Using Building Information Modeling (BIM) and the Last Planner System (LPS) to Reduce Construction Process Delay

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USING BUILDING INFORMATION MODELING (BIM) AND THE LAST PLANNER SYSTEM (LPS) TO REDUCE CONSTRUCTION PROCESS DELAY

A Thesis
Presented to
The Faculty of the Department of Architectural and Manufacturing Sciences
Western Kentucky University
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Master of Science

By
Zaid Al Hussein (Al Mamoori)
December 2016
USING BUILDING INFORMATION MODELING (BIM) AND THE LAST PLANNER SYSTEM (LPS) TO REDUCE CONSTRUCTION PROCESS DELAY

Date Recommended 10/31/16

Douglas Chelson, Director of Thesis

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Dean, Graduate School  11/17/16  Date
I dedicate this thesis to the souls of my parents and to my family members, brothers and sisters. Also, I would like to dedicate this thesis to my lovely wife, Zahraa Kamal Aldeen to whom I am grateful for her help, patience and support, and to my wonderful children, my son “Mustafa” and my daughter “Rub” for relieving my stress and making my life happy.
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USING BUILDING INFORMATION MODELING (BIM) AND THE LAST PLANNER SYSTEM (LPS) TO REDUCE CONSTRUCTION PROCESS DELAY

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Directed by: Dr. Douglas Chelson, Dr. Daniel Jackson, and Prof. Shahnaz Aly
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The construction industry suffers from many practical problems and challenges; most being related to construction management. One of the most common recurring problems in construction projects is delay. Delay is a primary factor that can have an effect on project duration, scheduled delivery date, as well as the overhead cost of the project. This study investigated the problem of delays in construction projects. The research focused on the combination of Building Information Modeling (BIM) and Last Planner System (LPS) together to measure the execution time of construction projects. The aim of this study was to determine whether using BIM and LPS together affect construction process delay differently than using BIM or LPS alone. The methodology of this study relied on data collection through administration of survey questionnaires to key players and participants at construction companies. Interviews were conducted with construction experts from four construction companies that used BIM and LPS individually in their system as case studies to verify and validate the findings. The outcomes of this survey will be helpful to construction practitioners to reduce delay in construction operations and to shorten projects duration.
Chapter 1

Introduction

Today’s construction industry suffers from many practical problems and challenges. Most of these are a result of poor construction management (AlSehaimi, Koskela, & Patricia 2014). The most common and recurring problem is delay in construction processes. Assaf and Al-Hejji (2006) defined delay as “the time overrun either beyond the completion date specified in a contract, or beyond the date that the parties agreed upon for delivery of a project” (p.350). Delay negatively affects both owners and contractors. Owners can lose revenue because they are not able to use their buildings to produce goods or provide services as scheduled. Delay can cause contractors to lose money because of an increase in overhead costs of a project and by increasing the labor costs and the duration of temporary facility maintenance (Assaf & Al-Hejji, 2006).

Delay in construction projects is usually related to two dimensions: project management and project environment. The project management factors are inefficient planning and control, poor communication between the project’s participants, inefficient site management, and unreliable availability of materials, etc. Project environmental factors are labor shortages, problems in supply material, and financial problems, etc., which are related to the economic status of a project (AlSehaimi et al., 2014).

In an attempt to improve the practice of project management, some past studies adopted the Last Planner System (LPS) or Building Information Modeling (BIM) individually to test their effectiveness on the development of the practice of project management. Few studies have focused on using (BIM) and (LPS) together in the
construction industry to reduce variation in workflow and improve project-planning workflow in the design and construction phases (Bhatla & Leite 2012; Sacks, Koskela, Dave, & Owen, 2010). Sacks et al. (2010) and Eastman et al. (2011) hypothesized that implementing LPS and BIM as an integrated framework, as they are in the Integration Project Delivery system (IPD), can achieve the full potential of improvement for the construction project. Also the American Institute of Architect expressed the same notion when documenting on Integrated Project Delivery (IPD), “Although it is possible to achieve Integrated Project Delivery without Building Information Modeling, it is the opinion and recommendation of this study that it is essential to efficiently achieve the collaboration required for Integrated Project Delivery” (Esteman et al., 2011, P.300). Moreover, Lukowski (2010) stated that construction companies can take advantage of these two tools to reduce lead times and delays as well as introduce sustainability improvements in a construction project.

The LPS is a powerful lean construction system that works to manage the construction process, stabilize the workflow, and monitor efficiency planning. It has four levels of planning and scheduling that are master scheduling, phase scheduling, look-ahead planning, and a weekly work plan. In addition, the metrics tools, Percent Planning Complete (PPC) and root causes analysis are used in the planning process to analyze incomplete assignments. Figure 3 shows the planning activities that are conducted at each level of these four levels. Implementing these five integrated elements systematically in any construction project could increase the project reliability, and improve the workflow as well as the safety and work quality (AlSehaimi et al., 2014; Ballard & Howell, 2003).
Figure 3 planning stages in the LPS (Hamzeh & Bergstrom, 2010).

BIM is a creation and coordination tool that works in conjunction with lean thinking to increase the collaboration among participants in the entire project life cycle. It enables the end users to attain control of the project processes through visualizing the project components and processes. In addition, it contributes to reducing project duration and cost through collecting digital information about construction projects. This information can include cost, schedule, fabrication, maintenance, energy, and 3D models (Lukowski, 2010).

**Problem Statement**

The research problem of this study was delay in the processes of construction projects. For many decades, delay has been a common problem in construction projects. Past studies identified ineffective planning and control as common causes as well as the
other causes related to project management such as poor site management, labor shortage and productivity, material supply chain and procurement (AlSehaimi et al., 2013& 2014).

Furthermore, in attempting to improve management practice and eliminate or reduce construction process delay, some previous researchers applied BIM or LPS individually in their studies. However, the result was not significant because each one of them could eliminate a certain percentage of delay. For example, Alsehaimi et al., (2014) completed two case studies consisting of two governmental construction projects in Saudi Arabia and reported that time was reduced by 50% when LPS was implemented properly.

Chelson (2010) presented eight BIM case studies including various sizes and types of construction companies in different areas in the US and reported that time was reduced by about 9% when BIM was implemented. In addition, Parvan (2012) reviewed a sample of data consisting of 30 construction projects, some of them non-BIM projects and the others utilizing BIM. The one that utilized BIM reported the following statistical information: 30% time reduction in design process, 10% time reduction in construction process, and 16% time reduction in an entire project.

Applying BIM and LPS together in this research contributes significantly to solve most of construction process delay and reduce project duration. The strong synergies between BIM and LPS could enhance management practice and could improve planning and control systems (Chelson, 2010; Sacks et al., 2010).

**Significance of the Research**

The findings of this study will be significant to construction companies in the sense that it will determine whether the application of BIM and LPS will have any
positive effect on the execution time of construction projects. This involves the application of BIM and LPS and the potential effects on project duration. In addition, the findings of this research can be helpful to general contractors (GCs) and practitioners in the construction industry such as contractors, subcontractors, engineers, architects, and superintendents to help them to improve project planning and control as well as reduce the project duration and cost.

**Purpose of the Research**

This thesis aims to determine whether using BIM and LPS together affect construction process delay differently than using BIM or LPS alone. The methodology of this study relies on data collection through administration of survey questionnaires to key players and participants in construction projects and conducting interviews with construction practitioners as case studies to verify and validate the findings. The outcomes of this study will enable the construction practitioners such as contractors, subcontractors, project managers, engineers, and architects to control the construction operations of projects and reduce the duration, cost, and conflicts between participants.

**Hypothesis**

Implementing BIM and the LPS together in construction projects would lead to reduced project duration and enhance project delivery through reducing delay in the construction process. The author expected significant reduction in project time and delay when using BIM and LPS in concert.
Assumptions

- The construction companies that used BIM were familiar with it, which means they utilized their own trained staff and had used BIM to complete more than two projects.
- The construction companies that used LPS were familiar with it, meaning they adopted LPS in more than two completed projects as well as have experienced and trained Last Planner and other staff who were involved in the process.
- All members and sponsors who participated in the lean construction website were more likely interested in using BIM because it enhances lean practice.
- All the data collected from the construction companies through the survey was accurate.

Limitations and Delimitations

The scope of this research was limited to implementation and evaluation of BIM and LPS together in construction projects. Due to time constraints, the author conducted a random selection of construction companies that use BIM and LPS. In addition, the study was limited to the survey response and responder knowledge. The outcomes of the analysis were then generalized to the other construction projects.

The author focused on one kind of delay called procedure delay that is related to the level of planning and plan details provided by management. Moreover, it was limited to the different types and sizes of construction companies that use BIM and LPS. It was also limited to the survey response and the responders' knowledge. In addition, the author has selected the United States to conduct the survey study.
Chapter 2

Review of Literature

This section includes four sections. The first section discusses the lean philosophy history, an overview about the LPS including planning levels, principles, constraints, Percent Planning Complete (PPC), and challenges and barriers. The second section presents BIM’s definition, importance, benefits, challenges and barriers to implementation. The third section discusses delays in construction projects and causes of delay that could affect project performance, time, and cost. The fourth section discusses the interaction area and the synergies between LPS and BIM.

Lean Theory

Womack, Jones, and Roos were the first people to introduce lean thinking into the automotive industry; John Krafcik, a researcher with the International Motor Vehicle Program (IMPVP), discovered the lean production concept. Then Eiji Toyoda and Taiichi Ohno of Toyota Motor Company implemented the concept of Just in Time (JIT) in manufacturing industry. JIT focuses on eliminating waste and creating value for the customers through understanding their needs, the amount of these needs, and the time frame of these needs (Liu, 2013).

Thereafter, in the 1990s, Glen Ballard and Greg Howell modified and adjusted the lean manufacturing concept and implemented it into construction industry. Liu (2013) defined lean construction as “the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream, and pursuing perfection in the execution of a construction project” (P. 31). Each construction project
had objectives to accomplish a high level of quality and safety while using less time and money. In order to achieve these objectives, it required a reliable management system for managing effectively all the project resources such as equipment, labors, material, money, and time, etc. Howell and Ballard discovered that the lean production system is the best way to manage all construction project activities and resources effectively and meet all the aforementioned goals (Liu, 2013).

One of the lean production tools studied was LPS. This is a powerful production control system that could be utilized to stabilize workflow, reduce variations and the amount of uncertainty in the construction operations, and improve work productivity (Ballard, 2000).

**Last Planner System**

Ballard (2000) defined the Last Planner System as a production control system derived by someone (individual or group) in the field who assigns work directly to the crews and decides what specific work needs to be accomplished in a sequence in the future. Ballard and Howell developed this system to improve construction workflow by reducing variation in construction operations, enhancing project planning and scheduling, and reducing the level of uncertainty in construction operations. In the beginning, LPS only tracked the development process of the project through weekly work planning; thereafter, it was expanded to include other planning levels such as master scheduling, phase scheduling, look ahead planning and weekly work planning. Figure 2 shows all these four planning levels and how activities were broken down across these levels from phases (boulders) to processes (rocks) then operations (pebbles).
In addition, there were metric tools associated with this system such as Percent Plan Complete (PPC) and root causes analysis which were used to measure and evaluate the reliability of the work plan through comparing the percentage of tasks completed to those planned at the weekly work plan level. These measurements also were used to find how to gain advantages from breakdowns. Furthermore, PPC is beneficial to measure the extent to which the commitments are kept and to predict the future workload (Ballard, 2000; Hamzeh & Bergstrom, 2010).

LPS also has some principles. Ballard, Hammond, and Nickerson (2009) stated these principles in their research paper:

- Plan in detail as far as the workable assignment dates allows,
- Involve the people who are responsible to achieve the work in the planning stage,
- Make workable assignments by identifying and removing all constraints as a team,
- Be reliable by ensuring the quality of the work plan according to coordination with the team,
- Gain advantages from breakdowns through analysis root causes and taking preventative action.
Figure 2 LPS planning mechanism (Hamzeh, Ballard, & Tommelein, 2012)
In addition, LPS added new production components to the traditional management model as shown in Figure 3, and changed the traditional management term of what SHOULD be done into what CAN be done with the commitment of the LPS (Project manager, foreman or someone else) to what WILL they actually do from the weekly plan assignments (Ballard, 2000).

![Figure 3 LPS & traditional management model (Adopted from Ballard, 2000).]

**Should-Can-Will-Did.** In the planning process, the Last Planner decides what work needs to be accomplished, in what sequence, how long it could take, and what resources have to be used. This procedure leads to direct physical production known as “assignments,” these assignments are commitment (WILL) to the other people in the
organization that result in stabilizing workflow. Figure 4 shows the LPS sets up commitments (WILL) to what has to be done (SHOULD) within constraints of CAN.

Selecting assignments from workable backlogs has general rules such as selecting activities that CAN be done. The observation by Last Planner for this rule of work selection results in avoiding variation and uncertainty in workflow and reduces non-productive time that can demoralize workforce and make them less willing to overcome the obstacles and challenges (Ballard, 1994&2000).

![Diagram](image)

*Figure 4 LPS model (Ballard, 1994&2000).*

**Milestone schedule (Master schedule).** Hamzah, Ballard and Tommelein (2012) defined master schedule as a front-end planning process that produced a schedule describing work to be carried out over the entire duration of a project. It involves project-level activities and identifies major milestone dates and long lead times items mostly in relation to contract documents and the owner’s value proposition. Usually the master plan is established from either historical data of previous projects or it depends on average productivity rate; it includes 20-30 tasks (Seppänen, Ballard, & Pesonen, 2010).
**Phase schedule.** Phase schedule is an important component in scheduling activities. It is a link between work structuring and production control and makes work assignments ready to be executed. Furthermore, it breaks down the milestone schedule into manageable assignments with more details to be executed through the look ahead plan and weekly work plan. The benefits of phase scheduling are to maximize a project's value and set up the handoff between specialists who are involved in that phase to be achieved through production control (Ballard & Howell, 2003).

In LPS, the phase scheduling plays a big part in scheduling meetings. A pull technique used in this phase works backwards from the target delivery date so that tasks completion releases work. Sticky notes with the name and duration of items were used to carry out the phase scheduling meetings. The phase scheduling produces efficient scheduling and planning due to involvement of the specialists; they have knowledge and experience in the planning process and have advantages in knowing about availability and capability of the resources (Seppänen, Ballard, & Pesonen, 2010).

**Look-ahead Plan.** The Look Ahead Plan breaks down phase schedule activities into manageable and workable assignments and allows the work assignments to take place after removing all the constraints (Seppänen, Ballard, & Pesonen, 2010). It works on increasing workflow stability and reduces process variation. Usually the period of this plan covers two to six weeks in advance and it can produce several functions that can be accomplished through various processes. These functions include activity definition, constraints analysis, pulling work from upstream production units, and matching load and capacity. Figure 5 shows an example of look ahead form (Ballard, 2000).
**Figure 5** Construction look-ahead schedule (Adopted from Ballard, 1997)
**Weekly Work Plan (WWP).** This is the highly detailed plan in the LPS; it drives and controls the entire production process for one-week through the present and shows the ready to work assignments and their interdependence. Figure 6 shows the WWP form including activity name, the name of a person responsible to accomplish an activity, the number of days required for each activity, and the reasons for variance in scheduled work and uncompleted assignments. This plan works to shield the production unit by producing high quality work assignments and reliable commitments, thus reducing uncertainty in the work operations. All the assignments are measurable and presented in high details with the idea of making them easy to accomplish. Ballard (2004) mentioned that the quality characteristics of this plan ensure the work selection is in the right sequences, in the right amount, and that it can be accomplished.

