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# **IMPROVING PRODUCTIVITY AND WORKER SAFETY: AN ACTION RESEARCH USING OSM WITH CRANE ERECT**

Kenneth Lawani, Michael Tong, Billy Hare and Franklin Emina

The challenge of improving productivity and worker safety within construction is always a daunting task as workers feel they are squeezed with an ever dwindling resource pool. However, improving productivity and safety using OSM with crane-erect requires workers to have appropriate expertise. The potential benefits of Off-Site Manufacturing and the integration of timber kit crane-erect homes is considered as one of the most viable options in terms of delivering homes that are affordable, and minimising many of the safety hazards associated with the build process. This paper adopts an action research approach to evaluate the challenges regarding improving site productivity and safety through the implementation of OSM using crane-erect. The data collection involved assessing the labour uptime and downtime to install the wall panels, floor cassettes and the roof truss for six plots including labour and crane utilization. The findings suggest that the implementation of crane-erect requires adequate planning to avoid disruptions for other plants and tradesmen. Incorporating the delivery of the roof truss together with the timber kit will simplify the roof truss installation and also minimise the exposure time for the joiners to work at height. The operatives involved in loading of plasterboards to plot floor decks experienced significant increase in manual handling. However, it takes three days to complete the fittings of the shell, make it water tight with the internal kit, fire stop and installation of external fixtures (fascia & soffits). This is considered to significantly reduce time, health and safety risks, and productivity. Overall, the average percentage uptime for the six plots was 83%, but the housebuilder is keen to further improve and maximise efficiency above 90% per plot as this could lead to more plots erected per day using the crane erect.

Keywords: crane erect, productivity, timber kit, worker safety.

## **INTRODUCTION**

The UK house building business faces significant challenges in the delivery of new cost-effective homes of quality, quantity, and environmental sustainability within a very limited time frame. The potential benefits of Off-Site Manufacturing (OSM) and the integration of mobile crane-erect build for the timber kit is now considered as one of the most viable options by housebuilders for constructing new private homes,

(Venables et al., 2004; Hinze, et al., 2013; Eastman & Sacks 2008; Blismas & Wakefield 2009; Fulford & Standing 2014). The use of mobile-cranes with telescopic boom (high lifting capacity and short set up time) and the capability to travel within rugged site terrain made it useful due to its rapid deployment to mechanically lift heavy loads such as the OSM timber kits. However, the uptake of the non-traditional timber kit using crane-erect within the UK construction has been lower than expected (Taylor 2010), as opposed to the traditional linear construction where each individual step is constructed entirely or largely on site. Goodier & Gibb (2007) define offsite construction (OSC) or offsite manufacturing (OSM) as the manufacture and preassembly of building components, elements or modules before installation into their final locations on a construction site. Based on the degree of offsite work undertaken on the product, OSM can be classed into four different levels such as component and subassembly; non-volumetric preassembly; volumetric preassembly; and modular building (Gibb 1999). There are ongoing considerations regarding fully adopting the use of non-volumetric preassembly timber kit crane-erect method of house building by UK house builders in terms of delivering homes that are affordable, and removing or reducing many of the safety hazards associated with the build process. This is because timber kit OSM with crane-erect is considered to include reductions in time, defects, health and safety risks, environmental impact, and whole-life cost, and a consequent increase in predictability, productivity, whole-life performance and profitability when satisfactorily implemented (Venables et al., 2004; Hinze et al., 2013; Blismas & Wakefield 2009; Fulford & Standing 2014). This action research evaluates the challenges regarding improving site productivity in house building through the implementation of timber kit OSM using crane-erect by the contractor and to potentially roll it out across their entire business units. This study was carried out with one of the UK's largest independent house builders towards improving productivity and worker safety within its current development.

## **PRODUCTIVITY AND CONSTRUCTION WORKER SAFETY**

The construction industry is always seeking ways of improving its productivity and management processes whilst reducing project duration, cost, defects and eliminating Occupational Health and Safety (OSH) incidents. The traditional methods of construction where each individual step is entirely or largely constructed on site before the project can move on to the next phase struggles to deliver on these objectives. Therefore, a way of resolving some of these challenges by one of the independent housebuilders is the incorporation of timber kit OSM with crane-erect as an alternative to improving productivity and safety.

