PREFABRICATION FOR LEAN BUILDING SERVICES DISTRIBUTION

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ABSTRACT

This paper is concerned with the use of prefabrication for the distribution of building services (HVAC), concentrating mainly on the construction of office facilities. This is a good example of an application of lean construction methods. It assures reliable workflow and predictability in the project, it minimises waste and increases performance; it enables concurrent engineering to occur and delivers value throughout the project's life. An analysis of the use of off-site fabricated building services as a method of lean construction is given with reference to features of its use such as design freezes, Just-in-Time (JIT) deliveries and predictable processes. However, it requires different procurement processes to be totally effective.

The paper compares two procurement routes both theoretically and by the use of two real examples of construction projects. It illustrates some potential problems and shows that the solutions lie not in the technical aspects but in better communication and planning throughout the life of the project.

KEY WORDS

Prefabrication, Building Services, Lean Construction, Procurement

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INTRODUCTION

Lean construction is concerned with providing a better service for the client through consideration of the whole construction process. It has its roots in the concepts of lean production developed in Japan. As such, many construction practitioners may be sceptical of its applicability to their industry in the belief that construction is different. Manufacturers make parts that go into projects but the design and construction of unique and complex projects in highly uncertain environments under great time and schedule pressure is fundamentally different from making tin cans. (Howell 1999) Such a view can only be considered as partly true. Construction must be prepared to adopt those practices from manufacturing that are suitable and must be prepared to change old practices to enable this to happen.

Lean construction can be said to be predominantly about the minimization of waste. As such, most construction professionals would agree that it is a good and necessary thing. What they find more difficult to agree on is the definition of waste and the balance between the different types of waste. Lean construction takes the widest possible definition.

In the UK, the construction industry has spent a decade examining itself and has recognized areas where improvement is necessary and possible. These have been set out in two government-sponsored reports: the Latham report (Latham 1994) and more recently the Egan report (Egan 1998). Both of these have encouraged widespread discussion and together have been in the vanguard of a significant change in British construction.

Many of their ideas are coincident with those of lean construction in that they all aim to maximize performance for the customer at the project level.

In order to do this, it is necessary to broaden the traditional concentration on construction methods and consider the wider aspects of projects from inception to completion.

This paper takes two examples of projects procured in different ways and compares them against the objectives of lean construction. All of the projects were for the provision of multi-storey office blocks.

The first three sections of the paper set out the background under which the British construction industry works and how prefabrication of building services (HVAC) distribution is used. Following this, the two examples are laid out, compared and discussed. Finally conclusions are drawn.

PREFABRICATION OF BUILDING SERVICES (HVAC) DISTRIBUTION

Prefabrication offers the potential to achieve many of the goals of lean construction. It can reduce waste on site in terms of labour and materials; it can increase quality and reduce uncertainty. Unfortunately, it can also have the opposite effects.

Building services (HVAC) distribution in the UK are traditionally fabricated on site from elemental units fixed in place at the final site. Different trades often follow one another through the project fixing their own particular units in place. For example, a first gang of workers might fix the cable runs, followed a second gang fixing the water supply and a third fixing the air conditioning ducting. There could easily be as many as five different gangs with different skills and different resource requirements passing through all areas of a building. The potential for interference and waste is enormous.

When prefabrication is used, units containing all the service distribution elements are manufactured off-site in factory controlled conditions. The manufacture of the modules runs concurrently with the structural construction of the building and is timed such that the core of the building is complete and awaiting their delivery. In such situations it is envisaged that the building structure and the modules themselves are ready at the proposed time, thus allowing full benefits to be reaped from their use. If the structure or the modules are delivered later, or earlier, than expected, this causes substantial delays in the construction phase. Strict adherence to the programme thus ensures that risk is greatly reduced. Completed modules are transported to site and erected rapidly. The size of unit will depend on the project but a typical figure would be 6m x 2.5m x 1m.

Typical installations using the traditional and prefabricated approaches are shown in figure 1.

