EVALUATING THE VALUE OF EARLY PLANNING FOR BUILDING INFORMATION MODELING USING LEAN THEORY

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ABSTRACT

Building Information Modeling (BIM) provides a means for owners, designers, contractors, and operators to generate, organize and use detailed information throughout a project lifecycle. An important aspect to the success of BIM is the process in which information is exchanged between project team members. In theory, information should be both accessible and usable, when required. Because the AEC industry is project centered, and several companies work collectively towards the design and construction of a facility, the availability and accuracy of information can become constrained. Building Information Modeling has the potential to improve efficiency in the AEC industry; however, if the information exchange (IE) process is not planned early in the project lifecycle, the benefits of using the authored data may be mitigated by process waste.

This paper serves to evaluate the value of early team planning as it pertains to performing BIM tasks in the construction phase of a project. The rationale behind lean theory is to increase efficiency by eliminating waste, consequently increasing value. To illustrate the value of early project planning for BIM, this research focuses on the information exchange waste produced on a case study project. During the case study process actual information exchanges were evaluated using the seven types of waste: overproduction, inventory, extra processing, motivation, defects, waiting, and transportation. Finally, time and resources were allocated to each non-value added aspect of information exchange through interviews with the project team members. This procedure produces a total cost of IE waste which was then correlated to the lack of early planning. Using this methodology, the Millennium Science Center (MSC) project on the Pennsylvania State University campus was evaluated to determine the economic benefit associated with the early planning of BIM on future projects.

Keywords: BIM, Lean Thinking, Information Exchange, Knowledge Management

1. INTRODUCTION

Over the past 40 years, the construction industry has made little advancements in terms of increasing its productivity. According to Figure 1, the labor productivity index has actually decreased slightly from 1964 to 2004. This index represents an average for the entire industry by dividing the total contracted work in the U.S. by the labor field work hours. Therefore, over the past four decades construction projects have inccurred additional cost from using more resources than necessary (Teicholz 2004). This concept is especially staggering when coupled with the vast advancement of non-farm industries (manufacturing), which has seen more than a two-fold increase in productivity since 1964.

A few reasons for the decreased construction productivity are: segmented project teams due to the use traditional delivery methods (design-bid-build); little investment in research and development in AEC firms; large human factor caused by lower pay scale and expensive equipment; and slow rate of change inside companies and workforce. According to Young and Bernstein (2006), in their McGraw Hill Smart Report, improvements in construction productivity are being made due to innovation with new technologies, processes, and services. However the fragmentation of firms that form a construction project team (Architect, Engineers, Contractor, and Subcontractors) limits the success of technology implementation ultimately leading to a wash of productivity enhancement.

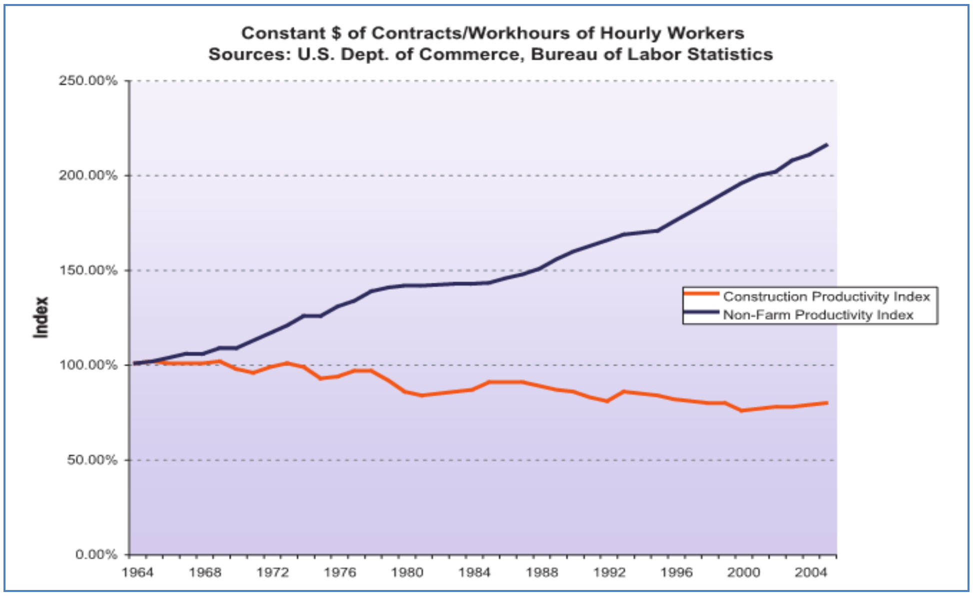


Figure 1: Labor productivity index for US construction industry from 1964 through 2004.

