Public Infrastructure Bulletin

Volume 1 | Issue 9 Article 5

5-29-2014

Lean construction

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LEAN CONSTRUCTION

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ABSTRACT

Traditional project delivery and procurement methodology has evolved into an inherently inefficient and adversarial process. Lean construction provides an approach to modern construction that significantly improves collaboration, innovation, delivery, control and quality within projects. Lean construction is based on fundamentals such as maximum value generation, flows of activities, pull demand systems and perfection in execution at every level of the project. For this reason identification of the real value of lean construction within the construction industry is required.

An analysis of traditional methods has revealed significant deficiencies in current delivery methods and efficiency standards. This has subsequently illuminated the key benefits of lean construction techniques such as "Just-In-Time' scheduling, the 'Lean Project Delivery System' and the 'Last Planner System'. These techniques will provide the most beneficial parameters for progression and innovation within the construction industry. Although barriers to integration exist, lean construction holds direct value in the creation of collaboration, efficiency, quality and delivery of modern projects and provides significant scope for innovation and maximum value generation within present and future construction projects.

INTRODUCTION

In essence, construction is a highly complex sequence of activities, plans and designs that culminate in the physical execution and completion of a structure for a desired use. Mossman (2009), talks about construction as the creation of value and transformation of raw materials into usable structures and facilities. Mossman goes on to suggest that construction is centred on the relationships and flows between people, information, equipment, materials, prior work, safe external conditions and safe space. This representation of the flows between elements within a project stands testament to the complexity inherent within the construction industry. It is through careful appointment, management and control of Mossman's (Seven) flows that successful projects can be achieved.

Construction is fundamentally collaborative in nature, a concept that was initially prevalent within the industry. The evolution and progression of the construction industry, however, has led to highly specialised marketplace where stakeholders act within silos in order to minimise risk exposure or liability. This has given rise to an industry that is highly adversarial in nature with little room for collaboration. With this in mind, lean construction boasts significant strategic delivery systems that re-direct the focus of adversarial relationships onto collaborative modelling. The scope for innovation preceding the successful integration of lean construction into the construction industry is significant and may pave the way for large technological adoption and increased efficiency (waste reduction).

The basis of investigation for this report is into the field of lean construction. Evaluations will be conducted on the performance of current industry practice, with comparisons made against the propositions associated with lean construction. Analysis of the key tools and techniques incorporated in lean construction such as the 'Lean Project Delivery System' and the 'Last Planner System' will be conducted, with thorough examination of the relevance of these processes within the broader construction industry. Comparisons will be drawn regarding the benefits and feasibility of lean construction against current industry practice. Finally, conclusions will be drawn as to the real value of lean construction against traditional practice, with consideration for the future benefits within collaborative technological models.

1. BRIEFING LEAN CONSTRUCTION

TRADITIONAL CONSTRUCTION

The construction industry in Australia accounts for approximately 7.7% (Australian Bureau of Statistics,

2012) of Gross Domestic Product (GDP) and employs approximately 9.1% (ABS, 2012) of the workforce. The industry is labour intensive and has strong multiplier effects into the market in the short term (i.e. projects boost employment and consumption in areas of highest activity). The industry is largely trend orientated in that it follows basic GDP movement suggesting that it is considerably more demand driven in nature. The importance of the industry is as a "value add" sector, in which 2012 data records that the industry sits within the 7-7.7% range (ABS, 2012), suggesting that it largely underperformed as a whole when compared to GDP growth.

It is important at this stage to consider the possible reasons for underperformance, as these issues may be regarded as the fundamental flaws in construction practice in Australia and traditional construction generally. Low productivity in the construction industry can be influenced by a number of externalities; however, within traditional construction there are a number of inadequacies that provide opportunity for active innovation.

