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Maximizing Construction of Timber Kit Homes Using Telescopic Crane to Improve Efficiency and Safety: A Case Study

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Abstract: The challenges of improving efficiency and safety is a daunting task as workers are squeezed with an ever-dwindling resource pool and yet expected to deliver construction projects at optimum capacity. Improving efficiency and safety using telescopic cranes for the construction of Off-Site Manufacturing (OSM) timber kit homes is a viable option for the speedy delivery of new homes. An action research evaluated the maximization of the build and process efficiency and safety using a crane to erect wall panels, floors, and roofs. Data collection through direct observation assessed the labor uptime and downtime, including crane usage. A balanced score card was used by management for strategic organizational decision-making regarding the crane erection. The use of the crane reduced workplace manual handling of OSM panels, minimized the exposure of operatives to work at height risks, and eliminated alterations to scaffolds. However, the manual loading of thermal-insulated plasterboards to floor decks impacted the process efficiency and speed of installing the fixtures and increased the risk of musculoskeletal disorders. High labor downtimes were associated with the adverse weather conditions, which slowed the efficiency of the workforce during construction. The management’s inability to adequately plan the work program further hindered aspects of lifting operations and the speed and number of houses built.

Keywords: telescopic crane; timber kit; efficiency; worker safety

1. Context

The UK house building sector faces significant challenges in the timely delivery of new cost-effective homes of satisfactory quality and quantity and that are environmentally sustainable. The potential benefits of Off-Site Manufacturing (OSM) and the integration of the telescopic crane construction of timber kit homes is considered to be one of the most viable options by house builders in the construction of new private homes, [1–6]. The adoption of off-site construction using Design for Manufacture and Assembly (DfMA) is considered to be the trend and thus has significantly influenced the global construction trade and industry. It is thought that integrating these sustainable ideas and technologies potentially improves the efficiency, quality, health and safety and reduces costs; and the UK government considers that all these will shift the traditional practices of the industry towards the OSM methodology [7]. The use of mobile cranes with a telescopic boom (high lifting capacity and short set-up time) and the capability to travel within rugged site terrain makes it useful for house building combined with the ability to be rapidly deployed and to mechanically lift heavy loads, such as OSM timber kits. [8]. However, the uptake of non-traditional construction OSM timber kit homes using a
telescopic crane within UK construction has been lower than expected [9], as opposed to traditional linear construction, where each individual step is constructed entirely or largely on site. Within the UK, a 2015 analysis showed that 50% of construction projects conducted on-site without the use of DfMA struggled to accurately predict completion dates, and that is why most house builders are currently diversifying into OSM, as they could benefit from as high as 60% schedule savings compared to the traditional construction methods. Although OSM timber kit construction using cranes might not be the most applicable methodology in some projects, house builders have realized its suitability for their projects due to its ability to replicate repetitive designs; its construction speed; its improved safety, construction quality, sustainability, environmental performance, and construction productivity; its reduced lifecycle cost, CO$_2$ emissions, and construction waste/materials management [7,10].

Goodier and Gibb [11] define off-site construction (OSC) or off-site manufacturing (OSM) as the manufacture and preassemblage of building components, elements, or modules before installation into their final locations on a construction site; see [12,13]. Depending 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 [14]. This was further reclassified by [15] into the following four categories for improving the differences between volumetric preassembly and modular building: component manufacture and sub-assembly, prefabrication and sub-assembly, prefabrication and preassembly, and modular building. There are ongoing considerations regarding fully adopting non-volumetric preassembled timber kit homes using telescopic crane-erect methodology by UK house builders to successfully deliver affordable homes and prevent or reduce many of the site safety hazards associated with the build process. This is important, because the OSM timber kit with telescopic crane construction has been evaluated to include reductions in time, defects, site health and safety risks, environmental impact, and whole-lifecycle cost and a consequent increase in predictability, efficiency, whole-lifecycle performance, and profitability when satisfactorily implemented [2,3,5,6,10]. This study evaluates the challenges regarding improving build efficiency through the implementation of OSM timber kit homes using telescopic crane lifting methodology by the contractor towards future roll-out across their entire business units. This case study was carried out with one of the UK’s largest independent house builders towards maximizing the efficiency and site safety and health of the workers in line with the UN Sustainable Development Goals (Goal 8: Decent Work and Economic Growth; Goal 9: Industry, Innovation, and Infrastructure; and Goal 11: Sustainable Cities and Communities) as a blueprint for their future developments.

