REVIEW ON LEAN CONSTRUCTION AND TPS APPROXIMATION WITH BIM

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ABSTRACT

Lean construction is a substantial feature of construction including both pre-construction and post-construction activities which leads a project towards a successive or catastrophe end result. Nowadays, most of projects frequently face uncertainty and it causes to produce continuous waste throughout the construction process making negative outcomes of quality, cost, time and scope. Synergy of TPS (Toyota Production System) philosophy and BIM (Building Information Modelling) methodology is the key to diminish the above-mentioned project hazards which creates an opportunity to stimulate the construction process by avoiding negativity for a better lean future. Hence, aim of the paper focuses on determining most effective potentials that could be derived from the Toyota way philosophy to incorporate to BIM to benefit the lean construction industry.

A qualitative approach has been used considering the nature of the research, comprises of primary and secondary data collection which totally ran across information grabbed from online publications concerning the reliability of sources.

Evidences revealed that TPS-BIM model has agreeably accepted by construction field and the features of this model need to be more precised and refined to achieve more accomplishments in conditions of leanness. It was revealed that even if the method of synchronizing TPS capabilities on BIM tools by balancing nature of human dynamics along with technological endeavours, TPS-BIM integrated elements need more amendments and verifications to perform with its superlatives. Moreover, lean principles derived from TPS contain adequate capabilities to up heave BIM potentials to maximize the benefits in construction with all the positivity throughout the process.

Keywords: *Building Information Modelling (BIM); Lean Construction; Toyota Production System (TPS).*

1. INTRODUCTION

In the present context, which heading to a digit imminent; draws parallels in between technology and humanity as a respond to necessities gathered around. Building Information Modelling (BIM) can be identified as an incipient approach which guides to achieve better lean construction through principles by eliminating negative aspects behind. Though the BIM procedure is already in practice elsewhere in the field with positive responses, still it has potential to explore to deepen the existing knowledge through theoretical understanding and sometimes with collaborations. One such possibility is integration and resembling of Toyota Production System (TPS) philosophy along with BIM. TPS is the well-known example for the best practice of lean concepts to improve production cycle. Hence, this paper pursued to study the improvements that could be made by the philosophy of above mentioned TPS on BIM to achieve and succeed better lean construction.

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2. BACKGROUND

Productivity in the construction field is challenged all over the world and in contemporary situation. There is a competitive pressure is steadily increasing among product manufacturing companies which demand increased quality, added functionality, lower prices and speed of innovation; so companies must develop more desirable products ahead of their competitors before new technology emerges or market conditions change (Welo, 2015). So, it is questionable, how new product development practices can be improved to sustain competiveness (Welo, 2015). With this recent necessity, construction field use to practice the concept of 'lean' in order to achieve maximum output with minimal waste based on the core idea of lean concept (Marhani *et al.*,2012). In another way lean can take to mean as generating more assessment for customers with fewer resources. Lean construction defines the connection in between lean thinking and construction including fast time adjustments, low wastage and contemporary market address. Collaboration of these ideas stand for 'lean thinking' which shaped around the main theme of value.

BIM is a great technological achievement in recent years from architecture, engineering and construction industry which designates building designing process integrated with a comprehensible system of computer models which link between separate sets of drawings (Boton *et al*., 2013). Although the features of BIM model is more like 3D geometrical, it reaches assured advance extend with its integration of other building analysis applications such as cost estimating, energy simulation, day light, computational fluid dynamics, space planning and building code checking within the model (Kumanayake and Bandara, 2009).

The term 'lean' was taken into act by Toyota's business in 1980's (Marhani *et al*., 2012). It is competent throughout many centuries with its thoughtful proficiencies which can be identified mainly under five principles of technological invention of Building Information Modelling; commonly known as BIM agreeably blend with this 'lean' concept and it focuses to deepen the scope of construction in positive manner. With regards to recognizing connection of BIM and lean thinking logic have been utilized independently as huge individual ways to deal with entire development ventures change. Their mix, given few situations, presents chances for development and difficulties in usage (Hamdi and Leite, 2012). BIM usage mainly concern on the reduction of time cycle which belongs to lean principles too. Also it highly requires accomplished individuals to find its maximum benefits. The second priority moves across the efficiency and redeemable of owner's money (Sacks *et al.*, 2010). In contemporary situation time and money are the significant and tempting facts to be concern which BIM process simply assists and cover up already with the connecting key factors of experience and skills. So, in that sense BIM can be identified as a context changer which addresses to the existing exact needs accordingly. As long as it addresses to the contemporary needs and requirements, it is being accepted for the current construction industry and last till new demands and challenges gets in. Despite the fact that the principle of BIM does not fulfil the criteria of three dimensional geometry demonstrating, it goes afar and accomplishes more over with precised data (Smith and Tardif, 2009). In that way the great synergic fitting of lean and BIM cure to invigorate activities of one another.