The Percent Plan Complete (PPC) is used at the end of each weekly plan to measure the percentage of completed work in comparison with the planned work. In addition, it is used to review the reliability of the work plan by discovering the strengths and weaknesses and taking proper actions against the weak areas as a part of continuous improvement (Hamzeh, Ballard, & Tommelein, 2012).
<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>Est Act</th>
<th>Mon</th>
<th>Tu</th>
<th>Wed</th>
<th>Thurs</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
<th>PPC</th>
<th>REASON FOR VARIANCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas/F.O. hangers O/H &quot;K&quot; (48 hangers)</td>
<td>XXXX</td>
<td>XXX</td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>XXX</td>
<td>0%</td>
<td>Owner stopped work (changing elevations)</td>
</tr>
<tr>
<td>Gas/F.O. risers to O/H &quot;K&quot; (3 risers)</td>
<td>XXXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td></td>
<td></td>
<td>XXX</td>
<td>0%</td>
<td>Same as above-worked on backlog &amp; boiler blowdown</td>
</tr>
<tr>
<td>36&quot; cond water &quot;K&quot; 42'</td>
<td>XXXX</td>
<td>XXX</td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>XXX</td>
<td>100%</td>
<td>Matl from shop rcvd late Thurs. Grooved couplings shipped late.</td>
</tr>
<tr>
<td>Chiller risers (2 chillers wk.)</td>
<td>XXXX</td>
<td></td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td></td>
<td>20%</td>
<td>Matl from shop rcvd late Thurs. Grooved couplings shipped late.</td>
</tr>
<tr>
<td>Hang H/W O/H &quot;J&quot; (240'-14&quot;)</td>
<td>XXXX</td>
<td></td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td></td>
<td>100%</td>
<td>Grooved couplings shipped late.</td>
</tr>
<tr>
<td>Cooling Tower 10&quot; tie-ins (steel) (2 towers per day)</td>
<td>XXXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>70%</td>
<td>Some work in next week's sched. was included this week</td>
</tr>
<tr>
<td>Weld out CHW pump headers &quot;J&quot; mezz. (18)</td>
<td>XXXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>100%</td>
<td>Eye injury. Lost 2 days welding time</td>
</tr>
<tr>
<td>Weld out cooling towers (12 towers)</td>
<td>XXXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>60%</td>
<td>Eye injury. Lost 2 days welding time</td>
</tr>
<tr>
<td>F.R.P. tie-in to E.T. (9 towers) 50%</td>
<td>XXXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>XXX</td>
<td>100%</td>
<td>Eye injury. Lost 2 days welding time</td>
</tr>
</tbody>
</table>

WORKABLE BACKLOG
Boiler blowdown-gas vents
-rupture disks

*Figure 6 Weekly work plan (Ballard, 1997)*
Identify Constraints

Constraints are the issues that prevent work assignments from being listed in the weekly plan schedule. Each individual assignment has different constraints. These constraints are classified into technical constraints such as contract, design, materials, submittals, prerequisite work, resources, etc., and the official approvals, permissions, and inspections of the project. The front line supervisors and engineers need to work on these constraints within a suitable lead-time and finish them before the scheduled date of the tasks (Ballard, 2000).

There are various reasons the WWP might result in failure to complete the assignments. These include the conditions that the instructions and the information submitted to the Last Planner are not efficient and are incorrect, the planned work is too great (lack in assignments’ quality), failure in coordination of shared resources, temporary change in the workforce positions such as workers being reassigned to another task, and design vendor’s error.

Challenges and Barriers

Adopting LPS or lean philosophy in any project needs to come from the organization’s upper management and to focus on the people and their culture rather than on the equipment, tools, methods, and software. The culture the team members create is the major support for lean implementation in any organization. Usually, adoption of lean philosophy in any organization is confronted with some obstacles and challenges; therefore, some of these organizations have either failed or only partially achieved implementation of lean production system in their management (Manos & Vincent, 2012;
Hamzeh & Bergstrom, 2010). Successfully implementing LPS in any project requires teamwork collaboration, continuous improvement, an efficient and reliable plan for the project, and a fundamental change in the organizational culture and system (Hamzeh & Bergstrom, 2010).

Ballard et al. (2007) conducted several studies and interviews with some organizations who implemented LPS. These studies found that commitment and leadership in management and cultural and behavioral change are two of the most important factors that could affect successful lean implementation through contributing to create a sense of urgency in an organization; therefore, any resistance that might come from upper management and stakeholders could result in failure of lean implementation. Training also is an important factor that could help in implementing lean by establishing classroom training, so people could understand lean philosophy rather than just depend on learning by doing. Other factors are less important, such as enhancing partner’s lean capability, standardization, information sharing, contractual problem, and confusion with existing control system. Figure 7 shows all these factors and barriers in percentages.

Hamzeh (2009) and Hamzeh and Bergstrom (2010) stated there are two types of challenges that could affect LPS implementation in an organization. These challenges are related to two factors. Local factors are those related to the project circumstances and team such as lack of experience and skills in lean methods, traditional project management, lack of leadership commitment, and newness of LPS methods to the team members. General factors are those such as human capital, organizational inertia, and resistance to change, technological barriers, and climate.
Summary of an existing LPS case study.

Alsehaimi et al. (2014) studied the impact of LPS on improvement of construction management practice and reported some benefits. The researcher presented two case studies including two governmental construction projects in Saudi Arabia. These two projects were selected based on contractors’ history and success in the construction business market. Table 3 summarizes these two projects in terms of type, contract size, duration, and benefits. The benefits include the following: increase in PPC over the implementation period, which represents the improvement in planning practices, better workload planning, accurate prediction of resources, improvement of management practice, development of learning process, reduction in the amount of uncertainty, and increase in the collaboration between participants. The LPS implementation started from
short-term planning, which is a weekly plan and then progressed upwards. The focus was on short-term planning and make ready plan, and less focus was given to the look ahead plan. All the main participants in each project were involved in two weekly meetings such as contractor’s team, client representatives, consultant engineers, etc.

Table 1

*Description of the projects studied (Adopted from Alsehaimi et al., 2014)*

<table>
<thead>
<tr>
<th>Project</th>
<th>Contract (USD)</th>
<th>Duration (months)</th>
<th>Percentage of Time reduction after LPS implemented</th>
<th>Benefits</th>
</tr>
</thead>
</table>
| 1       | 21 Million     | 17                | 50%                                               | 1. Increase in PPC from 69% in 1st week to 86% in the last week.  
2. Enabling site supervisors to plan their workload  
3. Improving learning process  
4. Improving planning and control practice  
5. Enabling accurate prediction of resources  
6. Reducing uncertainty  
7. Preparing team members to collaborate |
| 2       | 10 Million     | 17                | 50%                                               | 1. Increase in PPC from 56% in 1st week to 80% in the last 5 weeks.  
2. Enabling accurate prediction of resources  
2. Improving planning and control  
3. Enabling site supervisors to plan their workload  
4. Improving site management  
5. Improving learning process  
6. Reducing uncertainty |
Building Information Modeling (BIM)

BIM is a tool used by designers, engineers, and contractors to present the graphics and database of a construction project to enhance the communication between all project stockholders (Krygiel & Nies, 2008).

**BIM definition.** Defining BIM is difficult because there are many definitions. For instance, Katez and Gerald (2010) define BIM as a “multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized facility” (p. 26). Meanwhile, Krygiel and Nies (2008) define BIM as “the creation and use of coordinated, consistent, computable information about a building project in design-parametric information used for design decision making, production of high-quality construction documents, prediction of building performance, cost estimating, and construction planning” (p. 27). Furthermore, Azhar (2011) defines BIM as “a modeling technology and associated set of processes to produce, communicate, and analyze building models” (p. 215).

BIM presents the development processes of a project through computer-generated models to simulate the planning, design, construction, and operation process of a project. Although the software is a part of the BIM process, BIM is not just a piece of software or an application among the architectural, engineering, and construction industry (AEC). The discussion about BIM refers to the methodology and the process that BIM creates (Krygiel & Nies, 2008).

BIM has created a new development revolution in the design and construction industry. Recently, it has become a dynamic mobile methodology for design and
documentation (Krygiel & Nies, 2008). BIM can carry out all the project information and graphics in an integrated database. If there is any change in a project component, it will affect other views of the model. The BIM model presents the actual building construction and assemblies and two-dimensional drawings (Azhar, 2011). Figure 8 shows a 3D external model for a commercial building design in Iraq presenting the final design concept and the finishing materials of the building.

*Figure 8 A 3D BIM model for a commercial building design in Babylon city- Iraq.*

**The importance of BIM.** BIM is a significant tool that is used by designers, architects, and contractors to manage increasing information and complexity in construction projects (Chelson, 2010; Krygiel & Nies, 2008).

During the last century, building design and construction has changed dramatically. Complex interrelated and integrated systems are now included in the building layers. For example, the modern office building became more complicated
because of new systems such as data and telecom, air conditioning, security, underground parking, sustainability, etc. Figure 9 shows some of these layers, which include structural design, architectural, and material quantities (Krygiel & Nies, 2008).

Figure 9 A BIM model shows some layers of an office building (“Autodesk Revit Training,” 2015)

**BIM advantages.** BIM is a methodology of continuous improvement and refinement (Krygiel & Nies, 2008). It has multiple benefits that can directly affect several important issues in a construction project such as quality, time, cost, and safety (Ningappa, 2011). The basic benefits of a BIM-based methodology are:

**3D simulation.** A 3D geometric model illustrates the exterior and interior building design, including all the components. This simulation illustrates different building assemblies that can be combined in the project and it can show environmental variables.
on building designs, calculate building materials, time, and quantities (Krygiel & Nies, 2008).

*Increase design accuracy and reduce errors.* BIM simulates building construction and design on the computer before the real construction activities start on site, which leads to increased accuracy and reduced errors for both building quantities and qualities. Furthermore, it enables the design team to calculate building materials and environmental variables on the job site in real time rather than by manual estimation (Krygiel & Nies, 2008).

*Increase drawing efficiency.* With BIM, the design teams can create the design drawing once instead of creating many separate drawings such as plans, elevations, sections, and perspectives. This can save time and enable the team to focus on other design issues and details (Krygiel & Nies, 2008).

*Reduce conflict.* The data in a BIM project can help a designer to investigate the compatibility of the components of a project and identify potential conflicts in a construction project (Madsen, 2008). Identifying conflicts on digital files before the construction activities start on site can save time. In addition, identifying pre-construction conflicts can help to reduce bid amounts and decrease the difference between bids and actual costs (Krygiel & Nies, 2008).

*Increase collaboration.* BIM increases the collaboration between design teams, engineers, and contractors and increases project efficiency by sharing BIM information, especially at the beginning of the design process in project development. For instance, contractors can review BIM models and report useful feedback to the design team and
engineers regarding any deficiencies that might have occurred. That feedback could help the design team fix the issues early in the design process. This would save money and time by avoiding potential delays that might happen if the deficiencies were discovered late in the construction process. Moreover, increased collaboration can reduce the number of change orders and requests for information (RFIs) that could lengthen construction schedules (Katez & Gerald, 2010).

**Reduce fabrication and estimation time.** Fabricators are able to get the detailed specifications directly from the BIM models. This saves time and avoids errors that might happen when these fabrication specifications are extracted manually. Moreover, prefabrication components are more likely to fit when delivered because of the accuracy of the visualization design and to avoid conflicts. Similarly, suppliers, when they need to extract material quantities, can extract them directly from the BIM model, thus saving time and avoiding project delays (Katez & Gerald, 2010).

**Life-cycle management.** A BIM model can be effective not just during construction time; it can be used during the whole life cycle of a project. The BIM model includes all maintenance information regarding building components. Facility owners can use this model to determine when they need to do maintenance and repair and how much it will cost. In addition, BIM models can be used to analyze the compatibility of any extension or development that might happen for a project in the future, and estimate the real cost for that expense (Katez & Gerald, 2010). The BIM model can also help in better understanding the environmental performance and life cycle cost of a project. Figure 10 shows the data base infrastructure generated by BIM that stakeholders can use.
Increase the efficiency of processes. BIM models can illustrate planned work between teams easily and quickly (Azhar, 2008). According to the survey conducted by McGraw- Hill constructions, more than 48% of the owners say that with BIM, the benefits are high due to the lower number of RFIs and site problems (Ningappa, 2011).

Figure 10 Communication, collaboration and Visualization with BIM model (Arayici, Egbu & Coates, 2012).

Data entry errors. With BIM models, contractors can avoid many errors and mistakes that might happen during computation data entry. There is no need to extract the data manually from the design model and enter it back in to another computer program in order to perform building code or LEED checks. BIM models can accomplish this task
automatically through comparing building components to the relevant building codes and energy efficiency standards (Katez & Gerald, 2010).

**4D capabilities make scheduling easier with BIM.** BIM models can visualize spaces in excellent 3D views. Another characteristic of BIM is that it can visualize the construction phases over time; this ability is called 4D (3D plus time). BIM is a helpful tool that can be used in visualizing the construction process and illustrating it to coordinate and communicate between the audience, teamwork, and stakeholders (Ho & Matta, 2009).

**BIM Disadvantages.** BIM is a newer concept, so it is still developing. Most of the contractors, engineers, and architects still need to increase their experiences with BIM in order to understand it well. They have some concerns regarding the use of BIM because there are some risks associated with its practice (Katez & Gerald, 2010).

The main concern is that BIM will raise the level of liability for contractors towards owners through blurring the line between design and construction. According to the fundamental principles of construction law, a contractor who makes a project design and documents is not liable to the owner for defects that might look back in documents and/or specification. This protection is known as the “Spearin Doctrine.” There is an implied warranty from the party who provides design documents regarding any defects. Contractors are becoming more concerned because BIM involves them in the design process and development. This will lead to undercuts in the implied warranty behind the design documents and weaken protection for contractors under the Spearin doctrine (Katz & Crandall, 2010).
Technology is also another concern. BIM has many different software programs and versions such as Autodesk Revit Architecture, Bentley Architecture, and the latest versions of Graphisoft ArchiCAD. Since there is no universal BIM file format, it is difficult to find any BIM software program that can import or edit file formats used by other software programs.

Recording and archiving the models are another concern. Many specialists can review and modify BIM models multiple times during the design process. In this case, any defects that might happen on the original model such as the architectural model will make it hard to pinpoint the person who made those defects (Katez & Gerald, 2010).

Summary of existing BIM case studies. Chelson (2010) studied the effects of BIM on construction site productivity and reported some significant benefits of BIM. The study examined eight BIM case studies and presented the benefits. Table 2 summarizes these case studies.
<table>
<thead>
<tr>
<th>Case #</th>
<th>Company name</th>
<th>Participants</th>
<th>Model Generation Tools</th>
<th>BIM related Tools</th>
<th>Analysis Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Target (Owner)</td>
<td>General contractor, architects and engineers</td>
<td>PointCloud3D</td>
<td>Conceptual design, 4D and 6D in some projects</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Layton Construction Company (GC)</td>
<td>Contractor, Subcontractors/Fabricator, engineers, architects.</td>
<td>Revit</td>
<td>Auto Cad</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Hunt Construction (GC)</td>
<td>Contractor, engineers, operators</td>
<td>Revit</td>
<td>NavisWorks</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Deffenbaugh Construction (GC)</td>
<td>Contractor, Subcontractor</td>
<td>Revit</td>
<td>US cost</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Helix Electric, Inc. with Turner Construction</td>
<td>Contractor, subcontractor, architects and engineers</td>
<td>Revit</td>
<td>NavisWorks</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Southland Industries (Mechanical Subcontractor)</td>
<td>Owner, contractor and operator</td>
<td>AutoCAD MEP</td>
<td>NavisWorks</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Kinetics Mechanical (Mechanical Subcontractor)</td>
<td>Contractor and owner</td>
<td>Total station</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Raymond (Framing/Drywall Subcontractor)</td>
<td>Contractor, Owner, engineer</td>
<td>Autodesk’s Revit Architecture and AutoCAD 3-D</td>
<td>NavisWorks for clash detection</td>
<td></td>
</tr>
</tbody>
</table>
These case studies indicated many BIM benefits; some of these benefits are:

- Decrease the number of RFIs from 50% to 100% compared to non-BIM projects. This represents significant savings in time and cost.
- Reduce the amount of rework significantly, thus reducing the change order time and speeding up the construction process.
- Decrease the frequency of change orders and costs due to the use of plan conflicts. Chelson stated, “Owners claimed that change orders on BIM projects are reduced to virtually nothing for field coordination issues” (p. 215).
- Involve all the contractors and owners in the design process earlier, as well as support the BIM expenditure as an integral part of design process.
- Enhance schedule compliance significantly. For example, Layton Company compared two similar hospital projects in California, one utilized BIM and the other, not. The one with BIM was 11% ahead of schedule, while the other was 8% behind schedule.
- Layton case indicates that when using the model, the process of achieving shop drawings is 60% faster than using 2D clash detection.