Construction is considered as one of the most complex in nature, physically demanding, and labour intensive industry that is interdependent in terms of manpower and resources and this could often lead to some problems of inefficiencies in operations (Dubois & Gadde, 2002). As a result of this, workers tend to be more prone to significant risks of injuries, ill health or fatalities associated with their tasks/jobs within the workplace (Hinze, et al., 2013). Due to the complexity of the construction industry and the ever increasing drive for higher productivity, worker safety can sometimes take the back seat (van der Molen et al., 2005). However, the success of this industry could be considered to be dependent on the effectiveness of the management to increase productivity and performance whilst incorporating and implementing best practices in terms of safety, health and the environment. Studies have shown that OSM can contribute to addressing some of these challenges facing the construction industry (Blismas & Wakefield 2009) and the independent

housebuilder has considered the incorporation of crane-erect mechanism as a way of further improving productivity and safety. Venables et al., (2004) identified that OSM technology has the potential to reduce cost, time, defects, health and safety risks and environmental impact and consequently increase predictability, whole life performance and profits over long term. Eastman & Sacks (2008) indicated that OSM of building components have significantly become more labour productive compared to on-site activities and the overall growth rate of OSM productivity is greater than comparable on-site sectors. Therefore, the adoption of timber kit OSM with crane-erect could potentially reduce the time for on-site construction due to more factory based production; reduce build cost through the reduction of time spent on site thereby improving efficiency; reducing material wastage and enhancing construction OSH.

Initiatives such as joint management systems where safety management systems are integrated with operational management systems have also been put forward as an alternative towards further improving both safety and productivity within the construction industry, (Choudhry 2017). This indicates that elements of productivity and safety could be managed by the safety and project managers by sharing the responsibilities of safety and operations. These could influence the safety performance of the project due to improved safety records, having effective controls in place for both contractors and subcontractors and the ability to closely monitor and supervise ongoing work. Incorporating this initiative requires the management to consider safety as a core part of all operational decisions which could invariably have a positive impact on productivity. Therefore, improving productivity and safety using OSM with crane-erect could lead to stability which could mitigate work-related accidents, injuries or fatalities while delivering on the project with minimal quality defects, time delays or associated cost overruns.

Some housebuilders are now adopting the concept of OSM with crane-erect but, there are issues around uptake due to lack of expertise (skill, knowledge and experience), transport and logistical problems, the complexity of the interface between systems, and the inability to freeze the design during the early stages (Blismas & Wakefield 2009; Rahman 2014). Other factors such as the resistance culture within the workplace (e.g. attitudinal barriers); lack of knowledge amongst the house builders regarding the available systems and their use; manufacturing capacity that are somewhat unreliable are considered as some of the obvious concerns that are usually raised with timber kit OSM with crane-erect builds, coupled with the rigidity of sequences and the overlap of stages that make co-ordination difficult, (Dubois & Gadde 2002). Therefore, the potential for the housebuilder to maximise timber kit OSM with crane-erect can be achieved if the decision to implement OSM and crane-erect is better understood and properly managed.

The use of OSM with crane-erect for this project hinges on the fact that the construction industry amongst other things suffers from low levels of productivity and safety when compared to other industries (Fulford & Standing 2014), with labour productivity having a major impact on project performance and the housebuilder has linked this with their existing management strategies. The decision by the housebuilder (management) to use crane-erect mechanism to drive safety and to improve productivity and performance also indicates that management-driven safety could be mutually dependent on productivity and performance.

Studies have looked at the relationships between productivity and workplace safety in construction and there is a consensus that the commitment of the management to

safety could significantly influence the safety climate within the workplace (Zohar 2002; Zohar & Luria 2005; Newaz et al., 2019; Casey et al., 2017). When safety and productivity are assigned same amount of attention within the workplace, it suggests a sign of genuine commitment of the management towards workplace and task-based safety (Lawani et al., 2018), and this could often mean workers complying with safety to achieve productivity targets without necessarily increasing the complexity of the production systems. However, the concept of improving productivity is often perceived as additional pressure on workers to achieve higher job demands while still adhering to working safely (McLain & Jarrell, 2007). It has also been identified that when safety and productivity goals compete for workers' attention within the workplace due to pressures resulting from productivity, safety often deteriorates while productivity becomes a priority due to better production performance and the culminating financial incentives (Reason 2000; Mitropoulos & Cupido 2009).

