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Study of prefabricated building services components for residential buildings in Hong Kong

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ABSTRACT

Prefabrication techniques have been applied to residential buildings in Hong Kong for many years. Most of them are used on structural elements; prefabrication of building services components and their integration with architectural and structural elements are not yet fully explored. Well-planned prefabrication can help reduce construction time and on-site costs. By adopting off-site manufacture and pre-assembly, it is possible to improve efficiency and quality assurance of the components and enhance environmental performance and site safety.

This study investigates the application and potential of prefabricated building services components for residential buildings in Hong Kong. The technology development of off-site fabrication in some overseas countries is examined and the local experience for prefabrication is evaluated. It is found that the prefabrication approach will involve extensive use of standardisation and modularisation. To achieve the real benefit for building services equipment and distribution, prefabrication must form a fundamental part of the integrated and coordinated design strategy for the building. It is believed that further development of prefabrication will lead to a closer integration between building services and manufacturing engineering.

Keywords: Prefabrication, building services components, residential buildings, Hong Kong.

探討香港住宅樓宇的預製屋宇設備元件之應用

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預製技術在香港住宅樓宇應用已多年，目前大多用於結構部份，至於屋宇設備元件的預製，以及如何使它結合建築和結構方面，仍然未有全面探索。 良好規劃的預製技術可以減省建造時間和工地成本，同時，採用工地外製造和預先裝配方法，可以提高元件的效率和品質保證，更可改善工地之環保效能和安全情況。

本文探討香港住宅樓宇的預製屋宇設備元件之應用和潛力，研究一些海外國家在工地外製作技術的發展，以及分析預製技術在香港本地的經驗。 研究結果發現，預製方法涉及大量標準化和組件化的工作，若要從屋宇設備裝置和配管輸送中獲得真正益處，預製技術必須成爲該建築之綜合和協調設計的基本部份。 預製技術未來的發展，將會帶動出屋宇設備和製造工程之間更加緊密的結合。

1. INTRODUCTION

In the construction industry nowadays, the demands and requirements of the clients have continued to grow and it is essential to find ways of building faster, cheaper and better-quality buildings. Prefabrication has become an important and cost-effective concept in today's fast-track construction culture in the world (Percival, 2005; Ballard and Arbulu, 2004; BCA, 2000; Gibb, 1999; Bottom, et al., 1996). In some developed countries, prefabrication and off-site manufacturing of building services components is becoming more and more popular (Thomas, 2005). This approach to installing services in buildings addresses the problems associated with conventional methods and shortens the on-site construction period, thus enabling timely completion and a maximum return on investment (Harrop, 2004).

With growing concern about sustainable construction and design, it is helpful to develop and use more prefabricated components so as to minimise the environmental impact of building life cycle. This study investigates the application and potential of prefabricated building services components for residential buildings in Hong Kong. The technology development of off-site fabrication in some overseas countries is examined and the local experience for prefabrication is evaluated. The critical factors for achieving effective prefabrication are discussed. It is hoped that the benefits of the prefabrication approach can be utilised for enhancing buildability and quality of building projects.

2. PREFABRICATION TECHNIQUES

In the past, prefabrication has been used as a means of lowering the cost of housing and providing accommodation rapidly (Sheppard, 1946). The industrialisation of building is most effective when many of the building components are prefabricated in a factory with appropriate equipment and efficient technological and managerial methods (Warszawski, 1999).

2.1 Definitions

The term "fabricate" means to provide materials with specified properties including dimension, density, shape, conductivity, etc. according to a manufacturing process (Ballard and Arbulu, 2004). In practice, "prefabrication" means "the manufacture of component parts of a building and its services prior to their assembly on site" (Wilson, Smith and Deal, 1998). Prefabricated techniques can be used in a wide range of application during the construction process, from the simple prefabricated site hut, up to volumetric units that are designed for integrating into the building structure.

