EPiC Series in Built Environment
Volume 3, 2022, Pages 344–352
ASC2022. 58th Annual Associated Schools of Construction International Conference

Time, Cost, and Construction Intensity Comparison between Design-Manufacture-Construct and Traditional Design-Bid-Build Delivery Methods

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The Design-Manufacture-Construct (DMC) technique is a novel delivery method that decreases construction time and cost while increasing construction intensity compared to a traditional delivery method. The purpose of this study was to understand the time, cost, and construction intensity differences between DMC and the conventional Design-Bid-Build (DBB) delivery method. The study utilized semi-structured interviews (SSI) and quantitative data analysis for investigation. The study included interviews with employees from BLOX LLC (a firm specializing in the DMC delivery method) and includes an analysis of data collected on multiple free-standing emergency department (FSED) projects constructed using both the DMC and DBB delivery methods. Descriptive and inferential statistics were used to test hypotheses based on the two delivery methods' time, cost, and construction intensity performance factors to analyze the project data. The results suggested that DMC outperforms DBB in cost performance, supported by inferential statistics data ($p \approx 0.00$). Moreover, although inferential statistics do not show any significant difference between DMC and DBB ($p > 0.05$) concerning time and construction intensity performance, descriptive studies indicated that DMC still performs better than DBB in both these factors.

Key Words: Modular Construction, Design-Manufacture-Construct (DMC), Delivery Method, Business Model, Performance

Introduction

At present, the traditional construction industry's performance remains low, and productivity improvement is slight compared to other sectors such as the manufacturing industry (Mao et al., 2017). Unlike traditional construction, most studies suggest that modular construction reduces project duration and cost (Azhar et al., 2013; Blismas & Wakefield, 2009; Wuni & Shen, 2019; Jaillon & Poon, 2009) moving the productions to offsite factories. On the contrary, some studies argue that modular construction exhibits little difference in time and cost performance than conventional construction (Mao et al., 2016). Zhai et al. (2014) concluded their research by suggesting a thorough time and cost comparison between traditional and modular construction methods. The architecture, engineering, and construction (AEC) industry has been reluctant to drastically alter its business model of in-situ construction. It is suggested that the modular construction industry could learn from the manufacturing industry's more efficient production methods (Luo et al., 2017).

In contrast with manufacturing, construction is a project-oriented business producing a unique product, where more resources are involved and more stakeholder relationships exist between activities. The establishment of an innovative delivery method is essential to increase productivity. Architects need to learn from the manufacturing industry and view buildings as manufacturing products (Wuni & Shen, 2019; Hu et al., 2019) to consider the assembly process thoroughly. Some industry practitioners have taken the challenge to initiate a novel modular construction business model. One such company, BLOX LLC, proposes a Design-Manufacture-Construct (DMC) delivery method that oversees the means and methods from design to construction by intentionally leveraging manufacturing. A recent article in the *Engineering News Record* suggests that the DMC delivery method could provide a new platform for the AEC industry (Judy, 2020).

Research Rationale

While there are other studies that compare cost and time in favor of modular construction, none have been specifically focused on the design-manufacture-construct process that seems to be disrupting the conventional means of building the freestanding-emergency-department building classification type. Therefore, this study addresses this gap by conducting a time, cost, and construction intensity comparison between the DMC modular construction method and the traditional construction method of DBB. This research is unique in that it provides an analytical approach toward understanding the effectiveness of the DMC method used for the FSED building type through both a descriptive and inferential lens.

Methodology

A quantitative analysis was conducted using data collected from BLOX LLC for projects using the DMC method and similar projects using a traditional DBB method. These quantitative data and qualitative data via informal interviews were also collected to enrich the comparisons between the two delivery methods. The following sections describe the equations used to analyze the data.

Analysis of Time

The design and construction duration measures the time between the start of the design phase to the certificate of occupancy. This time analysis compares the projects' duration from design to construction between DMC and DBB. The format of the time analysis is displayed in EQ. (1):

$$Time = Final\ certificate\ of\ occupation\ date - Final\ design\ start\ date \quad (1)$$

Analysis of Cost

The cost comparison is calculated by dividing the final project cost, which includes transportation costs (the original contract amount plus all changes orders for the project) by the overall area in terms of square feet. The general format of cost analysis is presented in EQ. (2):

$$Cost = \frac{Final\ design\ and\ construction\ cost}{Total\ project\ square\ feet} \tag{2}$$

Analysis of Construction Intensity

The construction intensity compares the construction square footage installed over time as shown in the following equation EQ. (3):

$$Costruction\ intensity = \frac{Total\ project\ square\ feet}{Final\ design\ and\ construction\ duration} \tag{3}$$

Furthermore, these metrics were then analyzed using an inferential two paired-sample t-test to determine a significant difference between the DMC and DBB delivery methods on time, cost, and construction intensity performances. These data are then used to decide the following hypotheses and associated null hypotheses.