1.1 Building Information Modeling (BIM) Background

An important factor in improving construction efficiency is the emergence of Building Information Modeling (BIM). The National Building Information Modeling Standards (NBIMS) Committee defines BIM as "*a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder* (NIBS 2007)." In recent years, researchers have questioned the overall value of implementing BIM in the AEC (Architecture, Engineering, and Construction) Industry. However, few studies have been published that identify the overall value of BIM. The majority of the research focuses on specific areas of BIM, such as 4D Modeling (Dawood and Mallasi 2006; Jongeling et al. 2008); 3D mechanical, electrical, and plumbing (MEP) Coordination (Khanzode et al. 2008); or a combination of the two (Khanzode et al. 2005; Staub-French and Khanzode 2007). The use of 4D modeling, simulating sequence by combining a 3D model with the aspect of time, has grown in popularity since it was first implemented in the late 1980's by Bechtel and Hitachi (Smith, 2001). These models help involve more stakeholders early in a project to inject their business and engineering knowledge into the design of the facility (Jongeling et al. 2008).

3D Coordination is defined as using automated clash detection software to identify the location of two systems or elements that directly conflict. An important factor in the success of 3D Coordination is the identification of the level of detail required by team members for their system to be represented in the model (Khanzode et al. 2008). Some of the benefits that the project teams can achieve through the coordination of the MEP systems include: 60% fewer Requests for Information (RFI) than expected for a project of the same complexity (Staub-French and Khanzode,2007); and field labor savings ranging from 20 to 30 % for all the MEP subcontractors (Khanzode et al. 2008) due to increased productivity, less rework, and decreased schedule. Although these studies are very important to calculate the benefit of specific BIM Uses, there is a need to understand the effect of Building Information Modeling being implemented throughout the lifecycle of capital facility projects.

1.2 BIM Implementation Challenges

The success of BIM has been limited by several challenges associated within the Architecture, Engineering, and Construction (AEC) industry. According to the 2007 AISC (American Institute of Steel Construction)-ACCL (American College of Construction Lawyers) eConstution Roundtable, there are two main constraints associated with the use of BIM in practice (Hartman 2007): "First, and foremost, it seems to be a people problem." The AEC industry has yet to adopt the idea of total project collaboration as well as combining of resources for the benefit of the entire project team. Secondly, technology is still limiting the success of BIM Implementation; specifically the lack of interoperability or data exchange between different BIM tools. The workshop mentioned that BIM analysis tools are being developed rapidly as "stand-alone applications," and for the most part are not ready for main stream implementation. Additionally, the roundtable concludes that the construction firms have been utilizing BIM application for a number of years, even without the transfer of models / information from the design team (Hartman 2007). In this event, the contractors are willing to remodel the facility because they see the value added in their field operations and downstream users (Subcontractors, Owners).