The use of mobile cranes for lifting operations is considered as an important piece of machinery that facilitates the workflow but at the same time with severe consequences if things do go wrong. Using mobile crane-erect to improve safety and productivity could also enhance the ergonomic features within the workplace which could reduce occupational injuries whilst improving labour productivity and quality (Neumann & Dul 2010; Westgaard & Winkel 2011). This could result in eliminating potential hazards and safety risks within the construction site. However, research has shown that one-third of construction fatalities occurred in crane-related accidents (Neitzel, et al., 2001) and that mobile cranes account for nearly 70% of most crane-related fatalities within the industry (Fang, et al., 2016) as compared to tower cranes that operates within a stationary position. This is because the use of mobile cranes necessitates it to move across sections of the site and plots to enable it perform its lifting tasks for the build process such as lifting the wall panels, floor cassettes, installations of roofs and lifting of other materials required for the build phase. To improve productivity and safety within the site, adequate planning processes and monitoring of the mobile crane onsite movement and lifting operations would require enhanced monitoring which would directly have an impact on the safety of the workforce. That means there should be a lifting plan suitable and sufficient for the work being carried out by an experienced crane operator and banksmen based on the Lifting Operations and Lifting Equipment Regulations 1998 and Provision and Use of Work Equipment Regulations 1998.

This study evaluates the benefits of using OSM timber kit through an actual site trial using crane-erect. To assess the impact of OSM productivity and safety, the approaches evaluated the aspects of productivity related to the earlier shell completion of the houses using pre-fabricated wall panels; finished floor cassettes erected using a crane with no safe working platform; early ground roof assembly, felt and batten and lifted to final place and the OSH benefits that mitigates manual handling.

## **RATIONALE FOR THIS STUDY**

This study assessed a UK housebuilder in its quest to improve productivity, performance and safety practices through the implementation of mobile cranes to erect timber kit homes. To achieve this aim, the study fulfilled the following propositions:

1. How would addressing process efficiency and OSH related to the build processes improve productivity?

2. Will embracing OSM with crane-erect technological shift disrupt the established relationships with various trades and impact productivity?
3. Would improving the housekeeping and material management due to downstream site process delivery (just-in-time) have an impact on productivity?

## **METHODOLOGY**

This study required the researcher to be physically present on site and embedded within the workers. It required responsibility for on-site strategy through site monitoring and observations, informal interviews and analysis of on-site activities to address issues under study, (Creswell & Creswell 2018). Such an approach has been used in organizational studies to improve practice for example, managing technological innovation and processes of Swedish building component manufacturers (Larsson et al., 2006). The adopted methodology involved on-site monitoring and assessment of site productivity and safety of some specific tasks being undertaken by the tradesmen; like the joinery and roof work and tasks involving the crane operators and banksmen. This explains the focus of the examination of timber kit OSM with crane-erect as opposed to the conventional traditional build towards a business case that creates value and as a form of competitive advantage for the company. The information which is gathered by actually talking directly to the workers and seeing them perform, behave and act within their context defines this qualitative research, (Creswell 2014).

It involved cases within a real-life, present context or setting over time (Yin 2014; Creswell & Poth 2018), with the researcher gathering information from multiple sources e.g. observing and taking field notes on the behaviour and work activities of individuals on site (Creswell & Creswell 2018). The use of qualitative audio-visual and digital tools (a time-lapse camera with video capabilities) and adopting face-to-face unstructured and generally open-ended interviews with workers and managers to elicit views and opinions from the workforce was adopted (Creswell & Poth 2018; Creswell & Creswell 2018). The information collected was focused on multiple house types, dimensions and designs within the development by adopting the same logic of replication (Creswell & Poth 2018). This type of action research involved the researcher collaborating with the site operatives in the assessment of their labour productivity of the build process of timber kit OSM homes with crane-erect. This research approach could be effective for developing solutions to problems identified, of which the Dargavel Project is a good example. However, the researcher needed to be able to lay aside their own value judgments sharpened by own practice in order to allow other voices to inform the research. Therefore, maintaining the balance between drawing from those available resources and the researcher giving up their own ideology in order to objectively collect and analyse research information was important. This case study development could potentially inform the independent house builder towards developing strategies for optimizing the use of crane-erect technology, evaluating its commercial benefits and benchmarking the perceived good practice with a view to rolling out an improvement program across the wider business to enhance productivity and safety, efficiency, minimizing construction waste, and building sustainable homes.