In fact, production of building components offsite is not a novel concept. The so-called "off-site manufacture (OSM)" refers to "making all or part of an object in some places other than its final position" (Cooper, 2004). When applied to building construction, it includes fabrication and pre-assembly (Make = Fabricate + Assemble). By definition, "pre-assembly" means "the manufacture and assembly of a complex unit comprising several components prior to the unit's installation onsite" (Wilson, Smith and Deal, 1998). The off-site approach dramatically reduces the need for on-site work and can help reduce site installation times and hence on-site costs.

Another term commonly used is "modular construction" which means any building construction that is normally pre-assembled and shipped to the site by individual units. The word "modular" describes a construction method where individual modules stand-alone or are assembled together to make up larger structures. Prefabricated modules are usually factory-made and fully-finished to the point of being 'ready-to-use'. They are then transported to site and installed quickly with a minimum of on-site works (Ricketts, 2005).

Neale, Price and Sher (1993) pointed out that the off-site approach has been applied in U.K. for making hotel bathrooms, complete bedrooms, office toilets and washrooms, lifts, building services plantrooms and cladding units. Some hospital and airport building projects also benefited from prefabrication techniques (Mitchell, 2005; Thomas, 2005).

In Asia, Japan is a pioneer in prefabrication, using timber, metal, fibre glass and plastics as the main building materials. Development and use of industrialised and prefabricated housing technologies are quite common in Japan (Bottom, et al., 1996). On the other hand, prefabricated building construction systems using precast concrete are now widely adopted in Hong Kong (Wong, Hao and Ho, 2003) and Singapore (CIDB, 1997).

2.2 Benefits of Prefabrication

The benefits of prefabrication can be evaluated from four main aspects.

(a) *Cost implications*

Off-site manufacture of building components is a low-risk form of delivering complex services to building sites (Mawdesley, et al., 2002). The only other cost that differs from a standard installation is the enclosure to protect the prefabricated components. This cost will usually be recovered by overall labour-related savings and the reduced cost of maintenance made possible by components and plants being assembled in the optimum layout for access and servicing. The cost savings that can be achieved at every level of the construction supply chain is significant, and together with proper time control, this will enable faster return on investment for the client (Harrop, 2004).

(b) *Time control*

Past experience shows that prefabrication can reduce construction time (Mawdesley, et al., 2002; Pasquire and Connolly, 2002). In relation to overall time scale and project management, prefabrication relieves congestion and concurrent working from site. This helps reduce the time required for installation, site testing and commissioning. It also prevents any delays caused by trade contractors having to wait for one other to complete their work programme.

(c) *Site management*

Prefabrication can improve site activities and site management since less labour and materials handling are required onsite and possible congestion and concurrent working are reduced. When labour shortage and skills is an issue for site supervision, the off-site approach can help solve the problem of labour availability and cost. With prefabrication, other problems associated with onsite operations like health and safety, fire risks, workers'

insurance, cramped working environments and accidental product damage can be reduced or eliminated.

(d) *Quality control*

Prefabrication means that assembly is taken away from site and performed in factory conditions, leading to improved quality and consistent workmanship. It can also streamline work on site and enable site staff to continue with other essential works without being interrupted by other workers.

2.3 Building Services Components

Wilson, Smith and Deal (1998) pointed out four main methods to apply prefabricated techniques to building engineering services:

- Modular buildings with integrated services
- Preassembled building services units/modules, such as plantrooms, bathrooms and toilets
- Prefabricated horizontal and vertical distribution, for pipework, ductwork and wiring
- Terminal unit preassembly such as sanitary fittings and fan coil units