In addition, Parvan (2012) studied the impact of BIM utilization on project performance and indicated some numerical benefits. Parvan reviewed a sample consisting of 33 gathered projects, which represent the industry projects. This sample was divided into two categories: non-BIM and BIM utilized models. Performance indexes were used as an indicator to measure the BIM impact on the projects’ outcomes. It represents the
schedule performance index and the cost performance index. Table (3) shows these quantitative benefits.

Table 3

The impact of BIM utilization of Schedule PI and Cost PI (adopted from Parvan, 2012)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Schedule Performance Index (PI)</th>
<th>Impact rate</th>
<th>Cost Performance Index (PI)</th>
<th>Impact rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td></td>
<td>30%</td>
<td></td>
<td>8%</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td>10%</td>
<td></td>
<td>3%</td>
</tr>
<tr>
<td>Project</td>
<td></td>
<td>16%</td>
<td></td>
<td>4%</td>
</tr>
</tbody>
</table>

As noticed from the table, BIM has the highest impact rate on the design schedule (PI), which is 30% improvement. It has less impact on the construction schedule (PI) and project schedule (PI), which are 10% and 16% respectively. The cost (PI) indicates that the design cost is improved about 8% by BIM, while the construction cost and project cost are improved only 3% and 4% respectively.

**Interaction between BIM and Lean**

According to Sacks et al., (2010) there is a lack of research concerning the interaction between BIM and lean construction. The following paragraphs discuss the interdependence between these two terms.

A previous research concludes that using Computer Advance Visualization Tools (CAVT) in project design generates valuable advantages such as reduced waste, improved workflow, better customer value, and indicates the interdependence between
CAVT and lean construction. In addition, integrating lean construction processes with BIM, Visualizing Design and Construction (VDC), which represents BIM or aspects of BIM, enhances the lean project delivery process when implemented at the correct stages in a project (Sacks, Koskela, Dave, & Owen, 2010).

Although BIM and Lean can be adopted separately as indicated by several case studies in the past years, adopting Lean with little software support can be more efficient. Using BIM can achieve some lean construction principles as well as facilitate other lean principles. Usually the methods in which information is generated, managed, and communicated using drawings could result in extensive waste in construction. These wastes are results of inconsistencies between design documents, inefficient flow of design information in large batches, and long cycle time for requests for information, etc. Therefore, exploiting the strong synergy between BIM and Lean leads to improve workflow and eliminates wastes from construction operations (Eastman et al., 2011; Sacks et al., 2010).

A Sacks et al., (2010) presented a matrix consisting of 24 Lean principles and 18 functions of BIM and determined 52 positive interactions between them out of 56 interactions. Eastman et al. (2011) identified four areas of significant synergies between BIM and LPS, which are:

*Use of BIM reduces variation*

- Utilized to visualize design and evaluates function effectively.
- Generates alternatives design rapidly.
- Maintains all the project information and design model safely.
• Generates all the reports automatically.

• Reduces the rework amount and the time waiting for information by providing consistent results and reliable information.

*BIM reduces cycle time*

• Generates construction tasks automatically.

• Simulates construction process.

• Visualizes construction schedule in 4D model.

• All mentioned serve in reducing cycle times for construction operations through revealing process conflicts.

*BIM enables visualization of both construction products and processes*

• As presented in a BIM case study, the contractor’s model, designers, and the steel fabricator’s model were used at the site simultaneously to show detailed rebar installation and other plans that increased productivity.

• 4D animation is used to simulate and explore the process plans before and during the Last Planner System meetings.

• Integrated BIM systems with the supply chain databases are a strong method to provide signals to pull production and delivery of materials and product design information.

*BIM supports a number of lean principles in the design stages*

• BIM models can assist clients understand design intent better and enables the designers to perform better analyses.

• Improves information flows and requirements capture.
• The short cycle time for drawing production enables the designers to put more focus and spend more time on the conceptual design stages, allowing more design alternatives to be evaluated thoroughly.

• Prefabricates building parts and assemblies efficiently by reducing variation in product quality, process timing, and reducing cycle time for production and installation.

In addition, Bhatla and Leite (2012) emphasized the interdependence between BIM functionalities and most of the lean principles. The lean principles that have a unique interaction with BIM are reducing product variability through stabilizing workflow, achieving quality the first time, reducing production variability, improving the upstream workflow variability, and reducing project duration.

Implementing BIM and lean construction together in the construction process resulted in stabilizing workflow and communicating pull flow signals (Bhatla & Leite, 2012). For example, 4D CAD modeling stabilizes workflow and communicates standardized processes between workers. The project’s participants can get all the necessary information and details about the project by opening the BIM model that is available on the computer and reviewing all the drawing packages and necessary information. In addition, BIM aspects, which are 3D visualization, 4D CAD, and MEP clash detection, led to increased collaboration between the project participants, reduced uncertainty in project design, and assisted in just in time delivery of materials. All of these issues are lean construction goals. Therefore, BIM and LPS, when implemented together, work to filter the work packages to maturity to ensure stability.
Construction Delay

For many years, delay has been a common problem in construction industry (Alsehaimi et al., 2014). Ndekugri, Braimah and Gameson (2008), define delay as “any occurrence that affects contractor’s progress or makes it work less efficiently than would otherwise have been the case” (p. 693). Delay is inevitable in the construction industry due to high levels of uncertainty in the construction environment. Delay effects construction productivity, slows down the work progress, increases project time and cost, creates conflicts between project stakeholders, and possibly leads to abandoned or terminated contracts (Ndekugri, Braimah & Gameson, 2008).

Construction managers face many challenges while delegating resources (materials, equipment, and labor) to balance project time, cost, and quality. Managers can measure time delay in a project by comparing the actual time to the planned time, and this gives them a clear picture about project status. The tools that can be used to measure delay are static schedule techniques such as bar charts and dynamic scheduling techniques such as the critical path method (Al-Humaidi, 2007& 2010).

Causes of delay. According to Ndekugri, Braimah and Gameson (2008) delay is classified into various categories based on the interest analyst. The most common delay classifications are:

- A “Critical” or “non-critical” delay that affects the critical path of the project, thus affecting the overall project completion date.
- An “Excusible” or “non-excusable” delay depends on whether the contractor is entitled to time extension because of the delay.
A “Compensable” or “non-compensable” delay depends on whether the contractor is entitled to compensate cost due to the inefficiency consequences upon the delay.

There are three types of delay causes: procedural delay, triggering delay, and enabling delay. In this research, the focus was procedural causes, specifically the level of planning and plan detailing that are related to the managerial causes provided by management. The level of planning and scope definition in early project stages can significantly influence the construction time. Insufficient plans and planning generally result in project delay (Al-Humaidi, 2007 & 2010).

**Procedural causes.** These arise from the interaction between all the parties involved in a project. A procedural cause includes four categories: managerial, financial, legal, and operational. Figure 12 shows all of these types of delay and all the factors related to each type (Al-Humaidi, 2007 & 2010).
Figure 11 Procedural causes of delay (Al-Humaidi, 2010).
According to Al-Humaidi (2007) and (2010), managerial causes are any direct action or inaction taken by management that effects project time and delay project delivery. These actions are:

- Contracting strategy: The contract strategy selected to undertake the project such as cost plus fee or lump sum. It determines who is responsible for implementing most of the work, the contractor or the owner.

- Project delivery system: The project delivery system can affect project time and schedule. For example, in a design bid build type, each step should be complete before the next step begins. Using a design bid contract can save time because it is a fast way to track the project progress.

- Level of planning: The level of planning and plan details can both keep the project aligned with the work plan and prevent any deviation that might happen by providing management with all necessary information prior to the execution phase. Poor planning leads to an unclear scope definition for all project stakeholders and can affect the amount of accomplished work and the use of resources. An improper scope definition and making incorrect decisions in the planning phase can affect project execution, resulting in changes in the phase execution as well as deviation from the project work plan. This results in project delay.

Financial causes are represented by a lack of financing for project activities and tasks when needed and erroneous cost estimation, which are both related to financial resources.
These can affect project time, slow down the work progress, and may even stop work all together (Al-Humaidi, 2007 & 2010).

Legal causes are mostly related to the acquisition of permits and the disputes and conflicts among involved participants (Al-Humaidi, 2007 & 2010).

Operational tasks include the work undertaken in the project execution phase. The selection of construction methods has a significant effect on the project time and schedule. Determining the creative construction method and conducting constructability analysis reviews at the early planning stages by management minimizes the time needed to accomplish task(s) in a project (Al-Humaidi, 2007 & 2010).

Furthermore, implementing value-engineering concepts in terms of acquisition resources when needed benefits the project and saves time and money. If the value-engineering concept is not implemented in the project this allows non-creative methods that need time to be implemented in delayed projects. Reliable planning for using resources such as material, skills, equipment, and labor, and ensuring their availability in the project saves time (Al-Humaidi, 2007 & 2010).

*Triggering causes.* Triggering causes are external environmental causes that affect project progress and cause delays. They fall into three categories: weather conditions, underground conditions, and natural disasters as shown by figure 13.
Enabling causes. The enabling causes are considered internal causes that affect project time and schedule. They are mostly related to resources such as material, labor, and equipment. The functionality and availability of these resources can affect project efficiency, productivity, and work progress. If there is any shortage in these resources, it could result in delays in the project. Figure 14 shows the kinds of these causes.

Figure 12 Triggering delay causes (Al-Humaidi, 2010).

Figure 13 Enabling causes of delay (Al-Humaidi, 2010).
Summary

The review indicated LPS is a powerful lean construction tool that has significant effects on construction project quality, cost, and duration. Implementing it in construction projects could reduce construction project time by about 50%, stabilize the flow of construction operations, reduce uncertainty, increase collaboration between team members, and shield the production process system by using the look ahead plan and weekly work plan.

The review also illustrated that BIM is a modeling technology and associated processes that produce, communicate, and analyze building models. It is helpful in managing the increasing information and complexity in construction projects. It can reduce design process time by about 30% and construction process time by about 10%. The basic benefits of BIM-based methodology are 3D simulation, increased design accuracy and reduced errors, increased drawing efficiency, reduced conflict, increased collaboration, reduced fabrication and estimation time, usefulness in life-cycle management, increased efficiency of processes, eliminated data entry errors, and simplified scheduling activities by using 4D modeling. In spite of these stated advantages of BIM, there are some disadvantages too. Many contractors, engineers, and architects lack experience in using BIM. Contractors assume design liability when they use BIM to design detailed construction processes. This blurs the line between design and construction. Interoperability between BIM software programs is another concern. Therefore, it is important to plan and coordinate software programs to ensure ability to edit file formats or import files to other programs.
The review showed that BIM has some aspects that have high interaction with LPS. These aspects were 3D visualization, 4D modeling, and MEP clash detection; these have significant effects on the construction workflow. They work to increase collaboration between participants who are involved in a project, reduce uncertainty in project design and construction, and provide assistance in just in time delivery of materials. All of these mentioned issues are lean construction goals. In addition, the literature review highlighted some of the challenges and barriers that confront contractors during the implementation of LPS and BIM.

It also identified various causes of delay that can affect construction project operations. These fall into three categories: procedural, triggering, and enabling causes. It identified the causes that are most related to the research scope. This literature review aimed to identify procedural delay causes that are related to the level of planning and scheduling and plan details provided by management and that could affect project progress and operation flow. All other types of delay causes were beyond the scope of this research.
Chapter 3

Methodology

The focus in this research was the effect of BIM and LPS together on construction delay. The aim of this survey study was to examine whether adopting BIM and LPS together affect construction process delay differently than using BIM or LPS alone. The results of this survey could be helpful to the construction practitioners in the industry to improve project management practice through improving planning and control systems, eliminating delays, enhancing project delivery, and reducing project cost.

Population and Sample

Construction companies that participated in lean construction websites in the U.S were selected to be the population of this survey. The researcher selected 173 construction companies randomly as a sample. The survey was intended for all construction expert positions (construction managers, project managers, engineers, architects, contractors, and sub-contractors). The selected participants should have at least two years of experience in construction practice and be familiar with BIM and LPS.

Variables

The survey study aimed to investigate the research question, whether the reduction of time and eliminating delay would be significant with the coupling of BIM and LPS. The dependent variable in this research was the overall duration of a construction project, while BIM and LPS were considered the independent variables. The dependent variable was measured by surveying the companies who were applying BIM and LPS together in their system. Interviews were also conducted with four
construction companies as case studies, and then these were analyzed to see how those two independent variables affected project duration.

Moreover, there were many issues affecting construction project duration. These issues included: number of change orders, number of requests for information (RFIs), late materials delivery, rework amount, inventories and conflicts in the project, non-value added activities, etc. (Ballard, Elfving & Tommelein, 2002). The survey investigated whether adopting BIM and LPS would effectively eliminate or reduce these issues that cause delay in a construction project.

BIM presented the development process of a project with computer-generated models to simulate the planning, design, construction, and operation process of a facility (AGC, 2005 & Azhar, 2011). LPS worked to reduce variations in construction workflow, develop the project planning, and reduce uncertainty in construction operations by tracking the development process of the project from master scheduling to phase scheduling (Ballard, 2000).

Instrumentation

The survey questionnaires were developed by the researcher and tested by Sewell and Sewell, an architectural firm, and JE Dunn Construction Company. These questionnaires included three survey categories. The first category targeted the construction companies that implemented BIM in their system and asked (28) questions, while the second category solicited responses from the construction companies that adopted LPS in their system and also asked (28) questions. Finally, the third category targeted the construction companies that adopted both BIM and LPS together in their
system and included (31) questions (see appendix A, p.110). The purpose of these categories was to compare all of the responses and evaluate whether adopting BIM and LPS together had a significant statistical effect on project duration and cost.

The three categories had almost the same questionnaires with slight differences in each one. There were four sections under each category. Section “A” analyzed the respondents’ demographic data, such as familiarity with BIM, LPS or both through the number of projects they were involved in that utilized BIM and/or LPS. It also looked at the kind of BIM software utilized, years of participants’ experience, number of construction projects completed with BIM, LPS or both, training their own staff or outsourcing, the holder of the LPS role position, and the efficiency of BIM and LPS in the company.

Section “B” consisted of four questions to measure the effect of BIM, LPS or both on each of the following items: the number of RFIs, the number of change orders, the time of fabrication and assembling, and lastly the rework amount. The respondents had been asked to choose one of the following choices (Increase or no change, 0-25% Reduction, 26-50% Reduction, 51-75% Reduction, 76-100% Reduction) based on their experiences and background knowledge. The multiple choices could help the participants identify the approximate percentage of reduction in each item.

The third section “C” included 13 questions in a seven-point Likert Scale. The questions were coded from one to seven (Strongly Agree=7, Agree=6, Agree Somewhat=5, Neither Agree nor Disagree=4, Disagree somewhat=3, Disagree=2,
strongly Disagree=1). The Likert Scale provided participants a wide range of answers and took a short amount of time to answer the questions and get feedback.

The last section “D” consisted of five questions, most of them soliciting responses regarding whether adopting BIM, LPS, or both increased or decreased the execution time of construction projects, number of RFIs, and the number of change orders. The researcher asked the participants to state in their answers an approximate percentage for each question. This was done to get a clear number that could help in calculating the effect of BIM and/or LPS on each item in that section. The last two questions in this section were to investigate the perception of the respondents and tested their satisfaction with BIM and/or LPS. Finally, to test whether participants would like to recommend it to other construction companies in the future, they were asked to choose “Yes” or “No” for each question.

Furthermore, since the author attained only four responses regarding BIM implementation and two responses regarding LPS implementation, the author followed up with a construction company that adopted BIM in their system and interviewed three other new companies as case studies.

Data Collection Methods

A quantitative research approach was used during this research study. This approach was helpful in determining the participants’ opinion in numeric description (Creswell, J., 2013). In order to get a rapid turnaround of data and to ascertain how the aforementioned concept of applying BIM and LPS together influenced construction project duration, the survey study was sent to the random sample of construction
companies listed on a Lean Construction website by the internet via Qualtrics Survey Software. Each of the construction companies received a link to the survey form, which included a brief description of the questionnaires in order to make the survey more efficient and accurate. To ensure a high response rate, the author sent several reminders and phoned the non-respondents explaining to them the goals of the survey and encouraging them to answer the questionnaires.

