DESIGN FOR MANUFACTURING AND ASSEMBLY (DfMA) – WHAT AFFECTS ITS ADOPTION IN THE CONSTRUCTION PROJECTS?

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There is a consensus among industry leaders and scholars that the construction sector will lose its competitive advantages if its lethargy to adopt Industry 4.0 technologies continues. As a response, the construction industry has been advocating the more extensive use of the Design for Manufacturing and Assembly (DfMA) in projects. Research studies on this topic mainly reported technological advancement but rarely addressed the factors that lead to the development of positive organizational behavior towards the implementation of DfMA. A systematic literature review will be adopted to achieve the research aims. A total number of 18 behavioral traits were identified through the method, including client's interest, stakeholders support, availability of DfMA related resources, companies' capability, early involvement of all parties in design, development of DfMA-friendly procurement approach, the use of digital technology, government involvement, etc. The findings will shed light on DfMA adoption on behavioral aspects for global DfMA adoption in the construction industry.

Keywords: Offsite construction, Behavioral traits, Modular construction, Systematic review.

1 INTRODUCTION

There is a consensus among industry leaders and scholars that the construction sector will lose its competitive advantages if its lethargy to adopt Industry 4.0 technologies continues (Oesterreich and Teuteberg 2016). Industry 4.0 is described as the "fourth industrial revolution" that requires the industry to integrate advanced technologies into operations to enhance its efficiency, effectiveness and productivity (Dalenogare et al. 2018). As more extensive use of Internet of Things sensors, artificial intelligence, and real-time data capture is indispensable (Alaloul et al. 2021), many relevant ideas were proposed by the researchers, including the invention of robotics, the creation of multiple dimensions of Building Information Modelling (BIM), the introduction of 3D printing, and the development of digital twins (Wang et al. 2020, Das et al. 2021). Notwithstanding, the respective research outputs have reignited the industry’s interest in the use of Design for Manufacturing and Assembly (DfMA) (Langston and Zhang 2021).

DfMA is defined as "a construction where a substantial portion of work is designed and detailed to be done offsite in a controlled manufacturing environment" (BCA 2023). It is not a new concept. Since the 1980s, researchers have proposed many novel ideas about DfMA with the aim of optimizing offsite manufacturing (Weththasinghe and Wong 2023). However, over the past few decades, the two major hurdles to implementing DfMA in construction facing the industry remain unchanged – technology and behavior (Shang et al. 2021). The Industry 4.0 initiatives motivated
investments in advanced technologies; while, not until recent years were technologies needed for the implementation of DfMA readily available (Gao et al. 2018).

This study is prompted by a background that shows that little research into the behavioral aspects of DfMA implementation was done in previous years. It aims to identify the behavioral traits that can impact its successful adoption.

2 DEFINITIONS AND DEVELOPMENT OF DFMA IN CONSTRUCTION INDUSTRY

DfMA is not a new concept. This idea has been proposed since the 1980s when scholars called for simplifying production design and increasing manufacturing efficiency (Weththasinghe and Wong 2023). In construction, DfMA is described as a technical process that facilitates greater offsite manufacturing and minimizes onsite construction through different levels of offsite DfMA: 1) component manufacturing, 2) sub-assembly, 3) non-volumetric preassembly, 4) volumetric preassembly, and 5) modular building (RIBA 2016). It is to design and detail a substantial portion of the work offsite in a controlled manufacturing environment (BCA 2018). This study adopts the latest definition established by the Royal Institute of British Architects (RIBA 2016), which defines DfMA as "a construction where a substantial portion of work is designed and detailed to be done offsite in a controlled manufacturing environment".

Many people advocated the use of DfMA because it has been proven to bring various benefits to the industry, including reducing time and cost, improving the workplace environment, enhancing quality, improving sustainability, and lifting the reliability of construction operations (Ferreira et al. 2021, Hyun et al. 2022). More specifically, it reveals that the successful implementation of DfMA is affected by the attitudes and behavior of the construction project organizations (CPOs). In this study, CPOs are defined as the "organizations collaborating in a construction project including developers, design and cost, and main contractors/builders" (Qi et al. 2023).

However, these studies rarely provide empirical evidence to demonstrate the effect of behavior on adoption. These studies also rarely investigate how to foster a more extensive use of DfMA in behavioral aspects.

More importantly, while the developers often make the decisions to adopt DfMA in projects, the successful adoption should involve multiple CPOs collaborating at different stages of the project development. In other words, how CPOs collaborate, and their operations and business settings may affect the adoption of DfMA in projects. Nonetheless, previous studies in the construction management field rarely focused on the behavioral aspects of DfMA adoption.