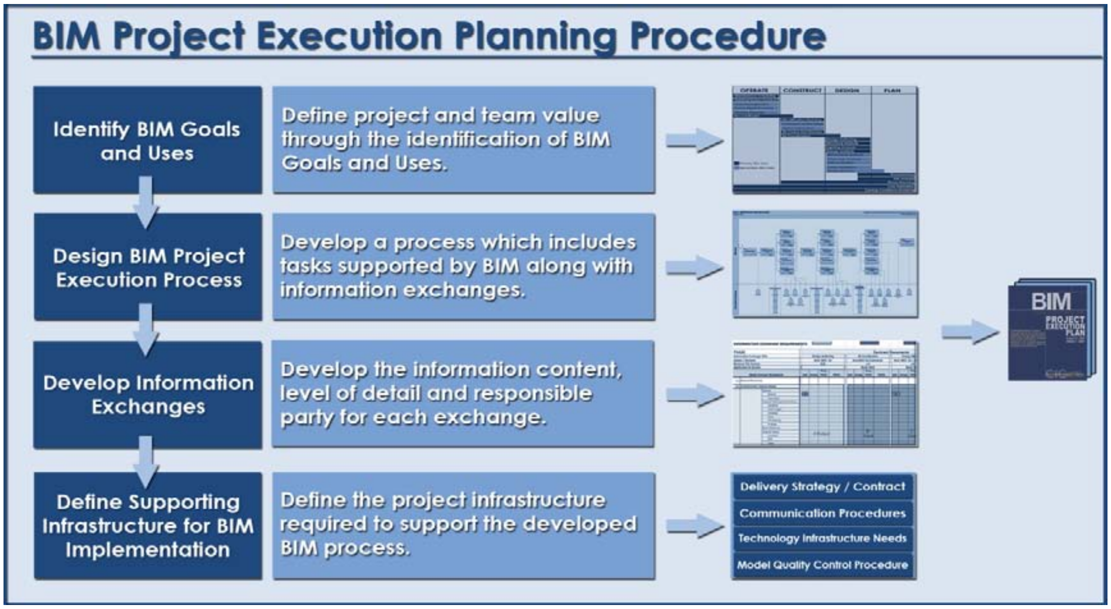
Upon further investigation, there are additional challenges that firms face regarding the success of BIM in the AEC industry. Files should be stored in a central location and templates need to be developed using a common language among the group (Changfeng 2006). Also, it is important to clearly define the limits of each discipline's responsibility to eliminate excessive overlap in areas of expertise. As previously stated, communication between the disciplines is essential to the success of the building project. It is very important that there is an open line of communication as well as a developed meeting schedule for improvements (Howell 2004). Although, an open line of communication and a central file location may not work well with the guidelines set up with American Institute of Architects (AIA) contractual rights, which could be a pitfall for the entire project. Other legal issues pertaining to Building Information Modeling are insurance coverage and contract documentation. Legal issues occur when information supplied for a specific purpose is used subsequently for another (Thompson 2007). The BIM model may be accurate for the intended purpose, but not for additional analysis. This could result in a change in scope that was not warranted by the author. Therefore, the current contract documents will need to be modified to provide the appropriate BIM deliverables earlier in the project lifecycle. This will also lead to the revision of the current payment schedule for the various disciplines involved, which could be considered potential benefit to the industry (Azhar 2008). Although the implementation of Building Information Modeling includes challenges, the value of virtual design and construction becomes more visible when the information exchange process is effectively planned early in a project's lifecycle.

2. BIM PROJECT EXECUTION PLANNING

BIM Project Execution Planning is "a process performed by a project team to design the execution strategy for implementing BIM on the project. The final product of the execution planning process is a documented BIM Project Execution Plan (CIC 2009)." To maximize the effectiveness of BIM, the execution plan should be designed in the early stages of a project and focus on the decisions required to define the scope of BIM implementation on the project, identify process impacts of using BIM, define the team characteristics needed to achieve the modeling, and quantify the value proposition for the appropriate level of modeling at the various stages in the project lifecycle.

During the development of a BIM Project Execution Plan, four steps should be followed: 1) Identify BIM Goals and Uses; 2) Design the BIM Project Execution Process; 3) Develop Information Exchanges; and 4) Define Supporting Infrastructure for BIM Implementation (CIC 2009). These steps, depicted in Figure 2, have been developed by the CIC Research Group through the BIM Execution Planning Research Project. Each step is described in further detail in the following sections.

Prior to implementing BIM, the project team should identify the appropriate tasks that the team would like to perform using BIM. This analysis of BIM Uses should be focused initially on the outcomes desired by the overall process. Therefore, the team should start with the Operations phase, and identify the priority for each of the BIM Uses on the project (High, Medium or Low priority), and then move through the project phases in reverse order (Operations, Construction, Design and Planning). This perspective of 'starting with the end in mind' will identify the downstream desired uses of BIM which should be supported by earlier processes in the lifecycle of the project.



Define project and team value through the identification of BIM Goals and Uses.