**Method of Data Analysis**

Microsoft Excel was used to analyze the data gathered through the survey. It helped in obtaining descriptive statistics of frequencies of responses, means, and standard deviations. It was also used to generate statistical graphs and tables to analyze the data and quantify the qualitative responses.

**Threats to Validity**

- Regression: There was the chance that participants with extreme scores would be selected in the survey, and their scores could change the survey, over time regressing towards the mean. To avoid this kind of threat, participants were chosen who did not have extreme scores as beginning characteristics.

- The limited knowledge of respondents to answer every question in the survey.

- The limited sample based on company contacts and available public listings (selection bias).
Chapter 4

Finding Results

Demographic Data

The survey was distributed through the Qualtrics web site and targeted a random sample that included 173 construction companies of different types and sizes that were members of Lean Construction institutes. Twenty-seven (16%) survey responses were collected. The responses were classified into three categories, 21 respondents indicated they utilized both BIM and LPS in their system (78%), while four respondents chose BIM category (15%), and only two respondents (7%), stated they adopted only LPS in their system. Figure 14 shows the demographic data.

![Demographic of Responses]

*Figure 14 The number of responses.*
Demographic data of companies who used BIM.

As shown in figure 14 there were only four (15%) participants in the sample which utilized only BIM in their system. The demographic data shown in table 4, reveals that the majority of the participants who were involved in more than 20 construction projects utilized BIM (75%), and 25% was involved in about 20 construction project using BIM. Each company used different kinds of software programs, most of them using more than one software program such as Revit, Navisworks, Glue, and CAAD. As for years of experience, 50% of the participants had six to 10 years of experience using BIM, and 25% had more than 10 years of experience in BIM, and one participant had no or zero years of experience with BIM (25%).

The results also showed 50% of the surveyed companies have their own trained internal staff, 25% of the construction companies have outsource staff, and 25% of companies have their internal staff that were trained through practical experience. Furthermore, 75% of participants had accomplished more than 200 construction projects using BIM, and 25% of the participants had completed several construction project using BIM. Lastly, in regards to BIM efficiency, 50% of surveyed companies rated BIM efficiency as excellent for their system, and 50% of construction companies had rated BIM at a very good level for their system.
Table 4.

**Demographic Characteristics of Construction Companies and Employees Using BIM.**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Frequency</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of construction projects participants have been involved in using BIM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 projects</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>&gt; 20 Projects</td>
<td>3</td>
<td>75%</td>
</tr>
<tr>
<td>Kinds of BIM software (s) have been used</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAD</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>AutoCAD, Navisworks, and Glu</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>Revit, Navisworks, and Dr. Proliler</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>ICE Software</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>Years of personal experiences using BIM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No or Zero year</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>6-10 years</td>
<td>2</td>
<td>50%</td>
</tr>
<tr>
<td>&gt; 10 years</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>Trained own staff or outsource</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal BIM Staff, trained</td>
<td>2</td>
<td>50%</td>
</tr>
<tr>
<td>Internal BIM Staff, trained by practice</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>Outsource Staff</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>The number of construction projects had accomplished using BIM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 3 Projects</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>More than 200 projects</td>
<td>3</td>
<td>75%</td>
</tr>
<tr>
<td>Rate of BIM efficiency in the company</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>2</td>
<td>50%</td>
</tr>
<tr>
<td>Very good</td>
<td>2</td>
<td>50%</td>
</tr>
<tr>
<td>Good</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Poor</td>
<td>0</td>
<td>0%</td>
</tr>
</tbody>
</table>
Demographic data of companies using LPS alone.

The demographic data shown in figure 14, revealed that two (7%) of the sampled construction companies utilized LPS but not BIM. All of them had been involved in construction projects that utilized LPS, and 50% of the participants had been involved in about two construction projects utilizing LPS. As for years of experiences, 50% of the participants indicated they had more than 15 years using LPS, and 50% of them had only a one-year experience with LPS.

The results also revealed that 50% of the participants indicated that the project manager normally held the role of the Last Planner System position in the company, and 50% of them mentioned that the superintendent holds the role of that position. In addition, 50% of the construction companies have their own and trained LPS staff, while 50% indicated their staff members had not been specifically trained for this program. Furthermore, 50% of participants had accomplished more than 100 construction projects with LPS, and 50% of the participants had completed about two construction projects using LPS. Lastly, LPS efficiency indicated 50% of the participants rated the LPS efficiency at an excellent level in their company’s system, followed by 50% of the participants who chose a good level for the LPS efficiency in their company’s system, see table 5.
Table 5.  
**Demographic Characteristics of Construction Companies and Employees Using LPS.**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Frequency</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of construction projects participants who have been involved in using LPS</td>
<td>2 projects</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>1</td>
</tr>
<tr>
<td>Years of personal experiences using BIM</td>
<td>One year</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>&gt; 15 years</td>
<td>1</td>
</tr>
<tr>
<td>The holder of Last Planner position in the company</td>
<td>Project Manager</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Superintendent</td>
<td>1</td>
</tr>
<tr>
<td>Trained own staff</td>
<td>Trained staff</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Not trained staff</td>
<td>1</td>
</tr>
<tr>
<td>The number of construction projects accomplished using LPS</td>
<td>2 projects</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>&gt; 100 projects</td>
<td>1</td>
</tr>
<tr>
<td>Rate of LPS efficiency in the company</td>
<td>Excellent</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Very good</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Poor</td>
<td>0</td>
</tr>
</tbody>
</table>

**Demographic data of companies used BIM and LPS.**

As shown in figure 14, the majority of the construction companies that participated in the survey (78% of the total sample participation) had utilized both BIM and LPS in their system. Most of the surveyed construction companies adopted BIM and Lean philosophy together in their system in an attempt to get significant potential reduction in time and cost. The demographic data gathered from participants revealed that the majority of participants had been involved in several construction projects utilizing BIM and LPS together. Thirty-eight percent of participants mentioned they had
been involved in three to five projects, 29% of participants indicated they had been involved in six to ten construction projects, and 29% of participants were involved in more than 10 projects, with the exception of one of the participants, who had not been involved in any project that utilized BIM and LPS together. Five percent (5%) of the respondents probably did not understand the question. These results indicated that most of the surveyed participants were familiar with BIM and LPS and aware of the advantages of implementing them together in a project.

Question two of the demographics section was regarding construction companies that used software. It revealed that out of 21 companies, most of them selected more than one software program. The majority of the companies who were surveyed indicated that they used Revit in their system (40%), followed by Autodesk (15%), Navisworks (15%), Tekla (12%), and the two lowest choices were CAD (9%) and other software programs (9%).

As for the question regarding years of experience, the results indicated the majority had three to five years of experiences using both BIM and LPS together (38%), followed by six to 10 years of experiences (29%), one to two years (14%), no answer or zero years of experiences (14%), and one participant had more than 10 years (5%). The results indicated that 62% of the surveyed companies had their own BIM staff, 29% had an outsource staff, and 10% had both an internal and an outsource staff. There were 48% of the internal staff who had received training, while 33% used the outsource staff, and 19% of participants did not answer this question. As for the number of construction projects accomplished by participants using BIM and LPS, the majority of the
participants indicated they completed three to 10 construction projects using BIM and LPS together (48%), followed by 11 to 20 construction projects (24%), and 29% of participants had completed more than 20 projects.

The demographics data also revealed that the majority of construction companies assigned the project manager and/or superintendent as a holder of the LPS role position (52%), followed by varies (19%), general contractor (10%), lean director (10%), and the lowest results were 5% construction manager and 5% project engineer. In addition, the training question revealed that (76%) of construction companies provided training to all or some of their LPS staff, while 14% of construction companies trained their staff by practicing it, and only 10% of construction companies did not provide any kind of training. The last two demographic questions were related to the BIM and LPS efficiency in the surveyed construction companies. They revealed that the majority of the participants chose “good” (48%), followed by 38% of participants chose very “good”, and 14% of participants chose the “excellent” level. The majority of participants rated LPS efficiency in their system as good (52%), followed by 19% of them chose very good, 19% choose excellent level, and 10% chose poor.

Table 6.

Demographic Characteristics of Construction Companies and Employees Using BIM & LPS.
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Frequency</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of construction projects participants have been involved in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero</td>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>3-5 projects</td>
<td>8</td>
<td>38%</td>
</tr>
<tr>
<td>6-10 projects</td>
<td>6</td>
<td>29%</td>
</tr>
<tr>
<td>&gt; 10 Projects</td>
<td>6</td>
<td>29%</td>
</tr>
<tr>
<td>Kinds of BIM software (s) have been used</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revit</td>
<td>14</td>
<td>41%</td>
</tr>
<tr>
<td>Autodesk</td>
<td>5</td>
<td>15%</td>
</tr>
<tr>
<td>Navisworks</td>
<td>5</td>
<td>15%</td>
</tr>
<tr>
<td>Tekla</td>
<td>4</td>
<td>12%</td>
</tr>
<tr>
<td>CAD</td>
<td>3</td>
<td>9%</td>
</tr>
<tr>
<td>Others</td>
<td>3</td>
<td>9%</td>
</tr>
<tr>
<td>Years of personal experiences using BIM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No or Zero</td>
<td>3</td>
<td>14%</td>
</tr>
<tr>
<td>1-2 years</td>
<td>3</td>
<td>14%</td>
</tr>
<tr>
<td>3-5 years</td>
<td>8</td>
<td>38%</td>
</tr>
<tr>
<td>6-10 years</td>
<td>6</td>
<td>29%</td>
</tr>
<tr>
<td>&gt; 10 years</td>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>Own BIM staff, outsource or both</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal BIM Staff</td>
<td>13</td>
<td>62%</td>
</tr>
<tr>
<td>Outsource staff</td>
<td>6</td>
<td>29%</td>
</tr>
<tr>
<td>Both</td>
<td>2</td>
<td>10%</td>
</tr>
<tr>
<td>Trained BIM staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trained staff</td>
<td>10</td>
<td>48%</td>
</tr>
<tr>
<td>No answer</td>
<td>4</td>
<td>19%</td>
</tr>
<tr>
<td>Outsource</td>
<td>7</td>
<td>33%</td>
</tr>
<tr>
<td>The number of construction projects accomplished</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-10 projects</td>
<td>10</td>
<td>48%</td>
</tr>
<tr>
<td>11-20 projects</td>
<td>5</td>
<td>24%</td>
</tr>
<tr>
<td>&gt;20</td>
<td>6</td>
<td>29%</td>
</tr>
<tr>
<td>The holder of Last Planner position in the company</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Manager and/or Superintendent</td>
<td>11</td>
<td>52%</td>
</tr>
<tr>
<td>Varies</td>
<td>4</td>
<td>19%</td>
</tr>
<tr>
<td>Contractor</td>
<td>2</td>
<td>10%</td>
</tr>
<tr>
<td>Lean Director</td>
<td>2</td>
<td>10%</td>
</tr>
<tr>
<td>Project Engineer</td>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>Construction Manager</td>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>The training of LPS coordinator and other LPS staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trained</td>
<td>16</td>
<td>76%</td>
</tr>
<tr>
<td>Not trained</td>
<td>2</td>
<td>10%</td>
</tr>
<tr>
<td>Trained by practice</td>
<td>3</td>
<td>14%</td>
</tr>
<tr>
<td>Rate of BIM efficiency in the company</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>3</td>
<td>14%</td>
</tr>
<tr>
<td>Very good</td>
<td>8</td>
<td>38%</td>
</tr>
<tr>
<td>Good</td>
<td>10</td>
<td>48%</td>
</tr>
<tr>
<td>Poor</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Rate of LPS efficiency in the company</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>4</td>
<td>19%</td>
</tr>
<tr>
<td>Very good</td>
<td>4</td>
<td>19%</td>
</tr>
<tr>
<td>Good</td>
<td>11</td>
<td>52%</td>
</tr>
<tr>
<td>Poor</td>
<td>2</td>
<td>10%</td>
</tr>
</tbody>
</table>
Results of BIM Responses

Section B: The questionnaire for this section solicited responses regarding the effect of BIM on the number of RFIs, the number of change orders, the time of fabrication and assembling, and lastly the rework amount. The respondents were asked to choose one of the following choices (Increase or no change, 0-25% Reduction, 26-50% Reduction, 51-75% Reduction, 76-100% Reduction) based on their experiences and knowledge. What follows are the graphic results of the respondents on each question:

**Question 1: How much percentage of change does Building Information Modeling (BIM) have on the number of Requests for Information (RFIs)?**

From figure 15, the results of that question indicated that 50% of the respondents chose 26-50% reduction in RFIs, followed by 25% of the respondents chose 1-25% reduction, and 25% of them chose 76-100% reduction. The average was 44% reduction, and the standard deviation was 27%.

![The Affect of BIM on The Number of RFIs](image)

*Figure 15 Graph response to question1b BIM.*
**Question 2: What is the effect of using Building Information Modeling (BIM) on the number of change orders?**

From figure 16, none of the choices received a higher score, 25% of the respondents chose 1-25% reduction, 25% of them chose 26-50% reduction, 25% of the respondents chose 51-75%, and 25% of the respondents chose 76-100% reduction. The mean was 50% reduction in number of change orders, and the standard deviation was 28%.

![The Effect of BIM on The Number of Change Orders](image)

*Figure 16* Graph response to question 2b BIM.

**Question 3: What is the effect of Building Information Modeling (BIM) on the time of fabrication and assembling?**

From figure 17, the result of that question shows 50% of the respondents chose 26-50% reduction, 25% chose increase or no change, and 25% chose 76-100% reduction.
The mean was 41\% reduction in time of fabrication and assembling, and the standard deviation was 31\%.

![The Effect of BIM on Fabrication & Assembling Time](image)

\textit{Figure 17} Graph response to question 3b BIM.

\textbf{Question 4:} What is the effect of Building Information Modeling (BIM) on rework amount?

From figure 18, the majority of the respondents chose 51-75\% reduction (50\%), 25\% of the respondents chose 1-25\% reduction, and 25\% of the respondents chose 76-100\% reduction. The average value was 56\% reduction in rework amount, and the standard deviation was 27\%. 

58
Figure 18 Graph response to question 4b BIM.

Section C: This section of the survey consisted of 13 questions in a seven-point – Likert-Scale. The questions were coded from one to seven (Strongly Agree=7, Agree=6, Agree Somewhat=5, Neither Agree nor Disagree=4, Disagree somewhat=3, Disagree=2, strongly Disagree=1). Table 7 contains the following information: The items and the response distribution, total of responses for each item, and the average.
<table>
<thead>
<tr>
<th>Item Code</th>
<th>Question</th>
<th>Strongly Agree 7</th>
<th>Agree 6</th>
<th>Agree 5</th>
<th>Somewhat Agree 4</th>
<th>Neither Agree nor Disagree 3</th>
<th>Disagree Some 2</th>
<th>Strongly Disagree 1</th>
<th>Total Responses</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Implementing BIM increases collaboration in project design and construction</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>B2</td>
<td>Implementing BIM reduces defects in the construction phase, design, and prevents rework</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>B3</td>
<td>Adopting BIM improves communication effectiveness among the project’s participants</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>7</td>
<td>0.5</td>
</tr>
<tr>
<td>B4</td>
<td>Adopting BIM reduces conflicts and number of claims among project’s stakeholders</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>7</td>
<td>0.5</td>
</tr>
<tr>
<td>B5</td>
<td>Adopting BIM stabilizes workflow and reduces construction process variability</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>1.64</td>
</tr>
<tr>
<td>B6</td>
<td>Adopting BIM helps in removing barriers and constraints from work assignments</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>0.83</td>
</tr>
<tr>
<td>B7</td>
<td>Adopting BIM reduces uncertainty inherent in the construction phase and design</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>0.83</td>
</tr>
<tr>
<td>B8</td>
<td>Adopting BIM reduces the time of project design and shop drawings</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>0.87</td>
</tr>
<tr>
<td>B9</td>
<td>Adopting BIM aids in Just In Time (JIT) delivery of materials and parts</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>1.22</td>
</tr>
<tr>
<td>B10</td>
<td>Adopting BIM provides accurate cost estimation and take off material quantities</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>1.3</td>
</tr>
<tr>
<td>B11</td>
<td>Adopting BIM generates and evaluates alternative construction plan rapidly</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>B12</td>
<td>Adopting BIM improves product quality and creates customer value</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>7</td>
<td>0.43</td>
</tr>
<tr>
<td>B13</td>
<td>Adopting BIM increases productivity</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>7</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>Overall mean and Standard Deviation</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td>0.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 19 presents a graphical representation regarding the BIM practice items. The highest rated items in this section were regarding the relationship of the practice of BIM to increased collaboration in project design and construction (B1) and BIM reducing defects in the construction phase, design, and preventing rework (B2). Where 100% of the participants “Strongly Agreed” on these two items, the recorded average score was 7 out of 7 per each item. The results also showed that BIM improved product quality and created customer value (B12). The concept that BIM increased productivity (B13) was another item in this section, which tended toward “Agree” and “Strongly Agree. The recorded average was seven for each item. The three items that received the same average scores in the “Agree” section were (B3, B4 and B8). B3 measures the improvement of the communication effectiveness among the project’s participants, B4 measures whether Adopting BIM reduces conflicts and number of claims among project’s stakeholders, and
B8 tests the strength of BIM in reducing the time of project design and shop drawings. The average score was seven.

