Understanding the Benefits of BIM/Lean/IPD framework when carried-out simultaneously

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Abstract: As a response to an increasingly growing complexity in construction projects, more sophisticated and advanced project delivery methods are being emerged to make the construction process more efficient, productive, and reliable. The methods have evolved from the more conventional methods of design-bid-build, design-build, and construction-manager-at-risk into what are known as Lean Construction (LC), Building Information Modelling (BIM), and Integrated Project Delivery (IPD). In theory, the application of such advanced methodologies provides improvements in the construction process, but recent research studies have reported their ineffectiveness when they are used in isolation. This paper aims to review the benefits of using BIM/LC/IPD framework when used simultaneously. The research begins with a comprehensive review of the literature and then adopts a Qualitative Comparative Analysis (QCA) methodology to study two building cases in the USA and Canada. This is the conclusion of this paper that the application of BIM/LC/IPD framework not only improves the project performance but also results in various advantages. The outcome of this research study is relevant to the companies who are considering implementing these methods, via the use of results to better perceiving and navigating the studied methods and to think about changes in the construction sector.

Keywords: Building Information Modelling (BIM); Lean construction (LC); Integrated Project Delivery (IPD); BIM/Lean/IPD.

1. Introduction

An efficient pathway from design to final product has always played one of the most important roles in the construction project's success. Today, information exchange is a key issue facing the evolution of the construction industry. The complexity of solutions and standards for producing better buildings is increasingly in demand, and the need to manage more and more risky projects with multiple stakeholders, often, become problematic concerning deficient communication management throughout the whole process caused inefficiency and low workers production (Otero, 2014).

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As occurs in other economic sectors, the technologies and the best working methodologies, together, should continue to be important allies to overcome the newly introduced complexities (Jiang, 2011). However, the construction industry is often recognized as a tough sector to change its culture and to implement innovative processes to overcome the historical hurdles. This is worrisome as the benefits of improved practices would be a factor to transform the industry into a more coordinated, competitive, and interoperable sector (da Mota, 2015).

Some construction companies have already used different tools, processes, and contractual bonds that tackles the miscommunication among the stakeholders. In this study, we address three innovative approaches, Lean Construction (LC), Building Information Modelling (BIM), and Integrated Project Delivery (IPD), which improve the quality in the construction projects, increase their performance, and eliminate weaknesses of current project delivery systems (Fakhimia et al., 2016). For visualization and design intentions, BIM has emerged as the appropriate solution leading to the digitalization of the construction industry (Tarrafa, 2012). LC proved its value in maximizing work productivity and reducing wastes in terms of time and cost (Sacks et al., 2010). Likewise, IPD is commonly regarded as the most valuable solution regarding the firms contributing to configure integrated organizations and sharing risks and rewards in the project (Fischer et al., 2014).

1.1. Problem statement

The application of LC, BIM, and IPD methodologies provides improvements in the construction process, but recent research studies have reported their ineffectiveness when used in isolation (El. Reifi and Emmitt, 2013; Neff et al., 2010). In addition, as several tools and protocols are being developed and applied, understanding and integration between them can be a complicated process. Methodologies that were supposed to be delivering optimized outcomes using innovative tools, appeared to have discrepancies between the theory and the practice.

Therefore, several studies have already tried to address the synergy between the aforementioned approaches using a bi-dimensional view, sometimes with IPD and BIM (Kahvandi et al., 2017), BIM and LC (Sacks et al., 2010), IPD and LC (Cheng and Johnson, 2016). IPD enabling the use of the virtual design and construction projects (refer to BIM) are already showing advances in large projects. LC and a continuous improved and integrated organization agenda have also been demonstrating significant achievements. But not a lot of studies have looked at the intersection between all the three ofthem.

There is a great potential for considering the trilateral collaboration of LC, IPD, and BIM methodologies simultaneously (Nguyen and Akhavia, 2019). A detailed analysis of such a combination is, however, critical to measuring the outcomes. To this end, we address the following research questions:

(1) Are there any potential benefits from using the BIM, IPD, and Lean methodologies simultaneously in a construction project?

(2) What lessons can be learned from the building projects that already use the BIM/LC/IPD framework?

1.2. Research structure

The paper is organized in Section 2, which reviews the concept of IPD, BIM, LC, and their application in the construction industry via exploring the relevant literature in these areas. Section 3 provides a short presentation of the research methodology, data collection, and analysis. In section 4, through the study of two construction projects, the paper investigates the real impact of the shift to BIM/LC/IPD

framework, and how it fosters collaboration as well as enhances the performance of the project in broader perspectives. Section 5 presents a brief conclusion and directions for further research.