1. $H1_A$: $Cost_{DMC} < Cost_{DBB}$ ($H1_0$: $Cost_{DMC} \geq Cost_{DBB}$)
2. $H2_A$: $Time_{DMC} < Time_{DBB}$ ($H2_0$: $Time_{DMC} \geq Time_{DBB}$)
3. $H3_A$: $Construction\ Intensity_{DMC} > Construction\ Intensity_{DBB}$ ($H3_0$: $Construction\ Intensity_{DMC} \leq Construction\ Intensity_{DBB}$)

The questions were asked to elicit views from participants in the design, manufacture, and construction process and obtain opinions on critical factors influencing time and cost using DMC. A series of data was then processed through equations to determine DMC's performance in terms of time and cost.

Semi-Structured Interviews

Data were also collected by conducting semi-face-to-face (Zoom) interviews with three team members who worked on the case study projects, they were the Design operations manager, the Superintendent, and the Lead- MEP vertical. The questions were asked to elicit views from participants in the design, manufacture, and construction process and obtain opinions on critical factors influencing time and cost using DMC.

Results

Samples

The researcher collected 21 DMC and 34 DBB project data sets. Of these projects, the 21 DMC projects were collected from BLOX LLC (modular building method). The 34 DBB data sets were collected from competitors to BLOX LCC that built FSED projects using the DBB delivery method. Out of these 21 DMC projects, 7 were health clinics that significantly differed in size and programs than the rest of the data and were therefore excluded from the analysis. Thus, for this research $n_{DMC} = 14$ and $n_{DBB} = 34$.

Time Results

Figure 1 illustrates the 14 DMC and 34 DBB projects' time in a boxplot. This figure shows DBB has a more concentrated distribution between 213 to 241 days with a median of 235 days. By comparison, DMC has a broader distribution range between 190 to 240 days with a median of 220 days. Both DBB and DMC have a significant duration gap between the shortest and longest project completion times.

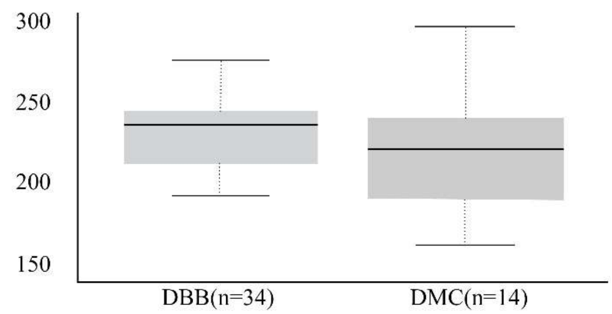

Figure 1. *DMC vs. DBB Design & Construction Duration (Calendar Days) Scatter Plot Comparison*

Figure 2 compares duration of the 14 DMC projects and 34 DBB projects in the same plot. This scattered plot illustrates that while the DMC projects and DBB projects have a relatively similar performance duration, DMC's duration decreases higher than DBB projects. The DBB trend line is unchanged over time. In other words, DMC has a better continuous improvement opportunity in design and construction duration, and over time, DMC tends to outperform DBB.