1.1. Optimizing Efficiency and Safety

The construction industry is always seeking ways of improving its efficiency and management processes in an attempt to reduce project duration, cost, and defects and eliminating Occupational Health and Safety (OSH) incidents [16–18]. The enhancement of quality and efficiency at every stage of the build process can improve site safety and drive optimum performance. 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 house builders is the building and incorporation of OSM timber kits using telescopic crane construction as an alternative to maximize efficiency, and demonstrating the management’s commitment to health and safety [17], which further reduces on-site labor and schedule savings. Construction work can be complex in nature, physically demanding, and labor-intensive and it is interdependent in terms of manpower and resources; this often lead to some problems of inefficiencies in operations, and the lack of workforce engagement can further impact workplace trust [19,20]. The complex and physically demanding nature of the industry and the management’s lack of genuine care about site health and safety issues means that workers are more prone to the risk of injuries, ill health, or fatalities associated with their tasks/jobs within the workplace [3,17]. Due to the complexity and fragmentation of the construction industry and the ever-increasing drive for higher efficiency, worker safety can sometimes be disregarded [16,21].
However, the success factors of the construction industry are dependent on the effectiveness of the management in collaborating and effectively communicating with key duty holders [10] towards increasing efficiency and performance whilst incorporating and implementing best practices in terms of safety, health, and environmental sustainability. Studies have shown that DFMA (OSM) can contribute to addressing and transforming some of these challenges facing the construction industry [1,5], and the house builder has evaluated that incorporating a telescopic crane-erect mechanism with an OSM timber kit will further maximize efficiency and safety. Venables et al. [2] identified that OSM technology has the potential to reduce cost, time, defects, health and safety risks, and environmental impact and consequently increase predictability, customer value, and profits over the long term, and this has been further re-emphasized by [22,23]. There is also progressive interest by the house builder in the whole-lifecycle performance of their buildings through this culture of innovation in terms of product maintenance, refurbishment, and replacement. Eastman and Sacks [4] indicated that the OSM of building components has become significantly more labor 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 OSM timber kits with a telescopic crane construction can potentially reduce the time for on-site construction due to more factory-based production; reduce build cost through the reduction in time spent on-site, thereby maximizing efficiency; reduce construction material wastage, preventing design hazards and enhancing the construction OSH [24].

Initiatives such as joint management systems where safety management systems are integrated with operational management systems have also been put forward as an alternative to further improve both the on-site safety and efficiency within the construction industry [17,25]. This indicates that elements of efficiency and safety can be managed by the safety and project managers by delegating the responsibilities for on-site safety and operations to workers considered as committed to health and safety. These can 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 proactively monitor and supervise ongoing work. Incorporating this initiative requires the management to consider safety as a core part of all operational decisions which can invariably have positive impact on efficiency. Therefore, maximizing efficiency and safety using an OSM timber kit with telescopic crane construction could lead to on-site stability, which could possibly mitigate work-related accidents, injuries, or fatalities whilst delivering on the project with minimal quality defects, time delays, or associated cost overruns and also deliver on innovative and integrated solutions.

Although some house building contractors now adopt the concept of OSM timber kits using telescopic crane erection, there are, however, issues around uptake due to lack of expertise (skill, knowledge, and experience), supply chain issues (transport and logistical problems), the complexity of the interface between systems, and the inability to freeze the design during the early stages [5,26–28]. Other factors, such as the resistance culture within the workplace (e.g., attitudinal barriers), a lack of knowledge amongst the contractors regarding the available systems and their use, and manufacturing capacity, that are somewhat unreliable are considered as some of the obvious concerns that are usually raised with OSM timber kit using telescopic crane erection, coupled with the rigidity of sequences and the overlap of stages that make co-ordination difficult [19]. Therefore, the potential for contractors to maximize OSM timber kit using crane erection can be achieved if the decision to implement the crane-erect methodology is better understood and properly managed [29,30]. From the clients’ perspective, they are able to compare costs but, sometimes, are often unsure regarding how to evaluate the benefits of building faster and safer; how to embark on a comparative analysis of products of diverse quality, sustainability, or energy performance; or how to assess alternatives on a holistic basis.

Cranes are machineries that are used extensively on construction projects for lifting and lowering operations—e.g., truck-mounted telescopic cranes for lifting OSM timber kit panels (Figure 1). The adoption of OSM timber kits using truck-mounted telescopic cranes for erection hinges on the premise that the construction industry amongst other things suffers from low levels of efficiency
and safety when compared to other industries [6,16], with labor efficiency having a major impact on project performance; house building contractors have linked this with their existing management strategies. The decision by the house builder (management) to use crane erection methodology to drive safety and to maximize efficiency and performance also indicates that management-driven safety could be mutually dependent on efficiency and performance. Studies have looked at the relationships between efficiency 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 [31–34]. When safety and efficiency are assigned equal amount of attention within the workplace, this suggests a sign of genuine commitment from the management towards workplace and task-based safety [17], and this can often mean workers complying with safety to achieve productivity targets without necessarily increasing the complexity of the production systems. However, it is often considered that the concept of maximizing productivity is perceived as additional pressure on workers to achieve higher job demands while still adhering to working safely [35]. It has also been identified that, when safety and efficiency goals compete for workers’ attention within the workplace due to pressures resulting from productivity, safety often deteriorates while efficiency becomes a priority due to better production performance and the culminating financial incentives [36,37]. Therefore, efficiency and safety can both be maximized by integrating manufactured components in the build process, which further simplifies the construction phase, increases the pace, and increases certainty regarding the completion timeframe.

