Learning from Previous BIM-Based Modular Construction Cases: Qualitative Comparative Analysis Approach

Tae Wan KIM[1*] and Jung-ho YU[2]

[1] *Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong*
[2] *Department of Architectural Engineering, Kwangwoon University, Korea*
**Corresponding author's e-mail: taewkim@cityu.edu.hk*

ABSTRACT

Successful implementation of Building Information Model (BIM) -based modular construction projects is not always guaranteed in different regions and their associated contexts, because success depends heavily on combinations of multiple conditions, including technological, political, social and cultural, and economic ones. Such difference in conditions often hinders a successful modular construction company in a region from continuing its success in other regions; however, understanding the complex causality between the conditions and the success in implementation from previous BIM-based modular construction cases is very challenging because (1) each case omits some conditions and focuses too much on others, which makes the comparison difficult, and (2) cases are insufficient in number for dealing with various conditions, i.e., a small-N or intermediate-N situation. To address this problem, based on the review of previous case studies and modular construction theories, this paper classifies and defines nine condition variables that can be utilized in developing and analyzing BIM-based modular construction cases more comprehensively and systematically. This paper then discusses how the qualitative comparative analysis (QCA) approach can be used to find sufficient and necessary combinations of conditions for successful BIM-based modular construction projects. Upon successful completion, the QCA approach will contribute more structured and generalized explanations of success and failure in BIM-based modular construction to the industrialized construction theory.

KEYWORDS

BIM; case study; modular construction; project success; QCA

INTRODUCTION

Modular construction has gained more attention from practitioners and researchers alike in recent decades because it supports sustainable development, facilitates the building process, and is less affected by external factors than traditional construction methods, such as weather and labor quality (Lawson et al. 2014). In tandem with the development of building information modeling (BIM) technologies, modular construction has emerged as a competitive solution for almost all types of buildings, including academic facilities, residential buildings, hotels, and commercial buildings; however, even if modular construction seems to be a promising solution for a certain project, and a company has long been successful in BIM-based modular construction in one region, that does not guarantee the successful implementation of the project, which depends heavily on a combination of multiple conditions, including technological (e.g., unskillfulness in

BIM), political (e.g., strong support for traditional methods), social and cultural (e.g., lack of demand for modular construction), and economic conditions (e.g., high transportation cost). Such difference in conditions often hinders a successful modular construction company in a region from continuing its success in other regions. In an effort to overcome this limitation, many BIM-based modular construction case studies have been developed and introduced to shed light on some relationships between condition variables and the outcome variable, i.e., the success of a project. Discerning the complex causality in previous cases, however, between various conditions and success is challenging because (1) each case omits some conditions and focuses on others, making the cross-case comparisons difficult, and (2) cases are insufficient in number for dealing with various conditions, i.e., a small-N or intermediate-N situation.

There have also been several qualitative approaches to explaining the causality based on previous case studies. The driver-barrier approach describes what situations would drive more use of modular construction by amplifying its benefits (i.e., drivers) and what situations would function as barriers to the use of modular construction by amplifying its limitations (Elnaas et al. 2012; Larsson and Simonsson 2012; Mao et al. 2013; Zhai et al. 2014). Although this approach helps project teams decide whether modular construction is suitable for their projects, it does not directly relate these situations with the project success when implemented. In the critical success factor (CSF) approach, factors that affect the success of modular construction projects are derived and explained, which are very similar to the conditions of success (Murtaza et al. 1993; O'Connor et al. 2014); however, this approach is for general use rather than offering project-specific answers. For example, are all CSFs needed in order to succeed? What if one factor is missing in a project? Under what circumstances? These questions cannot be answered by this approach. In addition, the driver-barrier approach and the CSF approach do not normally take into account the combinatorial impacts of drivers, barriers, or factors, and provide no means of measurement. The production strategy theory-based approach, proposed by Jonsson and Rudberg (2014), suggests the combinatorial impacts of drivers and barriers; however, it has been used only to discuss the strengths and weaknesses of different building production systems, including modular construction.