Traditional construction practice has evolved into a highly complex system of collaborative relationships centred on the transformation of raw material into usable and habitable structures. It is within the management and execution of the process as a whole that draws out the implicit deficiency in current construction philosophy (Koskela, L., Vrijhoef, R., 2000). Koskela and Vrijhoef (2000), suggest that the inherent nature in which we manage and deliver projects is responsible for fundamental flaws in adoption of radical innovation strategies (i.e. top-down adoption of technology coupled with appropriate downstream training). It is these flaws within current practice that highlight the opportunity for methodologies such as lean construction and Building Information Modelling (BIM) to act as the catalyst for empirical change within one of Australia's largest GDP contributors.

OBJECTIVE OF LEAN CONSTRUCTION

The first emergence of lean thinking was by Eiji Toyoda and Taichii Ohno, who recognised inefficiencies within the mass production models developed by Henry Ford and the 'Ford Motor Company'. Initially, Toyoda and Ohno, recognised a large quantum of waste within the production models used in the Ford Motor factory. Toyoda and Ohno recognised seven definable areas of waste within the Ford production system being:

1. Overproducing.
2. Idle Time Waste.
3. Transporting/conveyance waste.
4. Processing Waste (waste in work itself).
5. Inventory waste (having unnecessary stock on hand).
6. Wasted operator motion (using unnecessary motion).
7. Producing defective goods (waste of rejected production) (Forbes and Ahmed, 2011. p. 47).

These barriers essentially acted as the catalyst for the development of the Toyota Production model and subsequently lean Production/Organisation. Stemming from these ideals, lean construction draws on similar principles to be applied to the construction process. Identifiably, the construction process at its most basic level (physical) is layered with inefficiency (waste) in standard practice. The seven key barriers to efficiency align with significant recognisable deficiencies within construction practice (physical) including:

1. Oversupply based on push system.
2. Down-time/delays.
3. Delivery scheduling delays and inadequacies.
4. Waste inherent in physical construction (also related to estimation).
5. Storage on site.
6. Inadequate site planning
7. Re-work and quality

These inadequacies (among others) solely revolve around the construction phase of a project, which renders the question as to the depth of project deficiency. This being said, the process of development within a construction project is highly complex and manipulated by adversarial relationships and external stakeholders, which consequently could infer that deficiency at a physical level of a project is merely a symptom of a lack of up-stream collaboration and management control.

This is where lean construction can hold real value in terms of innovative control strategies and management of workflows at a project level.

WHAT IS LEAN CONSTRUCTION?

Glen Ballard and Greg Howell, co-founders of the Lean Construction Institute, view lean construction as a new way to manage construction utilising many of the tools and techniques prevalent in the theory to form the basis of a new project delivery process. Lean construction provides the foundation for an operations-based approach to project delivery systems and strives to create innovation in the design and construction of capital facilities. Opportunities consequently arise as a result of this making possible significant improvement in the delivery of complex, uncertain, and quick projects (Forbes and Ahmed., 2011).

The concept of lean construction is continually evolving which is seen in the Construction Industry Institutes (CII) view on lean being, "the continuous process of eliminating waste, meeting or exceeding customer requirements, focussing on the entire value stream, and pursuing perfection in the execution of a constructed project" (CII Lean Principles in Construction Project Team, PT 191, cited in Forbes and Ahmed. 2011). Many other definitions exist, with an over-arching concept of maximum value creation at a project level being prevalent.

KEY CONCEPTS

To determine where the intrinsic value of lean construction lies within the construction industry it is important to understand the core principles and critical processes involved in the concept that facilitate progression and innovation.

