O'Gorman, T. C., Daniel, E. I. & Chinyio, E. (2023). The impact of an offsite production approach on mechanical and electrical projects: evidence from the UK. *Proceedings of the 31st Annual Conference of the International Group for Lean Construction (IGLC31),* 767–777. doi.org/10.24928/2023/0165

THE IMPACT OF AN OFFSITE PRODUCTION APPROACH ON MECHANICAL AND ELECTRICAL PROJECTS: EVIDENCE FROM THE UK

Tonisha Carys O'Gorman[1], Emmanuel Itodo Daniel[2], and Ezekiel Chinyio[3]

ABSTRACT

Previous studies have reviewed the impact of offsite production on the delivery of construction projects, however, there have been limited studies examining the specific impact of offsite on mechanical and electrical installations (M&E). Therefore, the aim of this study was to determine the impact of offsite production in the delivery of mechanical and electrical installations for construction projects. In this study, a mixed method was adopted, using quantitative data obtained through a questionnaire survey and qualitative data through case study interviews. In total, primary data was collected from 36 questionnaire responses, and 3 case studies that involved 12 in-depth interviews.

This study shows that offsite production has a positive impact on construction project performance indicators for M&E installations regarding factors such as time, quality, health and safety, sustainability, logistics, and collaboration. However, the study showed no general conclusion as to the cost saving impact of offsite construction on the outcomes of projects. Nevertheless, the study established that the offsite approach offers the client more confidence relating to cost certainty.

Recommendations from this study are that offsite production should be selected based on its impact on project performance indicators rather than cost alone. The study argued that the offsite production method should be explored as much as possible when maximal benefits are sought; however, it should not be utilised simply for the sake of it but on a case-by-case basis.

KEYWORDS

Offsite construction, prefabrication, assembly, modular construction, M&E installations.

INTRODUCTION

Offsite production is a modern method of construction (MMC), often referred to as 'prefabrication' 'pre-assembly' or 'modularisation'. It is the process of completing construction elements away from the physical site in a controlled facility; to achieve time, cost, quality, health, and safety efficiencies (Vurren, 2020). In recent years, offsite has increased interest due to increased utilisation of Building Information Modelling (BIM) (Farmer, 2016). According to Sherratt, Dowsett and Sherratt (2020), the current concerns of the Global Construction Industry are labour shortages and the demand for shorter construction programmes, heightening

[1] BSc Graduate, School of Arch. and Built Envir., Faculty of Sci. and Engrg., Univ. of Wolverhampton, Wolverhampton, UK, togsog@aol.com orcid.org/0000-0002-7176-9234.
[2] Sr. Lecturer in Constr. Mgmt., School of Arch. and Built Envir., Faculty of Sci. and Engrg., Univ. of Wolverhampton, Wolverhampton, UK, E.Daniel2@wlv.ac.uk, orcid.org/0000-0002-5675-1845
[3] Reader in Constr. Mgmt., School of Arch. and Built Envir., Faculty of Sci. and Engrg., Univ. of Wolverhampton, Wolverhampton, UK, E.Chinyio@wlv.ac.uk, orcid.org/0000-0001-8448-5671

the need for innovative modern construction methods such as offsite production. Offsite production can achieve material efficiency, reduce waste, reduce timescales on site, improve health and safety and reduce disruption to construction projects (Hough, 2019). The UK Construction industry is being pushed to modernise and innovate, with Farmer (2016) stating the industry-wide issues of low productivity, low margins, an ageing workforce and lack of research and design. Samarasinghe et al. (2019) claim the past decade has seen a growing trend towards the offsite production of M&E systems.

Extant literature shows a range of information about adopting offsite in the construction industry. Smith and Quale (2017) focus on the theory and practicality of offsite concerning the demand for housing. Court, Pasquire and Gibb (2009) observe offsite as a solution for the UK's health, safety, and productivity issues. Marte Gómez et al. (2021) note the effects of implementing offsite construction within the UK housing sector. Sutrisna, Ramnauth and Zaman (2020) highlight the competitive advantages and risks of offsite production on construction projects.