Besides the three items mentioned above, there are four other items that received the same average scores in this section as well (Agree). These are related to whether BIM helps in removing barriers and constraints from work assignments (B6). These answers showed that BIM reduces uncertainty inherent in the construction phase and design (B7), BIM aids in “Just-In-Time” (JIT) delivery of materials and parts (B9), and the last one measures the power of BIM in generating and evaluating an alternative construction plan rapidly (B11). The average score was 6 for B9 and B11 and 6 for B6 and B7.

Lastly, according to these findings, the low average scores were related to B5 and B10, as to whether BIM stabilizes workflow and reduces construction process variability (B5) and BIM provides accurate cost estimation and take off material quantities (B10). The average was 6 for each item, meaning the participants “Agreed Somewhat” with a strong tendency to “Agree” regarding these two items.

In summary, a positive tendency across the Likert scale was noticed regarding the overall items in this section, the overall average tends to be “Agree.”

**Section D:** This section consisted of five questions, three of them were to test whether BIM, LPS, or both increased or decreased the execution time of construction projects, number of RFIs, and the number of change orders. The respondents stated an approximate percentage as an answer for each question. The last two questions included “Yes” or “No” answers, which were to test the respondents’ satisfaction regarding BIM, LPS, or both. What follows are the graphic results of the respondents to each question:
Q.1: Do you think BIM increases or decreases the execution time of construction projects?

From figure 20, the result shows 50% of the respondents stated BIM decreased the construction project’s duration by 25%, followed by 25% of them stated BIM reduced duration by 5%, and 25% stated it reduced project time by 75%. The mean was 33%, and the standard deviation was 26%.

![The Effect of BIM on Project time](image)

*Figure* 20 Graph response to question 1d BIM.

Q.2: Do you think BIM increases or decreases the number of RFIs in construction projects?

From figure 21, there were 50% of respondents stated BIM can decrease the number of RFIs by 25%, 25% stated it can decrease 15% of RFIs, and 25% stated it can increase 100% of RFIs. The last respondents seemed not to understand the question; therefore, the researcher eliminated that response from the calculation of the mean. The average was 22%, and the standard deviation was 5%.
**Q.3: Do you think BIM increases or decreases the number of change orders in construction projects?**

From figure 22, 50% of respondents stated BIM can decrease 25-30% of the number of change orders, followed by 25% stated it can decrease 15% of change orders, and 25% stated it can decrease 100% of change orders. The respondent with 100% increase seemed not to understand the question, as a result that answer was omitted from the calculation of the mean. The mean was 23, and the standard deviation was 6%. 

*Figure 21* Graph response to question 2c BIM.
Q.4: Are you feeling satisfied with BIM?

From figure 23, it seems the entire pool of respondents were satisfied with BIM and chose “Yes” as an answer for that question. The mean was one, and the standard deviation was zero.

Figure 22 Graph response to question 3c BIM.

Figure 23 Graph response to question 4c BIM.
Q.5: Would you recommend BIM to other companies that you might know?

Figure 24 indicates that all of the respondents recommended BIM be used by other construction companies; therefore, their answer for that question was “Yes.” The mean was one, and the standard deviation was “zero.”

![Graph response to question 5c BIM](image)

*Figure 24 Graph response to question 5c BIM.*

**Results of LPS Responses**

**Section B:** The questionnaire of this category solicited responses regarding the effect of LPS on the number of RFIs, the number of change orders, the time of fabrication and assembling, and lastly the rework amount. The respondents had been asked to choose one of the following choices (Increase or no change, 0-25% Reduction, 26-50% Reduction, 51-75% Reduction, 76-100% Reduction) based on their experiences and knowledge. What follows are the graphic results of the respondents to each question:
Question 1: How much change does the Last Planner System (LPS) have on the number of Requests for Information (RFIs)?

From figure 24, the results of that question indicated that 50% of the participants chose 26-50% reduction in RFIs and 50% of them chose 51-75%. The mean was a 50% reduction in RFIs.

![The Effect of LPS on the Number of RFIs](image)

Figure 24 Graph response to question 1b LPS.

Question 2: What is the effect of using the Last Planner System (LPS) on the number of change orders?

From figure 25, the result shows 100% of the respondents chose the answer that LPS reduces 26-50% of change orders. The mean was a 38% reduction in change orders.
Figure 25 Graph response to question 2b LPS.

**Question 3: What is the effect of the Last Planner System (LPS) on the time of fabrication and assembling?**

According to figure 26, 50% of the respondents chose 1-25% reduction, and 50% chose 26-50% reduction. The mean was a 25% reduction in time of fabrication and assembling.

Figure 26 Graph response to question 3b LPS.
**Question 4: What is the effect of the Last Planner System (LPS) on rework amount?**

From figure 27, 50% of the respondents chose 1-25% reduction, followed by 50% chose 51-75% reduction. The mean was a 25% reduction in the rework amount.

![The Effect of LPS on Rework Amount](image)

*Figure 27 Graph response to question 4b LPS.*

**Section C:** This section of the survey consisted of 13 questions in a seven-point Likert-Scale. The questions were coded from one to seven (Strongly Agree=7, Agree = 6, Agree Somewhat=5, Neither Agree nor Disagree=4, Disagree somewhat=3, Disagree=2, strongly Disagree=1). Table 8 contains the following information: The items and the response distribution, total of responses for each item, and the average.
### Table 8.

**LPS Practice Questions and Respondents Summary.**

<table>
<thead>
<tr>
<th>Item Code</th>
<th>Question</th>
<th>Strongly Agree</th>
<th>Agree 6</th>
<th>Agree 5</th>
<th>Neither Agree nor Disagree 4</th>
<th>Disagree Somewhat 3</th>
<th>Disagree 2</th>
<th>Strongly Disagree 1</th>
<th>Total Responses</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>Implementing LPS increases collaboration in project design and construction</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>6.5</td>
</tr>
<tr>
<td>L2</td>
<td>Implementing LPS reduces defects in the construction phase, design, and prevents rework</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>L3</td>
<td>Adopting LPS improves communication effectiveness among the project’s participants</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>6.5</td>
</tr>
<tr>
<td>L4</td>
<td>Adopting LPS reduces conflicts and number of claims among project’s stakeholders</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5.5</td>
</tr>
<tr>
<td>L5</td>
<td>Adopting LPS stabilizes workflow and reduces construction process variability</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>L6</td>
<td>Adopting LPS helps in removing barriers and constraints from work assignments</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>6.5</td>
</tr>
<tr>
<td>L7</td>
<td>Adopting LPS reduces uncertainty inherent in the construction phase and design</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5.5</td>
</tr>
<tr>
<td>L8</td>
<td>Adopting LPS reduces the time of project design and shop drawings</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5.5</td>
</tr>
<tr>
<td>L9</td>
<td>Adopting LPS aids in Just In Time (JIT) delivery of materials and parts</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5.5</td>
</tr>
<tr>
<td>L10</td>
<td>Adopting LPS provides accurate cost estimation and take off material quantities</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>4.5</td>
</tr>
<tr>
<td>L11</td>
<td>Adopting LPS generates and evaluates alternative construction plan rapidly</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>L12</td>
<td>Adopting LPS improves product quality and creates customer value</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5.5</td>
</tr>
<tr>
<td>L13</td>
<td>Adopting LPS increases productivity</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>
Figure 28 LPS practice average response.

There were three questions rated in the higher average that tended to be “Agree.”

These following three questions had an average of seven:

- LPS increases collaboration in project design and construction (L1)
- LPS improves communication effectiveness among the project’s participants (L3)
- LPS helps in removing barriers and constraints from work assignments (L6).

The result shows three items having the same average value that tend to be “Agree.”

These items were L2, L5 and L13. L2 corresponded to the effect of LPS on prevention of defect and rework amount in the design and construction phase. The other items (L5) were to test the effectiveness of LPS on the workflow and reduce variations, and (L13) was to test the improvement of the productivity that LPS makes in the project. The average score was 6 for each item.
There were five other items in this section that had the same average in the category of “Agree Somewhat,” with an average 5.5. These items were L4, L7, L8, L9 and L12, where L4 corresponded to LPS reduces conflicts and number of claims among project’s stakeholders. L7 was to test how LPS affects an uncertainty inherent in the construction phase and design. L8 was to measure the effect of LPS on the time of project design and shop drawings. L9 was related to the helpfulness of LPS in Just-In-Time (JIT) delivery of materials and parts. The last item (L12) was to see whether LPS affects product quality and creates customer value.

The lowest rated item was the item indicating that LPS provides accurate cost estimation and take off material quantities L10, which scored 5 and which tended to be Neutral, followed by LPS generates and evaluates alternative construction plan rapidly (L11). However, all of the items have an average rating greater than five.

Overall, the items in this section tend to be “Agree Somewhat,” leaning towards “Agree.”

**Section D:** This section consisted of five questions, three of them were to test whether LPS increased or decreased the execution time of construction projects, number of RFIs, and the number of change orders. The respondents stated an approximate percentage as an answer for each question. Also the last two questions had requested an answer of “Yes” or “No” to test the respondents’ satisfaction regarding BIM, LPS, or both. What follows are the graphic results of the respondents on each question:
**Q.1: Do you think LPS increases or decreases the execution time of construction projects?**

From figure 29, 50% of the respondents stated LPS decreased 25% of overall project duration, and 50% mentioned LPS decreased 5% duration of construction projects. The average is 15% of time reduction in construction projects.

*Figure 29 Graph response to question 1d LPS.*

**Q.2: Do you think LPS increases or decreases the number of RFIs in construction projects?**

From figure 30, there were 50% of respondents that stated LPS decreased 25% of the number of RFIs in construction projects, followed by 25% of respondents stated it decreased 30% of RFIs. The average answer for that item reflect a 28% reduction.
**Q.3: Do you think LPS increases or decreases the number of change orders in construction projects?**

From figure 31, 50% of respondents stated LPS decreased 25% of the number of change orders in construction projects, followed by 50% of them indicated it decreased RFIs by 30%. The average was 28% of change order reduction.
**Q.4: Are you feeling satisfied with LPS?**

From figure 32, it seemed all the respondents were satisfied with BIM, as a result they chose “Yes” as an answer for that question. The average value for that item was one.

*Figure 32 Graph response to question 4d LPS.*

**Q.5: Would you recommend LPS to other companies that you might know?**

From figure 33, it seemed all the participants were willing to recommend LPS to other construction companies that they might know or have a relationship with. The mean was one.
Results of BIM and LPS Responses

Section B: The questionnaire of this section solicited responses regarding the effect of BIM and LPS together on the number of RFIs, the number of change orders, the time of fabrication and assembling, and lastly the rework amount. The respondents were asked to choose one of the following choices (Increase or no change, 0-25% Reduction, 26-50% Reduction, 51-75% Reduction, 76-100% Reduction) based on their experiences and knowledge. What follows are the graphic results of the respondents on each question:

Question 1: Approximately what effect does BIM and LPS have on the number of Requests for Information (RFIs)?

From figure 34, the majority of the respondents indicated that BIM and LPS reduced about 26-50% of the number of RFIs in construction projects. In addition, 20% of them indicated BIM and LPS reduced 51-75% of RFIs, 15% stated BIM and LPS reduced 1-25% of RFIs, and 5% of the total responses mentioned BIM and LPS reduced
76-100% of RFIs. In addition, 10% out of the total respondents chose increase or no change in their answers. The average was 38% reduction in RFIs, and the standard deviation was 22.

![The Effect of BIM & LPS on The Number of RFIs](image)

*Figure 34* Graph response to question 1b BIM& LPS.

**Question 2: Approximately what effect does BIM and LPS have on the number of change orders?**

From figure 35, 35% of the respondents indicated that BIM and LPS reduced about 1-25% of the number of change orders in construction projects. Also 35% indicated that BIM and LPS reduced 26-50%. This was followed by 25% of respondents indicated BIM and LPS reduced 51-75% of change orders, and 5% stated BIM and LPS chose increase or no change. The average was 33% reduction, and the standard deviation was 20.
Question 3: Approximately what effect does BIM and Last Planner System (LPS) have on the time of fabrication and assembling?

From figure 36, the majority of the respondents (57%) chose the option that BIM and LPS reduced 1-25% of time and fabrication and assembling in construction projects. This was followed by 38% chose BIM and LPS reduced about 26-50%, and 5% chose 51-75% reduction. The average is 24%, and the standard deviation was 14.
**Question 4: Approximately what effect does BIM and LPS have on rework amount?**

From figure 37, the completed survey indicated that 38% out of total respondents indicated BIM and LPS reduced 1-25% of rework amount, 33% chose 26-50% reduction, and 28% chose 51-75%. The average was 35%, and the standard deviation was 20%.

![The Effect of BIM & LPS on Rework Amount](image)

*Figure 37 Graph response to question 4b BIM& LPS.*

**Section C:** This section of the survey consisted of 13 questions in a seven-point Likert- Scale. The questions were coded from one to seven (Strongly Agree= 7, Agree= 6, Agree Somewhat=5, Neither Agree nor Disagree=4, Disagree somewhat=3, Disagree=2, strongly Disagree=1). Table 9 contains the following information: The items and the response distribution, total of responses for each item, and average.
Table 9.

*BIM and LPS Practice Questions and Response Summary.*

<table>
<thead>
<tr>
<th>Item Code</th>
<th>Question</th>
<th>Strongly Agree 7</th>
<th>Agree 6</th>
<th>Agree Somewhat 5</th>
<th>Neither Agree nor Disagree 4</th>
<th>Disagree Somewhat</th>
<th>Disagree 2</th>
<th>Strongly Disagree 1</th>
<th>Total Responses</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>LB1</td>
<td>Adopting BIM and LPS increases collaboration in project design and construction</td>
<td>15</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>21</td>
<td>6</td>
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<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>LB2</td>
<td>Adopting BIM and LPS reduces defects in the construction phase and design and prevents rework</td>
<td>12</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>21</td>
<td>6</td>
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<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>LB3</td>
<td>Adopting BIM and LPS improves communication effectiveness among the project’s participants</td>
<td>13</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>21</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>LB4</td>
<td>Adopting BIM and LPS reduces conflicts and number of claims among project’s stakeholders</td>
<td>9</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>21</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>LB5</td>
<td>Adopting BIM and LPS stabilizes work flow and reduces construction process variability</td>
<td>11</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>21</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>LB6</td>
<td>Adopting BIM and LPS helps in removing barriers and constraints from work assignments</td>
<td>10</td>
<td>6</td>
<td>4</td>
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<td></td>
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</tr>
<tr>
<td>LB7</td>
<td>Adopting BIM and LPS reduces uncertainty inherent in the construction phase and design</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>21</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>LB8</td>
<td>Adopting BIM and LPS reduces the time of project design and shop drawings</td>
<td>6</td>
<td>4</td>
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<td>4</td>
<td>2</td>
<td>21</td>
<td>4</td>
<td>2</td>
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<td></td>
</tr>
<tr>
<td>LB9</td>
<td>Adopting BIM and LPS aids in just in time delivery of materials and parts</td>
<td>5</td>
<td>6</td>
<td>9</td>
<td>1</td>
<td>21</td>
<td>5</td>
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<td></td>
<td></td>
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<tr>
<td>LB10</td>
<td>Adopting BIM and LPS provides accurate cost estimation and take off material quantities</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>21</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LB11</td>
<td>Adopting BIM and LPS generates and evaluates alternative construction plans rapidly</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>21</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LB12</td>
<td>Adopting BIM and LPS improves product quality and creates customer value</td>
<td>7</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>21</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LB13</td>
<td>Adopting BIM and LPS increases productivity</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>2</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 38 BIM and LPS practice average response.