Womack and Jones (Jessop, 1997) defined five key principles that are central to the core philosophy of lean construction and are essentially applicable to any organizational structure in regard to lean thinking. The principles are:

1. Value: Lean organizations identify and capture the actual desired value by customers, resisting the tendency to persuade customers that they desire what the organization finds easiest to make.
2. Value Stream: Mapping the value stream for each product or service provided by organizations exposes waste and facilitates its removal; collaboration between the participants and stakeholders results in lean process.
3. Flow: It is essential that value creation and the value stream flow. Unimpeded flow between work packages (i.e. Business, job site and supply flows) facilitates successful and efficient delivery of maximum value.
4. Pull: 'Just-In-Time' philosophy in regard to stabilization of market demand-pulls; keeping with the demands of the customer (antithesis of mass production).
5. Perfection: Strive for perfection (although it may never happen) by developing work instructions, procedures and quality control (Quality Assurance).

These principles work in collaboration with three central processes involved in lean construction being: Just-In-Time scheduling (Toyota Production System), the 'Lean Project Delivery System' (LPDS) and the 'Last Planner System' (Ballard, 2000) (see Section B for detailed analysis). These processes among others appear to be the most applicable in terms of orientation and shaping of the construction industry and performance.

PROJECT SCHEDULING (JUST-IN-TIME)

Unlike Henry Ford's mass production system, which utilised a push system to dictate production volume, 'Just-In-Time' (JIT) scheduling pioneered a pull system that responds to physical market demand. The major flaw in push models is forecasting, whereby inaccurate forecasts can lead to under or over supply of product. The JIT system minimises this risk by eliminating the need for detailed forecasting and rather bases production on physical market demand. The JIT system effectively results in a lower inventory of raw materials and parts, less work in progress, and shorter lead times. This results in reductions in floor space, less overheads and lower costs. The inherent risk attached to the system is that inventories may fall to critically low levels resulting in an undersupply of product, which reflects negatively on customer relationships and business models. For this reason, the JIT is highly dependent on high quality, reduced set-up times, whereby raw materials and components reach production operation in desired quantities and when needed, not before. This requires highly collaborated and advanced supplier relationships to ensure delivery schedules are highly efficient.

The application of JIT to construction can significantly improve the efficiency of projects by improving delivery schedules of materials and allowing higher integration of construction techniques such as prefabrication. This could significantly reduce time delays due to lead and set-up times as well as installation times. External influences such as weather and latent conditions are also minimised through careful planning and flexible schedules ('Last Planner System' of control/management).

PHILOSOPHICAL DIFFERENCES

It is important to understand where the fundamental differences lie between traditional construction philosophy and lean construction philosophy. Table 1 summarises the key differences and demonstrates where lean philosophy strives for innovation against traditional practice.

TABLE 1

TRADITIONAL CONSTRUCTION	LEAN CONSTRUCTION
Reactive Control	Active Control
Optimization at individual actively level – rewards individual crew performance	Optimization at a project level – rewards multiple crews involved in the delivery of major work packages
Relies on individual innovation within the Project Management Body of Knowledge (PMBOK)	Builds upon the basic infrastructure of PMBOK instituting a different approach to project management
Traditional practice and scheduling methods such as CPM play a large role in project scheduling and identification of milestones. Higher emphasis on whole project scheduling, with little attention to short-term workflows	Short-term planning and control of jobs improves time completion of tasks. Emphasis on work flows between crews without interruption – not self-interest (adversarial).
Planning viewed as the key to success and management by control as most important to organise cost and time and achieve scope of work. Marginal flexibility.	Recognises the occurrence of unplanned events within every project and institutes downstream control to facilitate management decisions at the source of the problem. Utilises the 'Last Planner System' scheduling technique.
Highly effective for simple and predictable projects.	Highly effective for complex and uncertain projects.

Source: Forbes and Ahmed, 2011. P. 59-60

The comparisons drawn in Table 1 illuminate the scope for innovation regarding where lean philosophy can take affect within the construction industry. The utilisation of methodologies such as the 'Last Planner System' and 'Just-In-Time' delivery scheduling will form critical pathways to radical innovation in the project management sphere of the construction industry.

This is where consideration must be given as to the barriers to integration of lean construction into traditional practice.

