Abstract

The incorporation of off-site production into construction projects can offer many benefits. However it has become clear that this approach can conflict with traditional management of construction processes, double design work, poor sizing and thus material waste, failure to take into account interdependencies between preassembled and site elements and processes are just some of problems appearing in the project delivery. It is proposed that the true value of an off-site strategy can only be fully realised when the decision to use it is taken before design commences. In this way design and construction processes can be developed together to enable the benefits to be maximised. The application of Lean production methods in the off-site manufacturing combined with the use of a Lean project delivery system on site can provide a further step towards to improvement. This paper will identify elements of the design process, Lean project delivery and offsite strategy that need to be integrated and propose a conceptual framework within which this can be achieved. The paper argues that this framework introduces a new approach converting traditional construction into a process of modern assembly which can help to reduce uncertainty and variability of outcome and adds a new classification of “kitting” as a category of pre-assembly.

Keywords: off-site, kitting, lean construction, design for life cycle
1. Introduction

In 2004 the UK market for off-site technologies was estimated as £2.2bn, or 2.1% of total UK construction (Goodier, Gibb 2007). Such small figure can partially be explained by the resistance of clients and contractors to off-site partially caused by lack of information to assist objective decision-making. In common with other industries, decisions made in construction are often highly subjective, based on emotive and irrational elements rather than evidence based (Edge et al. 2002).

The main concerns expressed by representatives of the construction industry about off-site technologies were its high cost, limited design opportunities and the negative image of prefabricated elements (Goodier, Gibb 2007, Edge et al. 2002, Venables, Barlow & Gann 2004). Using current cost comparison methods the direct cost of off-site products is often higher when compared to the traditional construction solutions. However a judgment based on direct costs only hides the bigger picture of expenditure involved in the project and product life cycle. Narrow approach to cost estimating dictated by current commercial management practices excludes from the calculations the advantages the off-site strategy bears, such as higher quality, reduced waste, time benefits, labour savings etc. It also fails to see the project as a whole or to capture benefits for the following activities in the project delivery sequence. For example BuildoffSite case study of a commercial office building describes the positive effect on workflow in the fitting of the traditional pipe branches that arose as a result of installation of services modules produced off-site. Significant savings achieved could easily be overlooked if traditional cost comparison was applied (BuildOffSite).

There is a general belief that the off-site market capacity is limited. However Goodier, Gibb (2007) mention that suppliers themselves do not see any obstacle for expansion of production capacity apart from constraints in demand. The Manufacturing Excellence survey shows that suppliers involved in the off-site business are working on 70% of their capacity only and have room for significant growth (Venables, Barlow & Gann 2004).

The biggest barriers for wider utilisation of the off-site manufacturing lie in the inadequate organisation of the project delivery process. Uncertainty in off-site elements production and delivery times make the probability of delays in projects higher increasing contractor and client reluctance to use off-site (Goodier, Gibb 2007). At the same time poor supply chain management and poor briefing accompanied by the inability to freeze design at the optimal stages are highly troublesome for suppliers. Manufacturers face difficulties with establishing production schedules and protection from the risk of capacity loss as a result of the late arrival or frequent change in design information, and constant modifications of installation timing and sequence (Ballard, Arbulu 2004). They attempt to stabilise their production processes and protect themselves from variability of demand with contingencies such as setting up longer lead time, double booking of capacity, designing and fabricating in advance to build up stocks (ibid). In turn such mass production methods create waste (duplicated design, inventory, waiting, etc.) boosting the price unnecessarily high and increasing lead time. Hence poor production system organisation reduces the reliability of the supplier, which in turn burdens the customer with increased risk.
Problems in project delivery often have their roots in design that fails to consider construction processes exacerbated by the traditional planning and management used to design and control the on-site activities. Organisation of the design process is limited by the dominant preference of bespoke solutions and traditional procurement methods. Design activity distributed among separate teams gives rise to poor co-ordination. With each team focused on their own product such matters as the impact of using particular components or modules on the remaining building structure and fabric elements are out of their consideration (Pasquire, Connolly 2003). As long as none of the project teams volunteer to take responsibility for the project as a system its delivery indicators can only keep deteriorating.