In this context, the authors suggest that the qualitative comparative analysis (QCA) method can be applied to reveal the complex causality between multiple condition variables and the outcome variable, i.e., BIM-based modular construction project success, due to the following advantages (Berg-Schlosser et al. 2009): (1) The QCA enables researchers to characterize cases using the condition and outcome variables and compare them in a formalized way. (2) It takes into account the combinatorial effects of conditions when developing the "recipes" for success or failure. According to the QCA method, multiple recipes can exist, and a condition can be a positive factor in one recipe and a negative factor in another. (3) It has been designed to deal with a small-N or an intermediate-N situation, where there are a limited number of cases characterized with a large number of conditions. (4) More importantly, while the QCA method discovers the recipes with quantitative measures, such as consistency and coverage, it also allows researchers to revisit the cases during the development of the recipes in order to gain deeper understanding of modular construction and its success in implementation.

Therefore, as a first step for conducting the QCA method to discover the multiple complex causalities between condition variables and success in BIM-based modular construction projects, this paper describes the condition variables we identified in the following groups: company-related, project-related, and region-related. We limited our scope to comparisons between cases where a company conducts a BIM-based modular construction project in a region with which the company is not familiar. This paper then discusses how the QCA approach can be used to find recipes for successful BIM-based modular construction projects from case studies.

METHODS

This research considers applying the fuzzy-set QCA (fsQCA) method (Ragin 2009), among other types of QCA methods, because it allows researchers to define a partial membership when grouping cases according to the condition and outcome variables. This characteristic is important in this research because many conditions (e.g., unskillfulness in BIM, high transportation costs) and project success cannot be categorized simply as 0 (non-membership, meaning not at all agreeable) or 1 (full-membership, meaning totally agreeable).

To define the variables in fuzzy sets, we first identified and summarized possible conditions that were described normatively in literature (e.g., "*Building volume* is a critical factor in achieving economics of scale when using prefabrication in Hong Kong" (Jaillon and Poon 2009)) or descriptively in case studies (e.g., "Project A was expected to have more difficulties since Australia tends to have *high turnover of personnel* and *labor issues with union agreements*" (O'Connor et al. 2014)). We then developed the measures for each condition and outcome variable in either a four-value fuzzy set (i.e., membership = 0, 0.33, 0.67, and 1) or a continuous fuzzy set. In the case of a continuous fuzzy set, we further identified three important qualitative anchors (i.e., values where non-membership (0) is reached, values where full-membership (1) is reached, and values where the maximum ambiguity (0.5) resides). Usability of these measures was tested via existing case studies to ensure that these measures could reasonably characterize the cases. While developing the measures, we were able to use our improved understanding to further elaborate the definitions of the variables and subsequently divide or combine some of them.

RESULTS AND DISCUSSION

The first two sections describe the condition and outcome variables that we identified, as well as our suggestions for measuring them. Then, the third section discusses how these results can be used in fsQCA for deriving the causality between the conditions and the outcome based on case studies of modular construction projects.

Success of BIM-Based Modular Construction Projects

Although it is very challenging to define the success of a project in one variable, the fsQCA approach enables researchers to investigate each case in a careful manner, including extensive documentation reviews and in-depth interviews with project participants, and to evaluate the success of a project based on their holistic view (Basurto and Speer 2012). Therefore, our suggestion is to measure the outcome variable in a four-value fuzzy set as follows: 0 (non-membership) when project participants express a strong sense of failure (e.g., "We should never come again and do the project in this region."), 0.33 (partial membership leaning towards a failure) when the project meets the break-even point and yields no loss, 0.67 (partial membership leaning towards a success) when the project is deemed profitable, and 1 (full-membership) when not only is the project deemed profitable but the company also establishes a foundation for long-term success.

Conditions Possibly Affecting the Success of Modular Construction Projects

We have identified 25 condition variables that could possibly affect the outcome variable, i.e., the success of modular construction projects, based on our literature review. As these are too many to be included in the fsQCA, we have selected nine condition variables according to their frequencies (i.e., how often they are mentioned in the literature) and developed measures for them in a fuzzy set. The nine variables are comprised of three company-related, three project-related, and three region-related ones (Table 1).

Table 1. Condition variables that may affect the success of modular construction projects.

