LEAN CONSTRUCTION, BUILDING INFORMATION MODELLING AND SUSTAINABILITY

Lauri Koskela[1], Bob Owen[2], Bhargav Dave[3]

ABSTRACT

This paper investigates the mutual relations of three current drivers of construction: lean construction, building information modelling and sustainability. These drivers are based on infrequently occurring changes, only incidentally simultaneous, in their respective domains. It is contended that the drivers are mutually supportive and thus synergistic. They are aligned in the sense that all require, promote or enable collaboration. It is argued that these three drivers should be implemented in a unified manner for rapid and robust improvements in construction industry performance and the quality of the constructed facilities and their benefits for stakeholders and wider society.

KEY WORDS

Lean construction, building information modelling, sustainability.

INTRODUCTION

There are three major drivers in construction today: lean construction, building information modelling and sustainability. Each topic is addressed through conferences and workshops, dedicated journals or at least special issues, and organizations established specifically to promote the topic. In this situation, a question arises: What are the mutual relationships of these drivers? Are they mutually neutral, or perhaps contradictory and conflicting, or synergistic? This is the issue to be addressed in this paper.

THE LONG VIEW

It is contended that the nature of changes implied in the three topics addressed will become clearly visible only through an historical consideration. Lean construction is an innovation in production theory, building information modelling in product representation, and sustainability in product requirements. Thus, it is opportune to have a long view outline on these wider domains.

[1] Professor, School of the Built Environment, University of Salford, Maxwell Building, Salford, M5 4WT, UK, phone +44 (0) 161 295 6378, l.j.koskela@salford.ac.uk.

[2] Senior Research Fellow, School of the Built Environment, University of Salford, Maxwell Building, Salford, M5 4WT, UK, r.l.owen@salford.ac.uk

[3] Research Fellow, School of the Built Environment, University of Salford, Maxwell Building, Salford, M5 4WT, UK, b.dave@salford.ac.uk.

PRODUCTION THEORY

In modern times, ideas for organizing and carrying out production have come from economics and scientific management. Economics sees production as a transformation of inputs to outputs. For Taylor (1913), the key idea was the notion of task: production management was about task management. The connecting element between these two seminal approaches is decomposition: the total transformation is decomposed into smaller ones and ultimately into tasks. An implicit, but for its consequences, very real assumption here is that the decomposed tasks can be treated as mutually independent. This led to the possibility of hierarchical, functional organization, where all departments were internally homogenous and pursued internal optimisation; hence, it was thought, the total optimum would emerge through simple addition.

This transformation model was a big improvement in its time. Unfortunately, it has an inherent weakness: the dependencies between tasks are abstracted away. Thus, the more complex and dependency-intense a given situation is, the greater will be the risk that the transformation model is not only ineffective but also very harmful.

Lean production, and consequently also lean construction, is based on two other theories of production: flow and value generation (Koskela 2000). The flow concept introduces the reduction of waste as an object of production management, whilst the value generation concept, of course, brings value to the customer into the picture. The methods and practices of lean construction, deriving from these two theories, are very different from those associated with the transformation concept.

PRODUCT REPRESENTATION

In the 1760s, the Frenchman Gaspard Monge developed a precise standardised method of describing three dimensional objects in two dimensions, called descriptive geometry. The method was deemed so powerful that it was kept in secrecy for many years, and Monge published the details only in 1799 (Monge 1799). Since then, descriptive geometry has been the basis for construction design drawings. Together with written description, such as bills of materials, drawings have been used to represent the object to be built, both for contractual purposes and for site execution.

Building information modelling (BIM) refers to a computer representation of a building as objects (Eastman 2009). The basic concept was previously presented in the mid 1970s (Eastman 1975), but gained wider industry interest only since the mid 1990s once affordable computers enabled practical implementations of the idea. There are two major features in BIM. First, the objects usually are three dimensional, as in reality. Second, the objects are parametric: the objects are defined as parameters and relations to other objects, so that if an object changes, related ones will also change (Eastman 2009). Thus, there are two main improvements in comparison to the earlier situation: there is no fundamental need for several drawings to describe one building element, and changing of the design solution is eased, as not all affected elements need to be redesigned – they change automatically to adjust to the changed detail. In addition, models of individual building elements can be combined to ensure that design 'clashes' can be resolved prior to construction, bills of material can be semi-automatically derived and construction sequences rehearsed and optimised through bi-directional linkage with project plans. BIMs can also be used as the fundamental information source for modelling of energy usage through the use of geometric and parametric data using computational flow dynamics. There are also many other benefits resulting from a computer model of the building during design, construction and use.

