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Investigation of Design for Manufacturing and Assembly (DfMA) Application at Precast Concrete Manufacturing Plants in Johor

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Abstract: *Design for manufacturing and assembly (DfMA) has been applied in the construction industry by simplifying manufacturing and assembly activities. This has raised the issue of whether the implementation of DfMA can streamline manufacturing and assembly activities in precast concrete manufacturing plants, and its implementation remains doubtful as there is no information on either company websites or leaflets stating that they practice the DfMA concept. Considering these issues, this study sought to investigate the DfMA application of this concept in precast concrete manufacturing actual practice. This study used semi-structured interviews to collect all the data needed from 3 selected interviewees, each representing different precast concrete plants in Johor Bahru, Malaysia. As a result, each of the DfMA principles studied was discussed, and all the interviewees had their different opinions and perspectives on each of the DfMA principles examined. The study revealed that each of the selected manufacturing plants had only applied some of the principles of this concept. The linkage between the literature review and the results obtained revealed that some of the precast manufacturing plants have applied the DfMA principles, whereas others have only partially applied the principles studied. In conclusion, the DfMA principles studied have provided different views and opinions to the researcher for a better understanding of DfMA application and real practice in precast manufacturing plants.*

Keywords: design for manufacturing and assembly, DfMA, Industrialised Building System, precast concrete, construction

1. Introduction

In the construction industry, discoveries for improving the quality of the construction process either in terms of construction methods, construction materials, construction components, and other aspects are always being made. Many large construction projects in the country have encouraged many players in the construction industry to look to more systematic and efficient methods that are in line with the economic conditions of today. In the past few years, the Malaysian construction industry has been the transformation of conventional technology to more systematic and mechanized system technology (Qays, 2016). The Industrialised Building System (IBS) has been identified as a potential solution for improving the overall performance of the construction industry in terms of cost-effectiveness, labor reduction, quality, and many more aspects (Abas, 2015). The manufacturers of IBS components usually produce a variety of IBS products, such as precast concrete components, blockwork, prefabricated steel, and timber trusses (Zulkifli, 2014).

In developed countries like Australia, the prefabrication industry has adopted the concept of design for manufacturing and assemble (DfMA) for efficiency in product manufacturing and assembly and to save time and cost despite improvements in the quality of the product (Khalfan & Maqsood, 2012). Traditionally, the DfMA approach has been applied to the design of automotive and consumer products, which are both sectors that need to efficiently produce high-quality products in large numbers. The application of DfMA in the construction industry can enhance project management in a manner that is well-controlled, systematic, and more productive (Kalyun & Wodajo, 2012). DfMA is an approach to design that focuses on ease of manufacture and efficiency of assembly. It is a well-established approach in a construction sector that is driven by the need to produce large numbers of consistently high-quality products very efficiently; however, in the construction sector, the 'repeatability' of end products may appear to be less critical than that of other sectors, at least at the first glance (Davies, 20130.

It is important for those who are involved in the civil engineering field to be aware and exposed to the DfMA concept as it parallels with the Malaysian government's objectives in the Construction Industry Transformation Programme (CITP) 2016-2020 (CIDB, 2016). In Malaysia, it is believed that some of the large IBS component manufacturers, particularly those who produce precast concrete components, have adopted the DfMA concept in their production. However, the implementation of this concept at precast concrete manufacturing factories remains doubtful as there is no previous study on the topic, and information either on manufacturer websites or leaflets about whether or not they practice the DfMA concept is unavailable. From a research perspective, investigations regarding the application of DfMA in prefabrication or industrialized building systems remain lacking.

Therefore, this study aims to explore the application of DfMA principles in the construction industry at precast concrete manufacturing plants. Two objectives have been established to achieve this aim:

i. Studying the principles of DfMA application in precast concrete manufacturing plants
ii. Investigating the application of DfMA at precast concrete manufacturing plants.