Type	Variable	Freq.	Measure
Company-related	Local experts (including assembly teams)	9	0: Limited access to local experts; 0.33: Local experts in the market with weak connections; 0.67: Local experts as strategic partners; 1: Local experts who have been involved in the project development.
	Technology innovation	5	0: Technologies and experiences limited to a certain type of buildings; 0.33: Sufficient technologies with a few successes in projects; 0.67: Sufficient technologies with rich success history in project; 1: Equipped with novel technologies developed by in-house development teams.
	Company culture (including training and education)	4	0: Lack of effective organizational mechanism for communication, team building, and problem solving; 0.33: Effective organizational mechanism with limited education and training program for frontline employees; 0.67: Effective organizational mechanism and employee development program; 1: Strong emphasis on modular construction education and training for employees.
Project-related	Construction cost	8	Expected cost savings compared to the traditional methods (0: -50%; 0.5: -10%; 1: 0%)
	Level of industrialization	6	Mass production coverage (0: 20%; 0.5: 50%; 1: 80%)
	Design changeability	5	0: Design still in development; 0.33: Design layout with expected major changes or variations; 0.67: Design layout with expected minor changes or variations; 1: Design layout ready for mass production.
Region-related	Governmental regulations	7	0: Lack of relevant codes, standards, and legislation; 0.33: Regulations that cover off-site aspects limitedly or are too old; 0.67: Regulations that cover most parts of off-site aspects; 1: Regulation deemed best practice.
	Stakeholders' attitudes	6	0: Resistant to change with little knowledge about modular construction; 0.33: Reluctant due to past failure in modular construction projects; 0.67: Willing to adopt and benefit from modular construction technologies; 1: Supportive from the start, providing opinions and resources if necessary.
	Governmental incentives	5	0: No governmental incentive such as tax relief and site coverage; 0.33: Incentive scheme in developing stage; 0.67: Incentive scheme placed and implemented; 1: Strong incentive scheme to promote modular construction methods in the region.

In terms of company-related conditions, involving experienced local experts is deemed critical to the success of modular construction projects because it can heavily affect the implementation of module assembly and module completion stages (Jonsson and Rudberg 2014). Technological innovation affects the project success by speeding up the construction process, reducing the construction wastes and labor hours, and responding to unforeseen situations quickly and effectively. In addition, a company's mechanism for communication, team building, problem solving, education, and training could better deal with the work in an unfamiliar region. As for project-related conditions, construction cost of modular construction methods, including the cost of precast components and manufacturing units, can often be more expensive than that of traditional methods (Elnaas et al. 2012; Zhang et al. 2014). However, the cost can be saved by reduced wastage and less use of labor (Tam et al. 2007) aside from other benefits that modular construction methods can bring. Level of industrialization and design changeability are also critical to project success because they affect the volume and timing of mass production. Finally, region-related conditions includes governmental regulations, stakeholders' attitudes, and governmental incentives. Although we established some important qualitative anchors arbitrarily, these anchors can be modified to categorize the cases in a meaningful way once they are gathered and analyzed for fsQCA. Conditions that are identified in literature review less frequently include material used, climate constraints (Aburas 2011), building volume (Jaillon and Poon 2009), company size (Jonsson and Rudberg 2014), and module size (Chiang et al. 2006).

Learning about the Causality from Modular Construction Project Cases

Using the measures we suggested in the frame of the fsQCA approach, BIM-based modular construction project cases could be collected and compared in a more comprehensive and systematic manner. Each case study would provide a description of the project in terms of the condition and outcome variables and measure each variable with justifications. The fsQCA can then derive the multiple causalities between the condition and the outcome variables in the following two forms: conjunctively sufficient conditions, which almost invariably lead to the success of a modular construction project, and conjunctively necessary conditions, which are almost always present in successful modular construction projects (Ragin 1999). The more cases the fsQCA employs, the less logical remainders (i.e., configurations of the variables that have not yet been observed and thus need to be interpreted based on theoretical knowledge and engineering judgment) are left.

Once such information is provided, a company that considers conducting a project in a new region would be able to use the derived causalities in its go/no-go decision and preparation for the project. For example, if the region-related condition A and the project-related condition B are considered to comprise one recipe that leads to the success of the project (i.e., conjunctively sufficient conditions), and condition A is deemed satisfied after investigation, then the company can focus on satisfying condition B during its preparation. If the company-related conditions C and D are considered to be present together in successful projects (i.e., conjunctively necessary conditions), then the company can attempt to improve its skills related to those conditions.