2. Literature review

Innovation in the construction industry can take many forms, including changes in project delivery, collaboration, and product improvement. Three of the trending concepts in the construction industry have proven to be highly value-adding and forward-thinking approaches (Ashcraft, 2012). BIM is a concept made up of four key elements: collaboration, representation, process, and lifecycle, in which all interact to generate efficient information management within a digital model, forming a reliable basis for decisions throughout the building life cycle (Bradley et al., 2016).

While LC creates the possibility to achieve improved outcomes of the final product, considering the economic, social, and environmental aspects of the building (Fischer et al., 2014), its operating system seeks to reduce inefficiencies, wastes and maximize the values perceived for the client, from the significant advance of workers' productivity to the final quality of the product (Sacks et al., 2010; Jaaron and Backhouse, 2012).

Likewise, the IPD based on a single/multiparty construction contract agreements is the way of tying the multiple participants towards the goals outlined in a collaborative environment (Gilligan and Kunz, 2007). The jointly shared risks and rewards among the stakeholders, who are essential to developing a sense of commitment and collaboration, increase communication and creativity and reduces litigation costs (Ashcraft, 2012).

2.1. BIM/LC/IPD

From a construction perspective, the effective and efficient usage of BIM technologies is best accomplished by utilizing mechanisms that foster principles of collaboration and continuous improvement of the daily activities on site (Ghaffarianhoseini et al., 2017).

Similarly, IPD needs to benefit from advanced techniques, including BIM and LC practices collaboration (Ashcraft, 2012). The integration requirement that can be effectively accomplished by BIM implantation to achieve better decision-making and remove its implementation barriers to deliver high-performance buildings (Azhar et al., 2014; Kamari and Kirkegaard, 2019). In contrast, Cheng and Johnson (2016) explore the powerful complementary strength of IPD and LC to support success. They conclude that IPD sets the terms and provides the motivation for collaboration, and LC provides the means for teams to optimize their performance and achieve project goals. Figure 1 illustrates the three components of IPD process and how BIM and LC are incorporated to achieve its success.

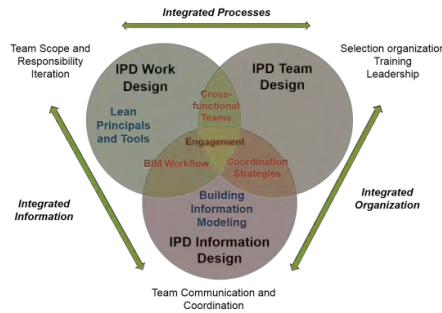

Figure 1: The three key components of the IPD process and their synergy with BIM and LC (adapted from Ashcraft, 2012)

Fakhimia et al. (2016) argue that IPD, BIM, and LC should play together complementary and synergistically to provide more pragmatic and effective solutions to complex project issues. Nguyen and Akhavia (2019) evaluate this synergy in terms of cost and schedule performance measures. The results have shown considerable effectiveness in terms of schedule performance, while the effect on cost performance was not as significant. The collaborative supply chain management could significantly enhance the proper communication (Lostuvali et al., 2012) to decrease the number of conflicts, enhance the design and construction process efficiency, reducing errors, and assuring cost and time optimization (Mesa et al., 2019). On the other side, some companies, with the help of scholars, are running projects and studying their results to measure the final productivity of projects by trying the elements together, to harvest improvements in the future (Hyatt, 2011; Hunzeker and Selezan, 2015).

Added to this, we conduct a Qualitative Comparative Analysis (QCA) in the following two successful projects to understand in more detail how the BIM, IPD, LC framework enhances the construction industry performance. The two building cases' analysis facilitates exploring and comparing different process changes and outcomes to gain new insights.

3. Methodology

The aim of this paper is to fill in the current underlying research gaps of incorporating IPD, LC, and BIM together. A Qualitative Comparative Analysis (QCA) methodology is used from (Ragin, 1987, 2000) as an effort to thoroughly assess and compare two real building projects to consider where and how the use of BIM (Kamari et al., 2018a,b,c), LC, and IPD can result in changes in the construction process. The QCA methodology is often undertaken when there is not sufficient data to consider a case study statistically, but when the richness of the information about each case allows powerful and compelling stories about the likely causes for desired outcomes to be told (Ragin 2000).