(a) (b)

Figure 1: (a) Traditional horizontal distribution of building services (b) Installed prefabricated horizontal distribution units

PROCUREMENT SYSTEMS AND BUILDING SERVICES

For the purpose of clarification, the authors identified two distinct procurement routes – 'traditional' and 'alternative'.

In practice, many projects are currently procured by a method somewhere in between the two described below. This is often typified by procurement methods such as *design and build* or *construction management*. Mawdesley (Mawdesley et al. 2001) gives more details on such intermediate procurement methods.

'TRADITIONAL' PROCUREMENT

In 'traditionally' procured construction projects, building services and structural design are not integrated. In most cases construction is well under way before any thought is given to the building services design; the design and construction of M&E services are, generally, overlapping processes. This results in problems associated all too often with building services, including:

- Insufficient planning
- Considerable waste
- Many visits by many trades
- Conflict in service paths

- Leading to greater health and safety risks
- Questions over maintenance and access issues.

A barchart for a typical project procured in the traditional manner has been developed (Long et al. 2001) and is shown in figure 2. This model is a stereotypical example of a traditionally procured construction project and is not intended to represent any specific project. It illustrates the major components of most traditionally procured projects and has been derived from a number of sources such as the work by the UK Construction Best Practice Programme (CBPP 1998) and agreed with a number of construction industry professionals.

In the 'traditional' approach, building services are not considered at the front-end of the project, thus resulting in work hastily being completed in difficult conditions; services distribution and installation are often unplanned processes. The team is fragmented, thus leading to dissatisfaction and waste in many areas. This is illustrated in figure 2 by the amount of design rework, number of alterations required, overlap between design work and construction and the limited communication between parties involved.

The amount of changes typically required in the 'traditional' approach makes it difficult to enforce a *design freeze* for the project. This is a major area for concern when employing off-site manufacturing.

The other main problem when employing off-site fabricated services on a 'traditionally' procured project is the late involvement of the building services consultants (designer and contractor). This limits the potential for making alterations to the project and can therefore reduce the benefits to be gained by their use.