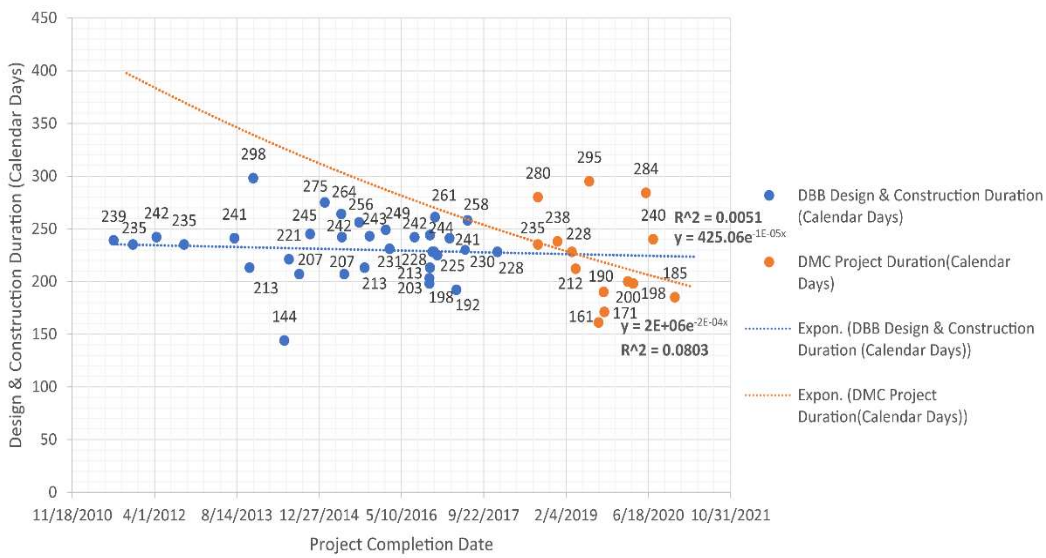

Figure 2 *DMC and DBB Time (Calendar Days) Scatter Plot Comparison*

Design and Construction Cost Results

The distributions of the 34 DBB projects are from the year 2011 to 2017, and the 14 DMC projects are from 2018 to 2019. The DMC cost data includes all change order costs. Due to lack of specification, the researcher assumed that all DBB cost data included change order costs as well. The researcher realized the inflation and material prices could significantly vary due to the different time periods of the DMC and DBB projects. To make the cost data more comparable, the researcher uniformly adjusted all values to a future value in 2021 with a 2% annual inflation rate using the equation:

$$Future\ Value = Present\ Value \times (1 + i)^n$$

Figure 3 illustrates the 14 DMC and 34 DBB projects cost in the boxplot. This figure shows DBB has a broader distribution between \$801/SF to \$992/SF with a median of \$895.5/SF cost. By comparison, DMC has a tighter distribution range between \$560/SF to \$664/SF with a median of \$621/SF cost. The figure clearly shows DMC outperforms DBB in the design and construction cost metrics by a significant amount.

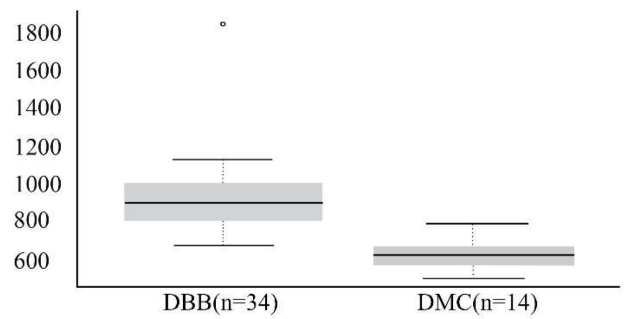

Figure 3 *DMC vs. DBB Design & Construction Cost (\$/SF) Boxplot Comparison*

Figure 4 compares the cost tendency of the 14 DMC projects and 34 DBB projects in the same plot and indicates that the DMC cost is significantly lower than that of DBB projects. The cost is steadily increasing for both DBB and DMC-delivered projects. However, the DMC projects are growing at a slightly higher rate when compared to DBB projects.

