MODULAR ASSEMBLY IN HEALTHCARE CONSTRUCTION – A MECHANICAL AND ELECTRICAL CASE STUDY

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ABSTRACT

This paper presents findings as part of a research project to develop and implement a lean and agile construction system on a case study project. The objective of the research project for the sponsor company is to improve its projects site operations, making them safer for the worker, and improving efficiency and productivity. A principle output of the research is the development and use of an innovative method for assembling offsite, transporting and installing mechanical and electrical distribution modules. In total 196 modules were installed in 17 construction zones on the case study project and the results show that zero accidents occurred either onsite or offsite associated with this work; an 8.62% cost saving is achieved over an estimation of traditional methods (with an estimated productivity loss of 25% for traditional method site labour); a higher quality is achieved with less site rework; 93% less hours are required onsite for the S&P method (much fewer operatives onsite at risk of injury); and a shorter overall cycle-time is required to complete the work when compared to traditional methods.

This paper reports on the findings using IMMPREST software as a tool for assessing the benefits derived from the use of modular offsite assembly against what would otherwise have been traditional installation methods for this case study.

KEY WORDS

construction system, IMMPREST, health, safety, productivity

INTRODUCTION

This is a practical paper drawn from a collaborative research project (the research project) being undertaken at the Centre for Innovative Collaborative Engineering at Loughborough University, UK. The programme is funded by the Engineering and Physical Sciences Research Council (EPSRC) and is sponsored by a major UK mechanical and electrical contractor (the company). The research project has specific objectives, which will be capable of making a significant contribution to the performance of the sponsor company.

The company is developing a construction system in order to improve the performance of its projects, and earlier research in this field (Court et al. 2005) has shown that lean interventions when applied to a case study project had positive results.

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The next phase of the research (Court et al. 2006, 2007), using leading edge research and learning, designed a lean and agile construction system which is to be implemented on a major private finance initiative (PFI) hospital development, and in particular the mechanical and electrical (M&E) elements within it (the case study project). This paper reports on the findings from the implementation of a component of the construction system, the offsite modular assembly of corridor mechanical and electrical distribution services using assembly, transportation and installation frames (ATIF's), described in Court et al. 2007. This case study uses using the IMMPREST[1] toolkit which Pasquire et al. (2005) describe as a tool for assessing the benefits derived from the use of modular offsite assembly against what would have been traditional installation methods. The benefits are classified into six categories and these are cost; time; quality; health and safety; sustainability and site benefits.

RESEARCH PROJECT OBJECTIVES

The objective of this project for the company is to improve site operations, making them safer for the worker and to improve productivity as a countermeasure to the prevailing conditions in UK construction and the company itself. Safety is at the core of the company and according to the business leaders *"…it is an absolute right for people to return home safely at the end of a productive day's work,"* and *"failure to do so renders the company valueless."* The key words here being *safely* and *productive,* these are therefore the key objectives of this research project, which is to design and implement a way of working on site, the countermeasures, that will satisfy these objectives.

THE CONSTRUCTION SYSTEM

The construction system is the methodology to deliver the objectives of the sponsor company and is represented in figure 1. Its underpinning theory incorporates manufacturing concepts such as modular assembly, postponement, reflective manufacture, pulse driven scheduling and ABC parts classification (Court et al. 2006). The system is designed with lean and agile concepts to specifically eliminate waste from M&E (and key interfacing trades) construction activities (the lean dimension). The agile dimension is designed to provide each trade team exactly what they want, when they want it and where they want it. These lean and agile attributes are designed to standardise the work, process and products to create flow, pull and value delivery. The ergonomic and workplace organization attributes are designed to specifically improve workers health, safety and productive output (Court et al. 2005). Its key components are its supply chain with a postponement function and its site operations. The supply chain component has been categorised using ABC parts classification with modules (type A) being delivered directly to site on a call-off system. Components and consumables (type B and C) being parts kitted or replenished for delivery to site via the postponement function also on a call-off system and to the exact requirements for the site

[1] Interactive Model for Measuring Preassembly and Standardisation in construction.

operations. The kits are to be postponed until the moment they are needed. Site operations are conducted by trade teams (T1, T2 etc.) using mobile work cells and ergonomic access equipment (Court et al. 2005). The system operates using a pulse-driven system which has been called the week-beat.