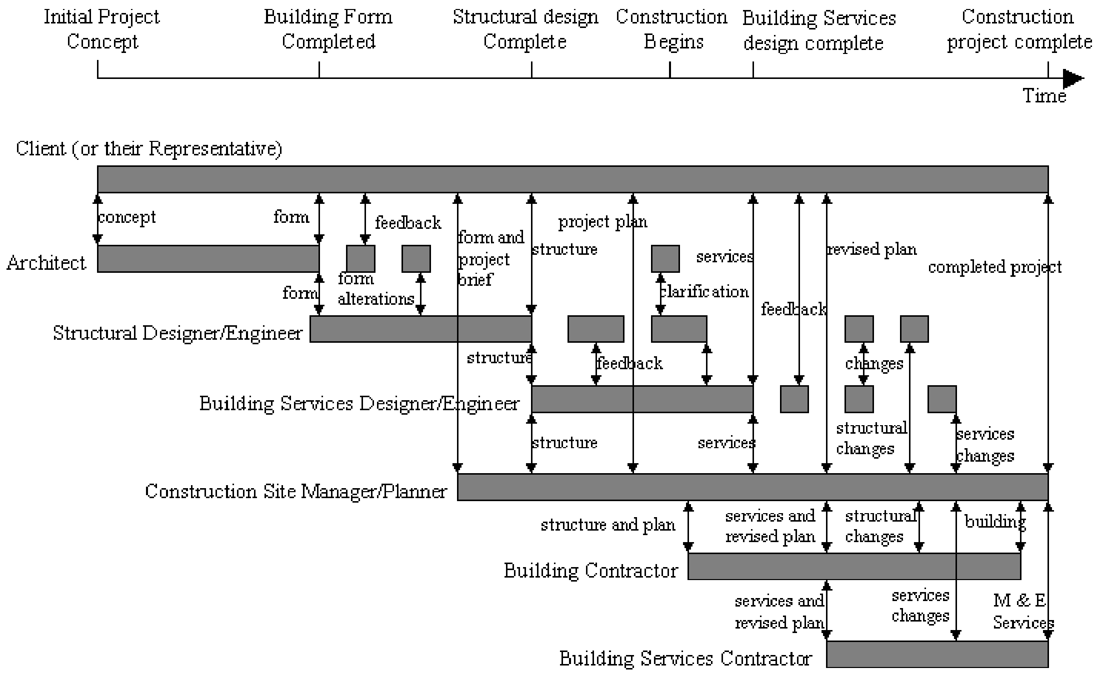

Figure 2: Typical project procured by 'traditional' route

'ALTERNATIVE' PROCUREMENT

The 'alternative' procurement method requires all parties to the construction process to be involved much earlier in the project. This is achieved by the formation of a project team that consists of members from all key stakeholders of the project with each member's influence given equal weighting. As such it is similar to many procurement methods currently used in the construction industry such as *strategic partnering*, *prime contracting* or *framework partnering*.

On 'alternative' projects using off-site manufactured services, there is input to the design from all involved parties from the beginning. This ensures that the necessary information for service module production is available, and manufacture can begin immediately that the design is completed. In practice it is rare for all of the information to be available; however, module manufacturers are making their needs known to the rest of the project team through education. This approach aims to make the 'alternative' model of procurement the standard method used.

A suggested barchart for a typical project procured in the 'alternative' manner is shown in figure 3. This model is a simplification for illustration purposes and to highlight important features relating such as the removal of post-phase changes and design rework along with an increase in initial design time due to increased interaction between parties involved. The reductions in construction time more than make up for the increased design time providing the project is managed effectively.

It was produced using the same method as the previous model (figure 2) in collaboration with industry design consultants with experience on projects involving the use of this type of procurement and off-site manufacture of building services components.

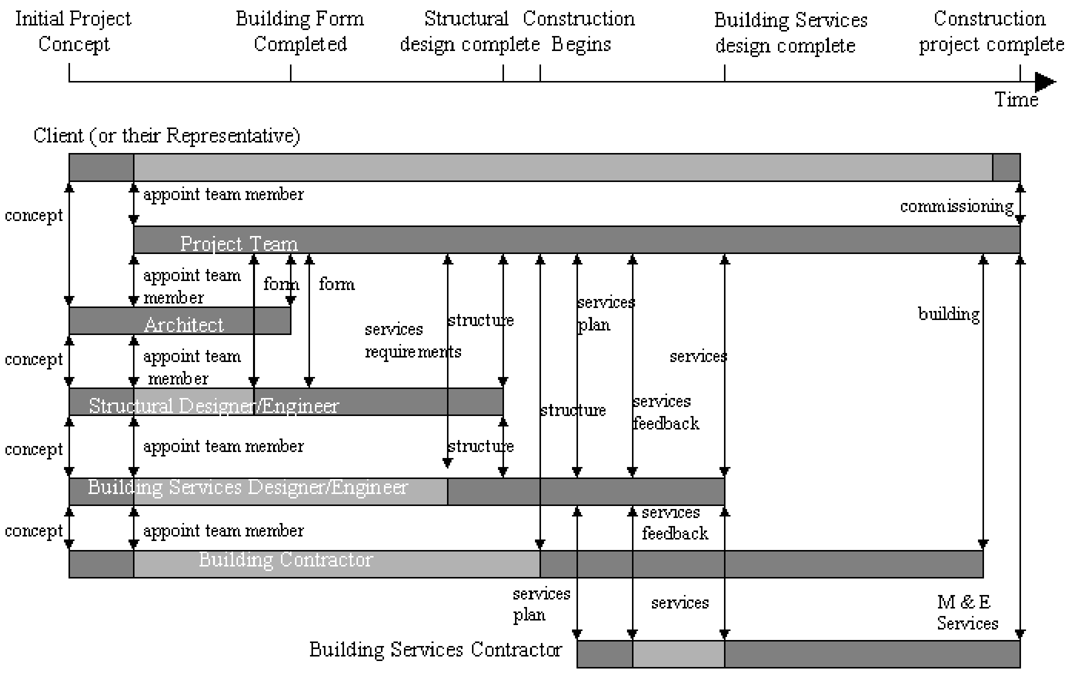

Figure 3: Project procurement by an 'alternative' route

CASE STUDIES

CASE STUDY 1

(a) (b)