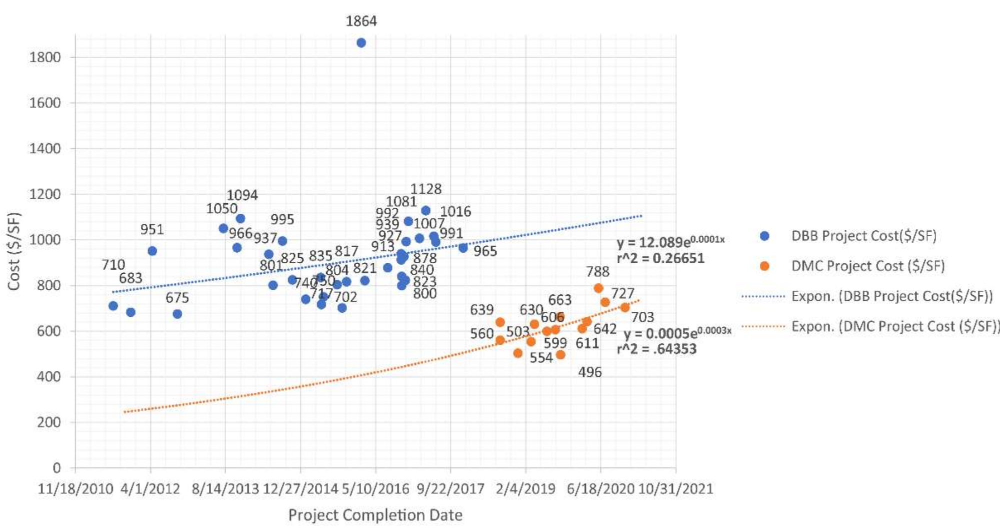

Figure 4 *DMC and DBB cost per square foot scatter plot*

Construction Intensity Results

The final design and construction intensity is calculated by the completion date less the final start date. The DMC data specified that the start date is when the team first started the project's design stage. Due to lack of information, it was assumed that the DBB start date was when the project team first started the project design stage. Figure 5 illustrates the intensity of the 14 DMC and 34 DBB projects in the boxplot. This figure shows that DBB has a more concentrated distribution between 41.9 to 49.1 SF per day with a median of 46.9 SF per day. In comparison, DMC has a broader distribution range between 42.6 to 58.8 SF per day with a median of 56.4 SF per.

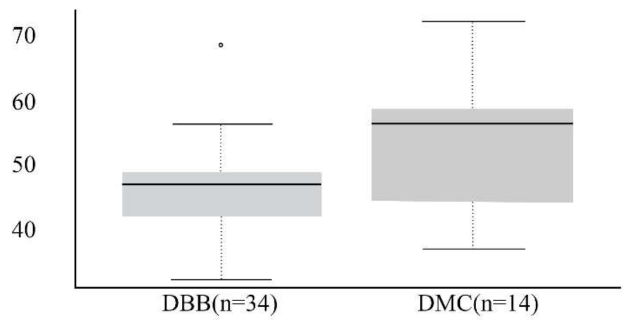

Figure 5 *DMC vs. DBB Design & Construction Intensity (SF/Calendar Days) Boxplot Comparison*

Figure 6 illustrates the construction intensity tendency data of DMC and DBB delivered projects. This figure shows that the DMC delivered projects seem to have a little bit higher construction intensity. The slope suggests that DMC's construction intensity increases at a much higher rate than DBB showed projects. In other words, DMC is improving construction intensity at a much higher rate while DBB remains stable.