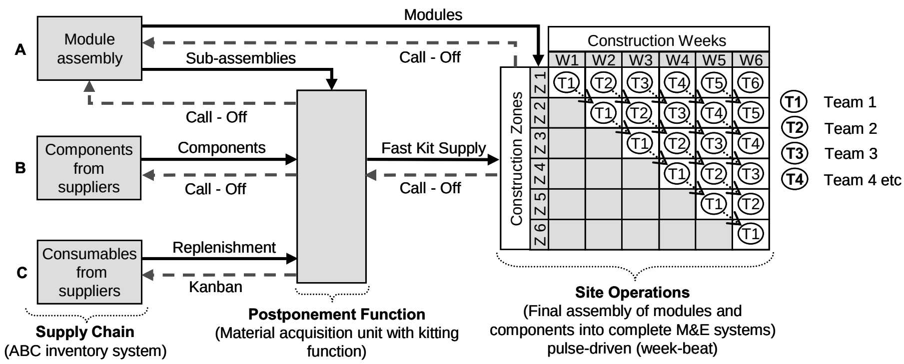

Figure 1: The construction system (from Court et al. 2007).

As described, the construction system has been specifically designed as a set of countermeasures to overcome the historically poor health, safety and productivity issues facing the construction industry today. The Health and Safety Executive (HSE 2007), report that in the last 25 years over 2,800 people have died from injuries they received as a result of construction work, with many more injured or made ill. Further research (HSE 2007a) has identified that construction has the highest rate of musculoskeletal disorders (MSD's). These are mostly back injuries from manual handling. In their research into MSD's, the HSE (2007b) have indentified areas that create risk, which include; repetitive and heavy lifting; bending and twisting; repeating an action too frequently; uncomfortable working position; exerting too much force; working too long without breaks; adverse working environment; psychosocial factors (e.g. high job demands, time pressures and lack of control); not receiving and acting upon reports of symptoms quickly enough.

Considering other health and safety factors, occupational health has been ignored in favour of the more immediate, high impact occupational safety (Gibb 2006). Gibb argues that occupational health incidents are to be considered as "slow accidents" – the period over which the incident occurs may be lengthy and may creep up on you unawares. Gibb's keynote paper reports that in the UK 4,500 construction workers are absent from work every day because of injuries caused by accidents, but there are 11,000 construction workers off sick at any one time with a work-related illness. Research conducted for its better backs campaign, the Health and Safety Executive (HSE 2000) found that a change to prefabricated modules for mechanical and electrical works and the use of mechanical aids to lift them significantly reduced the risk of manual handling injury. This enabled employees to maintain an improved posture when connecting and testing the units.

An investigative study by the Building Services Research and Information Association (BSRIA) set a foundation for understanding the problems and issues that the UK M&E industry faces within the construction sector (Hawkins 1997). Significantly, the UK projects monitored had an average overall productivity of only 37% when compared to observed best practice and an average task productivity of only 56% by comparison. Subsequent research conducted by BSRIA (Hawkins 2002) concluded that UK construction project teams that implemented improvement strategies and actions in accordance with the BSRIA best practice recommendations have realised significant improvements in site productivity. The research found that teams that designed for high site productivity used innovative components and exploited offsite manufacture realised a step-change improvement in construction site productivity rates. Modular assembly is also a method recommended to overcome symbiotic crew relationships (Thomas et al. 2005). These relationships exist where the pace of a crew depends on the pace of a preceding crew and that the performance of crews with symbiotic relationships is shown to be consistently worse than when these relationships are not present. The ATIF's are a component of the construction system specifically designed as a countermeasure to overcome these construction issues that would otherwise occur on the case study project.

APPLICATION OF THE CONSTRUCTION SYSTEM

The construction system is being applied on each phase of a case study project the first being a new Maternity and Oncology Centre (Court et al. 2007). Earlier work for this research project has described how the parts to be used that form the complete M&E systems on the case study project were categorised using ABC parts classification, with type A being modules, type B being loose components and type C being consumables such as nuts, bolts, washers and the like. Described also was the research involved in setting the supply chain strategy. This is to pre-assemble as much as possible offsite (type A parts) to be delivered just-in-time and incorporated into the final assembled systems along with component kits (type B and C parts) in a series of small and simple tasks. In Court et al. 2007 it was described how the mechanical and electrical works (MEP1-5) and building fabric works (BFP 1-6) were sequenced within an agreed assembly process and within MEP1 a sub-process is the installation of corridor modules. This is shown in figure 2. These modules are made offsite at the companies manufacturing centre which has been producing modular M&E assemblies since the mid 1990's and has previously been the subject of research studies (Pasquire and Connolly 2002; Mawdesley and Long 2002; Pasquire and Connolly 2003). The authors believe that the contribution to research is how modularisation can be incorporated into a wider construction system in the same way that manufacturing has used this strategy. Also, by using an innovative method for assembling, transporting and installing corridor and riser modules elements of modularisation can be achieved with or without offsite manufacturing capability.

