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Factory Manufactured Modular Construction of Process Plants

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Abstract

Off-Site Modular Construction (OSMC) research has been a growing research area over the past two decades because of low productivity in construction. Tools are superior in factories and productivity is much higher compared to a stick built site. This has spawned the development small, factory built, rapidly deployable and flexible process plants to take advantage of the gains in OSMC productivity. Chemical process plant research is studying fast, automated design and configuration.

In this paper, a literature review was performed on modular factory manufactured process plants. The literature review found that moving to small scale OSMC plant systems could enable cost and schedule savings and months of design time compared to the previous on-site assembly design. It was also found that while automation has been applied in earlier stages of the plant design process, a layout optimisation methodology has not been applied to small OSMC process plants.

The paper then proposes to utilise a mathematical layout optimisation model to help design and construct modular process plants and considers how this may fit into the process plant design process, as well as considering the transport requirements for modules.

Keywords. Off-Site Modular Construction, prefabricated manufacture of industrial process plants,

1. Introduction

Low productivity in the construction industry (Figure 1) has seen the move to off site modular manufacting over the past few decades [1] [2], whereas there are suggestions that automation will be required for further productivity enhancements [3]. This off site modular manufacting has greatly increased the amount of research conducted on BIM [4].

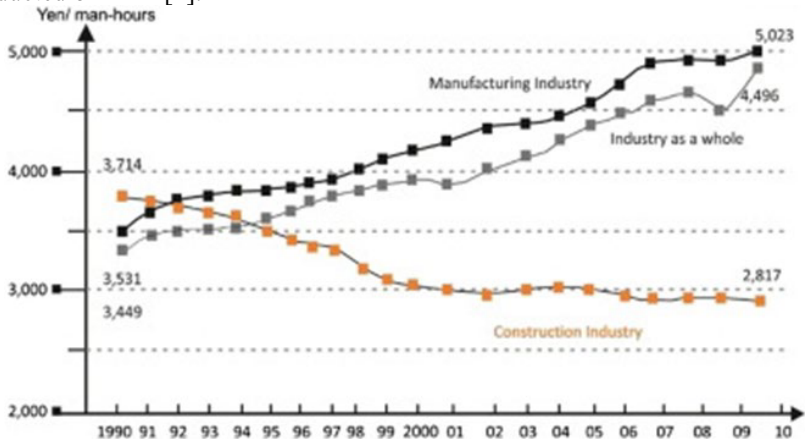

Figure 1. Labour productivity in industry and in the manufacturing industry is continuously rising; labour productivity in construction has been decreasing for decades [5] © Elsevier

Modularisation of process plants has mainly focused on large modules in recent decades such as those in remote locations (Figure 2) with poor availability of labour and adverse weather conditions. Recent literature suggests up to a 20% capital cost saving and up to 50% schedule saving [6].

Figure 2 A modular industrial plant project in Alberta Canada [7] © Elsevier

A heuristic rule from experience in shipbuilding, recognised that work completed in a factory is 8x more cost and time efficient (Figure 3) than completing the same work on a construction site [8].

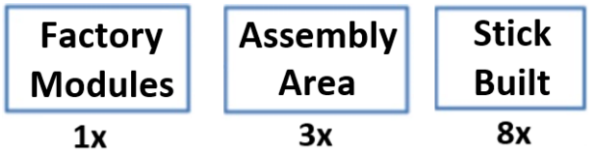

Figure 3. 1-3-8 rule from shipbuilding [8] © Elsevier

However, small scale, modular factory manufactured process plants (Figure 4) has been a growing area of research over the past decade [9]. This is mainly due to the low productivity experienced in the construction industry shown in Figure 1.

Figure 4. Modular factory manufactured process plants [9] © Elsevier

2. Literature

Seifert et al., highlighted that small modular plants (example in Figure 5) can decrease the construction schedule by over 2 years (66%) and improve value by 35%. Changing to a continuous process rather than batch can achieve 30% better value [10].

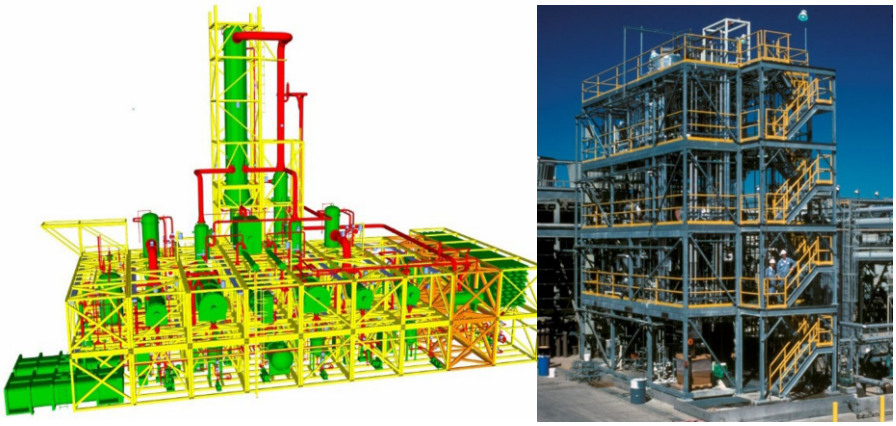

Figure 5 - Off site modular constructed process plants [11] (Photos Courtesy of Zeton [12])