Develop a process which includes tasks supported by BIM along with information exchanges.

Develop the information content, level of detail and responsible party for each exchange.

Define the project infrastructure required to support the developed BIM process.

Figure 2: BIM Project Execution Planning Procedure

Although this is a substantial procedure, it is important that team members work together to further develop requirements that arise after each projects completion. Also, the planning decisions should be made early on in a project lifecycle. In the event that the information or resources are not available, effort should be made to revisit the subject matter when the resource can be tapped. Therefore, a BIM Project Execution Plan should be a continuously developing set of rules based on lessons learned from previous successful or unsuccessful attempts of Building Information Modeling Implementation.

2.1 Project Execution Planning using Lean Theory

A large part of the BIM Project Execution Planning procedure was grounded in lean theory. The overarching concept is “Begin with the End in Mind,” which means project team members should identify what the information is to be used for once the project is turned over to the owner and/or end user. Different from the traditional design/bid/build approach, the downstream stakeholders should have a say in the information produced and transferred to create value. This concept as well as others in the BIM Plan falls in line with the five principles of Lean Thinking (Womack & Jones 2003);

1. **Value** – Specify value in the eyes of the customer
2. **Value Stream** – Identify all the steps in the value stream and eliminate waste
3. **Flow** – Allow the value to flow without interruptions
4. **Pull** – Let the customer pull value from the process
5. **Continuously improve** in pursuit of perfection

The main theory behind the lean approach is to improve process speed and reduce cost by eliminating waste (Jugulum & Samuel 2008). This concept is discussed in further detail in section 4.1. By following the five basic principles, team members can increase the effectiveness of design and improve downstream processes on a building project.

3. RESEARCH METHODS

The goal of this research is to provide a standardized method in which future studies can more precisely measure the waste associated with the information exchange process on projects implementing BIM. This paper investigates whether there is a relationship between the early planning of BIM and the minimization of information exchange waste. Therefore, a case study project was utilized to calculate the information exchange waste in correlation to the BIM planning measures implemented.

An important aspect to the success of Building Information Modeling relies on the information exchange between parties (buidlingSMART Norway 2009). The specific focus of this study is the exchange of information amid the Design stakeholders (Architect, Engineers and Consultants) and the Contractors (Construction Manager, General Contractor and Specialty Contractors). Therefore, the value associated with the exchange was collected from the Contractors since they are the downstream stakeholder.

The following research steps were conducted to develop the results addressed in this paper:

1. Identify the information exchange waste that occurred through the information exchange between Design and Construction teams on the case study project
2. Calculate the resource cost required to mitigate the identified IE waste
3. Evaluate the IE waste for correlation with the lack of early planning on the sample project

The case study results were gathered through participation in meetings and interviews with project participants. Research team members attended each of the following meetings to evaluate the information exchange process: a BIM Execution Planning meeting, a Pre-Coordination meeting, four 3D Coordination meetings, and a 4D schedule review meeting. In addition to meetings, the project manager responsible for BIM implementation was interviewed using the breakdown of information exchange waste categories in this document. During the semi-structured interview, the lean concepts were described in terms of information exchange, and the interviewee identified waste that pertains to each topic area. This structure was used to determine the effectiveness of lean theory as it pertains to the IE process. Finally, cost information was collected from team members that were affected by each area of waste, and each activity was evaluated for correlation with the lack of early planning for the case study project. Additional details regarding the calculation procedure are described in section 4.2.

4. EVALUATING THE VALUE OF EARLY PLANNING

An important aspect to the success of a building project is the planning of information exchanged between project team members. Because the AEC industry is project centered, and several companies work collaboratively towards the design and construction of a facility, the availability and accuracy of information can become constrained. Building Information Modeling has the potential to improve efficiency in the AEC industry; however, if the information exchange process is not planned early in the project lifecycle, the benefits of using the authored data may be mitigated by process waste. From a company perspective, the objective of information management is to ensure that valuable information is acquired and exploited to its fullest extent (Willpower 2005).