2. DfMA Concept in Construction Industry

DfMA is the combination of two methodologies: a design for assembly (DFA) and design for manufacturing (DFM). This combination enables a product design to be efficiently manufactured and easily assembled with minimum labor cost, and through the use of the DfMA concept, a company can prevent, detect, quantify, and eliminate waste and manufacturing inefficiency within a product design (Rikhi & Rusu, 2006). The word "manufacture" is used to describe the business of producing goods in large numbers, usually in a factory using machines, and the word "assembly" is used to describe the process of putting parts of a machine or structure together, or it is alternatively used to refer to the structure produced by this process of putting the parts together (Kalyun & Wodajo, 2012). Different definitions of DfMA have been established by a few researchers as illustrated in Table 1.

Table 1: Definitions of DfMA

Authors	DfMA definition
Molloy et al. (2006)	DfMA is a new approach to the construction industry. By planning more works offsite, manpower and time needed to construct buildings are reduced, while ensuring work sites are safe, conducive and have minimal impact on the surrounding living environment.

Mcfarlane & Stephen (2014)	DfMA is the design and manufacture of discrete sections of a product (or structure) which are then assembled at one location, typically a factory for mass-production. The individual sections can be manufactured at geographically dispersed locations from the factory. However, when applied to the construction industry, DfMA involves the manufacture of discrete sections of the final construction in a factory and these are then transported to the site for final assembly.
Buildoffsite (2018)	DfMA is a tool used to choose the most cost-effective material, which is then used from the earliest stages in a structure's design to deliver cost reductions and shorten construction processes.
Hairstans (2016)	DFMA is the concept of designing products and systems that are tailored for ease of manufacture, transport and assembly. It is therefore important to understand the supply chain components available, capabilities of the manufacturing process, logistical arrangements and any on-site restrictions.

DFM techniques are closely linked to DFA techniques but at oriented primarily to individual parts and components rather than to DFA's sub-assemblies, assemblies, and products [8]. In an attempt to increase off-site manufactured construction, some companies have been exploring new design and delivery techniques over the last decade. Design for manufacturing and assembly (DfMA) is the combination of two methodologies which are design for assembly (DFA) and design for manufacturing (DFM) where both of this combination has enabled a product design to be efficiently manufactured and easily assembled with minimum labor cost and through the use of DfMA concept, one company can prevent, detect, quantify and eliminate waste and manufacturing inefficiency within a product design (Rikhi & Rusu, 2006). DfMA is the design and manufacture of discrete sections of a product (or structure) which are then assembled at one location, typically a factory for mass-production. The individual sections can be manufactured at geographically dispersed locations from the factory. However, when applied to the construction industry, DfMA involves the manufacture of discrete sections of the final construction in a factory and these are then transported to the site for final assembly (Mcfarlane A. & Stehle, 2014).

Figure 1: An illustration shows a general concept of DfMA (Dalgleish & Williams, 2014)

2.1 DfMA Principles

Design for manufacturing (DFM) techniques is focused on individual parts and components to reduce or eliminate expensive, complex or unnecessary features which would make them difficult to manufacture and design for assembly (DFA) techniques focus on reduction and standardization of parts, sub-assemblies and assemblies (Rikhi & Rusu, 2006). The principles for DfMA are detailed as below:

i. Minimise the Number of Components

With fewer components, the final product is more stable and reliable, and it is also easier to disassemble for repair and maintenance. The cost for both ordering and assembling the parts is reduced. This also allows for the easier implementation of automation, so that labor costs also go down (Matheson, 2018).

ii. Design for ease of assembly

The easier the assembly process, the less the procedure requires the involvement of expertise and extra intensive tooling. This lowers the cost incurred for involving professional personnel as existing workers can handle the operation with minimal training (Kalyun & Wodajo, 2012). Complex orientation and assembly movements in various directions should be avoided and it can minimize the need to reorient the assembly (Anon., n.d.).