3. LEAN CONCEPT

The big picture of 'Lean' is generating customer based significance over less possessions (Dombrowskia and Mielkea, 2014). The connecting fact can be identified as 'productivity' of these two ends of customer value and diminished waste and foremost focus is gathered around this connecting fact to exhaust the possibilities. With compare to mass production, it uses only half of human power, work spaces, investment and also most importantly the fact of time (Sundara *et al*., 2014).

Statement of most claims this 'lean' concept as a key cause of Japanese accomplishment. Developing lean management at Toyota Motor Company for the first time could be the reason for that and it happened just after the great impairment of Second World War would be backing up it in all the way (Jayaram *et al*., 2010). In that way even the initiate stage of developing the concept of 'Lean' hits the market where it's necessary and success of car industry which was established by TPS motivates to move parallel to it with all the way success with powerful and significant techniques (Jayaram *et al*., 2010). With the flexible quality of the concept most of the concerns have implemented lean in their own unique adequate way by evaluating its utilizable potentials (Torielli *et al.,* 2010).

4. THE TOYOTA PRODUCTION SYSTEM (TPS)

TPS is a lean manufacturing process initiated in Japan, around 1940 after great loss of World War II and Taiich Ohno has been credited as the father of TPS. In between 1948 and 1975 the system developed with the collaboration of Taiich Ohno, Shigeo Shingo and Eiji Toyoda and it was very famous after oil crisis occurred in 1973 with respect to its effective performances. The essence of TPS can be concluded into three figures of reduced set up times, small-lot production and employee involvement/empowerment with the inclusion of seven numbers of principles (Jayaram *et al*., 2010). Also, TPS is consisted of three concepts named JIDOKA (highlights the causes of problems because work stops immediately when a problem first occurs), Just-in-time (JIT) and Kanban system (Koskela, 1992; Liker, 2003). While the JIDOKA concept highlights problems, JIT complete elimination of waste and the duty of reducing excess production by the concept of Kanban. Goals of TPS have been identified as flexible production process, participation of all employees in the work process, reduce inventory through elimination of imperfection or problem, highly interdependent systems thinking-tools and techniques etc. and outcome of TPS, such as reduction of lead time to a great extent, quality improvement, one of ten largest companies in the world, largest car manufacturer low cost and fast response always back-up by them with a nice synergetic influence (Liker, 2003).

4.1. MAJOR THEMES IN TPS RULES AND TPS PRACTICES

The mandates of rooting out defects, eliminating waste and reducing lead time nicely blend the lean philosophy and TPS with respect to the actionable principles. The principles come along with the TPS are not represented through individual practices but through the processes of production system related to Toyota designs. Identification of new practices and principles causes innovations of Toyota and that stresses on the design decisions of TPS. The production system is defined in terms of 'activities', 'connections' and 'pathways' by the TPS experts and system design decisions guide splitting of business processes into individual activities, making direct connections between activities and streamlining pathways. Furthermore, TPS continues exploring new approaches and work methods based on the systematic problem solving method.

As per TPS guidelines are stressed under two topics of, making structural work plan facilitators for critical thinking by structurally organizing learning at the most minimal conceivable level in association and systematic critical thinking (Spear and Brown, 1999). As indicated by TPS, both inner and outside connections are associated when understanding the whole framework (See Figure 1). Its primary goal is to distinguish, evaluate and eliminate sources of variety with respect to whole framework.