BARRIERS TO INTEGRATION

Lean construction is essentially a derivative of lean production (as discussed in the Toyota model). This consequently brings to light the notion that industrial practices have a large role to play in the applicability of the lean construction within the construction industry. A basic comparative analysis of both industries reveals some of the key barriers to the integration of lean methods.

Forbes and Ahmed (2011), discuss some of the key challenges facing the application of lean methods into the construction industry. A number of fundamental differences have arisen including:

- The uniqueness of construction projects in comparison to the repetitious nature of manufacturing.
- The level of internal and external environmental control (i.e. manufacturing performed in a highly controlled environment). Projects vary considerably in terms of location, and site conditions.
- Detailed design of manufacturing process lends to optimization.
- Construction processes are determined by the performance of crews leading to increased variability.
- Manufacturing projects are short-term and easily quantified. Thus, they are more easily improved in real time. Construction projects are considerably more complex.
- Commissioning in construction varies on a project-by-project basis.
- Construction industry has is highly specialised, partly due to liability concerns.
- Organization and facilities involved in production are dispensed with after project completion.
- Appraisal of projects varies significantly on an individual basis.

Source: Forbes and Ahmed, 2011. Pp. 60

The comparisons drawn in these evaluations highlight the key barriers to integration facing lean methods. Evidently, on a side-by-side comparative basis, lean methodology appears to lack applicability, however, the transfer of lean philosophy is not direct and consequently can be tailored to accommodate the environments present within the construction industry. The conceptual basis of lean philosophy holds greater influence over innovation within construction industry, subsequently giving rise to enhanced delivery, management and control systems and reductions in project waste.

It may not be so much the physical nature of the construction industry, as the adaptability of industry representatives and policy makers that is the root cause of low integration into industry practice.

Howell and Ballard (1998), advise that one of the most significant barriers to overcome in the integration of lean models is at a mental development level. Howell and Ballard recognise the importance of training/learning and the sequential integration and development of lean thinking within a company. The process of integration is constant and will require an open-minded approach to learning, development and optimization, which will ultimately come through supported change and collaboration (internal and external).

ANALYSIS

FUNCTIONAL PROGRESSION

The essential function of lean construction is as a system facilitator for the reduction or elimination of waste in all construction activities and processes. The progression of lean construction relies on the realisation of five key principles that underpin lean philosophy. These are; real value, the value stream, flow, demand-pull, and perfection. At the most basic level of integration, these principles should work to create the most robust delivery systems and subsequent innovation strategies for the successful delivery of construction projects.

Forbes and Ahmed (2011, p. 68) provide a working insight into an industry model for the establishment of lean principles at a real project level. The "Five Big Ideas" concept examines five areas in which project progression and innovation can be optimized with consideration for lean principles.

- The concept suggests that increased collaboration will result in less fragmentation of the design and building processes. Close collaboration between teams early in the project development process significantly reduces scope changes later in the project.
- Increased relatedness between project participants is suggested as critical in establishing fundamental project elements such as trust, openness, willingness to innovate and ability to learn. These factors will consequently affect the growth of relational contracting and largely dictate the nature of the project (i.e. Adversarial or Non-adversarial).
- An understanding of the essential function of a project is required. The concept highlights that projects are a network of commitments rather than a process or value stream. Commitments are the fibres that bind teams and team members within projects, allowing for project direction to occur in real time.
- Stemming from lean principles it is proposed that optimization should occur at a project level not within individual work packages (pieces). Collaboration and optimization at a project level reduces conflict and disputes caused by push management and productivity management at a task level.
- In order to functionally combine the "Five Big Ideas" in is important to consider coupling action with learning. Essentially, work should be carried out in a manner that facilitates ready observation of specific actions. Specifically, this relates to the inspection of work at regular/staged intervals, which allows identification of deficiencies early consequently reducing the risk of future re-work.