Figure 1. Truck-mounted telescopic crane.

The telescopic cranes used for lifting operations are considered as important pieces of machinery that facilitate workflow but at the same time have severe consequences if things do go wrong. Using telescopic cranes to maximize efficiency and site safety can also enhance the ergonomic features within the workplace, which can potentially reduce occupational injuries whilst improving labor productivity and quality [38,39]. The adequate consideration of ergonomic hazards during building can also mitigate musculoskeletal injuries, lifetime disability, and early retirement. This could result in eliminating potential hazards and safety risks within the construction site. However, research has shown that one third of construction fatalities occur in crane-related accidents [40] and that mobile cranes account for nearly 70% of most crane-related fatalities within the construction industry [41].
as compared to tower cranes, which operate within a stationary position. This is because the use of mobile telescopic cranes necessitates it to move across sections of the construction site to enable it to perform its lifting operations during the build process—e.g., the lifting and installation of OSM wall panels, floor cassettes, and roof trusses and the lifting of other materials required for the build phase towards improving the speed of the build. To maximize site efficiency and safety, adequate planning and scheduling processes of the mobile crane’s onsite movement and lifting operations would require enhanced supervision and monitoring, which would directly have an impact on the safety and productivity of the workforce. That means there should be a lifting plan that is suitable and sufficient for the work being carried out by an experienced crane operator and banksmen, as prescribed by the UK Lifting Operations and Lifting Equipment Regulations (LOLER) 1998 and the Provision and Use of Work Equipment Regulations (PUWER) 1998.

This study, through direct observation, evaluated the adoption of an OSM timber kit through an actual site trial using a telescopic crane to lift OSM panels into place during the construction phase. To assess the impact of the OSM timber kit’s efficiency and safety, the study evaluated aspects of build efficiency related to the shell completion of the houses using pre-fabricated wall panels, finished floor cassettes erected using the telescopic crane without the need for a working platform, early ground roof assembly lifted to final place, and the OSH benefits through the prevention of manual handling and mitigating of other issues that could result in musculoskeletal disorders.

1.2. Emerging Challenges/Opportunities

This study, which is underpinned by site observation/monitoring and emerging scenario findings, provides insight into where OSM efficiency and safety opportunities lie. The house builder identified that research was required to investigate a wider sample and consolidate the findings from multiple house plots and locations that could present results capable of allowing constructive workforce engagement between tradesmen, subcontractors, and in-house teams as one of their improvement strategies for commercial optimization. The direct observation on site offered the researcher the opportunity to study the engagement strategy between trades and sub-contractors towards unlocking benefits beyond the current mind-set of traditional building, which is one of the requirements of the Construction (Design and Management) Regulations 2015 for the construction phase. From the site safety perspective, there are advantages for adopting the use of the telescopic crane for the OSM timber kit build construction—e.g., avoiding the need to work at height and preventing the exposure of workers to falls from height. Although the implementation of telescopic cranes for lifting purposes is considered safe, there are other underlying risk profiles and safety measures that need to be in place to manage and control hazards within the site. Therefore, the use of the telescopic crane to erect the OSM timber kit homes brought in new risks, such as crane lifting/plant control, the management and coordination of new kit erect working practices, and also some positive behavioral changes and work co-ordination associated with lift days [42]. Other important features include a reduction in temporary works—e.g., scaffold adaptations.

To ensure a construction readiness plan was firmly in place for the potential shift to OSM timber kit using a telescopic crane for erection, an evaluation of the readiness and implementation plan was required. Risk assessment and method statements were reviewed and revised to account for any new changes or obsolete hazards introduced in accordance with the UK Management of Health and Safety at Work Regulations 1999, which explicitly makes clear the employers’ responsibilities in terms of managing health and safety under the Health and Safety at Work Act 1974. This is required to be in place and is applied to every work activity. The management of lifts using the telescopic crane required adequate planning to conform with industry guidance and approved code of practices (ACoP) and protocols in line with Lifting Operations and Lifting Equipment Regulations 1998, which places duties on people and companies who own, operate, or have control over lifting equipment. The requirement is that all equipment used for lifting must be fit for purpose; suitable for the task; appropriately marked; and, in many cases, subject to statutory periodic thorough inspection. Work activities that are covered
by Lifting Operations and Lifting Equipment Regulations 1998 are also guided by the Provision and Use of Work Equipment Regulations 1998 (PUWER), including inspection and maintenance. It is therefore of paramount importance that the lifting operations that involve lifting equipment are properly planned by a competent person, effectively supervised, and conducted in a safe manner.