In contrast, there is less information on adopting offsite for M&E installations. Said (2015) discusses best practices for offsite production; however, the paper focuses solely on electrical installations. Korman and Lu (2012) research focuses on the link between M&E but with a specialisation on the improvement in BIM. Although M&E installations contribute 40-60% of the total construction costs (Guo, Wang, and Park, 2020), limited studies have explored the impact of offsite construction in delivering M&E projects. Given this, this study aims to identify the effects of the offsite process on time, quality, safety, and cost in M& E projects in the UK.

The key research question is: **What is the impact of offsite production in the delivery of mechanical and electrical installation aspects in projects?** With the following research objectives:

To review the current knowledge relating to the use of off-site production on the M&E sector.

To determine the impact of utilising offsite production, relating to project performance indicators and cost, on M&E projects.

To draw conclusions from the findings and provide a decision on the suitability of using offsite production in the M&E sector.

Findings from this study are that offsite production should be selected based on its impact on project performance indicators rather than cost alone. With the argument that the offsite production method should be explored as much as possible when benefits are achieved; however, it should not be utilised simply for the sake of it but on a case-by-case basis. This research will help organisations understand the effects of offsite approach construction on delivery and performance indicators in M&E projects.

LITERATURE REVIEW

INDUSTRY VIEW OF OFFSITE CONSTRUCTION

According to Agarwal, Sridhar and Chandrasekaran (2022), the construction industry is subject to change; projects can take up to 20% longer than programmed and cost 80% more than budgeted. Ren, Atout, and Jones (2008) research suggest that main contractors are the root cause of 62% of project delays, consultants 27% and clients 11%. Common issues include poor communication, incomplete drawings, and compressed programmes. Agur, Chipatpo and Thom (2015) describe how offsite construction can impact projects by improving productivity, collaboration, and skills.

The key reports relating to the UK Construction Industry are of Latham (1994), Egan (1998), Wolstenholme (2009) and Farmer (2016). The recommendations offered by these

reports are primarily the same: standardisation and offsite. The House of Lords (2016) also suggests that offsite production could be the solution that would help the UK Government achieve its 2025 targets of 33% reduction in construction cost, 50% reduction in programmes and 50% reduction in greenhouse gasses.

CURRENT KNOWLEDGE RELATING TO THE USE OF OFFSITE PRODUCTION IN M&E

Guo, Wang, and Park (2020) discuss how M&E installations contribute 40-60% of the total construction costs. Issues affecting the installation of these systems include interface with the other trades on-site and general issues facing the industry, such as dangerous weather conditions and quality control. Sands and Quale (2019) specify further problems with M&E installation, such as limited space, health and safety and demanding programmes. Guo, Wang, and Park (2020) continue with, for the reasons described above, M&E installations are increasingly taking an offsite approach to delivery. Wilson, Smith, and Deal (1998) summarise that all projects utilising an offsite system to M&E have benefited. However, this must be balanced with the drawbacks. According to Goulding and Pour (2019), low design standardisation reduces the uptake. Farmer (2016) believes reluctancy is due to clients being unwilling to finalise designs at an earlier stage, a crucial requirement of offsite production.

METHOD

The research method adopted for this study was a mixed-method approach including triangulation (Palinkas et al., 2015). A questionnaire was used to gain quantitative data, and a case study analysis was used to gather qualitative data. According to Breach (2009), case study analysis is instrumental in collating ideas and perceptions. This was applied to obtain further in-depth information on how offsite is adopted on live and completed M&E projects.

RESEARCH DESIGN

The study commenced with a literature review, which according to Naoum (2019) is to create a focus for the data collection. The research instrument utilised for the subsequent quantitative phase was an online questionnaire survey administered via 'Google Forms'., Naoum (2019) suggests that this method increases the number of responses. The questionnaire was designed to be short and engaging, with 13 number close-ended questions relating to findings from the literature review and research objectives. An example of a question was, "Off-site is more cost effective in comparison to traditional on-site delivery of M&E installations". Please indicate your opinion of the above statement by ticking the appropriate response".

However, an additional 5 number open-ended questions were included to connect to the findings from the interview. An example of one of these questions was "What recommendations would you have for someone considering off-site production for the M&E installations on their next project?".

