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Exploiting automated technologies for reduction of rework in construction housing supply chain

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Abstract

Housing has been experiencing significant rework within the supply chain. Rework has afflicted both cost and schedule of projects due to the complex environment, intricate activities and highly fragmented nature of housing supply chain. Housing supply chain generate immense data and share information with different parties, which contribute to multitude of countless challenges. As a result of rework, productivity and workflow of information in construction supply chain has been affected with a catalogue of problems for the past few decades. Automation in construction supply chain with novel technological and analytical strategies has aspired industry to improve the productivity and change the trajectory of traditional, manual and analogue way of processing. The aim of this study is to explore possible opportunities of employing new technologies and challenges involved in utilising automated technologies for minimising rework in housing supply chain. The research methodology is based on a review of literature to investigate automated technologies to eliminate rework in housing supply chain. A conceptual framework is proposed to determine the suitability of various technologies to fully automate housing supply chain and facilitate the reduction of rework in construction housing supply chain.

Keywords: Automated technologies; housing supply chain; offsite manufacturing; robots; AI; reduction of rework

1. Introduction

Construction housing supply chain is characterised by highly fragmented data, and has often been criticised for low productivity and poor practices and inability to deliver high-quality products [26,44,51]. The workflow of process and the adaptation of innovation have always been elusive and/or obsolete [20,44]. The quality of information and the precise interpretation significantly affects both costs and scheduling throughout housing supply chain. Yet, interaction among different players at key stages of construction process with a broad spectrum of information is poorly co-ordinated and not readily shared due to the complex nature of housing supply chain. Reports by both Egan [14] and Latham [35] indicated that, the fragmented construction supply chain has been affecting the level of productivity and performance and there is a need for innovation to improve the overall performance of construction building industry.

Rework is a chronic issue in housing supply chain, and has an adverse impact on the level of productivity of building in the UK [5,17,25,26,40,42,43]. However, despite the considerable plethora of research on construction industry [37, 40], there is a very limited evidence of research on the barriers of minimising rework in housing chain, particularly in the light of recent technologies advancement [7,17,26,28,45,53,63]. Reduction of rework among the subcontractors in housing supply chain, plays a crucial role in the quality, time and cost of the production process. In housing supply chain, there is scope for the sources of rework to be controlled and managed through automation to avoid repetitive

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mistakes and errors caused by humans. Given the context, the sources and impact of rework has always been an issue for key players and contributors in the housing supply chain. The aim of this study is to identify possible opportunities on how automation in housing supply chain can lead to elimination of rework. Potential approaches for minimisation of rework will be reviewed by exploring various technologies to facilitate automation of housing production processes. The study involves a two-stage process to develop a strategic framework for minimisation of rework in housing supply chain. The first stage of the literature review focus on various technologies such as artificial intelligence, off-site technologies used for industrialised housing, robotics, and, digital twin to address the problems of rework within housing supply chain. The second stage involves the development of a conceptual framework based on the outcome of the literature review to determine the suitability of technologies that can be used to address the root causes of rework in the housing supply chain.

2. Literature Review

The following sections discuss the complexity of housing supply chain, causes of rework in housing supply chain and technologies that can be utilised to eliminate rework.

2.1 The unique characteristics of UK housing supply chain

The heterogeneous characteristic of housing supply is embedded with highly fragmented and intricate activities. Generally, the UK construction industry, and particularly housing supply chain has a plethora of privately-owned companies. As a consequence, high level of fragmentation is driven by a significant number of micro businesses in the UK housing supply chain [4]. Almost 70% to 90% of jobs in housing supply chain are subcontracted to small and specialised firms, where 99% of firms are Small Medium Enterprise (SMEs), with an employment ratio of 2 to 5 people [4]. However, there has been less attention paid to the importance role of the supply chain given the high level of fragmentation associated with large number of subcontractors. This particular feature has contributed to the significant level of fragmentation and rework occurrence in housing supply chain.

2.2 Causes of rework

Fragmentation has been considered as one of the main causes of rework generation within housing supply chain. [62,63]. Traditionally, the root cause of rework in housing supply chain has been identified as a poor management of main contractor [62]. A literature review suggests that managerial aspects are one of the crucial factors that is contributing to rework [29,38,39,43,45,53]. Project characteristics have also been identified as another factor affecting the performance of housing supply chain’s coordination. These include; project duration, project costs, number of stories, building type and procurement methods [40]. One of the predominant factors that causes rework is human error which can occur due to lack of knowledge and mistakes [39,41,45]. However, many studies on rework have failed to precisely assess the impact of human’s underperformance and how to address the issue [28,53,45]. Two prominent causes of rework during production process have been suggested as; information flow among contract control and client’s unexpected changes [38][63]. The root causes of rework in construction housing supply chain from a review of literature [1,15,43,46,62] are summarised as follow: 1) Fragmentation and subcontracting; 2) Noncompliance with specification; 3) Unrealistic scheduling; 4) Untimely supply of materials; 5) Poor documentation; 6) Lack of clear instruction to workers; 7) Lack of skilled labour; and 8) Ineffective project management.