1.3. Study Rationale

This study investigated a UK house builder and their quest to change construction practices and improve efficiency, performance, and safety practices through the implementation of mobile telescopic cranes for the construction of OSM timber kit shells, including the lifting of the roofs onto the decks and other downstream site process delivery. To achieve this, the study focused on the following:

1. Assessing the workforce (supervisory to senior manager level) potential uptake of telescopic crane erection methodology using the Balanced Score Card (BSC) for decision-making.
2. Evaluating process efficiency and site OSH and their impact on productivity.
3. Investigating the OSM timber kit with crane-erect technological shift and any disruption to the established relationships with various trades.
4. Appraising housekeeping and material management due to downstream site process delivery and impact on efficiency.

2. Materials and Methods

This emergent case study research which is needed to understand real-world scenarios [43,44] required the on-site physical presence of the researcher and for the researcher to be integrated within the workplace and with the workers. The researcher was responsible for liaising with the principal contractor and contractors for on-site strategy involving direct observation and site monitoring, informal non-structured interactions, and the examination of on-site activities to address the issues under study; see Figure 2. The approach involved the direct non-participant observation of workers, which is a qualitative data gathering technique in their work environment, revealing insights such as structures, processes, and behaviors [45–47]. This form of systematic observation approach tends to reveal a lot more information by providing insight into the complex nature of on-site practices. The case study direct observation approach was adopted from the inception of the research design to facilitate an observation data collection strategy. Such an approach has been used in organizational studies to improve practice—for example, managing the technological innovation and processes of Swedish building component manufacturers [48]. The adopted methodology focused on structured site observation and the monitoring and evaluation of site efficiency and the safety of site-specific tasks being undertaken by the tradesmen, such as the joinery and roof work (see Figure 3) and tasks involving the operation of the telescopic crane by the operator and banksman. The house builder initiated the Balanced Score Card (BSC) decision-making strategy to evaluate 30 workers’ (supervisory to senior manager level) perceptions of the benefits and downsides of the OSM timber kit using the telescopic crane for construction. The adoption of the BCS by the house builder to assess workers’ views is a simple performance evaluation system and a strategic management decision-making tool useful for clarifying and translating the organization’s mission, strategy, communication, and learning [29,30]. The work of Benkova, et al. [49] also identified the significant relationship for organizations adopting a BSC methodology and non-financial indicators, and the approach adopted for this research was useful in satisfying the managements’ requirements for organizational decision-making towards enhancing their corporate practice. The implementation of the telescopic crane construction further strengthened the house builders’ business case in terms of value creation and as a form of competitive advantage. The on-site data gathering process involved observing individual work packages, monitoring and recording the workflow, on-site interaction with frontline workers, and observing the behaviors and perceptions of site operatives regarding the acceptance of the telescopic crane for the construction phase.
This qualitative research design workflow (Figure 2) involved observing real-life on-site cases during the construction phase [46,50], with concurrent data gathering from multiple work packages—e.g., observing and taking field notes on the work packages and operatives undertaking their tasks [47]. The study also used qualitative audio-visual and digital tools (GoPro time-lapse camera with video capabilities) and unstructured, generally open-ended discussions with workers and managers to elicit views and opinions from the workforce [47,50]. The data gathering focused on multiple house types with different dimensions and designs within a new housing development, where the same logic would be replicated or adopted in successive builds. The study therefore required the researcher to holistically collaborate but without interfering with site operatives in the observation of their labor efficiency regarding the build process of the OSM timber kit homes using a telescopic crane to erect the buildings. This is considered as an effective approach for developing solutions to on-site problems of efficiency and safety, and it is also beneficial for the principal contractor responsible for the housing projects. It was ethical for the researcher to lay aside their own values and judgments shaped by practice to allow the direct observation of frontline workers to inform the research by being mindful of and attentive to the system and situational dynamics. Therefore, maintaining the balance between drawing from those available resources and the researcher giving up their own belief to subjectively collect data and analyze the research information was essential. This case study development was useful in potentially informing the principal contractor about 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 efficiency, site safety, and productivity; minimize construction material waste; and build sustainable homes.

The data collection involved observing the system and situational dynamics of labor uptime to install the shell, including the timber kit erection labor and crane utilization for the different house types for 10 plots, whilst the manual handling issues involving plasterboards were observed for another nine plots and recorded with a post-observation summary of the work activities. This involved observing and recording the labor time of the joiners involved in the installation of the roof truss; the timber kit erect installation (Figure 3); and any extra labor assistance of apprentice joiners for the floor cassette and wall panels for house plots 43, 44, 45, 46, 48, and 50. The observation captured the uptime and downtime of the crane usage covering both the operator and the banksman as part of the contract hire agreement for house plots 36, 41, 42, 43, 44, 45, 46, 48, 49, and 50, sometimes using the GoPro time-lapse camera with video capabilities where possible for the different plots.
Figure 3. Joinery fix for wall panels and roof assembly on the ground.