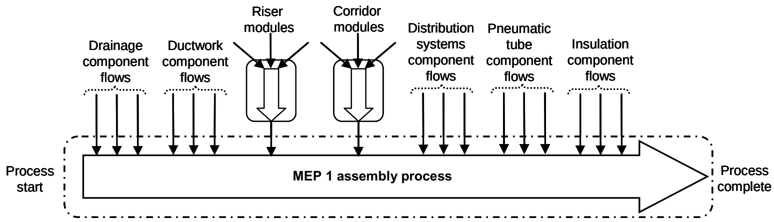

Figure 2: Mechanical and electrical process 1 (from Court et al. 2007).

MEP 1 – Corridor Modules

The initial corridor module design used a rigid welded unistrut steel frame which contains the M&E components within it. However, once the module has been installed, most of the steel frame is redundant, therefore not adding value to the module other than during assembly and transportation from the place of manufacture (manufacturing centre). This adds cost to the module, which has been seen as a barrier to offsite manufacture (Goodier and Gibb 2005). To overcome this, an assembly, transportation and installation frame (ATIF) was conceived. Here modules are assembled in the manufacturing centre, transported to site, incorporated into the building using mechanical hoists with the ATIF returning to the manufacturing centre for re-use. Figure 3 demonstrates digital prototypes of three stages of this sub-process. The modules when lifted on the ATIF are bolted to cast-in unistrut inserts running in tram-lines along corridor positions in the concrete soffit. This avoids the need for workers drilling for fixings into concrete, reducing the risk of injury from hand-arm vibration.

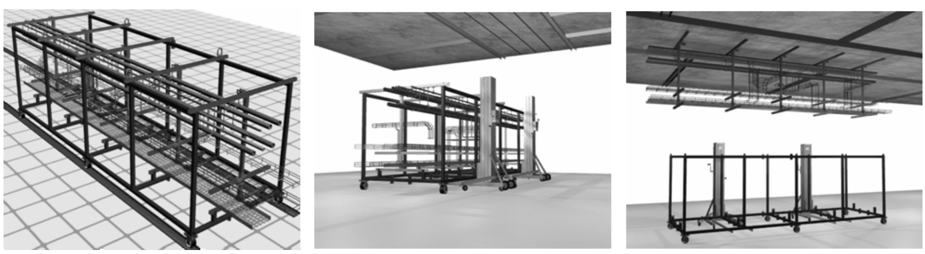

Figure 3: ATIF ready in manufacturing centre; onsite ready for elevation using mechanical lifting hoists; corridor module installed with ATIF to be returned to manufacturing centre for re-use.

The modules and ATIF's have been standardised during the design process, in that there are two corridor widths and two corridor ceiling void heights giving four size combinations. The ATIF is designed to accommodate each of these four sizes by being reconfigurable via removable or adaptable components. It is calculated that 40 ATIF's are required in the system and with 1,500 corridor modules required for the entire project, 1,460 welded frames are saved. Also the ATIF's can be re-used on other projects or their steelwork recycled for other uses. For the Maternity and Oncology phase of the project, a total of 196 ATIF corridor modules were used in 17 construction zones (average of 12 per zone). With each module being 6 metres long, this represents a total linear corridor length of 1.176 kilometres. Table 1 represents the total contents of all modules that would have been fitted onsite in a traditional manner had the modular method not been used. The planned onsite resource to elevate and install the modules is one pair of operatives from the duct fitting team. To connect modules together was also one pair of operatives from the composite pipework and electrical installation team.

Table 1: ATIF Statistics – Maternity and Oncology Building.

QUANTITY	COPPER AND STEEL PIPEWORK	VALVES AND FITTINGS	ELECTRICAL CONTAINMENT
196 ATIF's containing 980 pre-assembled brackets	7,762 metres, size range 15 – 108mm; associated thermal insulation	1,273 valves (isolation; commissioning; control valves etc.); 8,650 fittings (elbows; bends; reducers etc.)	5,139 metres basket tray, size range 100 – 300mm wide

RESULTS

This paper reports on the findings from this case study using the IMMPREST toolkit. Pasquire et al. (2005) describe the IMMPREST toolkit as a tool for assessing the benefits derived from the use of modular offsite assembly (hereafter known as S&P[1]) against what would have been traditional installation methods. The benefits are classified into six categories and these are cost; time; quality; health and safety; sustainability and site benefits. The traditional option described in the assessment is: site installation of corridor mechanical and electrical services using traditional methods (known hereafter as traditional) and the S&P option described is: modularising corridor services using the ATIF method.

