

Off-Site Manufacturing – A Way Towards Lean Construction

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Abstract—*The construction process anywhere in the world generates a huge amount of waste. There is an urgent need to address this issue. Prefabrication can provide a better solution to the problems in huge waste generation on site activities. Adoption of prefabrication has potential in the construction industry though there are still many problems in the applications on prefabrication. The adoption of prefabrication and modular construction should enhance environmental awareness focused by the government. A range of Off-Site manufactured products is in common use within the construction industry. Off-Site Manufacturing is used for several different reasons. At times it may be forced on a construction project due to restricted site access or time constraints. This paper would discuss Off-site manufacturing as a way forward for the integration of lean theory into construction. The paper highlights the benefits of off-site manufacturing over on-site manufacturing and how the three basis of successful projects, cost time and quality are not compromised while using prefabrication for construction projects.*

1. INTRODUCTION

Construction waste is considered as one of the main factors having an impact on the environment. Construction waste is defined as the by-product generated and removed from construction, renovation and demolition workplaces or sites of building and civil engineering structure [1]. Space for waste disposal is running out. Construction industry generates a huge quantity of waste everyday and this amount reaches 40% of the total waste intake at the landfills areas. For sustainable development and to conserve landfill capacity, there is an urgent need for the industry to adopt certain new construction methods or technologies, which can reduce waste effectively. Lean construction is a production management strategy for achieving significant, continuous improvement in the performance of the total business process of a contractor through elimination of all wastes of time and other resources that do not add value to the product or service delivered to the customer. [2]

After the 2nd world war, many prefabricated housing systems were built in the U.K., USA and other parts of globe to fill the gap in housing market and to address the acute shortage of dwelling units. During the 1950's, building systems became more widely used and prefabricated panel systems were introduced. Despite recent technological progress in different

aspects of the design and construction of buildings, the greatest potential for radical improvement of productivity and quality in building still remains with maximum prefabrication of building components off the construction site. Egan [3] identified supply chain partnerships, standardization and Off-Site Manufacturing (OSM) as having roles in improving construction processes. The benefits attributed to OSM are numerous and well documented. Gibb and Isack [4] conducted a large interview-based survey in which they determined construction clients' views on the benefits of Off-Site Manufacturing. Their findings showed that clients' perceived the benefits of Off-Site Manufacturing as being mainly time and quality based.

In India, OSM has the potential to meet challenges to ensure speed, quality & economy along with desired characteristics for Lean construction. Globalisation has ushered in an Era of Mergers Resulting in Formation of Mega construction Groups. The quality of products has improved. With the influx of modern technology with latest equipment and leasing companies available, emphasis on quality, time bound programs, incentives for timely execution and heavy penalties for delay, construction industry will be revolutionized wiping out the inefficient construction links. There is greater emphasis on mechanization and computerization of all activities, resulting in efficiency in time bound execution and minimal cost overruns.

2. OFF-SITE MANUFACTURING

The term *off-site manufacturing* is used to cover prefabrication and preassembly in a process which incorporates both. This process involves the design and manufacture of units usually remote from the work site, and their installation to form the permanent works at the work site. In its fullest sense, off-site fabrication requires a project strategy that will change the orientation of the project process from construction to manufacturing and installation. The extent of Off-Site Manufacturing in every project is different and it can be established in the type of elements that are included and how much of each element has to be completed at the worksite [5]. Off-Site Manufacturing can be used in housing, industries,

commercial building, offices, hotels and so on. Client's needs, site opportunities; prevailing manufacturing, construction culture and other relevant factors determine the use of these elements. For most building projects these elements are substructure, frame, envelope, services, internal works and facilities. The substructure includes foundations, which are available as precast concrete elements; basements where precast concrete wall elements and structural steel can be used but its limitation depends on the restriction of access to the work place and finally, works below ground where Off-Site Manufacturing is not often used. The frame is in itself the structure of the building and can be built with structural steel whose pieces can be assembled either off-site or at ground level.