The problems with project delivery are hidden mostly in the interface between the design engineer and the specialist contractor as well as insufficient work structuring (Miles, Ballard 2002). Common project delivery practice is devoted to monitoring of performance against the preliminary set of specifications as well as enforcement of contractual commitments of the specialist teams involved. In case of deviation from the plan (which is always the case) management introduces corrective actions (fire-fighting) and tracks results in order to identify which party is at fault. Thus project management focuses on ensuring that production units do their job ignoring how this work is being done (Ballard, Howell 1998). Both parts of the described problem originate from the lack of a well-considered strategy which treats the project as a system implemented via clear tactical steps.

### 1.1 Definitions

Off-site manufacturing (OSM) is defined by Gibb (1999) as a set of contemporary construction techniques in four levels: 1. simple sub-assemblies (door furniture, ceiling grilles, windows etc.); 2. non-volumetric (e.g. frame units, above ceiling services modules, cladding systems); 3. volumetric (e.g. plant rooms, service riser shafts); 4. modular building (e.g. houses, hotels, restaurants). OSM includes prefabrication and pre-assembly which have been separately defined as:

"Prefabrication is a manufacturing process, generally taking place at a specialised facility, in which various materials are joined to form a component part of the final installation"

"Pre-assembly is a process by which various materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a sub-unit" (Tatum 1986, cited in Gibb 1999, pp.1).

In this paper a further distinction is added to the definitions of Gibb and Tatum and that is the addition of pre-assembly in the form of “kitting”. Kitting is packing of related materials, components and tools together before delivering them to the place of installation thus assembling a complete “kit” of parts required for the installation. Kitting places a special implication on the supply chain to streamline the procurement of materials over and above the manufacturing processes involved in prefabrication.

The kitting function may take place in a consolidation centre (on- or off-site) but is more useful if undertaken as a function of supply chain management. The assembly of the kits may be a simple collection of required resources in the required quantities without jointing or it may involve an amount of temporary jointing such as loosely attaching connectors which are subsequently removed and re-fixed.
on permanent connection to the building. Such temporary jointing forms a system for avoiding errors in the collection of materials allowing omissions to be easily seen prior to final packaging. It is also possible for prefabricated items to be supplied with associated fixing and sundry materials and this is a form of kitting.

1.2 Definition of lean construction

Pulling elements of lean thinking derived from the Toyota production system and product development. The essence of these used here are:

- systematic approach,
- work flow
- Just in Time

This paper does not directly address the definition of value although this is the starting point for lean thinking. Improvement in performance (time, cost and quality) is the initial goal and forms a contribution to the delivery of value.

2. Developing a conceptual framework to optimise off-site strategy using lean thinking

Construction is a complex process, its behaviour is uncertain and final results (in terms of cost and time) difficult to predict. In the traditional approach the process is managed relying on contingency reserves of money, materials, workers, time, etc. Two methods for better predictability are summarised in Bertelsen (2004). The first one is to reduce the complexity to a manageable level through the transfer of a major part of the work off site and limiting on site works to assembly only. The second one accepts construction as a complex system and dedicates effort to the elaboration of new management methods. However, not all projects are suitable for extensive use of off-site manufacturing. For instance the majority of refurbishments are restricted in the application of off-site fabrication and have to rely on more traditional craft-based construction methods. Similarly, few projects are formed entirely offsite. Consequently a combination of complexity reduction and new management methods is required.

The ultimate goal of construction design is to create a facility which is functional, within the budget and able to satisfy criteria of buildability and maintenance throughout the life-cycle. The Lean Project Delivery System developed by Lean Construction Institute US (The American Institute of Architect 2007, Ballard 2008) emphasises the necessity for a “project definition” stage when client and the project team can work together to define clearly the project value “linking purposes and values, and linking values and engineering specifications/design criteria” (Ballard 2008, pp.5). It is assumed that early incorporation of the off-site strategy considered from an overall project perspective will allow maximising benefit from it (Gibb 1999).
By analogy with manufacturing concepts design for manufacture and assembly (DFMA) and life cycle design we introduce design for life cycle (DFLC) terminology in construction. These concepts revolutionised manufacturing industry in the 1980s. The simple understanding that the design team should consider factors determining the behaviour and performance of the product over its entire life cycle from the first phases of development (Giudice, Ballisteri & Risitano 2009) resulted in changes in the design process. This allowed smoother processes, improved quality, considerable savings in time and cost, not least due to the reduction of corrective interventions at the later stages of design (ibid).