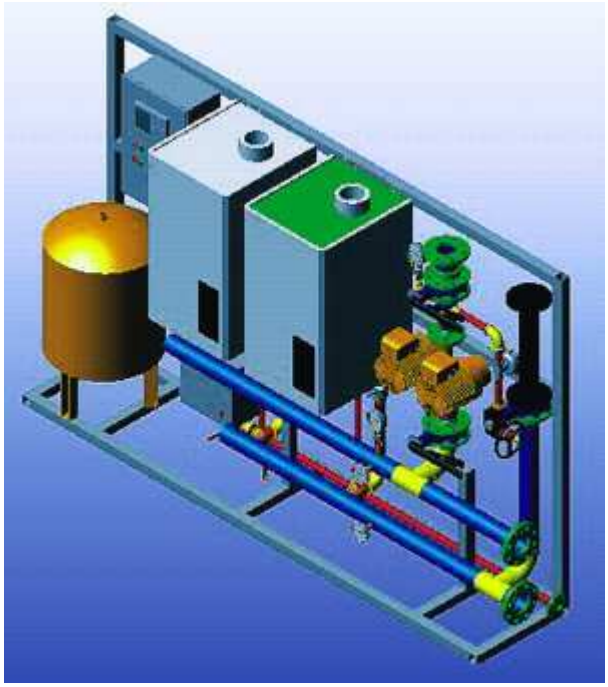
There are many trades involved with building services installations. Indeed, two thirds of the cost in building services is the labour aspect which is a commodity that can be optimised through an off-site approach. Prefabrication can provide a total solution that incorporates all the important building services components to offer a total slot-in module, which is fully commissioned and requires only simple attachment to utility supplies. The major elements of building services systems suitable for prefabrication are given in Table 1.

Table 1: Major building services elements suitable for prefabrication

Building services systems	Major elements
Mechanical ventilation & air conditioning	- Air duct system - Water pipework & fitting - Refrigerant pipework & fitting - Air conditioning equipment (e.g. air handling unit)
Fire services	- Water pipework & fitting - Pump sets & fittings
Plumbing & drainage	- Water supply pipework & fitting - Drainage pipework & fitting - Pump sets & fittings - Bathroom & toilet sanitary fittings
Electrical services	- Cable & busbar trunkings - Conduits & wiring - Power outlets & telecommunication - Electrical switchgear

To ensure quality, fully integrated building services modules are designed and prefabricated off site, completed with all necessary pipework and fittings, valves, containment, insulation and even supply and extract ductwork. For electrical services, modular wiring systems can be used to provide a more flexible alternative to conventional wiring for lighting, underfloor power and data/voice distribution systems. To achieve savings

in space with building services, the whole plant room can also be manufactured in the factory. Figure 1 shows two examples of prefabricated building services units.



(a) Integrated building services plant

(b) Prefabricated bathroom

Figure 1. Examples of prefabricated building services units (Sources: www.modbs.co.uk and www.horkew.com.sg)

3. DEVELOPMENT IN HONG KONG

Prefabrication techniques have been applied to the construction of residential buildings in Hong Kong for many years. At present, most of the prefabrication methods are used on structural components, such as precast façade, structured wall and column, semi-precast slab, staircase and refuse chute. Prefabricated architectural metal components such as handrails, gates, doors and frames are also commonly adopted. However, prefabrication of building services components and their integration with architectural and structural elements are not yet fully explored.

3.1 Prefabricated Concrete Structural Components

Yeung, Chan & Chan (2002) suggested that prefabrication approach associated with the extensive use of standardisation and modularisation should become essential principles in the design and construction of high-rise residential buildings in Hong Kong. Large panel formwork and prefabricated concrete components are widely used in public housing projects in Hong Kong, making up around 17% of building blocks in terms of concrete volume (Poon, Yu and Ng, 2003). Most precast concrete components are produced in factories in the mainland China and delivered to Hong Kong for installation.

However, due to inhibitive factors such as upfront investment, manufacturing lead-time and lack of expertise in supply chain management, prefabrication was not commonly accepted among private developers. To attract more attention in the private sector, the Hong Kong

Government in recent years had introduced new measures to encourage prefabrication such as formation of a study group on lean construction, provision of incentives in the form of gross floor area and site coverage exemptions, compilation of the codes for precast concrete and development of a green labeling scheme.

3.2 Building Services Installations

Soon (2004) explained that before 1980 all of the building services installations are carried out on site, using exposed pipeworks and conduits. As the standard of living was increasing, exposed pipeworks and conduits were not acceptable and concealed ones were being used. Coordinating the building services with concreting and builder's work became an essential task on site which often leads to delays and defects.