In general, information exchange waste can be considered to include additional activities and any inactivity that arise as a consequence of not providing information for immediate consumer access to an adequate amount of appropriate, accurate and up-to-date information. Value is in the eyes of the customer, therefore the received information is only valuable if the downstream customer can use the data. In a production / manufacturing system, this concept is easily understood because goods are mainly produced inside one company. Since the AEC Industry is project centric, information is handed from company to company without understanding the end use. Therefore, the design of a project specific information management system is a key to successful interoperability.

4.1 Identifying Information Exchange Waste

Lean Theory was developed by individuals that would not settle for "How things were always done." They questioned each method of production to invent a better way to manufacture a product: lowering inventory and moving decision making to production workers (Womack 1990). Over the years, these theories have been applied successfully across many disciplines. For example, Microsoft used lean theory to balance the interaction between operations and managers by standardizing practices and centralizing information (Herbold 2002). When appropriately applied; lean thinking is a well-tested and well-understood platform upon which to build an effective information exchange process.

Taiichi Ohno, the mastermind of the Toyota Production System, defined several areas of manufacturing waste (Ohno 1988). Table 1 is a summary of seven types of waste along with a definition that pertains to production systems. According to Ohno, overproduction means to produce sooner, faster or in greater quantities than the absolute customer demand. When applied to information exchange, overproduction occurs when the author includes additional information that is not needed for any downstream users. This leads to end users having to: 1) delete unnecessary components / information, 2) group and sort elements, and 3) manipulate large files.

Table 1: Seven Types of Manufacturing Waste

Production System Waste	Definition
1. Overproduction	To produce sooner, faster or in greater quantities than the absolute customer demand
2. Inventory	Any raw material, work in progress (WIP) or finished goods which are not having value added to them
3. Extra Processing Steps	Processing beyond the standard required by the customer
4. Motion	Individuals move more than is necessary for the process to be completed
5. Defects	A component which the customer would deem unacceptable to pass the quality standard
6. Waiting	People or parts that wait for a work cycle to be completed
7. Transportation	Unnecessary movement of parts between processes

In table 2 the seven types of waste are translated to define information exchange waste. This breakdown of waste was used to identify the waste associated with the transfer of information on a case study project at Penn State.

Table 2: Seven Types of Waste adapted for the Information Exchange Process

Type of Waste	Information Exchange Translation
1. Overproduction (O)	More information than required by BIM users; Early release of information causing revisions after initial release
2. Inventory (I)	Push instead of Pull – "Take what is given approach"; Underproduction of information
3. Extra Processing Steps (EPS)	More manipulation of information than is required by users
4. Motion (M)	More file transfers than is necessary; Not placing the model in a common location
5. Defects (D)	Model inaccuracy / Incorrect information
6. Waiting (W)	Late delivery of information
7. Transportation (T)	Inoperable hand-off of information - file type & version

4.2 Determining the Cost of IE Waste

The next step of evaluating the IE waste involves allocating time and resources to each non-value added aspect of information exchange. During this process the parties involved were interviewed based on the resources used and time spent on each wasteful activity. During the unstructured interviews the project team members were able to express their costs in terms of time and resources. The research team also requested the rates for each resource. If the rate was unavailable, R.S. Means was utilized as a substitution. It was important to also identify any overlap in resources used for each activity. For example, if a resource is utilized to author new information, as well as validate the model, this could be considered both inventory and defect waste. In the event of an overlap, the total value was determined and divided amongst each area of waste involved. Finally, each wasteful area is combined to determine the total cost of IE waste.

5. CASE STUDY RESULTS

The Pennsylvania State University is currently constructing a large laboratory science facility called the Millennium Science Center (MSC). Detailed project information is shown below. When the project was in the schematic design phase, the owner and design team decided to implement BIM, therefore the architect, structural engineer and MEP engineer were contracted to develop 3D information models for the design. Using a CM Agency delivery method, the contractor was brought onboard during design development with intensions to use the design team's model for 3D coordination and 4D planning (a 3D model with a time-based simulation).