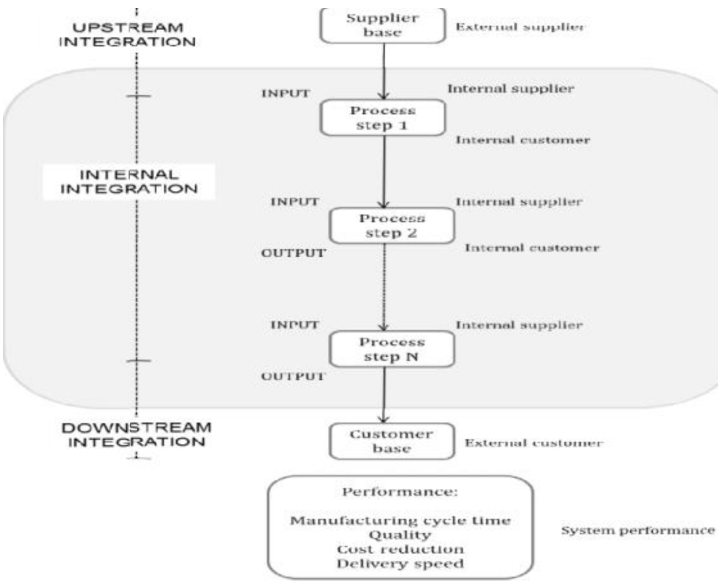

Figure 1: Structural Links Internal and External to the Organization

5. TPS VIRTUALLY TOWARDS BIM

The fundamentals of BIM have impressed the construction industry immensely. Though these two concepts TPS and BIM are autonomous in their origin, the collaboration of the two concepts have produced more impact (Eastman *et al*., 2008; Hattab and Hamzeh, 2015). The way BIM respond to eliminate waste in construction; approach of encouraging organizational forms by BIM regarding lean and characteristics generated by BIM to stand against to promote or interrupt flow could be pointed out as few synergies of them (Sacks *et al*., 2009a).

5.1. EMPIRICAL EVIDENCE LINKING BIM AND TPS PHILOSOPHY

A strong synergic effect has been observed between TPS principles and Computer Advanced Visualization Tool (CAVT), which concludes end results of improved flow, waste reduction and customer value by stressing on design stage of construction (Rischmoller *et al*., 2006). Similarly, integration of Virtual Design and Construction (VDC) and Lean Project Delivery System (LPDS) process is another attempt of linking TPS processes with BIM, due to the overlaps of underlying principles and technologies of them (Khanzode *et al*., 2006). The application of VDC at the correct stage is highly appreciated to meet its best improvements in the LPDS (Sacks *et al*., 2009a). Contribution of BIM potentials in regards to TPS principles to visualize the product and process aspects and found a significant reduction of 'variabilities' in the construction projects by allowing a "pull flow" mechanism (Sacks *et al*., 2009b)

Automated capture, semantic search capabilities and eternal data compatibility are identified as issues of knowledge management occur due to the integration of management and utilization databases (O'Brien and Hammer, 2006). Even though these capabilities are included in many projects, both BIM and TPS would be required to reach more capabilities all-inclusive and; preparation and organized careers are highly appreciated for backing both BIM and TPS philosophies (O'Brien and Hammer, 2006).

The interaction nature of BIM functionality and TPS philosophy always lead to success destination in a precised and detailed manner. The methodology part is given by the side of BIM and technical mechanism all the way come along with it and the utilization of that mechanism is fulfilled by the thoughtful ideas generated by TPS philosophy. With the synergy of technical and ideological ingredients it always creates logically acceptable effective results with more potential yet to be revealed.

5.2. BIM FUNCTIONALITY

BIM knowledge gives key aspects of functionality for assessing, altering, compiling and reporting data identify with building projects and this knowledge encourages BIM tools to develop building's structure, function and behaviour and that makes all conceivable functionality angles as underneath (Tommielein, 1999; Sacks *et al*., 2009c).

- Visualization of structure with the form
- Rapid generation and assessment of multiple design substitutions
- Maintenance of information and design model reliability
- Collaboration through design to construction
- Rapid generation and evaluation of multiple construction plan substitutions
- Online/electronic object-based communication

The shown functionality develop to the concern rather than the central technology, as for the reason for examination or more specified things touch exposed functionality concerning the advantages or disadvantages happen in their use.

6. METHODOLOGY

The preliminary stages of a research involve the review of the literature relevant to the topic under analysis. The main topics addressed within the literature synthesis were; lean concept, TPS and virtual to BIM towards lean construction. Literature review was done while developing the research methodology as well, as this study is a qualitative research which normally requires a broad knowledge to design the project. Since this research problem resembles a qualitative research approach rather than a quantitative one, the study was limited to a content analysis, whereby data are gathered by reading the data published on different sources. Interviews, questionnaires, and direct observation of human behaviour are highly sort after for the qualitative analysis. But was not achievable for this context as BIM and TPS is not in function in Sri Lanka.