3 THE RESEARCH METHODS

This paper researches how the traits contributing to DfMA adoption's success were identified. At the outset, desk research was conducted to identify these traits. Desk research is a research method that involves the use of existing data to summarize and organize information, thereby improving the overall effectiveness of the research.

Initially, an electronic search was conducted through (ProQuest Central, Scopus, and Web of Science) databases. The presence of two keywords clouds guided the search process: Cloud 1 (Design for Manufacture and Assembly AND DfMA) and Cloud 2 (barrier AND factor AND limitation AND challenge); eight pairs of keywords were searched, generating a total of 2224 results. Using the criteria of (i) the full-text article can be accessed, (ii) publication in a double-blind peer-reviewed journal, (iii) publication should be construction relevant, 221 papers were identified for review. To rationalize the scope of this review, only the top 100 most cited identified papers were reviewed.

The following searching and filtering criteria are used to select the literature (Fig. 1):
Fig. 1. Searching and filtering criteria used to select the literature.

(i) **Academic databases:** a set of databases is chosen, including ProQuest Central, Scopus, and Web of Science. References for each review article were used to identify relevant articles not included in the database.

(ii) **Keywords:** broad terms can be used when referring to a specific topic or concept. To search and locate all the required articles from academic databases, creating a complete combination of keywords is necessary. Therefore, two clouds of keywords have been identified: Cloud 1 (Design for Manufacture and Assembly AND DfMA) and Cloud 2 (barrier AND factor AND limitation AND challenge). Articles with a pair of keywords should be targeted. As such, eight combinations of keyword pairs were adopted.

(iii) **Publication year:** The main focus of this method is to investigate the latest information about the traits that contribute to the successful implementation of DfMA. Therefore, only articles published within the last ten years, from 2013-2023, were selected.

(iv) **Screening process:** Relevant articles are extracted from the initial broad search results by a two-stage screening method. In the first stage, only articles from 2013-2023 focused on the construction industry and written in English are included. The second phase includes only papers related to DfMA and its adoption behaviors.

4 **FINDINGS OF THE TRAITS CONTRIBUTING TO DFMA ADOPTION'S SUCCESS**

A number of systematic literature reviews and bibliometric analyses were undertaken to examine the concepts and the plans of DfMA in construction. To avoid duplication of efforts within this field, this part focuses on identifying the factors contributing to the successful adoption of DfMA.

Gao *et al.* (2018) identify 17 influencing factors through a literature review and classify them into six categories: 1) industry factors, including the presence of knowledge and supporting organizations; 2) government factors, including the presence of government legislation, the existence of government incentives, and presence of government investment; 3) stakeholder factors, including client factors, contractor factors, and integration of project teams; 4) design factors, including monotonous design due to standardization and changes to design process; 5) performance-driven factors; and 6) project-specific factors, including site constraints and storage, transportation considerations, and use of BIM. The most critical factors were identified based on the questionnaire survey within Singapore: "reduction in construction time", "site constraints and
storage", and "integration of project team". Similarly, Zhang et al. (2021) conducted a questionnaire survey in Hong Kong to identify the critical success factors of adopting modular integrated construction (MiC). A total of 15 factors were selected. The factors were divided into five categories: 1) industry factors, including recognition and acceptance by industry, the existence of knowledge and experience, and capability of supporting organization; 2) government factors, including the establishment of government legislation, provision of government incentives, and presence of government investment; 3) stakeholder factors, including client's understanding and willingness, contractor's leadership and support, and cooperation of critical stakeholders; 4) performance-driven factors, including reduction of construction time, reduction of construction cost, and enhancement of quality; 5) project-specific factors, including suitable site characteristics and layout, proper transportation evaluation, and the adoption of Information and Communication Technology. Structured interviews were conducted to identify the key challenges related to the adoption of MiC. The findings revealed that the most significant critical success factors for MiC, including the provision of government incentives, suitable site characteristics and layout, the establishment of government legislation, reduction of construction cost, comprehensive transportation evaluation, clients understanding and willingness, contractors' leadership and support, cooperation of critical stakeholders, and support from academia.

Wuni and Shen's (2020) research mainly focused on managing the early stages of PPVC (prefabricated prefinished volumetric construction). First, they listed 13 potential critical success factors for PPVC projects through literature review and expert review. Then, they conducted an international expert survey to determine the final list of critical factors. The nine factors are: 1) effective collaboration in the workplace, efficient communication and sharing of information among project participants; 2) early design freeze, detailed design and accurate drawing; 3) effective stakeholder management; 4) use of information and communication technology; 5) proper project planning and scheduling; 6) early decision-making and realistic economic analysis; 7) PPVC design and engineering experts engagement as the early stage; 8) key participants' previous experience and knowledge; and 9) early engagement of the key organizations.