Millennium Science Center
Owner: Penn State University
Project Type: New Construction
Facility Use: Laboratory/Classroom
Project Size: 250,000 SF
Construction Cost: $175 million
Delivery Method: CM at Risk
Location: University Park, PA
BIM Uses: Record Modeling, 3D Coordination, 4D Modeling, Design Authoring, Design Reviews

In terms of the information exchange process, the design team produced an element structure breakdown of the components in the model including: Structural, Mechanical Equipment, Exterior Façade, Interior Walls, and Ceilings. The level of detail was determined by the design team and was delivered to the contractor as an Autodesk Revit model via an ftp site. The results of the actual waste which occurred through information exchange between the design team and construction team on the case study are shown in Table 3. These results are the product of meeting evaluations and interviews of project team members.

Table 3: IE Waste identified on the Millennium Science Center (MSC) Project

Type of Waste	IE Description	Waste	Cost
1. Overproduction	Furniture and Electrical Outlets were modeled	Delete additional items	$ 4,000
	Additional detail in lab rooms for space studies	Remove detail	$ 4,000
2. Inventory	Push rather than Pull – use what was provided	Required information	$ 41,250
	Several ceilings were not drawn	Include ceilings	$ 4,000
3. Extra Processing	Building not broken into areas	Break-up model	$ 8,000*
4. Motion	Current files were not shared	Revisions for Clashes Design Change	$ 11, 250 $ 30,000*
5. Defects	Wall type was not confirmed	Model Validation	$ 4,200
	All walls were modeled to under-slab	Unnecessary Clashes	$ 750
6. Waiting	4D Information could have been delivered earlier	No actual delay	$ 0
7. Transportation	Revit –Navisworks; Revit–Synchro	Some learning factors	$ 200*

***Cost could not be mitigated through early Planning**

In addition to the actual waste, table 3 includes the cost of waste derived from interviews with project team members. in particular, inventory waste occurred because the delivery from the design team to construction was a push rather than a pull system. This means that the contractor had little influence on the information authored by the design team. Therefore, in order to produce coordinated systems and a 4D Model, different contractors had to author various information. The total time spent on the modeling process was determined to be 550 hours of subcontractor time, which averages at $75 per hour. Also, the construction manger modeled various ceilings around the building that were neglected by the design team.

Additionally, the floors were modeled as one solid structure. Therefore, the contractor spent time and resources reorganizing the design team's model into quadrants for the 4D model, and simplifying the coordination process. If this simplification was not done, the file size would have slowed down meeting productivity because of sluggish model manipulation. According to the project manager responsible for BIM on the construction team, "the most difficult task was breaking up the model into quadrants. Any revisions also needed broken up – and it was very time consuming." This process took the BIM Manager 1 week for the first breakdown, and a half of a week for each additional revision (2 weeks total at $100/hour). Although this is a substantial amount of waste, it would not have been mitigated through early project planning. According to the construction team, the variability of the floor breakdown would be tough to plan and is usually determined with the subcontractors after the design is delivered for construction. Upon completion of the

6. CONCLUSIONS AND FUTURE WORK

This paper illustrates the value of early planning for BIM by investigating the cost of the waste through the allocation of time and resources to each non-value added aspect of information exchange. Through a systematic process, it was determined that the Millennium Science Center project resulted in approximately $108,650 worth of information exchange waste from design to construction. Of this amount, $70,450 was directly related to the lack of early planning for BIM implementation. This accounts for approximately 0.04 percent of the total cost of construction. According to the MSC project team, this study also determined high potential value added improvements to the IE process that they should focus their attention on for future projects. To eliminate these non-value added processes it is essential that the information exchange process is defined early by project team members.

The overarching goal for this research is to provide a standardized method in which future studies can more precisely measure the waste associated with the information exchange process. Although this paper provides an initial study aimed toward this goal, additional research needs to be conducted to develop a standardized process. This could provide additional insight to the scale of the economic benefits that may be achieved by the industry. For example, currently the most frequently cited study related to the scale of the challenges related to inefficient interoperability is the important study performed at NIST (Gallihar et al. 2004) which projected an overall industry cost of $15.8 billion in 2002 due to poor interoperability. This counterfactual analysis study provides significant value toward identifying the scale of the challenges related to interoperability, but further, more detailed project analyses can provide additional insight into the root causes for the waste in the BIM process and identify more accurate means of measuring this waste at a project level. To extrapolate any future findings, case studies with different project characteristics would need to be evaluated to ensure the process can be standardized.

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