The comprehensive comparative analysis is conducted through using five categories from the study by Cheng (2015) and Cheng and Johnson (2016), including Overview/Context, Commercial Strategies, Leadership Strategies, Logistical and Process Tactics, and Building Outcomes. Moreover, these categories are further divided into 19 criteria to cope with the complexity of BIM/LC/IPD framework focus (see Table 1), and enables us to carry out the case studies in a structured and systematic manner to provide both a comprehensive view of the cases and comparison between them, with a set of defined variables. The 19 criteria are defined from past studies that analyzed the features of collaborative construction processes on using Lean, IPD, and BIM (Cheng 2016; Chudasma 2019)

Table 1: Criteria Categories (source: adapted from Cheng, 2015; Cheng and Johnson, 2016)

Overview/Context				Commercial Strategies				Leadership Strategies				Logistical & Process Strategies				Building outcomes		
Project overview	Project timeline	Team organization	Owner identity	Team selection	Contract selection	Process methods	Conflicts resolution	Champion	Decision structure	On Board - Off board	Team collaboration	Resources/Facilitations	Processes and Tools	Workplace environment	Technology	Profit/Payout	schedule	Achieved Quality

Two real-world projects were selected to conduct the comparative analysis.. The two projects have been executed using BIM/LC/IPD simultaneously, they were perceived as particularly suitable for offering relatively new practical and theoretical perspectives on the topic. The projects are located in two different countries (USA and Canada) where BIM, LC, and IPD methodologies are widely adopted by many companies. The data are collected from previous studies, published reports, technical magazines, and online services.

4. Case study

In this paper, two study cases are presented. The first case is the construction of the "Akron Children's Hospital" in the United States, and the second one is a residential building, "The UBC Brock Commons" located in Canada. This section analyzes and explores the potential shift of the BIM/LC/IPD framework in the two projects, using the coding scheme, including the categories presented in Table 1. We explore the strategies, business models, and tools applied by the projects' teams in achieving the projects' success.

4.1. Case study 1: The Akron Children's Hospital (Kay Jewelers Pavilion)

The Akron Children's Hospital (Kay Jewelers Pavilion) is a new seven-story healthcare facility located in Akron, Ohio, USA. It is part of the Akron Children's Hospital complex expansion (see Figure 2). The project, of 33,910 sq.m. (365,000 sq.ft.), comprises of several facilities, distinguished by 75 private bed Neonatal Intensive Care Units and a labour/delivery centre for high-risk births. The facility was planned to be a flexible environment with expansion thoughts in the future. The rooms are accommodated to be possible to shift in multiple different configurations with little efforts. The project began in November 2011 and ended in May 2015, with a total cost of $180 million. The project is considered as an innovative construction; their goals were set to impact the local business community and achieved the LEED Gold certification through the implementation of LC and IPD together. The approach consists of selecting local and national companies to work together to transfer knowledge and build expertise in the local industry.

4.2. Case study 2: The UBC Brock Commons

The UBC Brock Commons is a timber and concrete certified 18 story student dormitory of the University of British Columbia, located in Vancouver, British Columbia, Canada (see figure 3). This project of 15,250 sq.m. is intended to accommodate university students, and accountable for providing studios and quads rooms with a total of 404 beds and public sharing spaces on the access and the top floor. The project began in November 2014 and ended in July 2017, with a total cost of $52 million. The project is considered innovative since it topped the list of the highest timber structure building on the date of its inauguration as well as obtained the LEED Gold certification. As the project required unusual means of construction, the search for specialized teams was crucial for the construction, even if the partners were from distant locations.

Figure 2: The front façade of the Key Jewelers Pavilion (Source: photo by Thorson Baker)

Figure 3: Aerial view of the UBC Brock Commons (Source: photo by K.K. Law)

4.3. Qualitative Comparative Analysis (QCA) results

In this stage of the research work, a detailed and holistic assessment of the use of BIM/LC/IPD framework was addressed according to the categories and subcategories introduced in Table 1. As such, we assessed and evaluated to what degree the contractual form, the process, and the technology employed were applied in each case. Table 2 summarizes the main characteristics and differences between the two projects, organized into the five categories, and focusing on how the projects were performed. Each category is described below.