The exponential growth of technologies has created new avenues for automation in housing industry to optimise operation, minimises human errors and improves construction performance. Potential exists from utilising offsite manufacturing and partial application to fully robotically automated on-site fabrication process to eliminate rework and improve the productivity in construction industry [9].

2.3 Benefits of offsite manufacturing in housing

There are different terminologies used for industrialised construction in the literature, such as: off-site production (OSP) [39,49]; off-site manufacturing (OSM) [42]; prefab [57,58]; modern methods of construction (MMC) [54]

Fig. 1. The adaptation of industrialised housing hierarchy [19]

industrialised construction [36] and modular construction (Modular) [50]. A very simple hierarchical model was introduced to differentiate the level of industrialisation of construction works [19] as shown in Figure 1. Traditional construction is fully craft-based construction using workmanship in which all the processes happens at the site and involves *in situ* manufacturing and installation of prefabricated elements such as doors, windows, pipes, bricks, tiles, etc. On-site prefabrication is the assembly of building components *on-site which are then moved into position* (components such as timber framing, handmade roof trusses and façade units). As opposed to on-site prefabrication, the off-site prefabrication is *assembly of building components and then transporting them to site* and assembling in place such as air conditioning units or roof trusses. Pods are pre-assembled units such as such toilets or bathrooms manufactured off-site and then transported to site to connect them to other building elements. Complete modular encompasses fully finished units that form the complete structure and form a building [20]. However, manufactured modular housing has often been neglected, as construction industry has a tendency of being very slow to adopt and proceed with new advanced technologies.

Off-site technologies have enormous potential to reduce negative environmental impacts, increase re-use of recycling material [8,23,59], eliminating waste, minimising rework, reducing cost, and optimising the performance and the quality of construction projects [18,19,24,24]. There are countless advantages associated with manufactured housing over traditional construction method, such as higher precision, more energy efficient to operate and cost efficiency. This result in shortening the completion process of building with higher quality. One of the significant benefits of fully automated off-site manufacturing in construction projects is eliminating human errors (which results in rework generation) as well as preventing the adversity of site condition (i.e., weather, etc.) on the quality of the completed project. These aspects can significantly reduce rework and consequently prevent projects from cost and schedule overrun. It has been found that manufactured housing can save up to 20% of time compared to on-site construction in Hong Kong construction projects [27]. There are numerous indirect benefits associated with off-site prefabrication due to reduced site preliminary costs, reduced site congestion and earlier income generation for clients [19], [3]. [85]. In addition, it has been shown that off-site prefabrication can also reduce safety risks around 35% due to less site congestion and removing operatives from a dangerous site environment to a controlled factory environment with better working conditions [35, 23, 8].

A survey of the top 100 UK housing builders agreed that to attain high quality in utilising off-site prefabrication is the most crucial motivation [51]. Another study found that off-site prefabrication could reduce the need for many trades that are in short supply, thus, can eliminate necessary rework significantly within different supply chain [3]. However, capacity constraints in the supply chain, lack of technology awareness; cultural perception; lack of business process model; high initial investment costs; incompatibility and inflexibility of design are identified as the most challenging barriers for off-site manufacturing [7,19,21,37]. For instance, in Hong Kong the Provisional Construction Industry Coordination Board has noted that high initial investment remains a significant obstacle to the adaptation of off-site prefabrication techniques and to unleashing the full potential of cost savings [7,21]. [7][19][37] identified that the inflexibility of design was a major issue for off-site prefabrication due to the requirement of an early design freeze. The findings were supported [24,37] who argued that the main barriers of off-site prefabrication were cost, design incompatibility and flexibility issues. Logistics and transportation also have been seen as major impediments to the adaptation of off-site prefabrication [21,49].

2.4 The idea of Digital Twin

Digital Twin (DT) can help off-site prefabrication with inflexibility of design issues. A DT is a digital copy of a physical construction component in which by bridging the physical and the virtual world, data is transmitted seamlessly allowing the virtual copy to exist simultaneously with the physical component [68]. Construction is seen as a manufacturing process where DT can help to overcome the disadvantages of off-site manufacturing assembly, quality issues including design errors [65]. A fully robotically automated fabrication process in off-site manufacturing with the support of DT will enable digitised visualisation of a virtually replica of a physical subject in a factory floor to improve the quality issues and keep monitoring products' maintenance with installed chips. DT can help eliminate all modification needs, errors relating to design and human misprediction and detection. This will lead to a shorter lead-time, improve the quality of products, minimise rework and reduce costs in fully automated manufactured housing.