Trigunarsyah et al. (2020) conducted a study in Saudi Arabia to investigate the implementation of offsite construction. The study involved interviews to identify the factors contributing to successful adoption and the barriers faced by the construction industry. As a result, eight enablers were identified: 1) stakeholders' knowledge of offsite construction; 2) events to increase people's awareness of offsite construction; 3) a system or flexible design on projects; 4) government engagement in offsite construction government's housing projects; 5) transportation infrastructure improvement; 6) improvement on stakeholders' communication system during the early stage of design; 7) enhancing the capacity of manufacturer, and 8) using a pilot project as a model for offsite construction. After the survey, two more enablers were added: 9) establishing building regulations and standard guidelines for offsite construction methods, and 10) government participation by offering incentives to ensure funding and insurance.

The findings timely highlight the importance of developing a set of construction-specific traits to evaluate the behavior of DfMA adoption. Table 1 presents the long list of behavioral traits summarized from the previous studies. Following the electronic search and literature review approach reported in this Section, a total of 221 citations mentioned one or more of the behavioral traits. For clarity, only six articles (labelled as A to F) with the highest numbers of citations were presented in Table 1.
Table 1. Behavioral traits affecting DfMA adoption.

<table>
<thead>
<tr>
<th>Behavioral Traits</th>
<th>Respective operational statements (The following affects my company's/organization's decision to adopt DfMA:)</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client's interest</td>
<td>My client expresses strong interest in adopting DfMA in projects.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Stakeholders support</td>
<td>My collaborating organizations/partners/stakeholders want my company to work with them to adopt DfMA in projects.</td>
<td></td>
</tr>
<tr>
<td>Companies' willingness to change</td>
<td>My company is willing to change its operational and management practices to fit the adoption of DfMA.</td>
<td></td>
</tr>
<tr>
<td>Availability of resources</td>
<td>My company has allowed sufficient resources to adopt DfMA.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Companies' capability</td>
<td>My company is capable of adopting DfMA.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Competitiveness</td>
<td>My company will lose its competitiveness in the market if it does not adopt DfMA.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Early involvement in design</td>
<td>DfMA requires my company to work with others at the early stage of the project to confirm the building design.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Time spent in design</td>
<td>DfMA requires my company to spend more than usual time working with others to confirm the building design.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Transportation strategies</td>
<td>DfMA requires my company to devise more effective transportation strategies to foster the adoption.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Site management</td>
<td>DfMA requires my company to adjust the site management approach to foster the adoption.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Procurement approach</td>
<td>DfMA requires my company to adjust our project procurement approach to foster adoption.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Digital technology</td>
<td>DfMA requires my company to adopt more advanced digital technologies to enable collaborations among project stakeholders that can be located far apart.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>New standards establishment</td>
<td>DfMA requires my company to establish new standards for design, procurement, manufacturing, assembly, testing and inspection.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Stakeholders experience</td>
<td>My collaborating organizations/partners/stakeholders have relevant experience in DfMA projects.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Government involvement</td>
<td>Government policies/directions encourage us to adopt DfMA.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Companies' willingness to share information</td>
<td>My company is willing to share relevant project information with other stakeholders to enable the adoption of DfMA.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Personnel proficiency</td>
<td>My company has professional and/or skilled labors to carry out the DfMA processes involved in the manufacturing and assembly of building components.</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>Real benefits</td>
<td>DfMA can improve the profit margins of my company.</td>
<td>A B C D E F</td>
</tr>
</tbody>
</table>


5 CONCLUDING REMARKS

Researchers advocate the advantages of adopting DfMA in the construction industry. One problem with this area of research is that most studies focused on the technical barriers to DfMA adoption and ignored the behavioral barriers, making it challenging to apply the result to construction organizations that can decide to adopt DfMA. This study used the systematic literature review to identify the behavioral traits of DfMA adoption. 18 behavioral traits that affect the adoption of DfMA in construction projects were identified. The identified traits cover different aspects of behavior that may affect companies' responses to DfMA adoption. It is worth noting that some traits are relevant to how a party may collaborate with other stakeholders in the supply chain to enable adoption. Others are relevant to resource allocation, such as the pathway for further studies into understanding the relative importance and the inter-relationships of the traits. This will help devise solutions to foster cooperation among CPOs for more extensive use of DfMA in projects.
References