The data collection involved assessing the labour uptime to install the shell for six plots including the kit erect labour and crane utilization for the different house types. This involved measuring the labour time of the joiners involved in the installation of the roof truss, the kit erect installation and any extra labour assistance of apprentice

joiners for the floor cassette and wall panels. The measurement also captured the uptime and downtime of the crane usage covering both the operator and the banksman as part of the contract hire agreement.

## **FINDINGS, DISCUSSION & CONCLUSION**

*How would addressing process efficiency and OSH related to the build processes improve productivity?*

The use of mobile crane for the build process requires adequate planning for on-site access, and the planning of the crane hard standing position situated away from the job site access road and pedestrian walkway to avoid disruptions for other plants and tradesmen as this previously led to loss/delay of work programme, (Neitzel, et al., 2001; Fang, et al., 2016).

The formation of the roof truss on site could take up to two days to complete depending on the number of joiners assigned; their level of skill and experience; and the dimension of the roof truss. For process efficiency and progress, the timber kit and the roof truss required for subsequent plots should be delivered at the same time with the timber kit for reasonable progress to be made in forming the truss. Incorporating the delivery of the roof truss and timber kit together will simplify the roof truss installation and this could be achieved through proper planning of the joinery work as the allocated time for the formation of the roof truss on ground has no impact on other work packages. This would also minimise the need for joiners to work at height which thus minimise the risk of a fall from height.

This study indicates that the adoption of OSM timber kit erect significantly addressed workplace OSH issues most especially reduced manual handling involving wall panels, floor cassettes and roof trusses which are lifted into position using the crane. The use of crane-erect minimised the exposure times of operatives required to work at height thus preventing the need for safety decking and fewer risks to manage. Therefore, the use of scaffolds and their adaptations were completed quicker, closed off and usable (i.e. safer) and their management by competent scaffolders during and after the lift processes improved joinery efficiency and safety on site, (Hinze et al., 2013; Fulford & Standing 2014).

However, the two operatives assigned with the tasks of loading the plasterboards to the floor decks, and moving windows and doors into place for fittings experienced significant rise in manual handling whilst loading to the deck of the ground and first floor for joinery first fix. The two operatives manually lifted 240 – 515 sheets of plasterboards (24kg per sheet) depending on the different house type which amounts to 5,760kg – 12,360kg of manual handling without mechanical assistance. Based on the Manual Handling Operations Regulations 1992, it states that if, ‘so far as is reasonably practicable’, handling the load cannot be avoided, then consideration should be given to whether the lifting operation can be either automated or mechanised to eliminate the manual aspect of the handling. This specific task was found not to improve productivity neither did it improve safety practices but rather could lead to increased cases of musculoskeletal disorders (Neumann & Dul 2010; Westgaard & Winkel 2011). This indicates that joint management systems (Choudhry 2017) that are integrated with operational and safety management systems to potentially improve safety, process efficiency and productivity were not adequately considered.

*Will embracing OSM with crane-erect technological shift disrupt the established relationships with various trades and impact productivity?*

The findings present emerging challenges and opportunities associated with the site monitoring study. The site trials of the OSM with crane erect established a positive stance for the company as they plan to change their build process from traditional to crane-erect. The findings focusing on labour productivity assessed the kit erect joiners and crane systems being used for the build phase for the six plots. The acquisition of data for labour and cycle time was carried out by onsite researcher through observation and recording of the construction process - the start and completion times of individual activities and the number of operatives involved in undertaking such activities. In situations where concurrent measurements needed to take place, the researcher moved between such activities by documenting them through short time lapse video clips and photographic evidences.

The timber kit lifting operations for the ground and first floor wall panels, floor cassettes and the formed roof truss should adopt a planned sequence and drawings supplied with the kit to minimise OSH risk (Fulford & Standing 2014). The measurement of productivity for the kit erect joinery fix relied on the same available team of joiners based on their levels of skill and experience (Blismas & Wakefield 2009; Rahman 2014; Dubois & Gadde, 2002), the size and dimensions of the plots and the weather conditions. For the six plots, there was a consistent team of joiners responsible for the joinery fittings. The researcher measured the time taken to lift and install the ground floor panels, the lifting and installation of the floor cassettes to position and the first floor wall panels. The lifting of the roof truss craned into position involved the joiners completing the process of nailing and securing the roof while the full kit erect was achieved within a working day. Subsequent tasks like nailing of the internal kit, fire stop and installation of external fixtures (fascia & soffits) were completed within three days and water tight. This is considered to significantly reduce time, health and safety risks, environmental impact, and productivity (Venables et al., 2004; Hinze et al., 2013; Blismas & Wakefield 2009; Fulford & Standing 2014).