In recent years, off-site fabrication of some building services components was introduced, with fabrication workshops being set up in Guangdong and Hong Kong. One example of the application is a residential development at Fu Tei which makes use of precast concrete for making prefabricated assemblies of kitchen and bathroom (Soon, 2004). For residential buildings, the construction of a kitchen or bathroom requires the involvement of many building trades such as waterproofing, finishes, accessories, sanitary wares, plumbing systems, electrical systems and other building services installations. The use of prefabricated units, completed with sanitary fittings, pipe works and wall and floor tiles could offer significant opportunities for improving the delivery, quality assurance and productivity.

3.3 Culture of the Construction Industry

Generally speaking, the construction industry is very traditional and resistant to change. Prefabrication is often perceived to be a costly process that lacks industry standardisation. To tackle the inertia and knowledge gap, efforts are needed to enhance awareness within the industry as well as provide technical assistance for small contractors. Developers could also play an active part by sharing the risk and upfront investment.

In recent years, more and more projects are being awarded on a design-and-build basis, which creates a much tighter team environment. This method has allowed building services to be integrated into the build process much earlier, enabling contractors and sub-contractors to be brought into the frame at the initial design stage. This has allowed the concept of a modularised prefabricated system to be introduced and written into a detailed specification.

4. DISCUSSIONS

Problems with interface detailing, tolerances, and poor construction process management are affecting the full benefits of prefabrication. To achieve effective prefabrication, a high level of technical and managerial competence and co-operation of all the parties involved in the planning, design, co-ordination and overall management of the project is required.

4.1 Project Planning and Development

Wilson, Smith and Deal (1998) have discussed the critical success factors and important issues to fully achieve the benefits of prefabrication. A summary of them is shown in Table 2.

Table 2: Critical success factors and important issues for prefabrication

Critical success factors	Important issues
• Motivation • Design • Procurement • Logistics • Site installation and assembly • Testing and commissioning	• Early integration of expertise • Co-operation and buy-in by all parties • Co-ordination and planning for off-site production • Logistics integration • Attention to structural detail (tolerances) and site installed building services • Sharing lessons learned • Training and education

To take full advantage of the prefabricated approach, designers and consultants need to consider the space and system requirements at the earliest stages. This is especially important when designing building services systems, identifying load requirements and usage, as these elements are critical to standardising the requirements of a prefabricated system. It is beneficial to talk to the experts by seeking technical advice from a manufacturer in order to identify time and cost saving opportunities through adopting pre-designed and proven prefabricated solutions.

The use of prefabricated or modular building services calls for a restructuring of the traditional construction procurement process (Mawdesley, et al., 2002). The benefits of prefabrication cannot be harvested if the construction managers are unaware of the issues that need to be addressed to make prefabrication work on site. There is a need for information and training, as well as good communication with experienced specialist manufacturers. With prefabrication, the client and the contractor will manage less on site, but they need to manage different aspects of the process in order to let the specialists perform to their full ability. Here, greater use of integrated team working is important.

4.2 Standardisation and Modularisation

Standardisation is a function of mass production and is ancillary to prefabrication. Standardisation and large volume allow a high degree of specialisation within the production system. At present, standardised mass production in building services is rare; every job is unique. A system on one floor of a building will possibly not have the same functions and requirements as the floor above and, therefore, modular units need different combinations of components. This may increase the cost of the prefabrication.

Modularisation is the ability to match on site requirements by providing multiple pre-assembled units. It is a lean, streamlined process, which is undertaken under strict quality-controlled factory conditions. By constructing building services as a module, the units can be tested as a whole to ensure correct working performance prior to any installation. Modularisation reduces the need for labour intensity. On an assembly line in a factory, the element of multi tasking can also be employed.