COST BENEFIT SUMMARY

The IMMPREST detailed cost worksheet analyses benefits in three areas; construction/manufacturing costs, project costs and life-cycle costs. Overall, the detailed cost worksheets (construction/manufacturing and project costs together) show a benefit in favour of S&P of 8.62%. This is shown in table 2.

Basic material cost for S&P is higher due to offsite manufacturing centre overhead. This also includes an amortised cost allowance for the use of the ATIF frames, considered as an asset to the total project. Actual basic material cost for both methods is considered equal. Material waste for traditional is estimated higher than S&P due to increased probability of site wastage onsite. Traditional labour cost is estimated using installation times guide (Luckins 2003, 2004) using a bill of materials from the S&P manufacturing drawings. The Luckins times guide assumes average times under average conditions, installing

[1] S&P meaning standardisation and preassembly as an IMMPREST term.

good quality materials with good quality trained workmanship. No other site difficulty factors are included. S&P labour cost is actual cost and includes manufacturing centre overhead and the onsite cost to install modules and connect them together.

Productivity losses means a cost factor estimate of the productivity losses possible between the different methods, including weather, stoppages, damage, theft and interferences etc. The estimated cost of this has been assessed as 25% of traditional installation labour only to demonstrate this variable. As can be seen, the value of this variable provides the benefit assessed between the different methods. In other words, if estimated productivity losses for the traditional method were zero percent, then there would be no cost benefit of S&P; but this is unlikely in the opinion of the authors and according to previous research (Hawkins 1997). This measured average overall productivity as 37% on the UK projects monitored. Any actual cost for S&P loss of productivity is included in the S&P labour cost.

Table 2: Comparison of estimated traditional costs to actual S&P costs (values are £000's).

IMMPREST Items (by exception)	Traditional (estimated)	S&P (actual)
Basic materials	£197.09	£260.42
Material waste	£15.86	£3.96
Labour including supervision and testing	£273.67	£205.81
Productivity losses (25% of labour only)	£53.12	£0
Transport costs	Included	£44.84
Plant and access equipment	£40.80	£4.08
Rectification and rework	£10.62	£1.28
Design (assembly drawings)	£0	£19.80
Total	£591.16	£540.19
Variance traditional to S&P	£50.97 (8.62%)	

More plant and equipment is estimated for the traditional method and is required for each trade cycling through the site carrying out their work. Transport costs for traditional method is included in basic material costs, with much higher actual cost necessary for S&P. This is required to deliver the ATIF modules from the manufacturing centre to site; and then a back-haul cost to return ATIF's to the manufacturing centre for re-use. Assembly drawings are required for the S&P method for manufacturing purposes; these are not required for the traditional method.

The life-cycle summary did not show any significant benefit from S&P as the categories analysed were either similar or moderately better than a traditional approach.

TIME BENEFIT SUMMARY

The IMMPREST detailed time worksheet analyses benefits in two areas; offsite and pre-construction activities, and onsite activities. For offsite and pre-construction activities a zero percent benefit with moderate confidence is reported. This zero benefit is a result of equal durations for all pre-construction phases of the project. Whilst an additional week per construction zone is required for ATIF module assembly drawings driven from the 3D model, this is offset by the work required to produce paper-space drawing for a traditional onsite method. These would require time to add setting out and invert dimensions and the like. Further to this lead-in times for offsite manufacture of ATIF's is one week, as these are simple assembly processes of pre-made components into the assembly frame. Lead-in times to acquire site materials would also be one week.

For onsite activities, the summary shows a time benefit in favour of S&P with high confidence. Here, total site establishment is considered equal, as the start and end project date remains the same. A benefit is derived from shorter overall cycle-times to install ATIF modules versus the traditional method. The quantity of ATIF's per construction zone is 12 (average), and these are installed within the week beat allocation. With 17 construction zones, a 17 week overall cycle-time is required. Whilst the traditional method would utilise a week beat method, more onsite trades are required to cycle through each construction zone to complete their work, therefore taking longer. This has been estimated as follows: one week bracket assembly; three weeks pipe work assembly including one week testing; one week pipework insulation; and one week electrical containment installation. Overall cycle-time for the traditional method is five weeks, giving an overall cycle time for 17 construction zones of 22 weeks (using a week beat method). Finally, an additional week per construction zone is required to site test the traditional method, whereas the ATIF modules are tested offsite, this also provides a benefit.