The most popular use for precast concrete, however, is in components. This includes walls, beams, floors, columns, panels, lintels, stairs and cills. The benefits of such products for housing are well known. Items such as lintels and cills are mainly stock items, available in standard sizes, often concealed after first/second fix and very economical when procured in quantity. However, in many instances, other elements of the construction could also employ precast concrete components, such as walls, ground beams, structural frames, foundations and roofs. The use of these elements in a construction project depends on transportation and craneage. The envelope includes the external walls and roofs that form the perimeter. Services like the mechanical and electrical services can be pre-assembled off-site and sizes and details depend on the project parameters and access limitations. Finally facilities which are for the end use of user such as toilets, kitchens, lifts, plant rooms etc. are build offsite due to their high value and complex construction. These elements described above can also be classified into four main different types of offsite manufacturing: modular buildings, volumetric pre-assembly, non-volumetric preassembly and component sub-assembly [6].

Modular building includes 3 dimensional modules that can be used in isolation or in multiples to form the structure and envelop of the building and enclose usable space and most units are complete in themselves and only a small amount of work is necessary on site.

Volumetric sub assembly comprises units that enclose usable space and often installed within or onto a building or structure. Most modules are finished and require a very limited amount of installation work on site.

Non-volumetric pre-assembly usually includes solutions either for structural frame or internal works. They can be classified into open panel systems whose main feature is that services, insulations, cladding and internal finishes have to be installed in situ; and closed panel system that is similar to open panel system in that the structure is delivered but it includes services, insulations, doors, windows and so on. Component sub-assembly is the basic level of standardization and the scale is relatively small compared to the whole project so they are invariably assembled off-site.

3. OFF-SITE MANUFACTURING AND THE CONSTRUCTION INDUSTRY

The three issues i.e. time, cost and quality form the basis of construction management in all the projects since a number of years. Throughout the twentieth century, one stop building contractors have been replaced progressively by major contractors employing specialist trades contractors and subcontractors to do the actual construction work. Buildings and building systems have also become more complex. These changes have meant that the managers of the construction process have had to concentrate more on the interfaces between building elements and the work of different trades than on the work itself. The use of Off-Site Manufacturing affects the design and management of construction interfaces and coordination between different specialist contractors. Prefabrication of building components can achieve better quality product by having better supervision, as the prefabricated products are tested and inspected before site installation. If the standardized design layouts are used at the early stage similar as the previous successful prefabricated projects, the achievement on the performance in cost reduction will be much better. Adopting prefabrication and mass production of building components can reduce construction cost effectively.

Other than the cost that can be saved from the early-standardized design layout, time can also be reduced as the prefabrication can increase the productivity and efficiency of building construction. According to Gibb & Alistair [5] the main benefit of Off-Site Manufacturing is reduction in the on-site program duration. This is achieved by the overlapping of off and on-site activities that would be done in sequence using traditional methods. The actual human resource hours may also be reduced by the increased productivity achieved in a factory environment. The reduction in project duration will almost always be a benefit to the project environment. The client will obtain the facility at an earlier date, which will usually mean an earlier start to production, or an earlier letting of a commercial development both of which will lead to earlier income generation. The reduction in project time leads to reduction in the overall cost of the project. Preliminary costs associated with the major contractor's site set-up costs would also be reduced due to reduction in time. There would be savings due to effective use of off-site fabrication by reducing the extent of site activities. This would require less site-based human resources with its attendant costs. Shared welfare facilities such as canteens, drying rooms, changing facilities and even living accommodation can be minimized, leading to further cost reduction. There would also be some cost benefit due to increased productivity in the manufacturer's work.

It could be argued that additional cost is to be gained due to the use of larger cranes but when comparing with traditional construction where materials are often moved around site using as well craneage in an inefficient way, the benefit is

greater in the first instance. Another cost effect due to the use of Off-Site manufacturing is on the cash flow as a result of units being built before they are needed and therefore some payments have to be done earlier. It will have an implication in the capital cost.