PRODUCT REQUIREMENTS

Vitruvius (c.20BC) defined durability, convenience (equivalent to utility) and beauty as three main requirements to be met by builders. The next treatment of this topic was by Alberti (1452), who followed Vitruvius' format but covered wider scope. The overarching idea contained in these books is that the requirements derive from the immediate environment and context of the building: site, materials available, purported use and preferences of the client. The qualities required are manifest or at least directly observable. The range of requirements is relatively stable and well understood by professionals, and the means for their realization are generally known.

Sustainability implies that requirements coming from outside the immediate functional environment and context of the building are adopted; they are often not tangible but abstract, their realization cannot be directly observed but can be assessed through measurement and calculation. The range of such requirements is new, and there is little initial understanding of the means for realizing them.

DISCUSSION

Thus, all three drivers considered, namely lean construction, building information modelling and sustainability, imply abrupt changes to a situation that has prevailed for one or more centuries.

MUTUAL RELATIONS

BIM – LEAN CONSTRUCTION

A recent research addressing the relations between lean and BIM in construction (Sacks et al. 2010) identified fifty-six interactions, all but four of which represent constructive interaction in terms of BIM enabling lean implementation. The lean principles that have the highest concentration of unique interactions are "Get quality right the first time (reduce product variability)", "Focus on improving upstream flow variability (reduce production variability)" and "Reduce production cycle durations". The BIM functionalities that have the highest concentrations of unique interactions are "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". Sacks et al. argue that the sheer amount of constructive interaction mechanisms identified, although not all have empirical backing yet, strongly supports the argument of a significant synergy between BIM and lean.

On the other hand, it can be argued that the higher level of collaboration, standardization and plan reliability, typical of lean construction, contributes to a smooth application of BIM technology. In the past, the high level of variability, typical of traditional construction, has often hindered the use of IT in a beneficial manner, and IT solutions have, for their part, even increased this variability (Koskela & Kazi 2003). Thus lean construction arguably facilitates the implementation of BIM especially when this is based on robust and reliable technology. For further development of this interaction and research directions see Owen, et al. (2009) and

Prins and Owen (2010). Here BIM is seen very much as a developing set of technologies which facilitate and encourage change, particularly in the design and construction process improvement, best exemplified by lean construction.

LEAN CONSTRUCTION – SUSTAINABILITY

The contribution of lean construction to sustainability comes in three main forms. First, through its focus on waste reduction (in the sense of industrial engineering), lean construction will also reduce material and energy wastes during construction and maintenance (Koskela & Tommelein 2009). Secondly, the greater operational and product reliability achieved in lean processes will reduce the amount of harmful emissions (King & Lenox 2001). For the proponents of sustainability, these improvements will probably not seem extensive enough. However, here the other focus of lean, value, comes into the picture. The generic methods developed in lean product development for achieving challenging targets can also be used to achieve sustainability targets (Lapinski et al. 2006).

It can be argued that a reverse relation also exists, from sustainability to lean construction. The improvements in process efficiency, discipline and reliability motivated by sustainability concerns are broadly aligned to lean objectives, and thus strengthen the implementation of lean construction.

BIM – SUSTAINABILITY

The direct relation between BIM and sustainability comes mostly in the framework of rapid evaluation of design proposals from a sustainability viewpoint. As stated above, most sustainability features are not tangible but require abstract calculations for their assessment (e.g. through the use of computational flow dynamics). The ability to make such evaluations rapidly greatly enhances design work towards sustainability targets (Krygiel & Bies 2008). Also, advanced facility management systems are being developed that provide a visual interface to control the energy use of a building by interacting with sensors installed within structures and with the as-built BIM.

DISCUSSION

An initial overview on the relations between BIM, lean construction and sustainability is given in Table 1. Arguably, the synergies between BIM, lean construction and sustainability are strong and significant.

THE SHIFT FROM DIVISION OF WORK TO COLLABORATION

There is one issue requiring in-detail attention. Consider the following statements coming from proponents, respectively, of the three drivers:

- Lean proponent Sutter Health (Macomber 2004): “Collaborate, really collaborate”.
- BIM proponent Stebbins (2009): “I have been saying for years that BIM, in a word, means ‘Collaboration’.”
- Sustainability proponent Mazza (2007): “In order to design truly sustainable buildings, it is necessary that all members of the design team work in a fully integrated fashion and that the building be viewed as an integrated whole.”