iii. Design component for multi-use

Defined as different components or systems can share components that have been designed for multi-use. These components can have the same or different functions when used in different systems and it is necessary to identify the parts that are suitable for multi-use (Richard, 2018).

iv. Use modular design

Modular design is a design approach that creates things out of independent parts with standard interfaces and it can be said that modular design is like LEGO plastic construction toys (Spacey, 2016). Modular design is becoming more prevalent in many industries. Some of the advantages of modular design are: (a) the use of modules in the component or system design simplifies manufacturing activities such as inspection, testing, assembly, purchasing, redesign, maintenance, service (Pei, 2012) and; (b) modules may result in shorter learning curves when new employees require training on the assembly of the products (Rikhi & Rusu, 2006).

v. Use standard component

Standard components are less expensive than custom-made items. The high availability of these components reduces product lead times. Also, their reliability factors are well ascertained. Furthermore, the use of standard components refers to the production pressure to the supplier, relieving in part the manufacture's concern of meeting production schedules (Lahtinen, 2011).

3. Methodology

The research design of the study involved the case study method for data collection of the DfMA concept application at selected precast concrete manufacturing plants in Johor. There were 3 precast concrete plants involved, in which all plants are located in Johor Bahru area. The case study research participants (organizations) are shown in Table 2. This study employed an interview to collect information regarding the DfMA concept application at the selected precast concrete plants.

Table 2: Details of the case study plants and interviewees

Plant	Location	IBS component produced	Interviewee	Position	Experience (years)
A	Pontian	Prefabricated prefinished volumetric construction (PPVC) / prefabricated bathroom unit (PBU)	INT1	Head of production	12
B	Gelang Patah	Precast concrete wall, beam, column, slab, volumetric units	INT2	Senior planning engineer	5
C	Senai	Precast wall, beam, column, staircase	INT3	Quality control inspector	15

The strategy for this study began by gathering and studying some background information regarding the design for manufacturing and assembly (DfMA). An extensive literature review as secondary data was carried out to obtain information about the design for manufacturing and assembly (DfMA) in the construction industry. The literature review involved a comprehensive review that includes journals, articles, research reports and guidelines.

Next, questions for the interviews as primary data are structured based on the research from significant literature within the DfMA concept. A semi-structured interview has been chosen for the interview method. The reason for choosing this method because it is necessary to encourage and let the interviewees freely discuss their own opinion and their knowledge in design for manufacturing and assembly. Semi-structured interviews provide an opportunity to regulate the order of the questions and the respondents to have the possibility to expand their ideas and speak in great detail about diverse subjects rather than relying only on concepts and questions defined in advance of the interview. In collecting more information about the DfMA concept, an observation towards the process of DfMA also being conducted in conjunction with the interview at the precast concrete factory to strengthen the information that has been collected in this study.

3.1 Interview Process

For each interview, the author has made an appointment to set the date and location of the interview session. The interview was carried out by meeting them in person. The author has submitted a letter to all the interviewees through an email so that the interviewee can prepare themselves to answer the question and discuss freely based on their experience and knowledge. All interview session with the interviewees was conducted at their office. After the interview session, the author was brought by the interviewee to visit around the plant.

The interview session began with the author introducing her background before explaining the aim of the interview made. The author asked if the interviewee is clarified about the topic that has been mentioned in the letter provided. As all of them understood, the author asked all the interviewees if the conversation can be recorded and some photo documentation by a digital camera. They gave their concerned on the requested matters, allowed the conversation to be recorded and photo documentation around the manufacturing plant. The duration of the interview session was about 15-20 minutes.

4. Results and Analysis

The selected DfMA principles based on the literature review were taken as a reference for the researchers to explore whether the principles of DfMA executed at the selected precast manufacturing concrete plant. DfMA is the concept where this approach best described as 'improving quality through the application of efficiency (Buildoffsite, 2018). The principles of the DfMA concept identified include: 1) minimize the number of components; 2) design ease for assembly; 3) design components for multi-use; 4) use modular design; and 5) use of the standardized component. The summary of all interviewee’s answers is presented in the next section.