Firstly, the questionnaire was piloted with three industry professionals before data collection; according to Fellows and Liu (2015), this ensures the questionnaire is easy to understand and provides the opportunity for amendments. Purposive sampling was applied in this study, given that a limited number of people are available in this research area (Palinkas et al., 2015). According to The UK offsite Hub and Building and Design, the number of offsite construction organisations in the UK is 228 number. Using a confidence level of 90% and a margin of error of 10%, a sample size of 53 was determined. The questionnaire received 36 responses, 68% of the sample size. The questionnaire was live from the 1st until the 31st of March 2021.

CASE STUDY ANALYSIS

Case studies give a complete picture by drawing on multiple sources of evidence. Knight and Ruddock (2008) suggested that case study analysis is relevant for construction-driven research as the industry is project-specific. Following Yin (2018) the decision was made to utilise multiple (3) case studies for this study and adopt the unit analysis of the interview. This was to understand the real-life adoption of offsite M&E and the opinions of those involved in these projects. The M&E organisation utilised for this study is a national sub-contractor with an offsite manufacturing facility in the UK.

A mixture of 12 project participants from roles that included: Quantity Surveyor, Project Manager, Planner and offsite representative were selected to undertake the interview. The participants were selected based on their experience and active involvement in the case study projects. The case studies and project participants interviewed were selected utilising justified sampling, the 3 projects were selected as they used offsite methods, were completed within the past 12 months and were of a M&E value of £1m or over.

Below is a summary of the case studies assessed as part of this research.

Case Study 1 (CS01) - This project was a £3m M&E installation in an educational building.

Case Study 2 (CS02) - This project was a £11m M&E install in a leisure facility.

Case Study 3 (CS03) - This project was a £2m M&E installation in an educational building.

The interviews were kept open, which created the flexibility to ask the interviewee for further details. Each interview was targeted to be 60 minutes long, utilising online video communication tools Microsoft Teams. Examples of questions asked during the interview are as follows: “What in your opinion are the benefits of utilising off-site on this project?”, “What in your opinion are the downfalls of off-site on this project?” and “What is your overall opinion of the use of off-site for M&E?”. Ethical approval was obtained before the data collection.

To manage the data analysis process, Creswell, and Poth’s (2018) five step process was applied throughout the data collection stage. Silverio-Fernandez, Renukapppa and Suresh (2019) suggest that this methodology creates a deeper understanding of the completed interviews and a more straightforward way of extracting themes. Steps 1 to 4 were applied: recording and transcribing each interview, reading, and reviewing each transcript and making notes of any emerging themes, colour coding to organise transcripts into segments and finally, creating a summary of responses related to themes and producing meaningful information. To maintain confidentiality, the approach adopted to code the case study interviews followed that of Daniel et al., (2018). The case studies are referred to as ‘CS01: P01’ where C is case, S is study P is a participant. Table I lists each participant's job role, experience, and case study involvement.

Table 1: Case Study Participants

	Participant Information			Case study involvement		
Participant Code	Job Role	Years' Experience	Employment	CS01	CS02	CS03
PC01	Project Manager	10	M&E Sub-Contractor	Y		
PC02	Planner	32	M&E Sub-Contractor		Y	Y
PC03	Quantity Surveyor	20	Offsite Manufacturer		Y	Y
PC04	Factory Manager	13	Offsite Manufacturer	Y	Y	Y
PC05	Commercial Manager	40	Offsite Manufacturer	Y	Y	Y
PC06	Project Manager	40	M&E Sub-Contractor			Y
PC07	Estimator	45	Offsite Manufacturer	Y	Y	Y
PC08	BIM Manager	25	Offsite Manufacturer	Y	Y	Y
PC09	Project Engineer	6	M&E Sub-Contractor			Y
PC010	Project Manager	20	M&E Sub-Contractor		Y	
PC011	Quantity Surveyor	6	M&E Sub-Contractor	Y		
PC012	Quantity Surveyor	4	M&E Sub-Contractor			Y

Miles and Huberman (1994) suggested that interviewing project participants should continue until saturation of answers was achieved. As no new themes or ideas were emerging within interviews 10 to 12, the project interviews concluded at this point.