2.5 Robotics in construction

Housing supply chain consists of a defined set of sub-activities such as; handling, concreting, coating, measuring, and assembling in iterative stages. In construction sites, the degree of automation is relatively low, the final assembly of building components heavily rely on human. The most significant impact robotics systems have had on the housing construction has been on off-site fabrication, which involves using robots in a controlled environment. Housing characterised by highly fragmented tasks that has infinite opportunities for automation. The application of robotics is well advanced in manufacturing industry and continuously expanding into construction industry. The application of robotics in construction has been progressing well to reduce time and cost associated with operation, as robots have the potential to attain productivity in construction performance, and improve efficiency, safety, and quality [2]. Construction robots are classified into three types [55]: 1) teleoperated systems where robots are under human control 2) programmable construction machines, in which humans insert the specific programmed menu of function or provide the instruction of new function to robots, and 3) intelligent systems, in which fully autonomous robots accomplish required set of activities without human intervention. A plethora of research and development (R & D) in the utilisation of robotics in construction led to an extensive range of different application primarily on civil infrastructure and residential buildings, such as automation of road, concrete compaction, interior finishing and tunnel and bridge construction [2,10,22]. A few studies have been conducted to analyse productivity and cost of construction robots. It was noted that applying robotics for on-site surface finishing work, particularly for repetitive tasks can be plausible from the technical performance and economic perspective [11,60]. In a similar study, it was suggested that utilising robotics for straight forward and repetitive tasks in building construction is more economical than traditional methods [47]. Another study compared the level of productivity between robots to human in relations to time and cost, and demonstrated the significant improvement of productivity employing robots in building construction [64]. Other researchers [60],[66] examined the productivity improvement of concrete paving employing robotics for the operation, and the result was that the production rate improved 22% compare to traditional approaches [11,60].

2.6 Employing Artificial Intelligence for rework reduction

The prediction of rework in housing supply chain has always been determined using a trial and error process, which has a tendency of escalating the uncertainty of a project. Accurate prediction strategy for housing supply chain provides a remedy for the root causes of rework. The application of artificial intelligence (AI) in housing supply chain can improve the predictability of projects' outcome accurately, before construction take place [40,48]. This can address quality issues and detect human errors at the early stage of each task before proceeding into the next stage. AI can be used as a consultant to subcontractors in the housing supply chain for enhancing strategic decision making and to deploy the most optimised methods to eliminate rework and improve the quality of finished products in housing supply chain. AI can be also used to improve the performance of a fragmented housing supply chain embedded with a large number of subcontractors. However, there are obstacles to be considered. Understanding the real phenomena of AI and trust among subcontractors to deliver a project have been identified as a significant barrier over the past few decades in construction industry. Over the past few decades, number of prediction models including artificial neural networks (ANN) and Ant Colony Optimisation (ACO) have been developed for estimating and predicting construction wastes (including rework), based on regression analysis (RA), case-based reasoning (CBR), and support vector machine (SVM) [16,30,32,33,34]. However, there is limited evidence of research employing AI for elimination of rework in the housing supply chain.

3 Towards the development of a conceptual framework

Given the range of technological options and advances in automation, there is a need to determine the suitability of various technologies to fully automated housing supply chain and facilitate the reduction of rework. A conceptual framework is proposed initially to focus on the potential for automation in housing supply chain. The framework can identify technologies that are most suitable to address a particular problem or to optimise the performance of an activity, which can result in elimination of rework, and productivity improvement in housing supply chain (see table 1). For instance, one of the causes of rework in housing supply chain is human error [40,45], which can be addressed with support of robots. Another distinct example is unexpected design errors and changes as a consequence of unilateral client change [26,41,45]. This can be addressed with utilising offsite manufacturing to reduce errors and changes or employing AI to predict the possibility of error occurrence in early stage of design.

Table 1. The role of technologies to automate the characteristics of housing supply chain

	Requirement characteristics of housing supply chain	**Offsite prefabrication**	**AI**	**Robotics**	**Digital Twin**
Critical	Ability to rectify errors and mistakes	x	x	x	x
	Reduction of design errors and changes	x	x	x	x
	Effective communication		x	x	x
	Management of change	x	x	x	x
	Improvement of collaboration	x	x	x	
Core	Improvement of Transparency and trust		x		x
	Realistic scheduling	x	x		
	Reduction in reliance on skilled workforce	x	x	x	
	Effective document control and archiving		x	x	x

Co-ordination is extremely challenging due to the complex environment associated with production process. Some of the changes during the design and construction stages are inevitable due to errors, mistakes, untimely supply of material and unrealistic scheduling [61]. Automation has a capacity to address these issues as well as the catalogue of other challenges in the housing supply chain such as skills shortages, document control and archiving, collaboration, and defining appropriate construction methods to minimise the cost of changes, speed up the process, and improve productivity through digested platform can run for example with AI and robots. Automation can provide the most efficient way for an informed decision making to minimise the causes of rework.

Conclusion

Automated processes in the construction industry can improve the flow and accessibility of data. A fully automated process will facilitate the reduction of rework across different projects in housing supply chains. Technologies such as digital twin incorporated with off-site prefabrication can improve the quality of off-site manufacturing products in housing, reduce unintended errors and effectively monitor the maintenance of components over a period. Automation through visualisation model can help designers and engineers reduce the misinterpretation of data and improve collaboration and communication through digitised platform. Robots and AI can reduce design errors and changes and, improve the performance of projects, as demonstrated in other industries. Applying such technologies in housing supply chain can eliminate the unintended errors and mistakes and significantly reduce the occurrence of rework.

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