Figure 5: (a) Units being installed on site (b) damaged floor-pans causing installation problems

This example relates to the construction of an office building in a busy city centre. The building consisted of 5 storeys and a basement. The project used a traditional method of procurement where each member of the project was chosen via a tendering process. Members were appointed as and when necessary for the project with not all members of the project appointed initially.

The traditional procurement method used meant that the decision to employ prefabricated building services distribution was not taken until the architectural design was complete. Therefore the amount of scope for changes to the building design was limited by the previous work. Some design changes were essential for the use of prefabrication of services within the project as the building design was not intended or planned for the use of prefabricated services distribution.

Prefabrication was used to provide horizontal distribution, vertical distribution and plant-rooms on this project. The design limitations imposed by the fact that building services were not designed with the use of prefabrication in mind meant that only around 30% of horizontal distribution was delivered via horizontal distribution modules and vertical distribution modules delivered only mechanical services. However, the main motivation for employing off-site fabrication of services was too ensure that the project could be completed in a short length of time that would have been difficult, if not impossible, to achieve using entirely traditional techniques. Size of riser modules was kept reasonably low due to the location of the construction site, which had very limited access for large delivery vehicles, and the low number of storeys.

Late changes to the building design, occurring after commencement of structural construction, meant that some of the modules in the building, specifically for a particular floor, had to be designed and manufactured differently to the other modules. This could have possibly been avoided with earlier involvement of the services component of the project.

For example with respect to horizontal services distribution, the issue of large on-site tolerances meant that the floor design had to be altered on some floors to ensure that the designed modules would definitely fit on the floor-plan as intended. Otherwise, the module size would have had to be reduced for two of the floors (increasing design and manufacturing costs and therefore reducing benefits) or all modules would have had to be reduced in size for all floors (increasing design costs and on-site installation times). Another example with respect to vertical services distribution was that the traditional nature of the design meant that mechanical and electrical risers were placed at separated points on the floor-plan and therefore riser modules for one or both of electrical and mechanical risers must be produced. The higher volume of services present in mechanical risers (and work required) meant that it was most efficient to provide these services via riser modules and the electrical risers traditionally.

The modular services installation encountered some problems but overall the main motivation for the use of the modular services, to ensure the building was constructed within an otherwise unachievable timeframe, was completed. Some of the problems encountered will now be listed:

- Structural construction of the building was slightly delayed meaning that modules were delivered whilst there was still construction work to be completed. Modules had to be stored on a floor of the building whilst the walls were still not in place and water was present on the floor of the building due to heavy rain. Image 5a shows this.
- Imperfections in the ceiling screed as shown in the image 5b meant that potential problems with installing the modules as the connection from module to ceiling screed would not have fitted if the damaged sections had intersected with the connection point for the module. Luckily, the areas of damage did not intersect or were not badly damaged where intersections did occur.
- The insulation on some of the modules was slightly damaged during the delivery process as shown in the following images. The damage was not significant but did mean some small amount in extra work repairing the insulation material. This could have been fixed by taking greater care during the delivery process. Figures 6 shows an example of this.
- Errors in communication between the services contractor and the main contractor resulted in the inaccurate layout of one floor of modules. This meant that the services contractor had to reinstall a number of modules. This did not cause any delays to the overall work because the overall installation of modules proceeded quicker than the planned schedule.
- The on-site operatives performing the installation had some initial problems working out the exact layout of the modules on the floor. This only occurred with the first floor of modules and was due to a lack of effective training and communication between the on-site and off-site operatives. This did not cause any delay due to the faster than expected overall installation of modules.