The third effect of Off-Site Manufacturing is on the quality. Manufacturing industry has for many years been using developing quality assurance processes and procedures to enhance the products that they make. Under factory conditions this is much easier than on construction sites. These are by their very nature unique working locations. This has meant that much of the available information has been derived from manufacturing industry. It has also taken some time for such quality assurance practices to find their way into the design process industry through design management. Design management is an area that is often over looked, which can lead to waste and missed opportunities. Manufacturers claim that the most significant advantage of Off-Site Manufacturing is better quality of production and finishes over traditional methods. This is due to better working conditions in the factory, stable trained workforce and reduction in on-site damage. [5] By contrast, on-site projects are forced to accommodate workers who have to be briefed on each day's activities. It has to be considered that future workforce is more concerned about conditions of employment preferring to work indoors and not travel long distances to work.

4. BENEFITS

The advantages of Off-Site Manufacturing have been widely identified by CIRIA [7] research project. These can be briefly summarized under the following headings as:

4.1 ON SITE BENEFITS

- Reduces labour and consequent Health and Safety risk
- Reduces waste in off-cuts, breakages and other losses
- Reduces site co-ordination activity
- Reduces plant, tools and materials storage requirement
- Reduces installation time with Client control
- Reduces need for welfare facilities
- Reduces complexity
- Reduces overall construction costs
- Shortens construction time
- Environmental performance improves for waste minimization
- Integrity on the building design and construction
- Reduces investment cost
- Reduces inventory cost

4.2 PROGRAMME BENEFITS

- Increases up front commitment (from manufacturers and suppliers)
- Increases quality (due to factory quality control systems)
- Increases flexibility

- Increases efficiency of installation (fewer installation processes)
- Increases reliability of installation (right first time)
- Increases reliability of delivery (increases in line with proportion of Off-Site Manufacturing)
- Frozen design at the early design for better adoption of prefabrication
- Better supervision on improving the quality of prefabricated products

4.3 MANUFACTURING BENEFITS:

- Improves working conditions
- Improves productivity
- Improves processes
- Improves control
- Improves performance
- Improves cost
- Improves quality
- Improves safety records
- Improves delivery

According to the Egan Report [3] the health and safety record of construction is the second worst of any industry and this is because people are either not properly trained or working out of processes. Health and safety issues should be more easily controlled in a factory environment, as protective access equipment is close at hand. This is not always the case when building on-site because construction sites are hazardous especially when working at height. As Off-Site Manufacturing reduces the amount of work carried out onsite it therefore reduces exposure to hazards although some considerations have to be taken into account due to the use of craneage.

5. A WAY TOWARDS LEAN CONSTRUCTION

Another important effect of Off-Site Manufacturing is on Lean Construction and Sustainability. Manufacturing processes that reduce the number of workers on site play a big part in the Sustainability. This is because transportation of materials and personnel to construction sites accounts for a great percentage of all vehicle movements in India and also a huge amount of energy used in construction relates to the transportation of products and materials to site and the removal of waste.. So, if benefits through Off-Site Manufacturing such as reduction of material wastage, better controls on atmospheric pollution, less energy use in transportation and on-site works and recycling of materials can be achieved, then Sustainability could be better in terms of providing buildings while protecting the needs of future generations.

Lean production has made significant improvements within the manufacturing sector and there is a simple argument that increasing the amount of factory based manufacturing of buildings, their components, sections and elements would form one logical method for incorporating lean production into construction project delivery. In principle, this should facilitate some of the year on year improvements in

performance called for in the construction industry. Waste management is becoming an important issue in the construction industry. Prefabrication can provide a better solution to the problems in huge waste generation on site activities. Adoption of prefabrication has potential in the construction industry though there are still many problems in the applications on prefabrication.

