integrated project delivery (IPD) brings a team mentality to a project and results in higher levels of collaboration and more value to owners. In IPD projects, participants value relationship building and open communication more than costs.
- **Finding:** In this project, the integration of the architect and general contractor in a team as early as the proposal and selection process proved to be a key factor in establishing collaboration among project parties.
- **Confirmation:** Design decisions should be based on early reliable information from all parties including users, engineers, contractors, and subcontractors.
- **Confirmation**: Integrated team events in the design phase with the involvement of all project stakeholders have the potential to establish collaborative norms and generate an integrated team culture.
- **Finding:** An important criterion for success of a construction project is maximizing value to client. In this project, the goal of collaboration was to increase value-adding by design optimization, pull-planning, and standardization. This unified focus of collaboration helped to streamline the efforts of participating parties.
- **Finding:** Architectural spaces in this project were optimized in their layout, design, flow of users, function, and systems so that the best service to patient is provided and at the same time revenue-generating spaces are maximized. This could only be possible by the deep and early involvement of all AEC stakeholders and key team players.
- **Confirmation:** During construction, the pull planning process reinforced collaborative norms through discussion of interdependencies and obligations.
- **Finding:** Onsite mobile workstations (BIM kiosk) facilitated communication and the access of construction team to reliable information; and in this way extended the collaborative culture and the pull planning discussions into the field.
- **Confirmation:** Process and component standardization gives more predictability and controllability to a construction project team and thus, reduces the risks to various parties and improves quality. Also, it leads to significant cost and time savings and added value to client.
- **Finding:** BIMing should be developed by modelers with sufficient construction expertise. According to the general contractor's project manager, mechanical unions are more successful with respect to BIMing because their BIMers are usually people with field experience.
- **Finding:** No information has to be left to interpretation on construction site.

- **Finding:** In this project, construction processes were optimized to minimize the flow of construction laborers on site.
- **Finding:** The leadership on site should be maintained by keeping the foremen onsite (as compared to being consumed in administrative work in their offices) and facilitating the access of the construction crews to them.
- **Finding:** Delivery of materials and equipment should be optimized so that they could be readily assigned to their intended location of installation. In this project, the application of a tagging system for bundles of studs and organizing their penetration hole facilitated the installation of studs.
- **Confirmation:** Handling time of materials on site is a non-value adding activity that should be reduced by optimizing the flow of materials.
- **Confirmation:** Lean which was extensively applied in this project resulted in high levels of value-adding in design and construction. Pull planning, process flow charts, work simplifications, etc. are some examples of Lean tools applied in this project.
- **Confirmation:** More upfront planning reduces the risks and uncertainties, increases predictability and diminishes rework and waste as non-value.
- **Finding:** Resistance of the industry, immaturity with respect to new practices, the need to adoption of new practices, and the contractual issues are the major challenges to achieving IPD and standardization.

6 ACKNOWLEDGEMENT

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