4.1 DfMA Principle 1 - Minimize the Number of Component

Minimizing the number of components is crucial as there is an opportunity for a defective part and an assembly error to occur (Ramamoorthy, 2017). Inventory and work-in-process levels will go down with fewer components (Pei, 2012). Two interviewees (INT1 and INT2) pointed out that the method they are practicing has minimized the number of components needed because all components have been produced as one unit. The summary of the interview is shown in Table 3.

Table 3: Interview results for DfMA Principle 1

Interviewee	Remarks
INT1 (Plant A)	*"In this factory, we practice the prefabricated prefinished volumetric construction (PPVC) where the component can be minimized. With PPVC, we do not need to construct one by one of the components. Mold is prefabricated first with a complete basic component such as wall and slab followed by finishes such as windows, ceiling, M&E. When part of the building component is produced as one module, the inspection becomes lesser towards the final product because the quality is improved rather than inspecting one by one of the separated building components".*
INT2 (Plant B)	*"From my previous company job experienced, I was involved with modular construction work. This method produces almost the same shape between other modules. The module production is like a combination of the all-important element of construction that attach together. So the point is, it has minimized the number of the component by not inventing one by one of the component. They will just need to use the mold to produce a module".*
INT3 (Plant C)	*"Minimizing the number of components in the manufacturing stage is depends on the design that was given to us. I cannot declare that the DfMA can minimize the number of components because so far, the number of components manufactured in our plant was quite many. We are just following the design specifications from the drawing that had been sent to us."*

As highlighter by INT1, his plant involved PPVC manufacturing which supports the DfMA concept (Ramamoorthy, 2017). PPVC is a modular construction that able to reduce the process of many component inventories as the module has been incorporated the components into one unit. Besides that, it is found that Plant C is not producing modular components, and only producing 2-D precast components such as wall, beam and column. INT3 added that his company only uses a modular design if there is demand from the client or customer.

4.2 DfMA Principle 2 - Design ease for assembly

Design ease for assembly is one of the important DfMA principles as it focuses on the design of a product. Assembly that is automated will be more uniform, reliable and of higher quality (Tomczykowski, 2011). INT2 postulated that the automation system that they are currently practicing has made their product quality consistently high. Table 4 shows the interviewees' answers to the question.

Table 4: Interview results for DfMA Principle 2

Interviewee	Remarks
INT1 (Plant A)	*"When we talked about the assembly things, I admitted that the PPVC concept has that advantage from the aspect of assembly activity. When it's time to assemble the modules on construction sites, fewer workers are needed in handling the assembly process. It is easier and I can say that it is time-saving for one construction project. To be more straightforward, you can imagine that the process of assembly is like playing the "Lego". Before we delivered the modules, each of it will go through the quality control checking before being attached on-site".*
INT2 (Plant B)	*"Design ease for assembly is important since assembly is the last process after all the process of the component being manufactured. To me, there are no big obstacles in the assembly process because all construction components are manufactured to be easily assembled on site. This is one of our visions to ease the assembly process on construction sites. The assembly of the construction components can be a problem if there are technical breakdowns since our factory used the automation machine system to produce construction components to assemble in the construction site".*
INT3 (Plant C)	*"Assembly activity can be eased if the designer can simplify the design by eliminating some steps without neglecting the stability and uniformity of the component. The designer should design the product that has less possibility to be reassembled. The alignment of the component needs to be concerned because the problem might arise during assembly. In our plant, we use BIM to avoid error on the design before manufacturing the product."*

As notified by Kumar [23], the design of one product should be integrating into the components to ease the assembly process. Complicated designs will result in a delay in the manufacturing

of the products as stated by INT1. INT1 also commented that the PPVC method that they practiced has eased the process of assembly on construction sites.