The results from completed questionnaires and case study interviews are presented and discussed in the next section.

RESULTS AND DISCUSSION

This section presented and discussed the results of the data collected from both the questionnaires and the interviews.

RESPONDENT BACKGROUND

The 36 respondents to the questionnaire consisted of '22.2% Project Managers', '22.2% Engineers', '22.2% Quantity Surveyors', '8.3% Commercial Managers', '5.6% Planners', '2.8% Academics', '2.8% BIM Managers', '2.8% Estimators', '2.8% Factory Managers' and '2.8%

Team Leaders'. The results also showed that the respondents have varied backgrounds, are employed by different organisations, and have experience working in various sectors. 61.2% of the respondents had over ten years of experience, 89% had worked on projects utilising offsite construction for construction elements of the build, and 86% had experience working on projects using offsite for the M&E aspects of the build.

Like the questionnaire, the case study interview participants were of the same roles and level of experience. This shows that the projects and participants had sufficient knowledge, breadth and experience relating to M&E works and offsite construction; therefore, they were qualified in relation to this research.

THE IMPACT OF OFFSITE PRODUCTION ON M&E INSTALLATIONS

To understand the impact of offsite production in M&E installation, questionnaire respondents were asked to respond using the five-point Likert scale. The results of the analysis are presented in Figure 1. In summary, the questionnaire concludes that most respondents believe that offsite production has a positive on the project performance indicators listed concerning M&E installations.

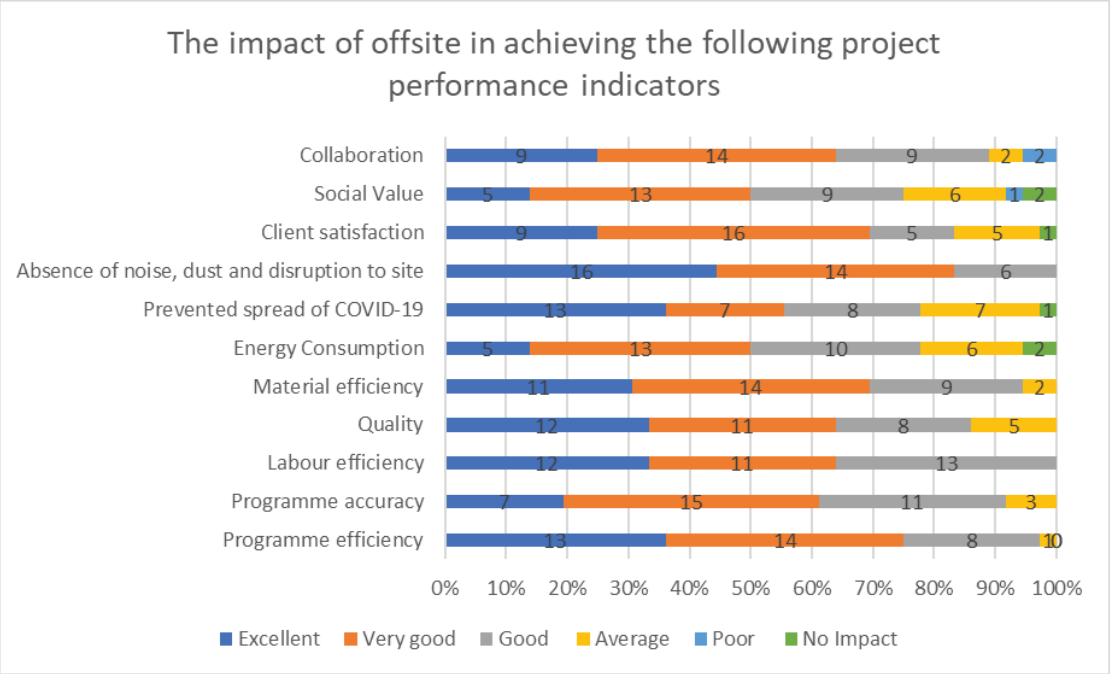

Figure 1: The impact of offsite production in achieving project performance indicators.

The findings from the 12 interviews were grouped into six sections and compared with the questionnaire and literature findings.