Table 1: Mutual impacts between BIM, lean construction and sustainability.

	Impacts on different drivers		
Impacting driver	**BIM**	**Lean construction**	**Sustainability**
BIM	-	Enables waste reduction and value creation in tens of ways, such as coherent design information, clash detection, visualization and evaluation of proposed design solutions, etc.	Enables sustainability evaluation of proposed solutions, for example simulations of energy consumption and CO2 footprint.
Lean construction	Facilitates the implementation of BIM through systematic approach; adds the necessary integrating process layer; and specifically requires collaboration between the parties.	-	Achieves higher resource efficiency through reduced waste. Leads to reduction of harmful emissions through higher operational and product reliability. Facilitates the achievement of sustainability targets through emphasis on value generation.
Sustainability	Reinforces the use of BIM through the need for complex analysis and simulations.	Reinforces lean efforts through partial alignment of purposes and methods.	-

Where does this aligned subscription to collaboration come from? Again, it is necessary to look at the history. In the timeline of production theory, product representation and product requirement, the traditional thinking searched for efficiencies from division of work, or at least supported this direction.

The idea of production as transformation, in focusing on decomposed transformations (tasks), addresses efficiencies inside each task – actually, dependencies between the tasks are abstracted away in this scheme, thus actively seeking to reduce the need for collaboration through decomposition and deterministic scheduling. In turn, precise drawings based on descriptive geometry enabled the separation of design and construction, and later the emergence of subcontracting and consultancy of different specialisations. Before precise drawings, the architect had to be continuously involved in construction for guidance. The relative stability of requirements set to buildings has supported this evolution towards greater division of work. As we know, this evolution has been occurring even in the last few decades, in the form of hollowing out of contractors and reduction of design and construction expertise in large, professional client organizations.

In contrast, the new thinking in production theory, product representation and product requirements seems to favour collaboration. Both of the new production theories, flow and value generation, support collaboration – both address the dependencies between tasks as a source of efficiency and effectiveness. The three dimensional representation of the design solution is merciless in pinpointing all the inconsistencies between decomposed partial designs, and thus pushes designers, engineers and sub-contractors towards collaboration. In turn, ambitious sustainability targets require that building components, which earlier served predominantly a narrow set of specific requirements, now contribute to the realization of a wider array of requirements, necessitating even wider collaboration to include both stakeholders of the individual building and of the wider community.

This coming-together pushes towards collaboration from three different directions and is a fortunate and remarkable coincidence, which has already started to invigorate both the practice and the theory of construction design.

CONCLUSIONS

A step change in construction, an industry marred with delays, cost overruns, shortcomings of quality and poor safety, has been long awaited. The synergy between the three drivers can be seen as a major opportunity to achieve such a step change. However, this will not happen, at least rapidly, by itself, but requires visionary and decisive action as well as persistence. The three drivers imply profound changes in themselves, and the difficulties of implementing any change are well known. One potential fallacy is to position these changes as management fashions, typically outsourced to consultants for implementation. Rather, the involvement, insight and championship of management are sorely needed.

However, the positive news is that there are pioneering stakeholders that have already embraced the integrated implementation of lean, BIM and sustainability, with good results. These stakeholders include clients, design offices, contractors and even trade associations. The new practices are starting to diffuse to the rest of the industry from these pioneering pockets, although we also see much variation in awareness between nations.

Regarding academic research, it seems that these developments have offered a surprise; the reorientation of academic research in view of the new situation started somewhat slowly. Nevertheless, profound changes are always excellent opportunities for relevant research to be done, and now promising signs of a renaissance of construction management research are already visible.

Lastly, it is opportune to discuss action options by the construction client that is usually the biggest in each country, namely the government. In a few countries, the agency for procuring and maintaining government buildings has taken proactive measures to require implementation of (especially) BIM and sustainability principles in capital procurement projects. This has effectively encouraged the uptake of related innovative tools and methods in the industry. However, even in these cases, the coverage of requirements should progressively be extended to address all three drivers. In the majority of countries, the procurement agencies may still be failing to utilize this unique opportunity of speeding up, for their part, a step change within construction.

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