The highest score in this section related to the probability that BIM and LPS increase collaboration in project design and construction (LB1) with an average score of 6, which is “Agree” and leans towards “Strongly Agree.” LB2 refers to the relationship of the use of BIM and LPS and the reduction of defects in the construction phase and design and prevention of rework. This had a high average value (6), compared to the other items in this section, which also tend to “Agree.” The other items that had an average value that tend to be “Agree” are the following:

- BIM and LPS improves communication effectiveness among the project’s participants (LB3)
• BIM and LPS reduces conflicts and number of claims among project’s (LB4), BIM and LPS stabilizes work flow and reduces construction process variability (LB5)

• BIM and LPS help in removing barriers and constraints from work assignments (LB6)

• BIM and LPS reduce uncertainty inherent in the construction phase and design (LB7)

• BIM and LPS increase productivity (LB13)

The other two items (LB9 and LB12) that measure the benefits of BIM and LPS on just in time delivery of materials and parts (LB9) and the improvement of product quality and the creation of customer value (LB12) had an average that tended to “Agree,” leaning towards “Strongly Agree.” The last two items had the lowest rated average scores, which tended to Agree Somewhat and are related to the LB10 that should measure the accurate cost estimation and take off material quantities that can be provided with BIM and LPS. LB8 measured whether BIM and LPS reduce the time of project design and shop drawings, which tended toward “Neutral” and a strong tendency to Agree Somewhat.

In summary, this section ranged from a strong tendency to “Agree” to “Agree Somewhat.”

Section D: This section consisted of five questions, three of them were to test whether BIM and LPS increased or decreased the execution time of construction projects, number of RFIs, and the number of change orders. The respondents stated an approximate percentage as an answer for each question. The last two questions required a
“Yes” or “No” answer to test the respondents’ satisfaction regarding the use of BIM and LPS together. What follows are the graphic results of the respondents on each question:

**Q.1: Do you think BIM and LPS together increase or decrease the execution time of construction projects?**

From figure 39, the completed survey showed that 40% of the respondents stated BIM and LPS decreased 10-15% of overall project duration, followed by 25% reported a decrease of 20-25%, 15% reduced 5-8%, and 10% of them mentioned zero or no change. Two participants chose disqualified answers. One of them stated BIM and LPS decreased 100% of project time and that means the respondent did not understand the question. The other participant stated BIM and LPS increased 30% of project time, which was too far from the other participants’ responses. The average was calculated after waiving the regress responses and showed about a 13% time reduction, and the standard deviation was seven.

*Figure 39* Graph response to question 1d BIM& LPS.

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Q.2: Do you think BIM and LPS together increase or decrease the number of RFIs in construction projects?

From figure 40, the majority of the participants 33% stated BIM and LPS decrease 25-35% of the number of RFIs in construction projects, 19% mentioned it reduced 10-20%, 10% stated it decreased 50%, and 10% stated it reduced 70-100%. While 14% of the respondents stated zero or no change, 14% stated it increased from 10-30%. The overall average was 23% reduction after eliminating the regress values, and the standard deviation was 28%.

![Graph response to question 2d BIM & LPS.](image)

Q.3: Do you think BIM and LPS together increase or decrease the number of change orders in construction projects?

From figure 41, the result showed 29% of participants stated BIM and LPS reduce 20-25% of change orders. Also 29% indicated that change orders could be decreased by 5-10%, while 14% of them indicated the reduction of change orders can be 50% with BIM and LPS, and only 10% stated it could be greater than 50%. Ten percent of
participants mentioned that BIM and LPS have zero or no change on change orders, also 10% of respondents mentioned change orders could be increased up to 10%. The average score for that question was 23% reduction, and the standard deviation was 28.

![The Effect of BIM & LPS on The Numbers of Change Orders](image)

*Figure 41 Graph response to question 3rd BIM & LPS.*

**Q.4: Are you feeling satisfied with BIM and LPS?**

From figure 42, the result indicated 90% of respondents were satisfied with BIM and LPS and as a result, they chose “Yes” as an answer for that question. On the other hand, only 10% of them were not happy with BIM and LPS; therefore, they chose “No” to answer that question. The mean was one, and the standard deviation was zero.
Would you recommend using BIM & LPS together to other companies that you might know?

From figure 43, the entire sample chose “Yes” for that answer, which means they were willing to recommend BIM and LPS to other construction companies. The average was one, and the standard deviation was zero.

Figure 42 Graph response to question 4d BIM & LPS.

Figure 43 Graph response to question 5d BIM & LPS.
Discussion

This section presents the analysis of the results through using descriptive statistics. The mean for each question in section "Bs" was tabulated and recorded in Table 10. Table 11 shows the mean for each question in section “Cs,” and Table 12 represents the mean for each question in section “Ds” to provide comparative analysis.

Section B. From section “B,” based on table 10, question one relates to the reduction in number of Requests for Information (RFIs) and reveals that LPS had the highest mean of 50%, followed by BIM that had a mean of 44%, and BIM and LPS together had the lowest mean of 38%. That means LPS had the highest effect on the number of RFI’s compared to other categories. As for question two that is related to the reduction of change orders, the result revealed that BIM had the highest mean of 50%, then LPS, which had a mean of 38%, and the last one was BIM and LPS together that had an average of 33%. Question 3 was related to the effect of each category on the time of fabrication and assembling and showed that the highest mean went to BIM with 41% reduction, then LPS with a mean of 25% reduction, and the lowest effect was seen by using BIM and LPS together with a 24% reduction. Lastly, question four was related to the reduction of rework amount. The revealed mean of using BIM was the highest with 56%, followed by adopting BIM and LPS together that had a 35% reduction, and the lowest was a 25% reduction that related to using LPS.

Overall, BIM had the highest average score 48%, followed by LPS 34% and BIM and LPS had the lowest 33%.
### Table 10

*The mean for each question in section “B” for all categories.*

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>BIM Reduction</strong></td>
</tr>
<tr>
<td>1</td>
<td>What is the effect of using BIM, LPS, or both BIM and LPS on the number of Requests for Information (RFIs)?</td>
<td>44%</td>
</tr>
<tr>
<td>2</td>
<td>What is the effect of using BIM, LPS, or both BIM and LPS on the number of change orders?</td>
<td>50%</td>
</tr>
<tr>
<td>3</td>
<td>What is the effect of BIM, LPS, or both BIM and LPS on the time of fabrication and assembling?</td>
<td>41%</td>
</tr>
<tr>
<td>4</td>
<td>What is the effect of BIM, LPS, or both BIM and LPS on rework amount?</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Mean</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>48%</td>
</tr>
</tbody>
</table>

**Section C.** Table 11 represents questions related to increasing collaboration in project design and construction. The revealed mean of BIM was 7 out of 7, and there was slight difference between the mean of LPS 6.5 and BIM and LPS together was 6.47. That means adopting BIM increased collaboration between participants more than other items. As for question two that relates to reducing defects and preventing rework, the mean of using BIM was 7 out of 7, followed by the mean of BIM and LPS together with a 6.33 and LPS was the lowest with a mean of 6. This showed that the reduction of defects and prevention of rework in construction projects by using BIM was higher compared to the other items. Question 3 was concerned with the improvement of communications between projects’ participants. This table showed the mean of BIM was 6.5, which is the same for LPS, while the mean of BIM and LPS together was 6.24.
From question four that is concerned with the lowering of conflicts and number of claims among a project’s stakeholders, the revealed mean of BIM was 6.5, the mean of BIM and LPS together was 6.19, while LPS had the lowest, which was 5.5. From question five that was about stabilizing workflow and reducing construction process variability, BIM and LPS had recorded the highest mean of 6.14, followed by LPS 6, and the lowest mean was 5.75 as related to BIM. That indicated that BIM and LPS together had the higher impact on the workflow stabilization. Question 5 was to measure the usefulness in removing barriers and constraints from work assignments. The revealed mean was very close for all items, where the mean of LPS was 6.5, the mean of BIM was 6.25, and the mean of BIM and LPS together was 6.19.

Question 7 which is related to reducing uncertainty inherent in the construction phase and design, showed a slight difference between the mean of BIM showing at 6.25 and the mean of BIM and LPS together equating to 6.09, while the mean of the LPS was 5.5. This indicated that BIM, and BIM and LPS together, were more effective in reducing uncertainty inherent in construction and design phase than LPS. Question 8, concerning the time reduction of design and shop drawings, revealed that BIM had the highest mean of 6.5, followed by LPS with 5.5, while BIM and LPS together had the lowest mean of 4.9. This shows that using BIM is more beneficial in reducing the time of designing and preparing shop drawings. Similarly, question nine regarding BIM’s usefulness in “Just In Time” delivery of materials indicated the mean of BIM was 6, which was higher compared to the mean of BIM and LPS together, 5.6. The lowest was 5.5 as for LPS.
These results indicated that BIM affected the delivery of materials and parts more than other items.

Table 11 also shows the result of question 10 that is related to providing accurate cost estimation and take off material quantities, where the mean of BIM was 5.75, the mean of BIM and LPS together was 5, and the mean of LPS was 4.5. That means BIM was more efficient in providing accurate cost estimation and take off material quantities. Question 11, which is concerned with the generation and evaluation of alternative construction plans rapidly, showed the revealed mean of BIM to be 6, followed by BIM and LPS together 5.23, and then LPS was 5. That indicated BIM was more beneficial in that matter than other items. Relating to the improvement of quality and providing customer values, the results of question 12 showed the mean of BIM to be 6.75 and was higher in comparison to the mean of BIM and LPS, coming in at 5.85 and the mean of LPS, which is 5.5. That means BIM improved quality and created more value than the other items. The last question in this table was related to productivity, where BIM recorded a higher mean of 6.75, and the LPS and BIM together and LPS in isolation had the same mean of six. This indicates that BIM is more efficient in improving product quality than the other items in the table.

In summary, BIM recorded the highest overall mean of 6.38, followed by BIM and LPS together of 5.86 and the LPS of 5.73. Although the overall results show a slight difference in the mean value between BIM and BIM and LPS together, this is probably due to the lack of data gathered from participants. BIM and LPS together are considered more effective in reducing project time and cost than LPS by itself.
Table 11

The mean for each question in section “C” for all categories.

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BIM</td>
</tr>
<tr>
<td>1</td>
<td>Adopting BIM and LPS increases collaboration in project design and</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>construction</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Adopting BIM and LPS reduces defects in the construction phase and</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>design and prevents rework</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Adopting BIM and LPS improves communication effectiveness among the</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>project’s participants</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Adopting BIM and LPS reduces conflicts and number of claims among</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>project’s stakeholders</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Adopting BIM and LPS stabilizes work flow and reduces construction</td>
<td>5.75</td>
</tr>
<tr>
<td></td>
<td>process variability</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Adopting BIM and LPS helps in removing barriers and constraints from</td>
<td>6.25</td>
</tr>
<tr>
<td></td>
<td>work assignments</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Adopting BIM and LPS reduces uncertainty inherent in the construction</td>
<td>6.25</td>
</tr>
<tr>
<td></td>
<td>phase and design</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Adopting BIM and LPS reduces the time of project design and shop</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>drawings</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Adopting BIM and LPS aids in just in time delivery of materials and</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>parts</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Adopting BIM and LPS provides accurate cost estimation and take off</td>
<td>5.75</td>
</tr>
<tr>
<td></td>
<td>material quantities</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Adopting BIM and LPS generates and evaluates alternative construction</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>plans rapidly</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Adopting BIM and LPS improves product quality and creates customer value</td>
<td>6.75</td>
</tr>
<tr>
<td>13</td>
<td>Adopting BIM and LPS increases productivity</td>
<td>6.75</td>
</tr>
</tbody>
</table>

|     |                                                            | 6.38| 5.73| 5.86 |

Section D. From table 12, question one is related to the measurement of the execution time of construction projects. The revealed mean of BIM was 33%, the mean of LPS was 15% and the mean of BIM and LPS was 13%. Since BIM had the largest mean among other items, this means that BIM is more efficient in reducing execution
time than other items. Question 2 is about the reduction of the number of RFIs in construction projects. The highest recorded mean was the LPS with 28%, followed by BIM and LPS with 22.86%, and the lowest was BIM with 21.66%. That indicates that LPS was more effective in reducing the number of RFIs than other items. Question 3 was to measure the reduction in the number of change orders and showed that the LPS mean of 28% was the highest in comparison with BIM 23%, and BIM and LPS 23%. This means that LPS reduced the number of RFIs in construction projects more than other items. As for question four, it relates to the participants’ satisfaction with BIM, LPS, or both, and the mean was almost the same - 1 for all participants. However, the mean of BIM and LPS together had a slight difference of 0.9%. That means all the participants were happy with the use of BIM, LPS or both. The last question in this section was to test the willingness of participants to recommend one of these items to the other construction companies. The result showed the mean of all the items to be equal to 1. That means that all participants were willing to recommend all the items to other companies.

Overall, according to this limited data, the mean of BIM was 16, higher than other items, where the LPS mean was 14 and the BIM and LPS mean was 12. This signified that BIM was considered more effective in reducing project time and overall cost compared with other items.
Table 12
*The mean for each question in section “D” for all categories.*

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BIM Reduction</td>
</tr>
<tr>
<td>1</td>
<td>Do you think BIM, LPS, or both increase or decrease the execution time of construction projects?</td>
<td>33%</td>
</tr>
<tr>
<td>2</td>
<td>Do you think BIM, LPS, or both increase or decrease the number of RFIs in construction projects?</td>
<td>22%</td>
</tr>
<tr>
<td>3</td>
<td>Do you think BIM, LPS, or both increase or decrease the number of change orders in construction projects?</td>
<td>23%</td>
</tr>
<tr>
<td>4</td>
<td>Are you feeling satisfied with BIM, LPS, or both BIM and LPS?</td>
<td>1%</td>
</tr>
<tr>
<td>5</td>
<td>Would you recommend BIM, LPS, or both BIM and LPS to other companies that you might know?</td>
<td>1%</td>
</tr>
</tbody>
</table>

**Non-Respondents and Respondents Analysis**

The researcher highlighted the important question items to see if there were any big differences between the answers of the respondents and non-respondents. Table 13, includes the item number, the question, the non-response average value and the respondents' average value.
Table 13

*The non-respondents’ and respondents’ answers.*

<table>
<thead>
<tr>
<th>#</th>
<th>Question</th>
<th>Respondents Reduction %</th>
<th>Non Respondents Reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The effect of using BIM and LPS together on the number of RFIs?</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>The effect of using BIM and LPS together on the number of change orders?</td>
<td>28</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>The effect of BIM and LPS together on the time of fabrication and assembling?</td>
<td>25</td>
<td>22</td>
</tr>
<tr>
<td>4</td>
<td>The effect of BIM and LPS together on rework amount?</td>
<td>36</td>
<td>33</td>
</tr>
<tr>
<td>5</td>
<td>The effect of BIM and LPS together on the execution time of construction projects?</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>

From table 13, in comparison between the respondents’ and non-respondents’ answers, a slight difference is noticed in the mean values for the highlighted items. As for the first item that relates to the effect of BIM and LPS together on the number of RFIs, the average value of the respondents was a 32% reduction in the number of RFIs, while the non-respondents average value was a 28% reduction. The average value of respondents regarding the reduction of change orders item of 28%. This was higher when compared to the non-respondents’ average of 23%. The third item in this table was to test the time of fabrication and assembling by using BIM & LPS. The results showed the respondents average value of 25% reduction is higher in comparison with the non-respondents’ average value of 23% reduction. In addition, the average value of the respondents that relates to the reduction of rework amount was 36%, while the non-respondents average value was a 33% reduction. The last item was to measure the overall
execution time of construction projects with BIM and LPS. The results showed there is a difference between the average value of respondents which was 13% and the non-respondents average value was 10%.