TIME

P01 described the impact of offsite on CS01 as saving "6,000-man hours on site and installation of the modules were four times quicker than traditional". The interviews also found that the utilisation of offsite can lead to elements of the installations being completed concurrently with on-site works such as demolition, resulting in M&E installations being able to start on-site later to achieve the same completion date. This creates programme certainty as elements of the programme subject to delay have been removed from the site. Similar findings have been shown in the questionnaire, whereby 97% of respondents believed that offsite has a good or above impact on programme efficiency and 92% respectively relating to programme accuracy. The results found in this investigation are like those of other researchers. Smith and Quale (2017)

describe how offsite production can reduce time on site, and Farmer (2016) discusses how offsite can improve labour productivity.

Quality

P09 describes how offsite can achieve better levels of quality, "It is easier to build in a factory compared to onsite". The interviews also found that offsite can improve M&E installations' quality through works being completed in a more controlled environment, with quality control checks such as witness, and pressure testing being conducted to the system before delivery to the site. P02 adds, "Offsite production also limits the systems, such as modules and risers, exposure to other trades, reducing damage to the works". The interview findings are comparable to the questionnaire result; 86% of respondents agreed that offsite production positively impacts the quality of M&E installations. This is in line with Sands and Quale (2017) description of how offsite can ensure that the right conditions for tasks are achieved, which leads to an improvement in quality. This is supported further by Farmer (2016) suggestion that offsite production is a more design focussed approach allowing a focus on quality.

Health & safety

The findings from the case study interview were that offsite production positively impacts a project's health and safety. P09 states that "a reduction in the amount of labour on-site reduces the accident frequency", P01 builds on this by saying, "offsite production reduces the spread of transmissible illnesses such as COVID-19". The achievement a higher standard of health and safety could be attributed to offsite works being completed in a controlled facility. This is as offsite enables containment, pipework, and wiring to be completed at a work-bench level compared to ceiling level, eliminating the need for access equipment, and reducing the potential of falls from height. Hot works such as soldering and welding can be completed offsite, reducing risks to other trades. This is supported by Court, Pasquire and Gibb (2008), in which it is detailed how prefabricating M&E modules create the need for mechanical lifting to position these modules, reducing manual handling and the risk of injury. This is additionally supported by Fraser et al. (2015) suggestion that by moving a proportion of the site installation works to a lower risk environment, the project injury rate would reduce.

Sustainability

The interviews highlighted that an offsite facility could achieve sustainability better than on-site, P09 details how "the facility has the resources available to implement re-use of materials which may have been over-ordered and create clear segregation of waste promoting recycling". This is supported by Farmer (2016) suggestion that offsite creates standardisation therefore reducing material waste. Additionally, 75.5% of the questionnaire respondents agreed that offsite positively impacts sustainability. Oakley (2017) found that offsite production can reduce CO2 tonnes and reduce material wastage.

Logistics

P02 details how offsite construction was necessary for CS03 as "location of the site was in a built-up area with limited parking; therefore, would not be possible to complete construction of the packaged plantroom". P02 details how offsite construction was also necessary for CS02: "The site was located in a busy residential area, allocating a proportion of the work to an offsite factory reduces congestion in that area". This builds on findings from Farmer (2016), showing that a reduced on-site programme positively impacts noise, air, and traffic pollution, which usually affects the neighboring residents to construction sites.

COLLABORATION

Surprisingly, collaboration was not discovered in the literature review, this being a sub-theme developed from this research. CS01:P08 described how a "traditional approach to M&E installations lends itself to becoming packaged into sub-contract elements. This is in contrasts to an offsite approach which encourages more collaboration allowing parties to discuss elements of the design which may not have been considered previously until site install. This is in line with the questionnaire findings, where 88% of respondents believed that offsite has a positive impact.

THE COST IMPACT OF APPLYING OFFSITE PRODUCTION ON M&E INSTALLATIONS

The questionnaire respondents were asked why offsite production may be more expensive compared to a traditional installation. The four themes developed were design, offsite facility costs, logistics and additional materials.