5.1 Hindrances in extensive adoption of Methodology

In reality though, the incorporation of off-site manufacturing (more usually called pre-assembly or prefabrication) into the construction process is meeting significant resistance from both Clients and many of their advisors. This resistance was revealed during research undertaken at Loughborough University [8] into the use of standardization and pre-assembly with factors such as inhibition of design creativity, increased capital cost, limited impact on critical path and increased waste through accidental damage/mishandling of units being cited as specific examples. To reap successful benefits from off-site manufacturing, the construction managers and the clients need to change their approach toward the project management. [9].

Hindrances in applying prefabrication:

- (i) Inflexible for changes of design
- (ii) Higher initial construction cost
- (iii) Lack of background research information
- (iv) Time consuming in the initial design development
- (v) Lack of consideration for the advantages in adopting conventional construction methods on site
- (vi) Limited site space for placing prefabricated building components
- (vii) Leakage problems that will occur while joining the prefabrication
- (viii) Lack of experiences of the contractors
- (ix) Monotone in aesthetics - issues for building
- (x) Lack of demand for prefabricated building components.

As a result of off-site manufacturing there is a tension between manufacturers and designers because of the degree of standardization versus variations in design. Therefore, manufactures need to consider how best to link design and production cycles to allow late alterations in design to permit customer opportunities; architects and designers need to get closer to Off-Site Manufacturing in order to adapt their design to the best use of OSM components. Design consultants have little understanding of the differences in designing for manufacture and assembly from designing for in-situ assembly. It is not merely a matter of carving off a piece of the work and saying it can be pre-assembled. Thought needs to be given as to how factory assembly is best undertaken to realize the benefits available. The manufacturing process must not be undertaken as a mini construction project i.e. enclose a space then fit in out. Thought must also be given to the arrival of the pre-assembled item on site, its incorporation into the structure and the effect this has on the rest of the construction work.

However the use of extensive off-site manufacturing can lead to degradation in design if all buildings are to be the same. It is precisely to say that construction industry has been benefited by good design and therefore a good balance has to be found. The change of production from in-site to off-site means that more extensive design needs to be carried out prior to manufacture and issues that would be resolved on site need to be specified at an earlier stage. In order to save cost, managers have to evaluate carefully all the costs involved in traditional construction against Off-Site Manufacturing, considering items of potential additional costs and potential cost savings. This issue of design and production scheduling has to be done with better coordination and management between each link in the supply chain and managers have to concentrate more on the interfaces between building elements and the work of different trades than on the work itself. A good management is also responsible for the quality of the finished product and considering that Off-Site Manufacturing includes the transport of many units already done, the risk of damage can be controlled by effective planning.

Many construction professionals and workers are much more familiar and comfortable with traditional construction methods than with Off-Site Manufacturing. This leads to cultural gaps and changes in the construction industry. Managers have to adopt a manufacturing rather than a construction philosophy and process in order to maximize the benefits from off-site manufacturing.

6. CONCLUSION

Off-site manufacturing of a part of a building may be quicker than assembly on-site but it still takes time. Whereas the components for in-situ installation maybe readily available, pre-assembled items will have a lead in time and this must be built into the construction process from the beginning. Although there are many hindrances to prefabrication, supervision can lead to achieving better environment and quality. Long-term construction costs can be reduced even if the initial construction cost is higher. For better implementation of prefabrication, early design stage should be considered for including the construction methods at the construction processes. The adoption of prefabrication and modular construction should enhance environmental awareness through education and training focused by the government.

To gain maximum benefit of Off-Site Manufacturing, managers need to involve all the members of the project in the process. Design decisions should be taken at an early stage and within the correct balance to assure all the benefits from a good design. Also, Off-Site manufacturing has to be done on a big enough scale to achieve improvement in productivity and quality required.

To reach the goal of Lean construction and Sustainability through Off-Site Manufacturing, the mass production involved has to be extensive to save enough cost and time overruns and

make a project better in value than a traditional construction project. This paper has tried to establish that wastage in a construction projects is not only in terms of material and energy wastage but also includes costs, time and quality. These are the three factors which make any construction project a successful project.

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