In much the same way as DFMA, DFLC is an embodiment of the next customer principle and acknowledgement of the design stage as a concordant part of the construction process, not a value in itself. DFLC can be split into a set of sub-activities, which reflect main stages of construction product creation and existence. Thus we distinguish between design for manufacturing (DFM), design for construction (DFC), design for installation (DFI), design for maintenance (DFMn), and design for decomposition (DFD). Each of these sub-activities has its own set of requirements against which the design of the product (building, prefabricated elements) has to be examined.

DFM is a function of the manufacturing processes and applicable only to the immediate manufacturing engineers. DFI serves as a link between the factory floor and the construction site where the off-site elements will be assembled and incorporated in the construction structure. This should at least include coordination of dimensions and tolerances, ways of transportation and details concerning installation. The exercise prevents clashes on the interfaces of different elements of the building so they will not be discovered unexpectedly later when corrections are costly or not possible. DFC includes traditional design activities with the difference of designing to clients’ value. It also considers how prefabricated elements will fit into the overall structure. DFMn and DFD work to optimise future management of the facility and decomposition process, encouraging a continuous dialogue between designers, facility management providers and decomposition specialists.

When splitting the design process into the stages the general picture should not be forgotten. Customer’s value which is assumed to be defined on the project definition stage is the thread that has to be passed through the whole construction process.

2.1. Collaborative approach to the design

An integral part of the DFLC strategic development is involvement of manufactures in the design process on the early stage. Heavy reliance on collaborative work makes it easier to approach the project systematically, taking into account interfaces between structural elements of the construction and working teams (The American Institute of Architect 2007). Generally such organisational integration brings better results in terms of costs, time and quality (Konchar 1998). The project also benefits from the improved communication and prevention of potential conflicts on the work place.

Building Information Modeling (BIM) is the technology capable of facilitating significantly and supporting the collaborative design. It allows smooth flow of information into downstream processes by giving the preference to direct digital exchange and elimination of arbitrary gates and handoffs be-
between different teams BIM enables early and direct input on the design from the fabricators to increase fabrication and pre-assembly efficiencies (Khemlani 2009).

Figure 1: Integrated Project Delivery (adopted from Lichtig, 2007; cited in Mossman, 2008)

### 2.2. Modularisation for the “leaner” off-site strategy

Recently many manufacturing companies adopted clustering method which turned into an important source of competitive advantage. Clustering is based on decomposition and compilation and its main idea is to arrange elements of the product architecture into clusters that become the building blocks for a product or family of products. This process requires consideration of the numerous elements and their multitude of relationships and design (or dependency) structure matrixes are employed to represent and analyse the architecture of individual systems (product, process, or organisation) (Danilovic, Browning 2007). In construction a building is created from separate elements and basic materials which require skilled craftsmen to join them together. Thus making it fit decisions are made at the very moment of joining. OSM opens opportunity for clustering in construction as these decisions are taken away from the site. Building can be decomposed into separate elements followed by the deep analysis of connections and interdependencies between these. Clustering in this way has advantages in simplicity of assembly and flexibility in the long-term (easy to be substituted, moved, etc). Although clustering and the application of DSM for building design is still a new area of research, it has potential of bringing construction to a new stage of development, through facilitation of the design for pre-assembly and enhancing long-term functionality.
2.3. Design of the production system

The production system has to be designed in parallel with the product design. Excellent organisation of logistics and joining parts into a kit before delivery onsite can be an easy as well as an effective way to improve project delivery and facilitate flow on site. According to Ronen (1992) who introduced the complete kit concept in manufacturing, some benefits of kitting include: 1) less work in progress, due to less waiting for additional components to arrive; 2) shorter lead time and reduced variance in delivery schedule; 3) easier control as less effort is required to ensure everything is ready for work to proceed. In addition kitting helps to enhance productivity, which is the advantage of off-site strategy, and facilitate just-in-time as elements and modules can be installed immediately after delivery.

However Forza (1996) claimed lean organisation of the supply chain via just-in-time, next customer’s pull and kitting might reveal to be too fragile in usual for the industry environment of uncertainty. Lean system makes provisions for such situations: an intermediate stage for buffering adds to evenness of the flow and reliability of the system. Court et al (2009) shows that delaying of final assembly until a customer order is received and pulling the elements through the system only after a signal is placed (kanban) can deliver better responsiveness, predictability and reliability from the supply chain. This complemented with kitting function makes just-in-time and increase efficiency of the project delivery possible.