3. Results & Discussion

3.1. Telescopic Crane Erect Methodology Using Sliding Scorecard

A set of 30 experienced workers (supervisory to the senior managerial level) were involved in assessing the potential benefits and disadvantages of adopting the OSM timber kit with telescopic crane erection methodology using a sliding scale balanced score card to satisfy the management’s requirements for strategic organizational decision-making; see Table 1. Aspects that were considered important by the management during decision-making [29,30] include focusing on client impact; health and safety; ease of build; business risk; associated cost; availability and consistency in the stream of highly skilled and trade workers capable of delivering the highest quality standards; the quality of build; the risk of disruptive weather changes; and supply chain management. The results from the balanced score card identified that clients are more likely to have fewer remedial issues such as settlement, shrinkage, and floor problems with the new build and the construction methods currently being adopted. The benefits of health and safety included a significant reduction in working at height and worker exposure to other forms of hazards; reduced manual handling, which was considered as a good indicator for preventing musculoskeletal disorder (MSD) issues; the minimal use of temporary works (scaffolds); and a tidier site with less material waste generation. The workers involved in the decision-making process considered the use of a telescopic crane for the construction and erection of the buildings to be of commercial benefit to the organization but regarded such a change as an expensive venture that could however lead to potential cost savings in the longer term [49], with low to moderate business risks involved. Quality issues and the ability to speedily and consistently build affordable, high-quality homes using high-quality construction materials very efficiently due to OSM was considered the best approach to deliver new homes that could offer an immediate to long-term solution to the housing crisis in Scotland. This not only reduces the timescale and cost of the build, but improves the overall quality. There was a general consensus that unpredictable weather patterns would have no major impact because the OSM panels are designed and manufactured with weatherproof and fire-resistant materials. Although there were significant time pressures that occurred due to adverse and unpredictable weather conditions, which drastically slowed or even stopped progress on site work, the houses were still completed and were wind- and watertight within a very short period (3 days) of time. The integration of the material and component supply chain and transport and logistics with the workflow could have worked more efficiently if large volumes of bespoke standard items which were ordered leveraged on holistic and effective collaboration. Overall, the three factors considered to have significantly improved the use of telescopic crane for the construction phase based on the balanced score card were health and safety, the ease of building, and the quality of the build.
Table 1. Telescopic OSM kit erection study of workers using a balanced score card for decision-making.

<table>
<thead>
<tr>
<th>CRANE BUILD</th>
<th>Measure</th>
<th>Negative [-]</th>
<th>Positive [+1]</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client impact</td>
<td>Weak</td>
<td>10 9 8 7 6 5 4 3 2 1</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td>Strong</td>
</tr>
<tr>
<td>Health &amp; Safety</td>
<td>Poor</td>
<td></td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Ease of build</td>
<td>Difficult</td>
<td></td>
<td></td>
<td>Easy</td>
</tr>
<tr>
<td>Business risk</td>
<td>High</td>
<td></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Cost</td>
<td>Costly</td>
<td></td>
<td></td>
<td>Cheap</td>
</tr>
<tr>
<td>Skills/Trades readiness</td>
<td>Scarce</td>
<td></td>
<td></td>
<td>Plenty</td>
</tr>
<tr>
<td>Quality</td>
<td>Poor</td>
<td></td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Weather risk</td>
<td>Poor</td>
<td></td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Supply Chain</td>
<td>Not set</td>
<td></td>
<td></td>
<td>Set</td>
</tr>
</tbody>
</table>

3.2. Evaluating Process Efficiency and Site OSH and Their Impact on Productivity

The use of a telescopic crane for the build process required adequate planning for on-site access, and the planning of the crane hard standing position was situated away from the job site access road and pedestrian walkway to avoid disruptions for other plants and tradesmen, as this could potentially lead to the loss and delay of the work program [40,41]. The formation of roof trusses on this project took about two full working days to be completed, and this was very much dependent on the number of available joiners allocated to the task, their skills and experience, and the dimension of the roof trusses. To improve the process efficiency and for workers to deliver on the work scope scheduled for each working week, the OSM timber kit and roof trusses required for successive house plots should be delivered concurrently, the same as the offsite manufactured wall panels to speed-up reasonable work progress and maximize the site space, time, and speed in forming the trusses as part of the supplier selection process and the determination of material deliveries [51]. The strategy of integrating the delivery of the roof trusses and OSM timber kit panels together will facilitate and speed up the roof truss installation, thus making the houses wind- and watertight and precluding them from adverse weather risks. This can be achieved through the adequate process planning of the joinery work package so that the onsite formation of the roof trusses on the ground would have no direct negative impact on other work packages. The formation of the roof trusses on the ground however minimized the need for joiners to work at height, which thus mitigated the risk of falls from height and any other violations, such as working at height without adequate fall protection [52]. The findings indicate that the adoption of the OSM timber kit using a telescopic crane significantly addressed and reduced the workplace safety and health issues involving manual handling and the lifting of the wall panels, floor cassettes, and roof trusses into position. The use of telescopic crane erection fundamentally minimized the exposure times of operatives required to work at height, thus preventing the need for safety decking, alterations to scaffolds, and other work at height-related risks. Additionally, the procedures for scaffold adaptations were completed quicker and made safer by involving competent scaffolders during and after the lift processes, and all these improved the joinery efficiency and onsite safety through the implementation of the work at height hierarchy—i.e., avoidance [3,6].