Meanwhile, INT2 highlighted that the design for assembly is important as it will affect the end of the product. Since Plant 2 uses automation for the manufacturing process of the component, it is important to ensure the smoothness of the operation by ensuring no technical breakdown. As for Plant C, the system has produced good quality products where the product has ease them to assemble the product in construction sites. The problem during assembly might rise from bad weather, material planning and machinery. According to INT3, in order to ease the assembly process, the designers should design the product with good alignment and less likely for the product to be rework. Plant C is currently used Building Information Modelling (BIM) software to avoid design errors before they manufactured the product desired and also to avoid reproducing other drawings.

4.3 DfMA Principle 3 - Design parts for multi-use

DfMA also focuses on the design of the component that has multiple uses, as well as reducing the number of the component produced as well. Designing the components should incorporate the knowledge of end products such as site, brief, specifications, constraints and key drivers, considers the range of suppliers and systems available (Bwail, 2017). Some of the interviewees commented and made their suggestion to design components for various use as presented in Table 5.

Table 5: Interview results for DfMA Principle 3

Interviewee	Remarks
INT1 (Plant A)	*"At the moment, we supply all PPVC modules for residential construction in Singapore. All 3D modules that have been manufactured are almost the same or we can say that it sort of repetition. The prefabricated mold that has been fabricated is used multi times in this factory. For this situation, it saves our time to manufacture one module instead of manufacturing separated parts of components".*
INT2 (Plant B)	*"All parts are manufactured according to the design in specific drawing and detailing. As this factory practiced the automation manufacturing that involves the robotic machine, rebar is a part that mostly used for a concrete element such as a shear wall, as a joint tool and reinforcement mesh. Rebar is a multi-use part of this factory and almost every day we produce it with the modernized machine. We also have a bending work machine to bend the reinforcement easily".*

In the manufacturing industry, a component is a synonym as a one-product production. Therefore, it is important for a component to be designed to facilitate the workmanship. It becomes easier if it is designed as a multi-use component (Anon., n.d.). Plant A, which produces the PPVC components, uses a modular design to produce fabricated mold. With regard to this principle, INT1 explained that their 3D module has the same shape as other modules. Thus, the prefabricated mold can be used for many times. Another interviewee (INT2) also voiced out that the reinforcement steel is a component that they are often used in their plant for various products such as the shear wall, joint tools and reinforcement mesh.

4.4 DfMA Principle 4 - Use modular design

Modular construction is one of the general terms in construction that describe the uses of technology that facilitates off-site manufacturing and prefabricated prefinished volumetric construction (PPVC). It is one of the game-changing technologies that support the DfMA concept where all the complete modules made of multiple units complete with internal finishes, fixtures and fittings are manufactured in factories then transported to site for assembly [9]. The use of modules in product design simplifies manufacturing activities such as inspection, testing,

assembly, purchasing, redesign, maintenance, service, and so on (Pei, 2012). Modular construction can reduce the need for on-site storage, plant and other equipment. All interviewee pointed out that the modular design has eased them to do testing on the product in the off-site manufacturing factory. One of the interviewees highlighted that the automation system for modules production produces a better quality product even the system is high cost. The automation system becomes more difficult and more expensive when more components are handled and processed [20]. There are some of the remarks made from the interview as shown in Table 6.