These ideals outline the context and circumstances necessary to facilitate the deployment of lean construction. Combining common objectives and relational behaviour aligns stakeholder sentiment and generates high value-add procurement strategies. This enables integration of innovative management systems and controls such as the 'Lean Project Delivery System' (LPDS) (Ballard, 2000) and the 'Last Planner System' (LPS) (Ballard, 2000).

LEAN PROJECT DELIVERY SYSTEM (LPDS)

The 'Lean Project Delivery System' (LPDS) (Ballard, 2000), was designed to reduce many of the deficiencies prevalent within traditional construction including, poor design and documentation, time and cost overruns, and high occurrences of rework (poor quality). Traditional models view the roles of designers and constructors within separate spheres, inherently instilling adversarial relationships with key project stakeholders. The LPDS model, however, views these roles as a continuum or collaborative function for the delivery of the product, maximisation of value and minimization of waste.

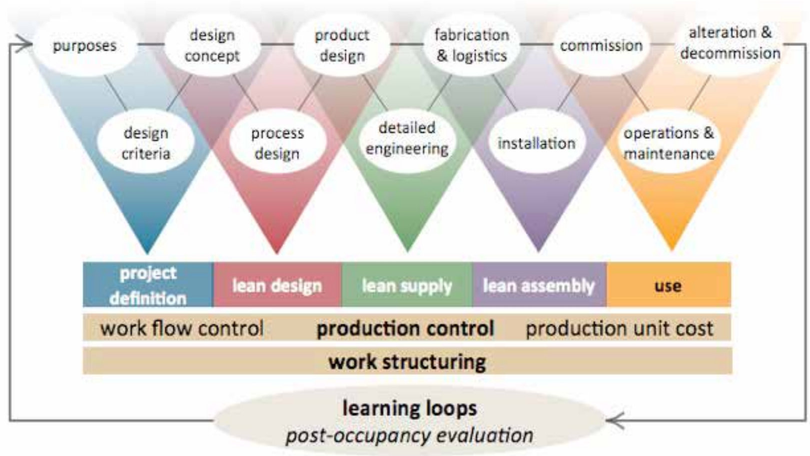
The fundamental philosophical criteria supporting the LPDS are centred on the ideals supplied in the 'Five Big Ideas' concept (Forbes & Ahmed, 2011). These concepts create the guidelines for interaction and flow between the various stages of the LPDS model. Figure 1 graphically represents the processes involved in the LPDS model, displaying the intrinsic flows between stages and project stakeholders.

This model for the re-design of the traditional project delivery system highlights a necessary collaboration between this model and the 'Last Planner System' (LPS), which aims at short-term micro-management of project work packages as facilitated by the teams producing the work. LPS comprises three critical

FIGURE 1

Lean Project Delivery System

Source: The Change Business, (2009). http://www.thechangebusiness.co.uk/TCB/LPDS.html



planning techniques including the master pull schedule, the look-ahead schedule and the weekly work plan. The intrinsic value of the LPDS will be realised through ongoing and open collaboration between the values instilled by the 'Five Big Ideas' (lean principles) and the value-add mechanisms of LPS driving the flow of work packages.

APPLICATION OF THE LPDS MODEL

The structure of the LPDS model encompasses five key phases within the project development system, however, applies lean principles to these phases in order to generate maximum value and successful delivery. The phases include:

1. Project Definition
2. Lean design
3. Lean supply
4. Lean assembly
5. Use

The goal of the system is to improve communication and collaboration at every level of the delivery system. This provides a solid foundation for the efficient delivery of construction projects with significant improvements in adversarial relationships, waste minimisation and maximising value.

PHASE 1: PROJECT DEFINITION

The project definition phase of the LPDS system acts much like the traditional inception phase of a project delivery system. The key difference in the LPDS model arises in the scope of initial definition planning. High emphasis is placed on early design management and the thorough analysis of the fundamental needs and values of the project. Scope is considered based on the pull of end-user demand, which ultimately streamlines the selection of fundamental project services. The project definition phase comprises:

- A thorough and detailed determination of the needs and values of the project.
- The construction of key design criteria
- Development of the conceptual design.