![Off-site process for construction diagram](image)

Figure 2: Off-site process for construction

The construction process should be designed in order to create flow. It requires coordination of on-site activities with delivery of modules and components produced off site, design of operations, management of labour and resources. Planning using short and mid-short-term schedules reviewed constantly to differentiate what should be done from what can be done (see, for example, Last Planner™) increase the reliability of the project process. It has been shown on multiple projects that regular plan-
ning activity with shorter time spans is an effective way of coping with uncertainty (Formoso, Moura 2009, Friblick, Olsson & Reslow 2009). The principle also applies to the work where small batch sizes increases reliability of performance giving the opportunity to plan work in measurable terms, making it easier to manage, levelling and stabilising the work flow.

3. Conclusions

Despite the fact OSM can result in numerous benefits on organisational and project levels in terms of cost, higher quality, time, manageability and reduced complexity of on and off-site activities (BuildOffSite), it potential remains underused. Poor organisation of supply chain, inability to treat the project as a holistic value delivery process and late consideration of off-site strategy are among the main factors explaining its relatively low use.

Construction is a complex process and it requires vigorous management abilities and brilliant process design to ensure successful project completion. A well-considered off-site strategy is the one that bases on lean construction principles: delivers customer value through DFLC, uses lean organisation of work on the project (early contractor involvement, truly cooperative work, set-based thinking, etc.) as well as takes care of the production system design. Delivery and installation of pre-assembled blocks has to be coordinated with other on-site activities and incorporated in the project delivery plan to make the best use of it. Excellent organisation of logistics and joining parts into a kit before transportation on site can be an easy as well effective way to improve project delivery and facilitate work flow on site.

Many factors contribute to the success of the off-site strategy within a project. First of all it has to match with the long-term strategy of the company undertaking it. The off-site strategy is not always able to reveal its potential in the short term due to several reasons: 1) the necessity of initial investment (excluding the constructors relying on outsourcing of prefabricated elements) which the company might find it infeasible for a single project; 2) benefits of standardisation spread across other projects; 3) learning curve and building on own experience. Persistency in following the same strategy brings vast prospects for efficiency and productivity improvement in the projects and the whole organisation opening a way to the process of constant perfection, which is one of the basis conceptions of the lean theory.

Movement towards DFLC would also call for adoption of commercial management practices alternative to traditional. As the changes are systemic, they will concern all elements of the project delivery system, and commercial relationship is an integral part of it. Pan et al (2008) note that adhesion to conventional procurement methods represents a considerable obstacle for the off-site strategy able to preclude or minimise the benefits it bears. Ballard and Arbulu (2004) refer to the traditional payment system as the one closer to the mass production principles, promoting long production runs and early delivery of the pre-assembled orders.

Effective design requires contribution of all parties into the process and comprehensive understanding of the value being delivered. Alternative ways of procurement can help in establishing long term relationship that will be supportive to DFLC, for example, in facilitating collaboration process due to pre-
vious experience of joint work. It might be also necessary to adopt different approach to accounting. The dominance of the design stage in the proposed system will naturally entail greater initial expenses, e.g. due to early involvement of contractors, whose contribution needs remuneration, but eventually the project is more likely to be delivered cheaper, faster and in better quality. The study conducted by Gransberg et al. (2007) concluded that the design fee should be treated as an investment which is done on that project stage when the ability to influence the final outcome in terms of cost is the highest.

No enterprise can be successful without a strong guidance of a leader, someone with enthusiasm for making things better, enough charisma to inflame others, clear goals and rejection of determinism. Good management is necessary but not enough to make a success story. Leaders and managers have different functions in the project. Bennis (1989) drew distinctions between the two groups describing managers as those who administer, accept the status-quo and rely on control. In contrast leaders innovate, challenge the status-quo and inspire trust. There is no reason to believe that the client is the only one capable initiating innovation in the industry. It is understood that construction is a market with exceptional purchaser power; naturally it is easier for client to introduce new rules for the project. However contractors and subcontractors can use their expertise to persuade the client to pursue an alternative way of project delivery in the negotiation process.

References


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