Ricketts (2005) indicated that one problem arising from modularisation is connections of the pipeworks. Most single components are designed for installation on site (e.g. pipes, flanges, tees, elbows), so connecting units and ensuring that all enclosed components are also fully sealed and functioning is a distinct challenge. To allow simple assembly and delivery, the materials should be lightweight. Traditional steel and copper and other materials that

require welding and soldering are simply not suitable for modularised units because of the sheer weight. Plastic is by far the preferred solution, offering ease of handling, especially where large-bore pipework is specified.

Architects, consultants and contractors have to adopt the mindset of manufacturers and see the finished building as a "product" and not a whole range of loosely connected parts. Standard objects that can be built into pre-fabricated plant rooms to meet a variety of needs are now being adopted by some building designers. The sizes and shapes of the finished product can be different, but made up of a series of easily replicable units — many of which could be taken out and reused. This enhances the environmental performance of the design.

4.3 The Role of Manufacturers

Manufacturers have an important role to play in prefabrication. From a manufacturer's viewpoint, prefabrication is the best way of ensuring customers get systems that are suited to their needs and designed to operate at maximum efficiency. Prefabrication offers manufacturers a window of opportunity for new-product development and for introducing new materials and methods. Table 3 shows the comparison between construction industry and manufacturing industry. One must understand the characteristics in order to investigate effective prefabricated solutions.

Table 3: Comparison between construction industry and manufacturing industry [adapted from Warszawski (1999, p. 9)]

Construction	Manufacturing
Work dispersed among many temporary locations	All the work performed at one permanent location
Long service life of a particular product	Short to medium service life of a typical product
Small extent of standardisation; each project has distinctive features	High degree of repetition and standardization
Large numbers of tasks requiring a high degree of manual skills necessary to complete a typical construction project	Small number of simplified tasks necessary to produce a typical product
Each task performed over large work area with workers moving from one place to another	All tasks performed at static workstations
Rugged and harsh work environment	Workplace carefully adjusted to human needs
High turnover of workers	Comparatively stable workforce
Authority divided among sponsor, designers, local government, contractor, and subcontractors	Unified decision-making authority for design, production, and marketing

Manufacturers who have recognised the potential for prefabricated solutions will invest time and expertise in designing, testing, installing and commissioning a variety of different projects over a number of years. Investment in product and system development is a key priority for manufacturers to allow this method to be adopted as a viable and cost effective procurement process for construction projects. It is also necessary to research and develop new products and systems specifically designed to accommodate the requirements of a prefabricated building services unit.

Supply chain management is crucial for the fabrication process. Procurement concept revolves around the creation of pre-assembled supply-chain modules, each consisting of closely integrated manufacturers and sub-contractors. Specialist contractors and manufacturers will work together with building services contractors.

Like any other manufacturing business, in order to achieve efficient production, prefabrication factories need a constant level of demand and they are committed to the volume and timing of their output. Fabrication shops and factories perform at the intersection of manufacturing and construction. Hopefully, industrialisation and automation will be used to replace manual labour in all phases of the building process (Warszawski, 1999).

A review in the approach to installations will lead to better co-ordination, a reduction in waste and downtime and a subsequent increase in efficiency and profitability for all parties. If needed, 3-D models will be prepared by specialised building services designers for careful coordination with architectural and structural data.

5. CONCLUSIONS

To cut costs and improve predictability and quality is the drive for greater use of prefabrication on construction sites. Well-planned prefabrication can help reduce construction time and on-site costs. By adopting off-site manufacture and pre-assembly, it is possible to improve efficiency and quality assurance of the components and enhance environmental performance and site safety.

Prefabrication approach will involve extensive use of standardisation and modularisation. This approach represents a major change in the way building services systems have traditionally been specified and designed. To achieve the real benefit for building services equipment and distribution, prefabrication must form a fundamental part of the integrated and coordinated design strategy for the building. It is believed that further development of prefabrication will lead to a closer integration between building services and manufacturing engineering.

Prefabrication is still in its infancy in the building services industry. Understanding the client's and contractor's needs, designing solutions and developing prefabricated components as a standard construction practice is the future for building services.

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