Source: Forbes, Ahmed. 2011

The value of comprehensive initial design and scope definition planning will have constructive flow-on effects into the efficiency of project execution, as late scope changes and disputes over contract work will be significantly reduced.

PHASE 2: LEAN DESIGN

The traditional design phase of projects is typically linear in nature with architects providing designs and engineers applying the respective design parameters (i.e. structural components). This methodology inherently creates additive and linear processes, as opposed to interactive designs. The separation of design for the product and the design of the process has evolved as a consequence of designers seeking avoidance of assuming the constructor's risk. Fundamentally, this creates adversarial project relationships, which negatively influence the progression of the project in the later stages. Early involvement of contractors and other influential parties to the project bridges the gap between design and practical execution. LPDS represents the elimination of these characteristic barriers as inter-locking triangles representing the breakdown of conventional communication and collaboration barriers and the creation of relational models. Constructability, reviews and value engineering are established as fundamental decision making strategies, not simply problem solving techniques.

PHASE 3: LEAN SUPPLY

LPDS identifies the requirements for interaction between material supply and project workflows. Detailed product and process design requirements are necessary for the application of integrated lean supply processes. Traditionally, material supply processes operate in silos and are managed by specialist procurement parties or buyers. Supply patterns have little regard for the master schedule and workflow structures within the project. This results in high variability in delivery schedules and often inefficient and unsafe storage on site (key element of waste in construction). Lean supply utilises three main approaches to solving these problems: improving workflow reliability, using web-based project management software to increase transparency across value streams, and linking production workflow with material supply (Forbes and Ahmed, 2011).

PHASES 4: LEAN ASSEMBLY

The physical assembly phase of a construction project represents, not only the end goal in a project, but a culmination of design, planning, scheduling, resources and relationships, all with the strategic goal of efficient physical production. The lean principles working within the assembly phase of a project specifically hold influence and application within incorporation of prefabrication construction techniques. The assembly phase incorporates key frameworks within logistics and fabrication, physical installation and commissioning. Arguably this phase of the delivery process is the most volatile as it exposed to the highest degree of risk. For this reason, robust workflow schedules and production control must be developed and monitored in order to create the most efficient assembly system.

The 'Last Planner System' (LPS) is highly influential in this phase of the delivery system and can significantly improve both the flow and control of project activities. Robust performance control of activity schedules within a project allows for significant improvements during the commissioning phase. Providing quality assurance to the client during the commissioning phase allows performance requirements and targets to be satisfied, which in turn creates timely delivery environments and non-adversarial closures.

PHASE 5: USE

The final stage in the LPDS evaluates the use of the building in terms of how it satisfies customer/user requirements. In essence this period is the foundation for testing the facilities and services supplied by the building. LPDS suggests the use of Post Occupancy Evaluations (POE) as a means of establishing whether the building is meeting the requirements of the user. POEs are generally biased, however, provide basic quantifiable data that can be used to optimize building performance and improve the environmental quality and services within a building. These processes are conceptualised as "learning loops" and are key to evaluation of the effects of decisions made during the execution/assembly phase of the project. This will ultimately indicate the success of the project and the processes/methods utilised during the design, planning, management and construction phases.

LAST PLANNER SYSTEM (LPS)

The 'Last Planner System' (LPS) is a critical component in 'Lean Project Delivery System' (LPDS), and effectively serves as the facilitator of effective communication, collaboration and flow between activities. The concept (as refined by Ballard, 2000) is essentially centred on providing downstream representatives (e.g. foremen, sub-contractors, etc.) the authority to schedule work packages and make decisions regarding the flow and execution of project activities. The overarching goal of the LPS is to provide parties in direct contact with the assembly phase of LPDS control to best match materials and resources with the construction of the project. Traditional work plans are effective in producing time frames and sequencing critical project tasks, however, are ineffective at establishing whether the tasks are capable of execution. Delays and re-work commonly occur as a result of this deficiency in traditional scheduling. The LPS decentralises decisions and empowers the crews that are in direct contact with the work, to plan and schedule detailed tasks (Forbes, Ahmed., 2011).