However, managing process efficiency related to tasks involving the loading of thermal-insulated plasterboards to floor decks, moving and handling, and fitting windows and doors into place by two operatives showed a significant rise in manual handling. The manual loading by two operatives to the deck of the ground and first floor of the houses for joinery first fix exacerbated issues of manual handling, which could increase the likelihood of musculoskeletal disorders (MSDs), [53]. Two operatives manually lifted a minimum of 240 and a maximum of 515 sheets of plasterboards (24 kg per sheet) for the different house types. This amounts to a minimum lift of 5760 kg and a maximum lift of 12,360 kg of thermal-insulated plasterboards without any mechanical assistance; see Table 2. The Manual Handling Operations Regulations 1992 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 mechanized to eliminate the manual aspect of the handling. The loading of the thermal-insulated plasterboards to the floor decks of the houses slowed down the workflow and negatively impacted the process efficiency and the speed of installing the
fixtures and compromised safety practices, with the potential for musculoskeletal disorder cases [38,39]. This suggests that joint management systems [25] that are integrated with operational and safety management systems to potentially improve safety, process efficiency, and productivity were not adequately considered for the loading of the thermal-insulated plasterboards to the floor decks for installation. Based on the number of sheets and total weight of the thermal-insulated plasterboards lifted by two operatives, as shown in Figures 4 and 5, it can be inferred that adequate risk assessments regarding the perceived MSD risks and the vulnerabilities of the two workers were not considered. It is imperative to design-out such hazardous manual handling operations to prevent workers from manually moving and lifting large volumes of thermal-insulated plasterboards or adopt an automated or mechanized process with a suitable and sufficient risk assessment for such repetitive tasks.

### Table 2. Plasterboard handling per plot.

<table>
<thead>
<tr>
<th>House Plot</th>
<th>Size (Sq.ft)</th>
<th>No. Op(s)</th>
<th>Hrs/Op</th>
<th>Total Sheets</th>
<th>Min/Sheet</th>
<th>Total Man hr (Min)</th>
<th>Total Weight (Kg)</th>
<th>Weight (Kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>2250</td>
<td>2</td>
<td>2</td>
<td>240</td>
<td>1.00</td>
<td>240</td>
<td>5760</td>
<td>24.00</td>
</tr>
<tr>
<td>9</td>
<td>1721</td>
<td>2</td>
<td>3.75</td>
<td>375</td>
<td>1.20</td>
<td>450</td>
<td>9000</td>
<td>20.00</td>
</tr>
<tr>
<td>10</td>
<td>1901</td>
<td>2</td>
<td>2.5</td>
<td>275</td>
<td>1.09</td>
<td>300</td>
<td>6600</td>
<td>22.00</td>
</tr>
<tr>
<td>35</td>
<td>2250</td>
<td>1</td>
<td>10</td>
<td>515</td>
<td>1.17</td>
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</table>

Figure 4. Total plasterboard sheets and man hour (min) per plot.

Figure 5. Total weight of the plasterboards used per plot.
3.3. Investigating OSM with Crane-Erect Technological Shift and Any Disruption to the Established Relationships with Various Trades

The findings present emerging challenges and opportunities associated with the direct observation, monitoring, and informal non-structured interactions with operatives regarding on-site activities. The site trials of the OSM timber kit using a telescopic crane for construction established a positive stance for the house builder in terms of changing their build process from the traditional approach to using a telescopic crane for the lifting and erection of the OSM panels. The findings focused on labor efficiency based on the direct observation of joiners for six house plots, whilst the telescopic crane lifting systems for construction and erection focused on 10 house plots for the build phase. The gathering of information through the direct observation of onsite work packages recorded the labor and cycle time of the construction processes—e.g., the start and completion times of the individual joinery and lifting activities and the number of operatives involved in undertaking such activities. For work packages that concurrently took place onsite, the observation strategy adopted by the researcher was to directly observe specific plots for data gathering (see Table 3), while tasks taking place in other plots were documented using stationary GoPro time lapse video clips and photographic evidence for comparative purposes.