QUALITY BENEFIT SUMMARY

The IMMPREST detailed quality worksheet analyses benefits in two areas; construction/manufacture quality and life-cycle quality. For construction/manufacture quality the assessment found that the project should benefit from an S&P approach with high confidence. The main drivers for this benefit (by exception) are; for category relating to the level of quality a significantly better grade of finish and degree of certainty of product quality was found. For the defects and damage category a significantly lower level of defects (failure to achieve the specifications, or damage to the product before final completion) was found. For customer requirements category; a significantly better visual appearance of the finished product and significantly lower level of customer / user complaints was found. The life-cycle summary did not show any significant benefit from S&P as the categories analysed were either similar or moderately better than a traditional approach.

HEALTH AND SAFETY BENEFIT SUMMARY

Firstly, there were zero accidents (minor or reportable) associated with this work, either onsite or offsite at the manufacturing centre. The IMMPREST detailed health and safety worksheet analyses benefits in two areas; construction/manufacture health and safety and life-cycle health and safety. For construction/manufacture health and safety it was found that the project should benefit from the S&P approach with high confidence. The biggest driver for improved health and safety with S&P is the fewer persons (H&S ratios category) required onsite to install and connect together the ATIF modules. In total S&P required 1,568 mans hours onsite, compared to 22,320 man hours estimated for traditional, all working at height (safety category – persons working in difficult or dangerous conditions). This equates to 93% less hours onsite using the S&P approach instead of the traditional. Finally, S&P has significantly lower housekeeping issues; the degree to which activity and process contributes to site waste and untidiness.

Life-cycle summary did not show any significant benefit from the S&P approach as the categories analysed were either similar or moderately better than a traditional approach.

SUSTAINABILITY BENEFIT SUMMARY

The IMMPREST detailed sustainability worksheet analyses benefits in two areas; sustainability issues and respect for people principles. For sustainability issues, the summary finds that the project may benefit from an S&P approach with high confidence. Most items are similar, for ecological impact and physical pollution; moderately better, for waste and materials; moderately lower, for energy consumption, water consumption and community pollution; and moderately higher, for transport. However, one item was significantly lower, and this was the general impact on the local community, the driver for this being the much reduced level of operatives required on site along with associated car parking in the adjacent residential areas due to limited or no car parking facilities onsite. For the respect for people principles, the assessment found that the project should benefit from S&P with high confidence. The main drivers for the benefit (by exception) are: for safety; a significantly lower risk of reportable accidents for S&P; for working hours (long working hours contribute to accidents, poor morale and efficiencies) and travelling time (travel time has an impact on staff morale, productivity and contributes to road traffic accidents which result in lost time), the assessment was significantly lower for S&P.

SITE BENEFIT SUMMARY

The IMMPREST detailed site benefits worksheet analyses site issues as constraints that are to be assessed as either high, low or none and these are; site space and storeage, multi-trade interfaces, skilled labour, access to site (including delivery), live working conditions, movement of units onsite and restrictions (on site work by external parties). The assessment found that all category constraints may be mitigated by S&P with high confidence. The main drivers for this are limited site space available for site storage of materials; a traditional method would require many interfacing trades onsite to undertake the work; shortage of skilled labour (Goodier and Gibb 2005); limited site access (live hospital environment); limited movement of vehicles onsite and restrictions on site work due to local constraints (car parking in adjacent neighbourhoods etc.).

CONCLUSIONS

The IMMPREST assessment undertaken has found that overall the use of ATIF's to modularise corridor mechanical and electrical distribution systems has benefitted the project with high confidence. The primary objective of this research project for the company is to improve site operations, making them safer for the worker, and improving efficiency and productivity. The results have shown that by using ATIF's to modularise corridor services; zero accidents occurred either onsite or offsite associated with this work; an 8.62% cost saving is achieved over an estimation of traditional methods (with an estimated productivity loss of 25% of traditional method site labour); a higher quality is achieved with less site rework; 93% less hours are required onsite for the S&P method (much fewer operatives onsite at risk of injury); a shorter overall cycle-time is required to complete the installation in 17 construction zones, 17 weeks versus 22 weeks (23% reduced cycle-time), with higher confidence in S&P.

The ATIF S&P method therefore has been shown to improve health, safety and productivity for onsite operatives, with much fewer being required, mitigating the further risk that the industry faces with shortage of skilled labour. Finally, cost certainty for this element is achieved because of the known actual offsite costs and much higher certainty of resultant onsite costs. A traditional method would not, in the opinion of the authors, achieve full productivity, therefore whatever productivity loss is estimated, a cost benefit will be achieved with an S&P method. If this method saves health and safety risks, costs less and takes less time, why would you not do it?

FURTHER RESEARCH

Further research is currently being conducted to finalise the implementation of the construction system on the case study project and to conduct analysis of the overall results, this being the final phase of research. The results emerging from this will be reported in future research papers.

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