The responses received have been built on through the interview responses. Like questionnaire findings, P01 details how "BIM and logistics costs are increased compared to a traditional install". P08 adds that material costs increase in an offsite build as "everything offsite is to be enclosed within a steel frame; this adds additional expense". Other findings from the case study interview were that transportation costs increased as materials must be delivered first to the offsite facility and then delivered to the site in their refined form. Additionally, heavy equipment will be required for lifting and positioning on-site. According to Court, Pasquire and Gibb, 2008), lifting and transportation increase offsite costs. The current study identified other costs associated with offsites, such as frame costs, storage, and coordination costs.

The overall impact of offsite on cost

To conclude on the overall impact on cost, the questionnaire respondents were asked to indicate their opinion on the following statement, "Offsite is more cost-effective in comparison to traditional on-site delivery of M&E installations". The majority (47%) of people believe offsite production has a neutral impact on the cost of M&E installations. The second highest response (33%) was that offsite is more cost-effective. This differs slightly from the findings from the case study interview. The overall opinion of the interviewees is that offsite production is either cost neutral or more expensive compared to a traditional approach. This suggests that there is no explicit agreement that offsite creates cost savings. Within the literature review Court, Pasquire and Gibb (2008), Wilson, Smith, and Deal (1998) and Dicks (2002) all suggest that offsite production can offer cost or time-related cost savings. This research suggests slightly different findings, that offsite can be but is not always the most cost-effective approach. This implies that an offsite method is not selected based on cost alone but factors such as labour efficiencies and reduced programme.

The questionnaire respondents were asked about the most essential cost-benefit of offsite production to further understand the reasons for cost savings. 42% of the respondents believed that this benefit was through achieving labour efficiencies and 31% by reducing time-related costs. This mirrors that of Dicks (2002) view that offsite reduced time-related expenses and Court, Pasquire, and Gibb's (2008) suggestion that offsite production reduces labour losses. The remaining 27% of responses were cost certainty, reduced defects, reduced time-related penalties, and reduced life cycle costs.

The case study interview responses show a more detailed understanding of the cost benefits. P08 details how "cost savings can be achieved through an offsite approach by utilising out-of-town low-skilled workforce. This can be compared to a skilled pipefitter from London compared to an out-of-town facility". P02 uses the example of CS03 Packaged Plantroom to describe cost savings. "Modularisation may result in increased costs to the M&E contractor in

the case of a plantroom as it includes cladding, concrete base, roof, flooring etc. However, overall savings can be seen on the project cost as a whole". P05 says that "offsite may be a more expensive approach when the assessment is first completed; however, the process involves considering aspects of the installation that is often not considered until construction, therefore reducing the overall build cost". Further findings from the interview were that the process of offsite construction includes a much more detailed analysis of costs which considers elements of the construction that may have previously been missed. This implies that offsite construction may improve the level of cost certainty.

CONCLUSIONS

This investigation aimed to explore offsite's impact in delivering M&E installation projects. To achieve the aim of this study, a mixed method was utilised. The study found that offsite production positively impacts the delivery of M&E projects, as demonstrated by the impact on project performance indicators such as time, quality, health and safety sustainability, logistics, and collaboration. However, in terms of cost impact, the respondents have no concession on this. The overall opinion of the interviewees is that offsite production is either cost neutral or more expensive compared to a traditional approach. However, this evidence does not align with a previous study by Pasquire and Gibb (2008). From the evidence gleaned from this study, it can be argued that there is no explicit agreement that offsite creates cost savings. Nevertheless, the study found that the detailed process associated with the offsite approach could give the client the confidence of cost certainty. Additionally, the study found that a more detailed understanding of offsite production's positive and negative implications on M&E installations is essential in costing it.

This study contributes to the future application of offsite production in the construction industry. First, the study has shown that offsite production should be selected based on its impact on project performance indicators rather than cost alone. The study argued that the offsite production method should be explored as much as possible when benefits are achieved; however, it should not be utilised simply for the sake of it but on a case-by-case basis

The limitations of this research were that there was not enough cost information available to compare a traditional and offsite approach based on these findings. Future studies should investigate a detailed cost comparison between offsite production and traditionally installed elements of either M&E or other installations within the build.

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