Figure 6: Damaged insulation within horizontal services distribution module

In summary, the problems encountered during installation were relatively minor and did not cause any significant delays to the installation. Almost all can be ascribed to a lack of communication and training between the parties involved. Indeed, they might be considered to be more attributable to management skills than procurement strategy, though the late involvement of building services consultants in the traditional procurement route is a likely contributory factor.

Overall, the on-site operatives were impressed with the ease and speed of the modular installation and the benefits of the prefabricated building services system should not be clouded by poor management skills. The key motivation for employing the use of off-site manufactured services distribution on the project, to ensure completion within a very tight construction timescale, were realised.

CASE STUDY 2

Figure 7: (a) Units being delivered to site via canal barge (b) Horizontal distribution units prior to installation

The project was to construct a new office building in a city centre location. The proposed building was an 8-storey facility. All members of project team were agreed on the potential benefits to be gained from use of off-site manufacture of building services components. Decision to investigate use of off-site manufactured services was taken early in the project's lifespan. The building services contractor, Crown House Engineering, won a specialist contractor award for the work on modular building services in this project and further details of this project can be found in the Contract Journal Awards, 2000 (Contract Journal 2000).

Since the idea for using off-site manufacturing for some of the building services was decided early in the project, the design of the building was able to incorporate input from the building services consultants and manufacturers of the modular services. This meant that the building design did not require many alterations to enable it to fit in the requirements of the modular building services. The increased input into the design from the viewpoint of the building services components did mean a slightly longer amount of initial design time was required than with the same project designed in a traditional manner. However, less rework of the design was needed during the detailed design of the building services. Rework, would also have been a major problem, as it would have affected the design of the modules, which had to be decided before building construction began. The increased communication and involvement between project members, together with the early involvement of the building services consultants, meant the project employed a *partnering* based approach to procurement.

Due to the early involvement of the building services component in the design, the project was enable to employ around 80% of the horizontal building services via the use of off-site manufactured modules. The images at the top of the page show a four-pipe fan coil unit developed especially for this project. The effectiveness of this module has led to the manufacturer seeking to employ this module for a number of other projects. More than 200 of these modules were installed for this project. The module contains:

- Ventilation heating
- Chilled Pipework
- Control Valves
- Modular Wiring
- Drainage Systems
- Electrical Containment
- Fan coil units
- Insulation

Due to a strategic partnership with the supplier of the components used in the modules, it was possible for the manufacturer to use more efficient components in the modules that were new to the market.

Increased communication between project members was essential to ensure that installation progressed smoothly. The top seven floors of the building used the modular services and the ground floor was fitted out using a non-modular traditional approach to building services provision. This enabled some benchmarking to take place, undertaken by the university of Loughborough, to provide an effective comparison between the modular services and the traditional services. Some of the results of this benchmarking are shown below:

- 98.3% efficiency measured at manufacturing centre
- 50% reduction in on-site operatives
- 180% increase in on-site efficiency against traditional (measured against BSRIA average figure of 37%)

- Zero time spent correcting defects on site
- On-site time based study for installation of one floor – Modular = 320 hrs Traditional = 1920 hrs
- 7435 items checked time in manufacturing centre. Right first time = 100%. Reject ratio = 0%
- Actual hours saved on site per floor = 1600

In terms of the cost based issues of employing modular building services components on this project figures cannot be provided. This is due to a confidentiality agreement between the services contractor and the MEDIC project. It is possible to state that the services contractor is currently tendering for construction projects using modular building services at the same rate as for traditional non-modular installations in order to increase market share.

EFFECT OF PROCUREMENT SYSTEMS ON THE EFFECTIVENESS OF PREFABRICATION

TRADITIONAL PROCUREMENT

The design and construction of building services traditionally suffer due to a lack of information about the system. It is not deemed necessary to provide the building services engineer with an up-front design. Installation is also often unplanned, thus adding further complications. With the introduction of off-site manufactured services this lack of planning can cause waste in terms of rework and delays.