Table 6: Interview results for DfMA Principle 3

Interviewee	Remarks
INT1 (Plant A)	*"The PPVC method itself is related to modular production and of course we are practicing it in our factory to produce the modules according to the modular designs that are given to us. The modules also can be tested before being assembled on site. The testing activities on the product in off-site of the construction can lead to producing more quality products. But sometimes it becomes difficult when one design of the building component is too complicated and our task is to turn the design into reality because we need to fabricate the mold first according to the design. We need to get the target quantity but at the beginning, it is quite difficult to achieve it. A worker has their learning curve so it took about 3-4 months to achieve the target quantities".*
INT2 (Plant B)	*"In this factory, most of the concrete components use the automation machines that can be categorized as high-end machines and very expensive. This automation system is specially brought from Germany to produce a better quality of construction components and also to fulfill the specifications of the designs, especially for modules production. The automation machine that I have mentioned is called the EBAWE circulation pallet system. This automation machine will start to plot on top of the pallet when the data was sent to the automation machine according to the desired design. When the desired concrete product is done, we will proceed with QC inspection testing on a product. All activities can proceed faster when it happened in the same place".*
INT3 (Plant C)	*"Our factory did apply the modular design because we manufactured the prefabricated bathroom unit (PBU). This modular design is important to produce the modules. One module can consist of all elements of construction components where we do not need to invent more components because it already includes all the components."*

INT1 and INT2 highlighted that the modular design has eased them to do testing on the product whether in the plant or at the site. INT2 also stated that his plant uses an automation system to produce a module as well as other building components. Meanwhile, INT3 explained that they are not producing a modular component and focusing on 2-D components only.

4.5 DfMA Principle 5 - Use standard component

Table 7 shows the interviewees' remarks on this principle. One of the interviewees that currently producing the PPVC method stated that their factory mostly used standard components for the precast component manufacturing process (INT1). For the mold fabrication process, steel is used to produce the molds as it is more durable. This is in agreement with Vanguard Modular (2015) the modules are fabricated using standard component building construction materials while leveraging assembly line production methods. The interview results show that all interviewees currently use the standard component in their plant respectively.

Table 7: Interview results for DfMA Principle 3

Interviewee	Remarks
INT1 (Plant A)	*"Our factory mostly used all standard component materials in construction. For mold prefabrication, we use steel for the module construction. This is because steel can withstand fire, more durable and we can repeatedly use the prefabricated mold to produce many modules."*
INT2 (Plant B)	*"We are currently using all standard component materials for construction but what makes it different is the manufacturing way of the concrete product with a high-end automation system. Most of the space in our production line is reserved for reinforcement steel production. The automatic machine here has been set up to cut the reinforcement according to standard size."*
INT3 (Plant C)	*"I think most precast manufacturing plants produce standard components, except if there is demand from the client for a custom-made product. Standard components are cheaper and can fulfill most of the design specifications."*

5. Conclusion

The literature review findings were used to design interview questions in investigating the implementation of DfMA principles in the precast concrete manufacturing plant. From the findings of the interviews, 2 out of 3 selected precast concrete plants applied the DfMA principles. Among the principles applied by all plants are 'design ease for the assembly' and 'use standard component'. Meanwhile, the DfMA principles that were not currently applied by all selected plants are 'minimize the number of components', 'design components for multi-use' and 'use modular design'. It is found that there is one particular plant (i.e. Plant C), which did not apply the above DfMA principles. Some possible reasons for the non-compliance to the principles are:

i. for certain principles, the industry players might be lacking in knowledge of DFMA fundamentals. The lack of knowledge on DfMA fundamentals will resulting in unsuccessful DfMA implementation;
ii. higher investment cost in implementing the DfMA concept might be causing the industry player to not invest in DfMA;
iii. the manufacturing plant does not prioritize the DfMA concept because of lacking motivation and exposure on DFMA application from the employer or top management; and
iv. client's old-fashioned preference while working on the design drawings.

As a conclusion, this study has explored the application of DfMA principles in 3 different manufacturing plants in Johor. There are 5 principles of DfMA being investigated, each of the principles has explained by the selected interviewee from each plant, based on their experience and knowledge. All interviewees from these three manufacturing plants have different opinions and different perspectives on the DfMA principles studied. It is found that 2 out of 3 selected plants are practicing all of the DfMA principles. The findings from this study provide knowledge on the DfMA application in real practice. Future study is sought to extend the population and samples of precast concrete plants to entire Malaysia.

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