The overall average value of respondents’ answers for all the items was 27% while the non-respondents was 23%. This indicates that the non-respondents either did not have enough experience with BIM and LPS or felt unhappy with them; therefore, their answers' average values were lower than the respondents’ average values.

**Qualitative Analysis**

**Case Studies.** This part includes four interviews with different construction companies, half of them adopting BIM in their system and the other half, adopting LPS in their system. The interviewees were the construction experts such as project manager, construction group manager, construction manager, and a mechanical designer. They were asked about the implementation of BIM and LPS individually and how they affected the number of RFIs, change orders, time of fabrication and assembling, rework amount and overall execution time. One of the BIM interviews was a follow up with a participant while the other was conducted with a mechanical engineer working for a consultant company. The other interviews were related to the LPS implementation; they were conducted with new construction companies that were familiar with LPS. The name of the companies and the interviewees remained anonymous per the participants’ request. The companies have been labeled as A, B, C, and D. The “A” and “B” companies were adopting BIM in their system, while “C” and “D” companies were adopting LPS in their system. The following is a brief commentary about each interview.
**Company “A.”** This company was adopting BIM in their system. The researcher did a follow up with a Construction Group Manager, who had about 30 years of experience in BIM, and was asked an open question regarding BIM. The interviewee indicated BIM could reduce project duration by 15% - 20%. The 3D modeling and clash detection could reduce the interferences in the field, and reduce the prefabrication time and rework amount. BIM could help a manager make a decision faster and reduce the change orders and RFIs. It was able to reduce change orders by 50- 75% relating to the design and drawings. It also could reduce other change orders related to the mission on site such as civil works by 1-25%. The overall reduction in change orders could be about 35%.

**Company “B.”** This interview was conducted with a consultant company specialist in mechanical and electrical design and construction. The interview was done with one of their team who was a mechanical engineer and who used Revit and Naviswork for more than three years. The interviewee indicated that BIM made a 15% reduction in the number of RFIs due to the 3D modeling that could help on site by answering many questions raised by contractors, and saved time. BIM reduced by about 20%, change orders, especially the ones that were related to the design and drawings. It increased the coordination between the disciplines and helped significantly in clash detection -- a method that could reduce the interferences between the architectural, electrical, mechanical, and plumbing components. Furthermore, BIM reduced a high amount of rework on site. It could produce accurate designs and drawings through utilizing some families related to the furniture and other equipment used in the design
that are usually done by different manufacturers. In addition, the work schedule and the priority of construction items became clearer to the contractors when using 4D modeling so that they could present the mechanical, electrical, plumbing works in different layers in the design phase. The time of preparing the design and drawings details could become short with BIM.

Overall, since BIM contributed significantly in reducing the number of RFIs, change orders, rework amount, and the time of the design phase and increased the level of coordination and communications between the participants, then the overall execution time of a construction project was reduced as well by about 10-15%.

*Company “C.”* This company was adopting LPS in their system. The researcher made this interview with a Construction Manager in company “B.” The company was using LPS in their system, but they did not know about lean construction until the researcher asked them some detailed questions about their planning system. The company used look-ahead planning for 30 days (this is four weeks in construction) and conducted a schedule meeting every Monday. All the participants have to be involved in the meeting, including the sub-contractors, superintendents, and other skilled builders on site. After weekly work plans are prepared, all the people who have to be involved in that plan had to be available on site during the week in order to accomplish their assignments and meet the plan schedule. LPS reduced execution time of a construction project by about 10%. It can reduce the number of RFIs through the planning process. It did not affect the number of change orders that happened during the mission on site. For example, three sinkholes were found in the ground while preparing for the raft foundation. An additional time and
cost were asked because it was not included in the contract. In order to push the schedule ahead, the prime company tries to make sure the sub-contractors do their commitments on time according to the contract. Lastly, the manager recommended LPS to other construction companies because it could reduce the time and cost of the project.

*Company “D.”* A Project Manager was interviewed in this company. The company implemented the philosophy of LPS in their system. They do two-three weeks look-ahead planning. They had a weekly meeting every Friday to discuss the work progress and make the weekly work plan. During the meetings, all the main players who have to work on site had to be involved in the meeting to incorporate their opinion in the schedule. They broke down the milestone schedule into phase schedules and then took a snapshot for some assignments to make it ready for the next two to three weeks. LPS reduced the number of RFI’s, especially the ones that were related to the design and drawings because they keep planning. It reduced the rework amount through enabling the workers to do the assignment right the first time. In addition, it helped to reduce prefabrication times, so when they made the look ahead plan, they could begin to prefabricate many building components off site. As for the change orders reduction, the interviewee was not sure whether LPS affected the number of change orders or not. Overall, it can reduce 10% of overall execution time of construction projects or save a month out of a year. The manager recommended LPS to other construction companies to save time and money.

**Summary of Case Studies.** In summary, the researcher solicited some statistical information from the interviewees during the interviews regarding the effect of adopting
BIM or LPS considering the number of RFIs, change orders, rework amount and the overall execution time. The participants of company “A” and “B” that are adopting BIM in their system indicated BIM reduced RFIs by about 20%, followed by 28% of change orders, 35% of rework amount, and 15% was the overall reduction in the execution time. The participants in company “C” and “D” that were adopting LPS in their system indicated that LPS helped in reducing about 10% of the overall execution time. Otherwise, the recorded answers of both participants in both companies confirmed that adopting LPS could reduce the number of RFIs, change orders, rework amount, but no explicit percentages were recorded regarding the reduction of any of these items.

Discussion

In comparing the results of the qualitative and quantitative analysis, the author highlighted some important items. These items were the number of RFIs, change orders, rework amount and the overall duration of construction projects. Table 14 shows both the quantitative and qualitative response data for BIM, LPS, and the quantitative responses of BIM and LPS together.

From table 14 regarding the BIM section, the qualitative data did not support the quantitative data, where the qualitative data indicated BIM reduced 20% of RFIs, which was low compared to the quantitative data 32%. There was also a slight difference between the qualitative and quantitative sections regarding the reduction of change orders. The qualitative data indicated BIM reduced change orders by about 27% while the quantitative indicated 36%. Furthermore, the rework amount reduction in qualitative section was 35%. That was less than the reduction in the quantitative section, which
showed 56%. The qualitative data indicated the reduction in the execution time of a construction project was 15%, which was lower than the reduction mentioned in the quantitative section of 32%.

Table 14 shows the difference between the qualitative and quantitative data of the LPS section. Although the participants did not state explicit numbers regarding the reduction of RFIs, and rework amount, their recorded answers indicated that LPS could reduce the number of RFIs, and rework amount in construction projects, but the participants were not sure whether LPS would affect the number of change orders. LPS increases the coordination and collaboration between the participants and helps in reducing the number of these items. The overall reduction in the execution time was 10% as stated in the qualitative section while the reduction was 15% as recorded in the quantitative section.

In comparison with the quantitative data of BIM and LPS together and the qualitative data of BIM and LPS individually, the result indicated that with BIM and LPS together the reduction of RFIs was 30%. That was considerably higher than in the qualitative section regarding BIM, which was 20%. The quantitative section also indicated that BIM and LPS together reduce about 28% of change orders while the qualitative data of BIM indicated 27%. As for the reduction in rework amount, it was 35% for BIM and LPS together and for BIM individually. Lastly, the reduction in overall execution time in BIM and LPS together was almost 13% while LPS stated a reduction of about 10% and BIM by 15%. 
In summary, the time reduction in execution time with the combination of BIM and LPS and BIM individually were almost the same and were higher than the reduction that happen with just LPS.

Table 14

Qualitative and Quantitative responses data of BIM, LPS and BIM and LPS.

<table>
<thead>
<tr>
<th>Item</th>
<th>Question</th>
<th>Quantitative Analysis Reduction%</th>
<th>Qualitative Analysis Reduction%</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIM</td>
<td>The effect of BIM on RFIs</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>The effect BIM on change orders</td>
<td>36</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>The effect of BIM on rework amount</td>
<td>56</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>The effect of BIM on overall execution time</td>
<td>32</td>
<td>15</td>
</tr>
<tr>
<td>LPS</td>
<td>The effect of LPS on RFIs</td>
<td>38</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>The effect of LPS on change orders</td>
<td>32</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>The effect of LPS on rework amount</td>
<td>25</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>The effect of LPS on overall execution time</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>BIM&amp;LPS</td>
<td>The effect of BIM and LPS on RFIs</td>
<td>30</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>The effect BIM and LPS on change orders</td>
<td>27</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>The effect of BIM and LPS on rework amount</td>
<td>35</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>The effect of BIM and LPS on overall execution time</td>
<td>12</td>
<td>--</td>
</tr>
</tbody>
</table>
Chapter 5

Conclusions

The main purpose of this research was to determine the relationship between delay in construction processes and the usage of BIM and LPS together. The outcomes of this study should enable the construction practitioners such as project managers, construction managers, engineers, architects, contractors, subcontractors, and superintendents to control the construction operations and reduce the project duration, overhead cost, and conflicts between participants. This chapter presents the outcomes, the conclusions and the recommendation for future research based on the quantitative and qualitative results.

The study hypothesized that implementing BIM and LPS together in construction projects would lead to significant reduction in project duration, eliminate delays from construction operations, and enhance project delivery. The conclusions were drawn from the resulting quantitative and qualitative analysis presented in the previous chapter as follows:

From the analysis findings, the majority of the surveyed sample who adopted BIM and LPS together in their system was 77%. This may suggest most of the construction companies prefer to use BIM and LPS together rather than use them individually due to the strong synergy between BIM and Lean that leads to improved workflow and reduces wastes from construction operations. In other words, companies may use LPS as a means for implementing BIM practices or vice versa.
The results indicated there was a difference between the recorded qualitative data and quantitative data regarding the adoption of BIM and LPS individually, where the average reduction in the number of RFIs, change orders, rework amount and overall execution time in qualitative data were lower compared to the quantitative data. That disparity is likely attributed to the lack of experience and interest of the people participating in quantitative study or to the rounding up of the result, while the people involved in the qualitative part were more likely to state numbers that are more accurate.

In comparison between the qualitative result of BIM and LPS individually and the quantitative result of adopting BIM and LPS together, the findings indicated the overall average reduction in number of RFIs with BIM and LPS together amounted to 30% and was higher than the reduction with BIM individually, amounting to only 20%. As for LPS, the participants in the qualitative part did not state an explicit number regarding the reduction of RFIs. That may suggest the effect of BIM and LPS together on the number of RFIs is higher than the effect of BIM and LPS individually. The strong synergy between BIM and LPS leads to an increase in the coordination and improvement of communications between the disciplines during the design phase and construction operations. This reduces the number of RFIs and shortens construction schedules.

The findings also indicated there is no difference between the effect of BIM and LPS together and BIM alone on the number of change orders and rework amounts, both of them could be reduced. The change orders were reduced by 28% and the rework amount was reduced by 35%. As for the LPS alone, the qualitative analysis indicated the influence of LPS on the number of change orders could be limited or very slight. This
may suggest BIM has a significant influence on the number of change orders and rework amount due to the 3D modeling, 4D scheduling, and clash detection that could increase the coordination and collaboration level between participants and simulate building construction and design, which leads to increased accuracy and reduced errors for both building quantities and qualities.

The results of the data also indicated that the average reduction in the overall execution time of a construction project with BIM and LPS is at 13% while BIM reduced that time by 15% and LPS by 10%. There was a slight difference in the average reduction between BIM and LPS together and LPS alone, but BIM and LPS together and BIM individually had almost the same influence. This means BIM had a more significant impact on the execution time of construction projects.

**Overall Conclusion**

Whereas the research results supported the hypothesis that the adoption of BIM and LPS together in construction projects would result in significant reduction in project time and cost, BIM alone was as affective as BIM and LPS together. Usage of BIM individually and BIM and LPS in combination had almost the same influence on the number of change orders, rework amount, and overall execution time. Except for the reduction in the number of RFIs, the average reduction in the number of RFIs with BIM and LPS together was higher than the average reduction with BIM individually. BIM aspects, which are 3D visualization, 4D scheduling, and MEP clash detection, led to increased collaboration and communication between the project participants, reduced uncertainty in project design, and assisted in just in time delivery of materials. All of
these issues are lean construction goals. Therefore, BIM and LPS when implemented together have almost the same influence as BIM on project time.

Whereas the literature review indicated LPS could increase project reliability and improve workflow and safety and quality in construction projects, the research results indicated that LPS alone did not have the impact of BIM alone or BIM and LPS together. The desired improvements were attributable primarily to BIM and not to LPS. To reduce delays in construction, contractors should invest money and time on BIM usage because it had a more significant effect than LPS on most issues that cause delay in construction projects. If LPS is the system that causes companies to implement BIM then it should be employed for that purpose.

**Recommendations**

This study focused on the influence of using BIM and LPS together on the project duration and elimination of delay from the construction process. It compared the effects of BIM and LPS in combination and their effect if implemented individually on the main issues that cause delay in construction processes such as the number of RFIs, change orders, reworks amount, prefabication and assembling time, and overall execution time. Further studies should focus on the effect of BIM and LPS on workflow stabilization, quality of the project and overhead cost. The sample size should be increased for the future research in order to target not only the companies that have membership with Lean Construction Institute (LC), but also include the top 100 construction companies in the USA, the Associated General Contractors of America (AGC), and/or the Mechanical
Contractors Association (MCA). Also, further studies should be conducted in different countries, not only in the USA in order to generalize the results.
Appendix A: Survey Questionnaire

INFORMED CONSENT DOCUMENT

Project Title: Using Building Information Modeling (BIM) and the Last Planner System (LPS) to Reduce Construction Process Delays

Investigator: Zaid Al Hussein, Department of Architectural and Manufacturing Sciences (AMS), zaid.alhussein692@topper.wku.edu

You are invited to participate in a study conducted as part of the requirement for my thesis, in the Department of Architecture and Manufacturing Sciences at Western Kentucky University. The University requires that you give your agreement to participate in this project.

All information obtained will be treated in the strictest confidentiality. The investigator will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You may ask any questions you have to help you understand the project. A basic explanation of the project is written below. Please read this explanation and discuss with the researcher any questions you may have. You should keep a copy of this form for your records.

1. Nature and Purpose of the Project:
As a master student in the department of Architecture and Manufacturing Sciences (AMS), and under the supervision of Dr. Douglas Chelson, Dr. Jackson and Prof. Aly. I am conducting research in construction management with a focus on “Using Building Information Modeling (BIM) and the Last Planner System (LPS) to Reduce Construction Process Delays”. The purpose of this study is to examine whether implementing BIM and LPS together can reduce delay in construction process significantly, enhance project delivery, and reduce cost.

2. Explanation of Procedures:
I ask that you complete a brief questionnaire. You will be asked to answer a series of questions on a short questionnaire and send your responses back to the researcher through the survey software. The instructions are provided for each section. Respondents should expect to spend no more than 15 minutes to complete the survey.

3. Discomfort and Risks:
There are no foreseeable risks associated with this research project and the probability and magnitude of harm or discomfort anticipated in the research is very minimal.

4. Benefits:
It is hoped that the knowledge gained through your participation will help you and other construction companies at a later time. The study is aimed at reducing project duration by improving construction management practices, developing the planning and control, and improving communication and collaboration between participants. The findings of this research can be helpful to the construction practitioners in the construction industry such as contractors, subcontractors, engineers, architects, and superintendents to improve project planning and control as well as reduce the project duration and cost.
5. **Confidentiality:**
The survey does not contain any identifiable information, and anonymity is assured. If the results of the study are published no personal information will be included.

6. **Refusal/Withdrawal:** Refusal to participate in this study will have no effect on any future services you may be entitled to from the University. Anyone who agrees to participate in this study is free to withdraw from the study at any time with no penalty.

You understand also that it is not possible to identify all potential risks in an experimental procedure, and you believe that reasonable safeguards have been taken to minimize both the known and potential but unknown risks.