Equipment module databases were first studied, supporting plant designers to rapidly pick equipment and equipment modules [11] [13] [14] [15]. Clustering approaches were suggested to design modules [16] as well as accumulating data from past projects [17]. A method to remove the need for an assembly factory was suggested where equipment is fit at the equipment manufacture, however more effort is necessary at site to join the module connections [18]. Selection techniques for equipment utilising reusable databases were then developed [19] and also for modules [20] [21] [22] [23] to speed up the design process. Modular Piping and Instrumentation Diagrams (P&ID) were configured out of "basic and auxiliary elements" [24]. Support tools were established to determine applicability of modular expansions of existing plants [25] and expansion planning for new plants [26]. Up to 70% decreases on construction costs and 41% of engineering costs for modular plants were shown with a capital investment estimation tool [27].

3. Method

Whereas a lot of work has been done on modular equipment databases, process flow diagrams, and P&IDs, very little work has been done on 3D layout for small, factory-built process plants [22]. A method to utilize layout optimisation to analyse concepts of off site modular factory manufactured process plants was proposed [28]. Automated design techniques were highlighted [29] and a method to arrange modules in a process plant developed [30]. Layout optimisation models have been applied for optimising construction, safety, operational costs [31] in the industrial process plant research.

Figure 6 shows the proposal for how a layout optimisation method for Factory manufactured modular process plants may fit in to the process plant design process.

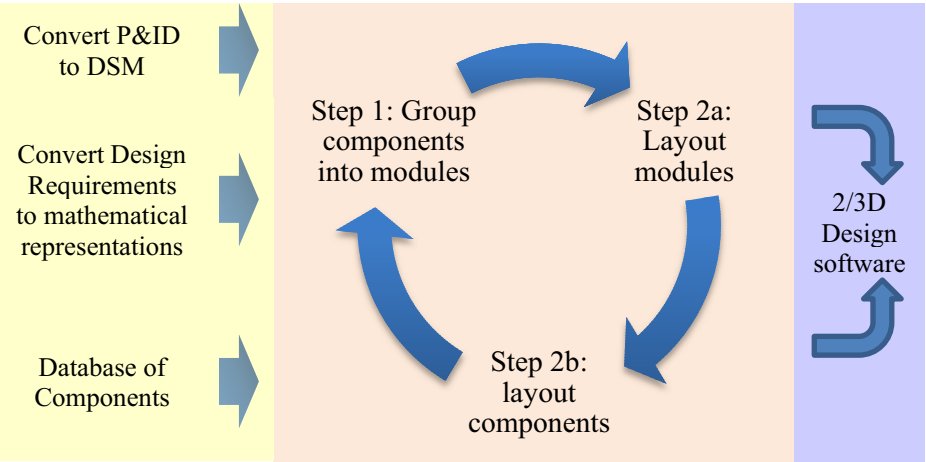

Figure 6. Factory manufactured modular process plants design process proposal

The design process needs to consider design for manufacture and transport such as factory build requirements Figure 7.

Figure 7 – Rolls-Royce concept for factory-built modules © Rolls-Royce Plc

The move to factory-built modules and transport (Figure 8) could become even more economical as the world moves towards a future of electric, driverless vehicles [28].

Figure 8 - Rolls-Royce concept for module transportation © Rolls-Royce Plc

4. Road Transport Requirements

Off-site construction in factory manufactured process plant modules improves productivity, quality and involves less rework, aiding the construction timetable.

So that work off site is increased, modules ought to be designed for upper limits of road transport. Site position is key for transport and is recommended to be chosen prior to more considerations being determined (insurance, special equipment, licences, quality control, possible incidents and obstructions, environment, etc) [32], [6]. In conjunction with Site position, module size and transportation constraints should be explored.

The UK and EU road transport restrictions are considered in Table 1.

Table 1 - Module dimensions for transport for UK police and Highways England (HE) notice [31]

Transportation Requirement	Weight (tonnes)	Width (metres)	Length (metres)	Height (metres)
STGO no permit	80	3	18.75	4.95
2 clear days' Police notice	150	5.0		4.95
HE form VR1*		6.1		4.95
HE Special Order*	> 150	> 6.1	> 30.0	4.95

Within the EU no permit is needed for vehicle loads [33] of:
Width - 3m, Length - 24m, Height -4m.

5. Conclusions

Factory manufactured process plants is a developing research area. This paper highlights previous research in small scale, off site manufactured and constructed industrial process plants. It recognises that although research into automation has been achieved in the earlier parts of the design process (PFD, P&ID, equipment databases), there is little available research on a layout optimisation method for modular process plants.

The paper then proposes how a layout optimisation method may fit into the process plant design process and considers transport requirements for modules.

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