Table 3 shows the workers’ (joiners) productivity by house type determined by the effective floor area and the Gross Internal Area (GIA). The effective floor area is the usable area of the rooms within a building measured to the internal face of the walls of those rooms, whilst the Gross Internal Area is the area of a building measured to the internal face of the perimeter walls at each floor level—i.e., areas occupied by internal walls and partitions [54]. The appropriate dimension of the house type was a major determining factor related to the uptime (on average, 83%) and downtime (on average, 17%) of the workforce involved in the joinery work. However, house plot 45 significantly had a disproportionate longer uptime and downtime compared to the other plots of similar dimensions. The cause–effect relationship of the longer uptime and downtime was associated with the adverse weather conditions, which slowed the efficiency of the workforce during the kit erection process. The efficiency/m² per man hour was calculated based on the gross internal area divided by the total time in hours. The overall average efficiency (m²/man hour) for the six plots based on direct observations was 1.15; see Table 3. Thus, an average efficiency value of 1.15 was adopted as the baseline and benchmarked by the principal contractor as the average productivity value for the joinery work for individual house types.

### Table 3. Overall productivity of joiners by house type.

<table>
<thead>
<tr>
<th>Plots</th>
<th>GIA m²</th>
<th>FF Area m²</th>
<th>Uptime h</th>
<th>Downtime h</th>
<th>Total Time h</th>
<th>Efficiency m²/man h</th>
<th>Uptime %</th>
<th>Downtime %</th>
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<tr>
<td>48</td>
<td>177</td>
<td>102</td>
<td>110</td>
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<tr>
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<tr>
<td>43</td>
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<td>17.9</td>
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<tr>
<td>Ave</td>
<td>156</td>
<td>87.2</td>
<td>111.8</td>
<td>23.3</td>
<td>135.2</td>
<td>1.15</td>
<td>82.8</td>
<td>17.3</td>
</tr>
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</table>

Commercial construction sites are generally regarded as the most common locations where crane accidents often occur due to improper use and operational failures. Problems associated with crane instability—e.g., outrigger instability due to lack of extension, improper cribbing or mats, and setting up auxiliary counterweights—were duly inspected during operator set-up by the site supervisor. The telescopic crane was deployed for lifting operations for the ground- and first-floor wall panels, floor cassettes, and the already formed roof trusses. The lifting operation was properly planned by a competent person, appropriately supervised, carried out in a safe manner, and adopted a planned and detailed sequence using drawings supplied with the kit to minimize safety and health risks [6]. Therefore, common issues, such as the fatigue of the operators and the misuse and overloading of the crane, which can often lead to crane instability, were mitigated through planning and adequate
onsite supervision. The direct observation of efficiency for the timber kit erection and joinery fix relied on the same team of crane operator, banksman, and joiners for consistency because of their expertise, skill, and experience [5,19,26]. These played a significant role in how various workers/trades seamlessly worked together to minimize any form of disruptions on site. Therefore, the 10 plots that were directly observed which comprised of different house types had a consistent team responsible for the lifting operations and joinery fittings to achieve some form of uniformity in the recording and data gathering process. The direct observation recorded the time taken for the telescopic crane to lift and install the ground-floor wall panels and the lifting and installation of the first-floor cassettes and the first-floor wall panels. The lifting operations of the roof trusses already formed on ground and craned into position required the joiners to also complete the process of nailing and securing the roof within one working day. Other subsequent tasks, such as the nailing of the internal kit, fire stop, and the installation of external fixtures (fascia and soffits), were completed within three days, after which the building was wind and water tight. These planned work processes reduced the construction time; improved health and safety risks, such as working at height; minimized environmental impacts, such as construction material waste and the waste sent to landfill; and improved the overall efficiency [2,3,5,6].

The deployment of the telescopic crane for lifting operations indicated an overall uptime of 30.75 h for all the lifting operations for the 10 house plots and an overall downtime of 39.75 h, with house plot 36 having the highest recorded downtime (see Figure 6). The findings indicate that the total uptime of the telescopic crane was less than the total downtime for seven plots. Two plots (46 and 43) had a higher total uptime than total downtime, while only plot 50 recorded a comparable time for uptime and downtime for the telescopic crane utilization. This suggests a significant underutilization of the telescopic crane for lifting and erecting the OSM panels. The lack of widespread adoption of the telescopic crane for house building is partly linked to some complexities and uncertainties associated with its implementation and the inability of the site management team to adequately plan the work program to maximize the lifting operations, which could have increased the speed of the build and the number of houses built.

![Figure 6. Total crane usage per plot: Total Uptime(TU)/Downtime (TDT).](image)

3.4. Appraise Housekeeping and Material Management due to Downstream Site Process Delivery (Just-In-Time) and Impact on Efficiency