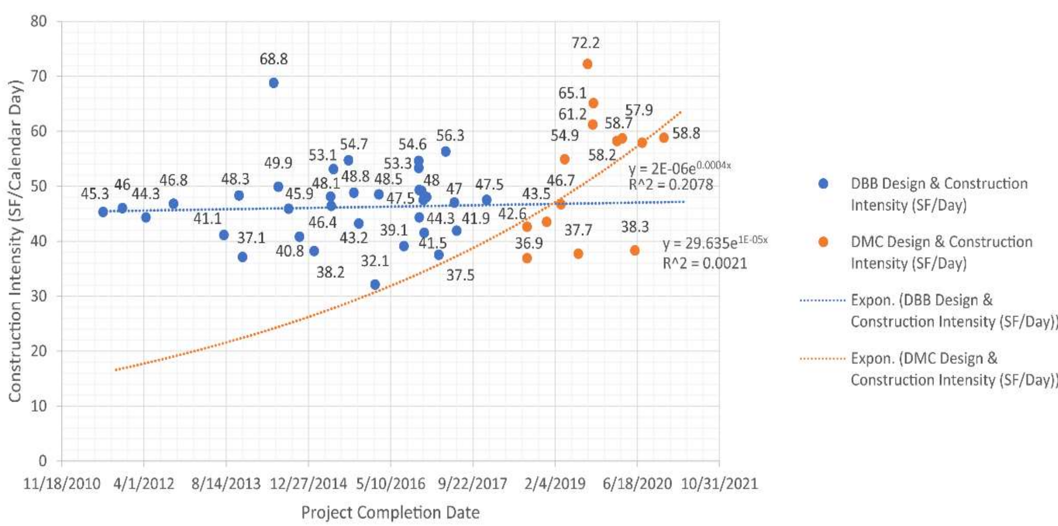

Figure 6 *DMC and DBB construction intensity scatter plot*

Inferential Two-Samples t-Test Results

Two samples t-test performed to test the alternate hypothesis for H1, H2, and H3 mentioned earlier in the paper. Outliers were not omitted. The performance metrics calculated according to the equations (1), (2), and (3). Mean ratings were used to compute the three determining performance metrics for each delivery method. Table 1 organizes the mean and standard deviations for each performance factors of the delivery methods were as follows: $Time_{DBB}$ (M=232.9, SD=27.2), $Time_{DMC}$ (M=222.6, SD=42.2), $Cost_{DBB}$ (M=912.9, SD=81.8), $Cost_{DMC}$ (M=622.9, SD=209.7), Construction $Intensity_{DBB}$ (M=46.6, SD=6.7), Construction $Intensity_{DMC}$ = (M=52.3, SD=11.3). There was a significant difference between the $Cost_{DBB}$ mean of 912.9 (SD=81.8) and $Cost_{DMC}$ mean of 622.9 (SD=209.7), t=6.89, p=0.00, in favor of the $Cost_{DMC}$. The null hypothesis $\mathbf{H1_0}$: X_{DBB} (cost) = X_{DMC} (cost), rejected. Therefore, the alternate hypothesis, $\mathbf{H1_A}$: X_{DMC} (cost) < X_{DBB} (cost), was correct, which the cost to DMC is significantly better than the cost of DBB delivered projects. However, the time hypothesis (p=0.77) and intensity hypothesis (p=0.09) are larger than 0.05. Therefore, the null hypothesis was not rejected, and there were no significant differences between DBB and DMC in time and intensity performance factors.

Table 1

Inferential study results on cost, time, and construction intensity performance factors

	H1-Cost Hypothesis		**H2-Time Hypothesis**		**H3-Intensity Hypothesis**	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
	($/SF)		(Calendar days)		(SF/Calendar Day)	
DBB (n=34)	912.9	81.8	232.9	27.2	46.6	6.7
DMC (n=14)	622.9	209.7	222.6	42.2	52.3	11.3
p	1.3 ^-08 (≈ 0.00)		0.41		0.09	
t	6.89		0.77		1.78	
Hypothesis Determination	$H1_0$: XDBB (cost) = XDMC (cost) REJECTED		$H2_0$: XDBB (time) = XDMC (time) ACCEPTED		$H3_0$: XDBB (intensity) = XDMC (intensity) ACCEPTED	

Discussion

Reduction in time and cost is argued to be the significant advantage of modular construction systems compared to conventional construction methods. (Azhar et al., 2013; Blimas & Wakefield, 2009; Jang et al., 2020). This study analyzed 14 DMC and 34 DBB project data using both descriptive and inferential two-tailed samples t-test. Respectively, both descriptive and inferential two-samples t-test confirmed DMC outperforms DBB in terms of cost. Figure 3 and 4 shows the DMC cost result (M=622.9, Median=621), and DBB cost result (M=912.9, Median=895.5). There is a mean difference of $290/ SF, and a median difference of $274/ SF. Descriptively, DMC performs better in terms of cost. Moreover, Table 1 indicates the inferential p-value for cost 0.00 is less than 0.05 ($p \leq 0.05$), which rejects the H_0, and concludes that the cost when using DBB is higher than using DMC. However, for time (p= 0.41) and construction intensity (p= 0.09) performances, the two-tailed p test accepted the null hypothesis ($p > 0.05$) that DMC shows no significant differences when compared to DBB at a 95% confidence level (Table 1). The conservative assumption on the DBB data could have influenced this result since the study conservatively included the design stage in DBB's time data. Nonetheless, the descriptive scatter plots and boxplot still showed advantages (Figure 1, 2, 5, and 6). With the DMC time result (M=222.6, Median=220), DBB time result (M=232.9, Median=235), DMC construction intensity result (M=52.3, Median=56.4), and DBB construction intensity data (M=46.6, Median=46.9). It still showed a time mean difference of 10.3 calendar days, time median difference of 15 calendar days, construction intensity mean difference of 5.7, and construction intensity median difference of 9.5. Descriptively, DMC performs better. In addition, the descriptive studies showed tremendous continuous improvement opportunities in DMC, which was illustrated in the plotted trend lines.

Based on the interview with BLOX, the researcher concluded that DMC has three major advantages: (1) DMC allows efficient communication between all stakeholders, (2) DMC cuts redundant work such as acquiring building permits by working on repeated well-established projects, and (3) DMC utilizes concurrent engineering to innovatively design standard parts that could improve efficiency.