Mossman (2009) provides a thorough analysis of the LPS and summarises the essence of the concept by highlighting the foundational concepts such as collaboration, teamwork, communication, empowerment and ownership that work within the LPS to create a new standard for scheduling in projects.

The LPS draws on these concepts to work within the three key planning and scheduling tools critical to the success of the system. The three techniques include:

1. The Master Pull Schedule
2. The Look-ahead Schedule
3. The Work Plan – Weekly (WWP), Daily (DWP-complex breakdowns)

For effective integration of the LPS system all three techniques must be utilised and tailored to project specific requirements. The Master Pull Schedule records and schedules key milestones within the project. It holds the overarching structure for progression within the project. The Look-ahead Schedule breaks activity schedules down into 6-8 week blocks. This is critical to the process of assignment allocation and workflow sequencing. The Weekly Work Plan (WWP) provides a detailed breakdown of short-term workflows that are to be completed during the planned week of assembly. It is imperative to the success of the LPS that all parties involved in the physical execution of work hold influence over the sequencing of these activity schedules. This will allow for maximum value generation and efficient use of resources.

SUMMARY OF FINDINGS

Lean construction modelling has undergone significant steps in the progression of the concepts, tools and philosophies that were initially represented in production and manufacturing models. Lean construction has evolved into a highly sophisticated set of management systems and sequencing tools/techniques that form the framework for definitive change within the construction industry and the traditional models currently practiced. The 'Lean Project Delivery System' (LPDS) in collaboration with the 'Last Planner System' (LPS) forms an integral foundation for the development and integration of lean construction models into the construction industry. The core values established within lean principles and encapsulated in the "Five Big Ideas" concept (Forbes, Ahmed., 2011) encourage innovation within fundamental systems such as the LPDS and the LPS.

3. INNOVATION

AN INNOVATIVE STRETCH: LEAN AND BIM

The integration of lean thinking into the construction industry will, intrinsically hold value within the foundation make of the tools and systems that will be implemented, however, there are flow-on effects into the broader scope of the industry that will generate further depth of innovation in a more holistic light.

Building Information Modelling (BIM), encapsulates some of the most innovative technological strategies and modelling tools in the construction industry. There are various forms of BIM packages and derivatives; however, the key concept driving the technology is collaboration and efficiency. BIM technology is centred on construction of resource based designs, whereby multiple parties to a contact/project have input into the design, planning and execution of the project. Essentially, BIM forms a technology based collaboration between stakeholders and project representatives to achieve the most efficient design and execution of projects. This approach to the design and development of a project ultimately creates higher value for external and internal users of the facility, efficient construction techniques and significant reduction in waste (i.e. categories of waste associated with lean).

Building Information Models provide a technological platform for the integration of lean delivery and scheduling techniques. Currently, lean thinking provides innovation in a more tangible sense, in that the systems and tools within the lean framework act in conjunction with physical project representatives and basic software packages (in comparison to BIM). The frameworks for delivery of projects and the scheduling techniques utilised within lean techniques could equally offer substantial benefits to BIM by way of locational planning systems.

Kala, Seppanen and Stein (2010), suggest that the principles and techniques utilised within lean construction can be applied to BIM by establishing local breakdown structures and location-based planning systems. Essentially, this allows for scheduling to occur within the BIM (5D) framework, thus forming a highly comprehensive model, whereby specific tasks and assignments can be taken directly from the model and executed in real time. Whether this level of collaboration is necessary within the present market is questionable, however, progressive innovation between technology and value-adding construction techniques (lean construction) will provide superior advancements in all construction spheres.