7. FINDINGS AND DISCUSSION

TPS philosophy and BIM methodology synergy has brief in matrix as revealed in Table 1 to get a better understanding of the big picture and this figure is totally based on the lean principles related to TPS philosophy and BIM functionality features related to BIM methodology. Interaction of BIM functionality and lean principles creates a framework to move steps ahead by revealing possible and related potentials accept by the context. The synergy of TPS philosophy and BIM methodology most of the time backing by issuing positive face of results, but in some times with negative results too. If BIM makes effective impacts on philosophy with higher percentage at the end it counts under positive reaction and if the percentage is zero or below the rate, counts as negative by stimulating to research further to improve up to the acceptable rate under positivity.

BIM-Lean influence analysis depends on two main criteria and that system utilizing strides can be identified as proposing conceivable connections and looking for exact evidence to either strengthen or challenge them. According to this analysis it proposes 55 particular cooperation based on both research evidences and literature. All the interactions based on research evidences are properly justifiable with all necessary proofs under a debatable logic. But other interactions based on writing study, comes with questionable arguments as they do not proof yet on a logical platform. BIM functionality effects make by every feature belongs to it; evaluated by definitions accommodated for both principles related to philosophy and functionality related to methodology. Positive interactions shown with (*) while (x) denote negative interactions.

As listed in Table 1, the clarifications accommodated for every interaction propose the conceivable connections. They are not esteemed to be demonstrated by empirical evidence; but instead they are nominees for corroboration or inconsistency through estimation in future examination. Where episodic or other proof is accessible, the proper sources are referenced in the third section. The areas of reported proof has not been discovered, have noted ‘not yet available’ and these extents are possibly prolific ground for future empirical examination to substantiate or repudiate the associations.

Table 1: Lean BIM Interaction Matrix

BIM functionality \ **Lean principles**		Reduce product variability	Reduce production variability	Reduce production cycle	Reduce inventory	Reduce Batch sizes	Reduce changeover times	Use multi skilled teams	Use pull systems	Level the production	Standardize	Institute continuous improvement	Visualize methods	Visualize processes	Simplify	Use parallel processing	Use only reliable technology	Ensure the capacity of the production system	Ensure comprehensive requirements capture	Focus on concept selection	Ensure requirement flow down	Verify and validate	Go and see for yourself	Decide by consensus, consider all options	Cultivate an extended network of partners
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Visualization of form	1	*													*				*		*	*	*	*	
Rapid generation of design alternatives	2	*		*									*	*		*									
Predictive analysis of performance	3	*	*	*			*												*	*		*			
Automated cost estimation	4		*	*												*						*			
Evaluation of conformances	5	*	*	*															*	*	*	*			
Single information source	6	*	*																		*				
Automated clash checking	7	*	*	*																		*			
Automated generation of drawings and documentations	8	*		*	x	*											*	*							
Multi user editing of a single discipline model	9			*						*						*									
Multi user viewing	10	*		*				*											*		*	*		*	
Automated generation of construction tasks	11	*		*	x		*								x										
Construction process simulation	12			*	x					*					x					*		*			
4D visualization of schedules	13	*		*	x						*		*	*		*						*		*	
Visualization of process status	14			*	*	*			*					*			x					*	*		
Online communication of process and product information	15	*		*	*	*			*		*		*	*			x				*			*	
Computer controlled fabrication	16	*		*			*																		
Integration with project partner databases	17		*	*					*								x								*
Provision of context fur states data collection	18		*		*	*			*			*					x					*	*		

7.1. POSITIVE AND NEGATIVE INTERACTIONS OF IMPLEMENTING INTEGRATED TPS-BIM FRAMEWORK

According to the matrix there are number of characteristics towards positive and negative interactions for specific BIM functionalities and lean principles. These characteristics help the management to observe and recommend guidelines while implementing lean and BIM, which will in return assist the managers to understand and realize the positive interactions in practice. Following are the highest concentration of unique interactions of lean principals

- “Get quality right the first time [reduce product variability]” (A),
- “Focus on improving upstream flow variability [reduce production variability]” (B),
- “Reduce production cycle durations” (C).