Table 2: QCA results for the two building projects

Construction	Overview/Context	Commercial Strategies	Leadership Strategies	Logistical & Process Tactics	Building Outcomes
 Akron Children's Hospital	• New construction in Akron's Hospital site. • Project had multiple users group: hospital, staff, patients. • Deliver the building with maximum value, at lowest cost and meeting the quality requirements. • Additional goal: build expertise for IPD and lean to all participants.	• Integrated project delivery contract. • Full wrap insurance to support collaborative behavior. • Pairs of national and local: architect, contractor, MEP engineer and MEP contractor. • Incentive pool shared tied to metrics achieved by each team stated in contract.	• Owner as an IPD and lean champion • Involvement of trade partners in design decisions. • Decentralized, transparent and group decision making. • On-boarding with lean boot camp and multiple workshops. • Fast off-boarding process. • Freedom for teams to negotiate and exchange scope between them.	• Personality profiling of human brain dominance indicator. • Lean tools: Target value design, CBA, A3, First run studies, located based scheduling, weekly meetings, PPC, daily huddles, visual metrics, plus/delta, video documented action, big room • BIM: BIM execution plan, 3D visualization, clash detection • Monthly satisfaction surveys • Full size mock-ups	• Profit and payout achieved with money saved to make improvements. • Delivered 2 months ahead the schedule. • LEED Gold label. 38 % energy reduction from national average. • User's satisfaction were 94% met. • Met safety goals. • Low punch-items rate.
 UBC Brock Commons	• New residential construction on UBC campus. • Minimize the duration of construction so that students could move before the semester starts. • Design with strict fire prevention measures. • Limited space on construction site • Additional goal: Be the tallest timber building at the time of construction.	• Construction management at risk. • Innovative timber solution incentive in the contract. • Risks and conflicts managed by the project manager. • Team selection based on expertise of the team in timber structures. • No incentive pool.	• BIM and timber design champions. • Centralized decisions but collaborative approach. • On -boarding with a 3-day workshop to identify constraints and solutions for construction. • Maintenance of the stakeholders until the end. • Scope of participants remained unchanged until the end.	• VDC company integrating all projects in one model. • Lean tools: Just-in-time, weekly meetings, work standardization, first run studies, extensive pre planning. • BIM: BIM execution plan, facilitation meetings around the model, clash detection, 4D simulation, quantity take-off. • Pre-fabrication • Full size mock-ups	• Budget achieved based on market expectations. • Delivered 2 months ahead the schedule. • LEED Gold label. 42% energy reduction to reference building. • High productivity: 2 floors constructed each week.

- Overview/ Context Variable:

The two projects had cost and schedule aspects governing the paths to be taken during the process. They both recurred to unusual, innovative construction methods and processes to achieve sustainability and user's satisfaction goals. Thus, the projects were risky from a traditional standpoint. For Akron Children's hospital, a clear budget limit to be followed was a real challenge and set a solid case to seek

integration, with the user's inputs, and LC process for the project stakeholders to improve the construction materials and processes. For UBC Brock Commons, since it had incentives for using timber elements in their structure, there was greater concern about the duration time and compliance with the code requirements of wooden buildings. In both projects, the level of pre-planning and defining the constraints in early stages fostered in a collaborative structure that allowed them to better control time, quality, and safety in advance compared to traditional projects.

- *Commercial Strategies Variable:*

The first important point to note is that the projects had different construction contract agreements. Akron's Hospital used the IPD format, and Brock Commons used the Construction Management at Risk contract. After the choice of the delivery schemes, the rest of the commercial strategies were all based on features and enhancements supported by the best practices for each setting. IPD enabled the use of the incentive pool and, with an innovative proposition, made the hospital client go for full wrap insurance for the project. That solution boosted the collaborative environment of the participants. For the Construction Management at Risk project, the strategy was to use the knowledge and the experience of the owner's project manager to keep a closer track of the process. Interesting to the latter project is that even with a clear central leader, there was a collaborative environment due to the level of innovation required to develop the timber structure solution, which needed frequent inputs from the project teams.

- *Logistics and Process Variable:*

Since the first day, the two projects have used continuous improvement techniques. The use of this resource is imperative as the process is innovative, where the learning takes place. In Akron's Children Hospital, LC principals and techniques have been incorporated to improve the design and construction as well as to find the bests trades to be part of the team. As mentioned earlier, the approach taken in the construction did not have clear leadership, and, while the process was advancing, the role of the leader was changing from phase to phase. This factor was one of the reasons that the owner resorted to making a personality profiling test to reveal the leadership preferences of the teams. Satisfaction surveys during the project were a useful tool used for obtaining feedback and taking necessary steps to keep the project running in the right direction.

In the UBC Brock Commons, the use of BIM had a central role in assessing the decisions and facilitating the participants' work. At first, the project had one model integrating all the disciplines. Then, a VDC (Virtual Design & Construction) company facilitated the BIM work by merging all the design projects. Through BIM, the accomplished simulations and details enabled the use of just-in-time delivery and prefabricated elements on the construction site.