The delivery of plasterboards, windows, and doors to the designated material delivery point was performed by a 20-tonne commercial lorry. To maximize housekeeping and material management, the delivered materials were inspected by the site foreman to ensure that they matched the order details; that there were no signs of damage during transit; that the materials were fully wrapped,
protected, and placed on pallets and then stored in the designated storage area. The plasterboards, doors, and windows earmarked for the different house plots were transferred around the site using a forklift truck (FLT) to the designated house plots, as required by the joinery team. The effective coordination of material movement from the storage area to the required plots minimized the time required by the operatives to manually move the materials across the site and thus positively improved the joinery labor time per plot. This process also kept the entire site clear of obstructions and material waste and promoted a tidy workplace. However, the lack of daily/weekly workflow planner onsite indicated the ineffective planning and scheduling of some work packages by the site management team. Additionally, the uncoordinated delivery arrangement of the OSM timber kits with the supply chain management (haulage and stacking) and inclement weather conditions both had impacts on attaining an optimum usage of the telescopic crane for the OSM timber kit erection and construction. These factors led to some delays and disruptions, which snowballed some of the costs incurred on the project as opposed to the assumptions that the OSM timber kit with the use of a telescopic crane for the construction phase would potentially result in cost savings [2]. Well-coordinated supply chain management and structured site management [28], including housekeeping and material management due to downstream site processes, can potentially improve the labor efficiency and construction cycle time, and reduce the construction material wastage.

4. Conclusions

This study serves as a roadmap modelled after a typical house building site for a commercial residential house builder with keen interest in improving efficiency and onsite safety. It involved developing a site observation/monitoring action plan to undertake an assessment of the as-built practical developments of housing plots that adopted the OSM timber kit and telescopic mobile crane for the erection of wall panels, floors, and roofs before the commencement of joinery work. The study evaluated the onsite OSM timber kit construction readiness plan with build program and kit erect methodologies for detached, terraced, and semi-detached houses and how telescopic crane deployment can be optimized based on operational data. The balanced score card approach was a useful visualization of the overall holistic perception of the workers regarding adopting the OSM timber kit and telescopic crane erection for the housing development and the build processes. The scorecard was based on the workers’ judgements regarding rolling out the crane erection and construction methodology based on the strategic decision criteria. The direct onsite observation suggests that there should be a process of developing an engagement strategy between the site management team, tradesmen, and sub-contractors to harness the benefits of the holistic integration of the current telescopic crane build to improve efficiency, lower cost, and improve onsite safety. Although the adoption of the telescopic crane erection brought in new risks such as crane lifting, plant control, and the management and coordination of new timber kit construction working practices, there were also elements of positive behavioral changes amongst the workforce and work co-ordination associated with lifting activities. The reduced scaffolding alterations also improved the safety aspects of scaffold accidents and collapse, and the crane erection was considered generally safer, albeit the risk profile, hazards, and potential lost time events. It is important to have a functional safety control system in place to enable the site management to review the systems for any new risks and practices being created and to ensure the OSM timber kit safety readiness plan is fully developed and integrated within their site operations. Additionally, the significance of reviewing the actual development layout and the housing mix could offer a more pragmatic crane set-up to enable concurrent crane utilization on multiple house plots. This will improve the efficiency and uptime of the crane usage and speed up the number of builds and the program. The re-evaluation of the crane set-up for onsite lifting purposes can also mitigate manual handling of plasterboards, doors, and windows by the operatives. The crane can be deployed to load materials to specified floor decks, thus saving time, preventing manual handling and lifting accidents, and increasing the overall efficiency of workers. The adoption of larger wall panels with fewer joints, the maximization of the haulage capacity of materials delivered on site, and the use of
factory pre-fitted windows and doors can save time, improve the site process efficiency, and mitigate the risk of musculoskeletal disorders. Adequate planning around inclement weather conditions such as fog, ice, and high winds, which were some of the causal factors that contributed to delays and downtime in the crane lift activities, should be adequately considered in terms of overall productivity and efficiency. The significance of an adequate lifting plan cannot be underestimated, as a large number of accidents normally occur due to a lack of adequate pre-lift precautions, and this could come with economic consequences too. The planning measures adopted by the crane operator and banksman and the site supervisor are contributory factors that prevented accidents during the construction phase. The most obvious health and safety challenges with the house building construction project include manual handling, scaffold alterations/management, working at height, forklift movements, traffic management, and multiple material handling and management. The adoption of the telescopic crane for lifting operations therefore significantly reduced manual handling during the erection of the OSM timber kit wall panels and floor cassettes lifted into position; minimized working at height and the exposure time of workers; and resulted in a tidier site with less construction material waste. It is important that the management should invest more time and resources in strategically planning work packages (explicit daily/weekly scheduling) with contingencies to maximize efficiency and site safety. Although the management made strategic organizational decisions which focused on client impact, health and safety, ease of build, business risk, associated cost, availability and consistency in the stream of highly skilled and trade workers, the quality of build, the risk of disruptive weather changes, and supply chain management; not all of these strategic decisions achieved all the managerial projections. The theory substantiated the requirement to have a functional safety control system in place to enable the site management to review the systems for any new risks and practices being created and to ensure that the OSM timber kit safety readiness plan is developed and integrated within the site operations. The theory around best practice offered pragmatic guidance on crane set-up capable of enabling concurrent crane utilization on multiple house plots towards improving efficiency, the uptime of crane usage, and the speed of the build. The limitation of this study is its inability to observe concurrent work packages. This would have resulted in a broader and larger data set, which would have made the study more robust.

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