Limitation

There were several limitations to the study. The first limitation was related to the sample and sample size. The sample size was small, with only 14 DMC, 34 DBB and 3 interviewees included in the study. A second limitation was that the quantitative data was solely collected from BLOX LLC. The researcher made assumptions about the data due to the lack of information provided with each data set. For example, the researcher assumed that the DBB duration included the design and construction phases, but this is unknown if true. Therefore, both limitations impact external validity and make the results challenging to generate the most accurate sample conclusions. The third limitation was related to project types. FSED projects are the only type included in this study and are typically conservative to explore DMC's full potential since they have a complex program. The fourth limitation was the lack of considerations of location. For example, the operation manager mentioned the cost differential to build an FSED project in Texas vs. Florida vs. Nevada could be millions of dollars based on site-specific conditions alone.

Conclusion

DMC demonstrated advantage compared to DBB in terms of cost, time, and construction intensity performance factors for the large-scale expansion of well-established projects. The continuous improvement opportunities simultaneously advance design simplification, process optimization, and product innovation, ultimately improving time, cost, and construction intensity performances. Future research should consider investigating other building types. Moreover, future studies should conduct in-depth qualitative research to measure the practitioners' opinions involved in the modular building process. Furthermore, future studies should specifically investigate potential opportunities available when the DMC process is used.

Reference

Arashpour, M., Wakefield, R., Blismas, N., & Minas, J. (2015). Optimization of process integration and multi-skilled resource utilization in offsite construction. *Automation in Construction*, *50*, 72–80. https://doi.org/10.1016/j.autcon.2014.12.002

Azhar, S., Lukkad, M., & Ahmad, I. (2013). An investigation of critical factors and constraints for selecting modular construction over conventional stick-built technique. *International Journal of Construction Education and Research*, *9*, 203–225. https://doi.org/10.1080/15578771.2012.723115

Blismas, N., & Wakefield, R. (2009). Drivers, constraints and the future of offsite manufacture in australia. *Construction Innovation: Information, Process, Management*, *9*, 72–83. https://doi.org/10.1108/14714170910931552

Goulding, J. S., Rahimian, F. P., Arif, M., & Sharp, M. D. (2015). New offsite production and business models in construction: Priorities for the future research agenda. *Architectural Engineering and Design Management*, *11*(3), 163–184.

Hu, X., Chong, H.-Y., Wang, X., & London, K. (2019). Understanding Stakeholders in Offsite Manufacturing: A Literature Review. *Journal of Construction Engineering and Management*, *145*(8), 03119003.

Jang, J., Ahn, S., Cha, S. H., Cho, K., Koo, C., & Kim, T. W. (2020). *Toward productivity in future construction: Mapping knowledge and finding insights for achieving successful offsite construction projects*. 14.

Judy, S. (2020). Blox looks for a better way to build projects. *ENR: Engineering News-Record*, *284*(12), 24–25.

Luo, J., Zhang, H., & Sher, W. (2017). Insights into Architects' Future Roles in Offsite Construction. *Construction Economics and Building*, *17*, 107. https://doi.org/10.5130/AJCEB.v17i1.5252

Mao, C., Xie, F., Hou, L., Wu, P., Wang, J., & Wang, X. (2016). Cost analysis for sustainable offsite construction based on a multiple-case study in china. *Habitat International*, *57*, 215–222. https://doi.org/10.1016/j.habitatint.2016.08.002

Wuni, I., & Shen, G. (2020). Stakeholder management in prefabricated prefinished volumetric construction projects: Benchmarking the key result areas. *Built Environment Project and Asset Management*, *10*, 407–421. https://doi.org/10.1108/BEPAM-02-2020-0025

Wuni, I. Y., & Shen, G. Q. (2020a). Critical success factors for management of the early stages of prefabricated prefinished volumetric construction project life cycle. *Engineering, Construction and Architectural Management*, *27*(9), 2315–2333. https://doi.org/10.1108/ECAM-10-2019-0534

Wuni, I. Y., & Shen, G. Q. (2020b). Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. *Journal of Cleaner Production*, *249*, N.PAG-N.PAG. https://doi.org/10.1016/j.jclepro.2019.119347

Zhai, X., Reed, R., & Mills, A. (2014). Factors impeding the offsite production of housing construction in china: An investigation of current practice. *Construction Management and Economics*, *32*(1–2), 40–52. https://doi.org/10.1080/01446193.2013.787491