Above points have higher interactions comparatively to any other principles. Nevertheless interactions are not just bound to BIM functionalities but also influenced in design and construction. “Aesthetic and functional evaluation”, “Multi-user viewing of merged or separate multi-discipline models”, “4D visualization of construction schedules” and “Online communication of product and process information” are the BIM functionalities which have the highest concentrations of unique interactions. Even though these factors are not precise compared to the leading lean principals, three of these four factors are reflected in fabrication and construction management as BIM is recognized primitively as a design tool by many. It is identified that “Reduce inventory” (D), “Simplify production systems” (N) and “Use only reliable technology” (P) are the negatively impacted or least served principals. BIM helps to increase information inventory, and also it helps to well organize the flow of information. Due to technological advancement of the BIM tools if the users lack knowledge, skill or ability or if the applications are not rich process can be unstable. Also if the tools are not properly implemented and managed process can be complicated. And also buyers of model information are reluctant to rely on the models due to margin of error as models are often incomplete and detailing in different areas varies. The single information source is the BIM functionality which least offers the support for lean principals.

It has shown that use of Information Technology (IT) in construction management was not always a win to provide a positive impact on the return on investment. Under-utilization and interoperability issues are the key issues identified in BIM adoption and lean construction initiatives can be complicated due to lack of conceptual understanding.

Also it was established that compatible re-alignment of business processes is an important piece of IT benefits. In other words IT benefits rely on compatible re-alignment of business processes. As a matter of fact they develop this scope in the context of construction in order to affirm that re-alignment is required for basic understanding of the unique features of construction. When it comes to lean construction and BIM, information and material processes should not only logically dependent on these two but also be established firmly in conceptual understanding of the theory of production in construction.

Compared to traditional measurements from drawings, shorter cycle time is gained by extracting the quantity take-off from a building model. If the management recognizes;

That the shortened cycle time shifts the bottleneck in the process to other activities, and

That the overall design management approach can be re-aligned to bring designers and estimators to work together

It would help to increase efficiency by reducing repetitive design. No matter whether the project participants have an idea or not the cycle-time is reduced by BIM, even though the comprehensive benefits can be gained via thorough understanding of its meaning. As a crucial fact, rather than considering the interaction of lean principles and BIM in construction as the sum of the isolated parts better to consider as a whole and complete process while interpreting the interaction matrix. Multiple lean principles are supported by each functionality and conversely and more effective when working together rather than working alone. Due to the same reason experts cannot identify all of the interactions and their impacts. Exploration and trialling by practitioners help some to get through.

As examples of such holistic interactions, topics of BIM as a boundary object and construction tolerances can be taken into consideration even though they are not mentioned in the interaction matrix. In business and social interactions it has been identified that BIM technology as the entity which enhances the capacity of the theory. Nevertheless, these business and social interactions need organizational change and also it make the process smooth in the organizational change. Even though this is not an issue that most are familiar, lean transformation can use BIM technology as a stimulant.

Management of dimensional tolerances in construction is not handled properly. Even though advanced tolerance analysis and management capabilities were unavailable in previous 2D CAD versions, it helps BIM to improve tolerances related to space. This helps prefabrication and assembly of high tolerance components. In order to put up with leaner processes higher precision tolerances are required. This is due to reduction of variability, resultant wasted in the construction process and reduction of losses. As the effect is comprehensive and deviant, experiments should be carried out or should be proven via observations etc.

8. SUMMARY AND CONCLUSION

TPS-BIM framework made out of TPS philosophy and BIM methodology, provide surfeit of benefits for construction industry mainly by revealing potential of JIT delivery, eliminated waste and shorter production cycles and interactions between all necessary parties by utilizing potential and benefits. As a whole TPS-BIM framework creates impact on the construction industry by maximizing benefits and influencing to gain more in the future.

Individuality of BIM and lean principles derived from TPS do not achieve the maximum leanness of the construction; but with the synergy of them. Even though BIM elements capable to find it's best at some application most of the time lean principles of TPS required to shape up and sharpen up the benefits of end result. The main reason for that is two different capabilities of these two components. That means, the strength of quantitative data handling by BIM get fills the gaps by TPS lean principles; where its' strength covers the aspects related to quantitative criteria. Also it was emphasized and prove the effectiveness of BIM-TPS synergy with evidences in practical platform by revealing the strategy behind every success. According to the above mentioned evidences it also emphasize the improvements made by TPS on BIM as lean principles related to TPS always all the way focus on the human factors which is hard to manage and control. But that is where the management should highly practice as all these construction projects run on the practical situation with all the raises and falls. So in that way lean principles derived from TPS philosophy covers a really important and highly essential area which BIM cannot pay attention with its capabilities. So at the end, the combination of BIM and TPS creates effective end results by maximizing benefits it generates with its setup.

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