*Table 1: Productivity by House Type*

Code	Plot	GIA m <sup>2</sup>	FF Area m <sup>2</sup>	Uptime Hrs	Downtime Hrs	Total Time Hrs	Productivity m <sup>2</sup> /man hr	Uptime %	Downtime %
NWD	48	177	102	110	21	131	1.35	84	16
HDN	50	140	77	105	22	127	1.1	82.7	17.3
LRT	46	150	75	115	22	137	1.09	83.9	16.1
NWD	45	177	102	124	28	152	1.16	81.6	18.4
NWD	44	177	102	116	25	141	1.26	82.3	17.7
DWD	43	117	65	101	22	123	0.95	82.1	17.9
Ave		156	87.2	111.8	23.3	135.2	1.15	82.8	17.3



Table 1 shows the productivity by house type based on the floor area and their gross internal area. The dimension of the house was a major determining factor related to the uptime and downtime of the workforce. However, Plot 45 (NWD) significantly had longer uptime and downtime compared to other plots of similar dimension. This longer uptime and downtime was associated to the adverse weather condition which slowed the productivity of the workforce during the kit erect process. The productivity m<sup>2</sup> per man hour is based on the gross internal (floor) area divided by the total time in hours with an average productivity m<sup>2</sup>/man hour at 1.15. Future plots to be developed are now benchmarked against this average productivity value of 1.15 for other development. Overall, the average percentage uptime for the six plots was 83%, but the housebuilder is keen to further improve and maximise efficiency above 90% per plot and this could lead to two or three plots erected per day using the crane lift.

*Would improving the housekeeping and material management due to downstream site process delivery (just-in-time) have an impact on productivity?*

The delivery of plasterboards, windows and doors onsite were on a 20-tonne commercial lorry and guided to the designated materials delivery point. The inspection of delivered materials is carried out by the site operative (forklift driver) to ensure it matches the order details; that there are no signs of damages during transit; they remain wrapped, protected and placed on pallets and stored on site at the storage area. The plasterboards, doors and windows are then moved around the site by the use of a forklift truck (FLT) to the designated plots where required by the joiners. This minimised the time for operatives to manually move materials across site thus having a positive knock-on effect on improved labour time per plot.

Housekeeping activities related to material movement and distribution around the site from storage to designated plots was carried out using forklifts. This process was carefully planned to ensure no damage was caused to the underside or faces of the plasterboards, windows or doors during conveyance and this process minimised the amount of materials damaged and dumped in the skips. The plastic packaging used for wrapping materials and pallets were adequately stored in designated areas or skips meant either for recycling or reuse thereby keeping the floors and entire site clear of obstructions and promoting a tidy workplace.

The use of the 50-tonne mobile crane had its own safety merits but with differing risk profiles and safety factors to manage and control during the build process (Neumann & Dul 2010; Westgaard & Winkel 2011; Neitzel, et al., 2001). The study identified that the crane was engaged in lifting activities for a total of 19.5 hours for the six plots with a downtime of 20.5 hours. Only two plots (46 and 43) were identified to have greater uptime than downtime, see Table 2.

*Table 2: Crane Uptime and Downtime in hours for six plots*

Crane Lift	Plot 48	Plot 50	Plot 46	Plot 45	Plot 44	Plot 43
Uptime Hrs	2.5	3	4	3	3	4
Downtime Hrs	3.5	3	3	4	4	3
Total Hrs	6	6	7	7	7	7

The absence of daily/weekly workflow as observed onsite suggests that inadequate planning and scheduling of work packages by the site management team (Choudhry 2017); disorganised delivery arrangement of the timber kits (haulage and stacking) and adverse weather conditions (very high winds) could have a negative impact attaining optimum use of the crane for the timber kit erect. All these factors could potentially have led to risk of delays and disruptions which could accelerate some costs incurred on the project as opposed to the assumptions that OSM technology has the potential to reduce cost, time, defects, health and safety risks and environmental impact, (Venables et al., 2004). Improving the housekeeping and material management due to downstream site processes has improved worker safety, impact on the quality of the build, improved labour productivity and construction cycle time to get the building water tight, and reduction in the construction material waste.

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