**Your continued cooperation with the following research implies your consent.**

THE DATED APPROVAL ON THIS CONSENT FORM INDICATES THAT THIS PROJECT HAS BEEN REVIEWED AND APPROVED BY THE WESTERN KENTUCKY UNIVERSITY INSTITUTIONAL REVIEW BOARD

Paul Mooney, Human Protections Administrator

TELEPHONE: (270) 745-2129

[Signature]

WKU IRB# 16-285
Approval - 1/25/2016
End Date - 4/15/2016
Expedited
Original - 1/25/2016
Name of Project: Last Planner System (LPS) and Building Information Modeling (BIM)  
Name of Researcher: Zaid Al Hussein  
Department: Architectural and Manufacturing Science AMS

How many total subjects have participated in the study since its inception? #22

How many subjects have participated in the project since the last review? #22

Is your data collection with human subjects complete? ☐ Yes ☐ No

1. Has there been any change in the level of risks to human subjects?  
   (If “Yes”, please explain changes on a separate sheet). ☐ Yes ☐ No

2. Have informed consent procedures changed so as to put subjects above minimal risk? (If “Yes”, please describe on a separate sheet). ☐ Yes ☐ No

3. Have any subjects withdrawn from the research due to adverse events or any unanticipated risks/problems? (If “Yes”, please describe on a separate sheet). ☐ Yes ☐ No

4. Have there been any changes to the source(s) of subjects and the Selection criteria? (If “Yes”, please describe on a separate sheet). ☐ Yes ☐ No

5. Have there been any changes to your research design that were not specified in your application, including the frequency, duration and location of each procedure. (If “Yes”, please describe on a separate sheet). ☐ Yes ☐ No

6. Has there been any change to the way in which confidentiality of the Data is maintained? (If “Yes”, please describe on a separate sheet). ☐ Yes ☐ No

7. Is there desire to extend the time line of the project? ☐ Yes ☐ No
   On what date do you anticipate data collection with human subjects to be completed? October 31, 2016
Survey Questionnaire

Introduction

Thank you for agreeing to participate in this academic survey. The results from this survey are completely anonymous, your personal information and your company information cannot be tracked.

I greatly appreciate your participation as we strive to increase our knowledge to improve the construction industry.

Best Regards,
Zaid Al Hussein
Graduate Student
Engineering Technology Management
Western Kentucky University (WKU)
C.Phone: (270) 320-0308
E-mail: zaid.alhussein692@topper.wku.edu

Some definitions:
Last Planner System (LPS): A production planning and control system that assist in reducing causes of variation in construction workflow through integrated should-can-will-did planning with constraint analysis, weekly work plan and analysis of plan percent completed.

Building Information Modeling (BIM): A modeling technology and associated set of processes to produce, communicate, and analyze building models.

Change orders: “A change order is work that is added to or deleted from the original scope of work of a contract, which alters the original contract amount and/or completion date.”

RFIs: “A request for information is a formal written procedure initiated by the contractor seeking additional information or clarification for issues related to design, construction, and other contract documents.”
Survey Questionnaire

**Instruction**: Please choose the one category which best describes your company and complete the associated survey. Complete only one survey.

1) My company only uses BIM. Please answer only questionnaire #1

2) My company only uses LPS. Please refer to answer the questions in questionnaire #2

3) My company uses a combination of BIM and LPS. Please use questionnaire #3

**Questionnaire -1-**

**Building Information Modeling (BIM)**

**Section A**

Instruction: For the section below, please give the answer that best describes your opinion or experience.

1. Have you been involved in any projects using BIM? If so, how many?
2. What BIM software(s) does your firm use?
3. How long have you used BIM?
4. Does your company have its own BIM staff or do they outsource? If it does have internal BIM staff, does your staff get trained?
5. How many projects has your company completed with BIM?
6. How would you rate BIM efficiency in your company? Please choose one answer.
   A) Excellent  B) Very good  C) Good  D) Poor

**Section B**

Instruction: For the section below, please indicate an approximate percentage change in the following items based on your experience. **CHOOSE** the response that best describes your opinion.

1. What is the effect of using BIM on the number of Requests for Information (RFIs)?
   Choose one of the following choices:
   A) Increase or no change  B) 1-25% Reduction  C) 26-50% Reduction  D) 51-75% Reduction  E) 76-100% Reduction

2. What is the effect of using BIM on the number of change orders issued? Choose one of the following choices:
   A) Increase or no change  B) 1-25% Reduction  C) 26-50% Reduction  D) 51-75% Reduction  E) 76-100% Reduction
3. What is the effect of BIM on the time of fabrication and assembling? Choose one of the following choices:

A) Increase or no change  
B) 1-25% Reduction  
C) 26-50% Reduction  
D) 51-75% Reduction  
E) 76-100% Reduction

4. What is the effect of BIM on rework amount? Choose one of the following choices:

A) Increase or no change  
B) 1-25% Reduction  
C) 26-50% Reduction  
D) 51-75% Reduction  
E) 76-100% Reduction

Section C

**Instruction:** For the section below, please indicate to what extent you agree or disagree with each statement based on your experience **CHOOSE** the response that best describes your opinion.

- 7 - Strongly Agree; 6 - Agree; 5 - Agree Some What; 4 - Neither Agree nor Disagree; 3 - Disagree Some What; 2 - Disagree; 1 - Strongly Disagree
<table>
<thead>
<tr>
<th>Section</th>
<th>Question</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Agree Some what</th>
<th>Neither Agree Nor Disagree</th>
<th>Disagree Some what</th>
<th>Disagree</th>
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<tr>
<td>C</td>
<td>Implementing BIM increases collaboration in project design and construction</td>
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<td>Implementing BIM reduces defects in the construction phase, design, and prevents rework</td>
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<td>Adopting BIM improves communication effectiveness among the project’s participants</td>
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<td>Adopting BIM reduces conflicts and number of claims among project’s stakeholders</td>
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<td>Adopting BIM stabilizes workflow and reduces construction process variability</td>
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<td>Adopting BIM helps in removing barriers and constraints from work assignments</td>
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<td>Adopting BIM reduces uncertainty inherent in the construction phase and design</td>
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<td>Adopting BIM reduces the time of project design and shop drawings</td>
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<td>Adopting BIM aids in Just In Time (JIT) delivery of materials and parts</td>
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<td>Adopting BIM provides accurate cost estimation and take off material quantities</td>
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<td>Adopting BIM generates and evaluates alternative construction plans rapidly</td>
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<td>Adopting BIM improves product quality and creates customer value</td>
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<td>Adopting BIM increases productivity</td>
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<td>5</td>
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</table>
**Section D**
Instruction: For the section below, **CHOOSE** the response that best describes your opinion and indicates the approximate percentage as needed.

1. Do you think BIM increases or decreases the execution time of the project?
   - Increase
   - Decrease
   How much percentages does BIM change the project time _________?

2. Do you think BIM increases or decrease the number of RFIs in construction projects?
   - Increase
   - Decrease
   How much in percentages does BIM affect RFIs _________?

3. Do you think BIM increases or decreases the number of change orders in construction projects?
   - Increases
   - Decreases
   How much percentage does BIM alter the number of change orders _____________?

4. Are you feeling satisfied with BIM?
   - Yes
   - No

5. Would you recommend BIM to other companies that you might know?
   - Yes
   - No

---

**Questionnaire -2-**

**Section A**
Instruction: For the section below, please give the answer that best describes your opinion.

1. Have you been involved in projects using LPS? If so, how many?
2. How long have you used LPS?
3. Which position in your company holds the role of Last Planner coordinator?
4. How many projects has your company completed using LPS?
5. How would you rate LPS efficiency in your company? Please choose one answer.
   - A) Excellent
   - B) Very good
   - A) Good
   - B) Poor

6. Are the Last Planner coordinator and other staff involved in LPS formally trained?
**Section B**

Instruction: For the section below, please indicate an approximate percentage of reduction based on your experience. CHOOSE the response that best describes your opinion.

1. What effect does LPS have on the number of Requests for Information (RFIs)?
   Choose one of the following choices:
   - A) Increase or no change
   - B) 1-25% Reduction
   - C) 26-50% Reduction
   - D) 51-75% Reduction
   - E) 76-100% Reduction

2. What effect does LPS have on the number of change orders? Choose one of the following choices:
   - A) Increase or no change
   - B) 1-25% Reduction
   - C) 26-50% Reduction
   - D) 51-75% Reduction
   - E) 76-100% Reduction

3. What effect does LPS have on the time of fabrication and assembling? Choose one of the following choices:
   - A) Increase or no change
   - B) 1-25% Reduction
   - C) 26-50% Reduction
   - D) 51-75% Reduction
   - E) 76-100% Reduction

4. What effect does LPS have on rework amount? Choose one of the following choices:
   - A) Increase or no change
   - B) 1-25% Reduction
   - C) 26-50% Reduction
   - D) 51-75% Reduction
   - E) 76-100% Reduction

**Section C**

Instruction: For the section below, please indicate to what extent you agree or disagree with each statement based on your experience. CHOOSE the response that best describes your opinion.

7 - Strongly Agree; 6 – Agree; 5 – Agree Some What; 4- Neither Agree nor Disagree
3 – Disagree Some What; 2- Disagree; 1 – Strongly Disagree
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<tr>
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<th>Question</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Agree Some</th>
<th>Neither Agree</th>
<th>Nor Disagree</th>
<th>Disagree Some</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
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<tr>
<td>1.</td>
<td>Implementing LPS increases collaboration in project design and construction</td>
<td>7</td>
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<td>2.</td>
<td>Implementing LPS reduces defects in the construction phase and design and prevents rework</td>
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<td>3.</td>
<td>Adopting LPS improves communication effectiveness among the project’s participants</td>
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<td>4.</td>
<td>Adopting LPS reduces conflicts and number of claims among project’s stakeholders</td>
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<td>5.</td>
<td>Adopting LPS stabilizes workflow and reduces construction process variability</td>
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<td>6.</td>
<td>Adopting LPS helps in removing barriers and constraints from work assignments</td>
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<td>7.</td>
<td>Adopting LPS reduces uncertainty inherent in the construction phase and design</td>
<td>7</td>
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<td>9.</td>
<td>Adopting LPS aids in Just In Time (JIT) delivery of materials and parts</td>
<td>7</td>
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<td>10.</td>
<td>Adopting LPS provides accurate cost estimation and take off material quantities</td>
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<td>5</td>
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<tr>
<td>11.</td>
<td>Adopting LPS generates and evaluates alternative construction plans rapidly</td>
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<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
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<tr>
<td>12.</td>
<td>Adopting LPS improves product quality and creates customer value</td>
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<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
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<tr>
<td>13.</td>
<td>Adopting LPS increases productivity</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Section D
Instruction: For the section below, please CHOOSE the response that best describes your opinion and indicate the approximate percentages as needed.

1. Do you think LPS increases or decreases the execution time of construction projects?
   - Increases
   - Decreases
   Approximately what percentage does it change? _______________.

2. Do you think LPS increases or decreases the number of RFIs in construction projects?
   - Increases
   - Decreases
   Approximately what percentage does it change? _______________.

3. Do you think LPS increases or decreases the number of change orders in construction projects?
   - Increases
   - Decreases
   Approximately what percentage does it change? _______________.

4. Are you feeling satisfied with LPS?
   - Yes
   - No

5. Would you recommend LPS to other companies that you might know?
   - Yes
   - No

Questionnaire -3- Building Information BIM and LPS together

Section A
Instruction: For the section below, please give the answer that best describes your opinion.

1. Have you been involved in projects that use both BIM and LPS? If so, how many?
2. What BIM software(s) does your firm use?
3. How long have you used BIM and LPS together?
4. Does your company have its own BIM staff or do they outsource? If it does have internal BIM staff, does your staff get trained?
5. How many projects did your company completed with BIM and LPS?
6. How would you rate BIM efficiency in your company? Please choose one answer.
   - B) Excellent
   - B) Very good
   - C) Good
   - D) Poor
7. How would you rate LPS efficiency in your company? Please choose one answer.
   - C) Excellent
   - B) Very good
   - E) Good
   - F) Poor
8. Which position in your company holds the role of Last Planner coordinator?

9. Are the Last Planner coordinator and other staff involved in LPS formally trained?

**Section B**
Instruction: For the section below, please indicate the percentage of reduction in the following questions based on your experience. **CHOOSE** the response that best describes your opinion.

1. Approximately what effect does BIM and LPS have on the number of Requests for Information (RFIs)? Choose one of the following choices:
   - A) Increase or no change
   - B) 1-25% Reduction
   - C) 26-50% Reduction
   - D) 51-75% Reduction
   - E) 76-100% Reduction

2. Approximately what effect does BIM and LPS have on the number of change orders? Choose one of the following choices:
   - F) Increase or no change
   - G) 1-25% Reduction
   - H) 26-50% Reduction
   - I) 51-75% Reduction
   - J) 76-100% Reduction

3. Approximately what effect does BIM and Last Planner System (LPS) have on the time of fabrication and assembling? Choose one of the following choices:
   - A) Increase or no change
   - B) 1-25% Reduction
   - C) 26-50% Reduction
   - D) 51-75% Reduction
   - E) 76-100% Reduction

4. Approximately what effect does BIM and LPS have on rework amount? Choose one of the following choices:
   - A) Increase or no change
   - B) 1-25% Reduction
   - C) 26-50% Reduction
   - D) 51-75% Reduction
   - E) 76-100% Reduction

**Section C**
Instruction: For the section below, please indicate to what extent you agree or disagree with each statement based on your experience. **CHOOSE** the response that best describes your opinion.

7 - Strongly Agree; 6 - Agree; 5 - Agree Some What; 4- Neither Agree nor Disagree
3 - Disagree Some What; 2- Disagree; 1 - Strongly Disagree
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<th>Disagree Somewhat</th>
<th>Disagree</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Implementing BIM and LPS increases collaboration in project design and construction</td>
<td>7</td>
<td>6</td>
<td>5</td>
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<tr>
<td>2.</td>
<td>Implementing BIM and LPS reduces defects in the construction phase and design and prevents rework</td>
<td>7</td>
<td>6</td>
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<td>2</td>
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<td>3.</td>
<td>Adopting BIM and LPS improves communication effectiveness among the project’s participants</td>
<td>7</td>
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<td>4.</td>
<td>Adopting BIM and LPS reduces conflicts and number of claims among project’s stakeholders</td>
<td>7</td>
<td>6</td>
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<td>5.</td>
<td>Adopting BIM and LPS stabilizes workflow and reduces construction process variability</td>
<td>7</td>
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<td>6.</td>
<td>Adopting BIM and LPS helps in removing barriers and constraints from work assignments</td>
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<td>7.</td>
<td>Adopting BIM and LPS reduces uncertainty inherent in the construction phase and design</td>
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<td>8.</td>
<td>Adopting BIM and LPS reduces the time of project design and shop drawings</td>
<td>7</td>
<td>6</td>
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<td>9.</td>
<td>Adopting BIM and LPS aids in just in time delivery of materials and parts</td>
<td>7</td>
<td>6</td>
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<td>10.</td>
<td>Adopting BIM and LPS provides accurate cost estimation and take off material quantities</td>
<td>7</td>
<td>6</td>
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<td>11.</td>
<td>Adopting BIM and LPS generates and evaluates alternative construction plans rapidly</td>
<td>7</td>
<td>6</td>
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<tr>
<td>12.</td>
<td>Adopting BIM and LPS improves product quality and creates customer value</td>
<td>7</td>
<td>6</td>
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<tr>
<td>13.</td>
<td>Adopting BIM and LPS increases productivity</td>
<td>7</td>
<td>6</td>
<td>5</td>
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</tbody>
</table>
Section D

Instruction: For the section below, CHOOSE the response that best describes your opinion and indicate the approximate percentages as needed.

1. Do you think BIM and LPS together increase or decrease the execution time of construction projects?
   - Increase
   - Decrease
   Approximately what percentage does it change? ________.

2. Do you think BIM and LPS together increase or decrease the number of RFIs in construction projects?
   - Increase
   - Decrease
   Approximately what percentage does it change? ________.

3. Do you think BIM and LPS together increase or decrease the number of change orders in construction projects?
   - Increase
   - Decrease
   By approximately what percentage does it change? ________.

4. Are you feeling satisfied with BIM and LPS?
   - Yes
   - No

5. Would you recommend BIM, LPS, or both (BIM &LPS) to other companies that you might know?
   - Yes
   - No
References