4. DISCUSSION

Traditional procurement systems and scheduling techniques are effective within the current marketplace, however, low productivity and limited expansion as a value-add sector in the Australian economy indicates that current practice may have reached the limits of useful application. The volatile economic conditions that have preceded the global financial crisis have halted productive growth within many industries, especially in regard to investor sentiment and market confidence. As the construction industry is largely trend orientated slow economic growth reflects negatively in terms of short-term economic growth within the industry. In broader terms this may provide a high level of opportunity within the industry for the introduction of new technologies (coupled with training) and approaches to project delivery and procurement.

Lean construction is at the cutting edge of management systems, scheduling and efficiency, and would be a highly beneficial adoption within the construction industry. Partial integration of lean techniques is present within the Australian market; however, a more focussed effort is required for greater value to be generated. Greater integration of lean construction philosophy and techniques will serve as a catalyst for increased innovation and productivity within the construction industry.

The integration of a collaborative model between BIM and lean construction is a somewhat romantic concept, however, in essence is less predictable to measure in terms of actual application within the market. The collaboration of these two concepts, more likely requires a form of standardisation to take real effect within the industry, specifically in regard to location based planning systems and localised breakdown structures within BIM. These systems will require careful attention to detail and a large scope for data monitoring. The possibility still exists, however, to form a collaborative project model that encapsulates all five dimensions of the project modelling, as well as, scheduling and activity sequencing. This model is a long-term vision for the future of innovative construction techniques and should not be dismissed.

Through careful planning and gradual/controlled integration lean methodologies, innovation within the construction industry will significantly increase producing flow-on effects into productivity and economic growth.

CONCLUSION

The construction industry is a complex facilitator of highly specialised processes and representatives, all working to achieve timely, high quality and profitable facilities and structural resources. The construction industry is largely reliant on demand factors within the economy and can be significantly affected by speculation and trend structures (i.e. GDP). The industries primary role within the economy is as a value-add sector largely contributing to growth within the economy due to the scale/reach of projects into the market. Research and analysis within this report has indicated that as a whole the industry has largely been underperforming for the last few years. This identifies deficiencies within the industry in regard to innovation and productivity, resulting from inadequate traditional practices.

Lean construction has been analysed in terms of the significant opportunities present within the philosophy that will improve the innovation and efficiency (waste reduction) within the construction industry. The 'Lean Project Delivery System' (LPDS) has undergone thorough evaluation as to where the key benefits lie for improvements within traditional systems. Fundamental changes such as the improvement of collaboration, increased lean thinking and structuring and project level optimization have been identified as the possible catalysts for innovative progression within the construction industry. Subsequent detailed analysis has been performed on the 'Last Planner System' (LPS), which has revealed inadequacies in traditional planning and scheduling and where significant improvements can be utilised by integrating the LPS into construction projects. Increased collaboration and flow between project activities is identified as offering the greatest benefit to project planning and scheduling through integration of the LPS. Final conclusions have been drawn as to the feasibility of integration of these techniques into traditional practice, resulting in a balanced argument for the implementation of both the physical systems and the training and development required for efficient execution of lean models.

BIM and lean construction collaborative modelling has been discussed as a potential future output for construction practice, however, it is unclear as to when, where or how this integration will occur. Significant barriers must be overcome and standardisation of models may be necessary in order to facilitate effective control and integration, and minimise risk.

In conclusion, this report has evaluated the effectiveness of traditional construction practice in terms of the fundamental processes that exist to facilitate effective and successful delivery of construction projects. These processes have been found to be inadequate in a number of key areas such as collaboration, planning and scheduling. Critically, these inefficiencies have been identified as opportunities for innovation through he integration of lean construction methodology. Effectively, this is where lean construction holds unrivalled value within the construction industry. Barriers to integration still exist specifically in relation to mental development and technical learning of systems; however, these can be overcome with the right understanding and conceptualisation of the fundamental benefits that lean construction will deliver to construction projects.

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