- *Leadership Strategies Variable:*

Both projects used some sort of mentoring during the process. Due to the different strategies that fit better in each of the end owner's goals, Akron Hospital invested time in introducing the IPD and LC practices to the team project. At the same time, the Brock Commons training focused mainly on timber and VDC solutions. For the first project, the decentralized decision-making provided more flexibility for the teams to change leadership's role during the process. There was also an opportunity to trade the scope between the firms inside the risk and reward pool. On the contrary, each firm in the second case

has defined roles in the process. The teams discussed and agreed upon the solutions during meetings coordinated by BIM and the mock-up model. After that, each team had a clear job to do.

- *Outcome Variables:*

The projects were considered successful, as the set goals were achieved. Building sustainability was one of the crucial success factors, and the energy performance was attained, ensuring the projects LEED gold labels. Due to the construction contract agreements nature, profit was more important in the Akron Children Hospital, since there was a fixed budget from the beginning. The companies could have the opportunity to improve their fixed payout with a variable payment related to deliver the project in a lower budget and accomplish all the success metrics. UBC Brock Commons anticipated the building completed within the market expectations cost, although it was almost impossible to use benchmarking from past projects to know how much the product would cost since such an innovative solution did not exist. Another satisfying outcome was the shorter time spent in the implementation of various activities.

The two projects similarly utilized almost half of the whole process time in the phase of defining and concluding the design buildings. This strategy was successful as the construction time of the two projects was reduced by two months. The thoroughly preplanning in the Akron Hospital Project shown positive direct results on the amount of punch list items, the safety during the construction, and the user's satisfaction. For Brock Commons, it was an opportunity to make the prefabricated timber construction feasible and accelerated.

4.4. Discussion

Figure 4 demonstrates the relative graphical positioning of the comparative assessment of the BIM/LC/IPD framework adoption in the two projects. The figure indicates that the Akron's Children Hospital project has attributed considerable importance to the commercial strategies by developing the IPD contract and the willingness to transfer knowledge to the team participants. On the contrary, the emphasis of the UBC Brock Commons project was on the facilitation of the construction progress using design modeling and simulation techniques.

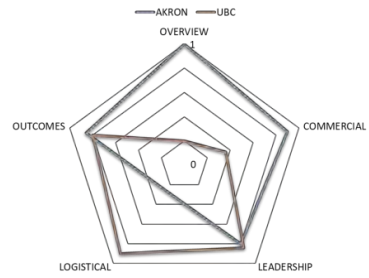

Figure 4. The relative graphical positioning of the comparison assessment outcome of the BIM/LC/IPD framework adoption on the two building projects

5. Conclusion and future study

The adoption of BIM/LC/IPD methodologies already demonstrates substantial improvements in the construction processes in response to the growth of stakeholder's motivations and the building performance. They are often used in isolation, as the BIM/LC/IPD framework has not been widely utilized together. To this end, a comprehensive literature review and practical case studies were carried out. The findings indicate that the use of BIM/LC/IPD simultaneously can improve the effectiveness of these methodologies compared when they are used individually. This synergy improves mostly the communication level and team collaboration during the whole construction process. The collaborative

environment is crucial to decrease the number of conflicts, enhance the design and construction process efficiency, and the time and cost spent on the construction phase are also lower than initially planned.

More specifically about the studied cases, it can be concluded that the applicability of IPD during the pre-planning phase was verified so as to a mean of selecting the project participants, gathering the stakeholders and discussing the best alternatives during the design phase, and during the construction to foster the involvement of the trades to help plan the next construction steps. Likewise, LC tools were used to choose collaborators and target the value streaming process during design and construction processes. Besides, BIM was mainly used in the design phase but also served as support for construction activities. Despite the fact that both of the cases used different types of contracts, they succeed in obtaining proper results regarding team collaboration; nevertheless, the IPD agreement of the Akron's Children Hospital was more a safeguard to stimulate it. On the other hand, the guidance and the leadership that the owners provided to the participants was crucial for the team culture building.

There are other aspects that may have contributed to the success of the projects and influenced the building outcomes, but they are difficult to assess since the research specifically focused on qualitative issues from the construction process perspective. It would be interesting to measure the BIM/LC/IPD framework implementation through quantitative studies, polls, and more comparative studies in different regions. However, the results of this study can be of particular value for construction companies who seek the shift into the BIM/LC/IPD framework in the future via using the resultant to better perceiving and navigating the studied methods and to think about changes shortly in the construction sector.

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