Construction quality is a major issue for traditionally procured building services. The services system is the last major part of construction and installation. The space within which the services are installed is restricted, and often cramped with more than one trade completing its part of the works. Due to a lack of full design and layout information there is little order to what occurs within the service voids. Consequently, the quality of workmanship suffers.

The requirements for management of risk are significantly increased on a traditionally procured project; there are more individuals on site, carrying out more activities. This not only contributes to logistical problems, but also introduces greater concerns for welfare and safety on site.

When using prefabrication on 'traditionally' procured projects all parties must be aware of the changes introduced by the use of prefabrication. Due to the fact that some design work will be completed before services professionals are consulted there is often an additional process introduced for the adaptation of the traditional design to be suitable for utilising prefabricated service units. This can add approximately 5-10% to the design time.

In cases where prefabrication of services is essential to the success of the project, for example in terms of construction time or labour availability, then it has been shown to be effective. However, the benefits realised are usually not at the level as those projects employing the 'alternative' form of procurement.

With greater experience of using prefabricated services amongst construction professionals and communication between parties involved in the construction process it is thought that problems encountered would be virtually eliminated.

'ALTERNATIVE' PROJECTS

On 'alternative' projects using off-site manufactured building services, all parties to the construction process provide input to decision making from very early in the project. The requirements of service module manufacturers are made explicit before any building design is completed and can be used as a constraint on the design process. This enables the maximum benefits to be realised from the use of off-site manufactured services.

Case study 2 provides a good example of this type of project. It is typical, from other projects examined, to find a higher level of off-site fabrication utilised in these types of projects.

CONCLUSIONS

The provision of building services through off-site fabrication of major distribution elements has been shown to provide many of the features ascribed to lean construction and with effective planning and control can provide some sizable benefits to the project.

- Waste inherent in the construction process can be reduced by successful application of off-site fabrication techniques. The main areas of waste reduction concern labour and installation time.
- The installation process for prefabricated units is highly predictable and requires less labour. The introduction of predictable processes is beneficial to introducing a more lean overall construction process (Howell 1999).
- The introduction of prefabricated service distribution means that *design freezes* are given greater priority in the project. This helps avoid many of the problems occurring on construction projects due to late changes or alterations to the design.
- Problems identified in the case studies are generally related to a lack of training or communication between parties involved. These are likely to be reduced or eliminated through greater usage and experience of employing prefabricated services. This is backed up by evidence from studies undertaken by BSRIA (Building Services Research and Information Association) in the UK (BSRIA 2000)

To fully realise these benefits requires increased planning throughout the life of the project and integration between those parties involved in the construction process. The procurement method employed plays a major role in encouraging this and it has been shown how an alternative to the traditional procurement method can help achieve this.

REFERENCES

BSRIA (2000). Uptake of Productivity Improvements, Report 70040/14, December 2000, compiled by A. Rowe-Roberts & G. Hawkins.

CBPP (1998). *Fact sheet on choice of procurement route*. Construction Best Practice Programme, DETR, UK.

Contract Journal (2000). Contract Journal Awards, October 2000. pp 34-35.

Egan, J. (1998). *Rethinking Construction* DETR, London

Howell, G (1999). *What is lean construction – 1999*, Proceedings 7th annual conference of the International Group for Lean Construction (IGLC-7), pp 1-10, University of California, Berkeley, USA, July 1999

Latham, M. (1994). *Constructing the Team –Final Report to the Government/Industry Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry* HMSO, London

Long. G., Brankovic, A., G.E. Connolly & M. J. Mawdesley. (2001). *Integrating services design to simplify the use of manufacturing*. In proceedings of First International Structural Engineering and Construction conference (ISEC-01), University of Hawaii at Manoa, USA, Jan24-26 2001.

Mawdesley, M. J., Long, G., Brankovic, A., Connolly, G. E. and Dickens, G. (2001). *Effects of innovative distribution of services on project procurement.* Published in the Proceedings of the International Conference on Innovation in Architecture, Engineering and Construction, Loughborough University, July 2001.