CONCLUSIONS

It is highly challenging to identify the multiple complex causalities between the various company-related, project-related, and region-related conditions and the success of modular construction projects by simply gathering previous BIM-based modular construction project cases and investigating them without a structured framework. Such comparison is difficult because each case omits some conditions and focuses overly on others, and there are too few cases to deal with various conditions, i.e., a small-N or intermediate-N situation. To alleviate these problems, this research sought to explore such complex causality by applying the fsQCA approach. As a first step for conducting the QCA method, this research identified nine condition variables (three company-related, three project-related, and three region-related) and suggested measures for the variables. It also suggested a measure of the success of a BIM-based modular construction project in a four-value fuzzy set. With the measures we suggested, BIM-based modular construction project cases could be collected and compared in a more comprehensive and systematic manner to reveal the causal complexity in two forms, i.e., sufficient sets of conditions and necessary sets of conditions. With such information, a company that considers conducting a project in a new region would be able to make more sound decisions about the project. Upon successful completion, the QCA approach will contribute more structured and generalized explanations of success and failure in BIM-based modular construction to the industrialized construction theory.

ACKNOWLEDGEMENTS

This research was supported by a grant (14AUDP-C067809-01) from Architecture & Urban Development Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

REFERENCES

Aburas, H. (2011). "Off-site construction in Saudi Arabia: The way forward." *Journal of Architectural Engineering*, 17(December), 122–124.

Basurto, X., and Speer, J. (2012). "Structuring the calibration of qualitative data as sets for qualitative comparative analysis (QCA)." *Field Methods*, 24, 155–174.

Berg-Schlosser, D., Meur, G. De, Rihoux, B., and Ragin, C. C. (2009). "Qualitative comparative analysis (QCA) as an approach." *Configurational Comparative Analysis*, B. Rihoux and C. C. Ragin, eds., SAGE Publications, 1–18.

Chiang, Y. H., Hon-Wan Chan, E., and Ka-Leung Lok, L. (2006). "Prefabrication and barriers to entry-a case study of public housing and institutional buildings in Hong Kong." *Habitat International*, 30, 482–499.

Elnaas, H., Gidado, K., and Ashton, P. (2012). "Factors and drivers effecting the decision of using off-site manufacturing (OSM) in house building industry." *Journal of Engineering, Project, and Production Management*, Pingtung: Association of Engineering, Project, and Production Management, 4(1), 51–58.

Jaillon, L., and Poon, C. S. (2009). "The evolution of prefabricated residential building systems in Hong Kong: A review of the public and the private sector." *Automation in Construction*, Elsevier, 18(3), 239–248.

Jonsson, H., and Rudberg, M. (2014). "Classification of production systems for industrialized building: a production strategy perspective." *Construction Management and Economics*, Taylor & Francis, 32, 53–69.

Larsson, J., and Simonsson, P. (2012). "Barriers and drivers for increased use of off-site bridge construction in Sweden." *28th Annual ARCOM Conference*, Association of Researchers in Construction Management, 3-5 September 2012, Edinburgh, UK, 751–761.

Lawson, M., Ogden, R., and Goodier, C. (2014). *Design in Modular Construction*. CRC Press, FL, USA.

Mao, C., Shen, Q., Pan, W., and Ye, K. (2013). "Major barriers to off-site construction: The developers' perspective in China." *Journal of Management in Engineering*, ASCE, 31(3), 04014043.

Murtaza, M. B., Fisher, D. J., and Skibniewski, M. J. (1993). "Knowledge-based approach to modular construction decision support." *Journal of Construction Engineering and Management*, ASCE, 119(1), 115–130.

O'Connor, J. T., O'Brien, W. J., and Choi, J. O. (2014). "Critical success factors and enablers for optimum and maximum industrial modularization." *Journal of Construction Engineering and Management*, ASCE, 140(6), 04014012.

Ragin, C. C. (1999). "Using qualitative comparative analysis to study causal complexity." *Health Services Research*, Blackwell, 34, 1225–1239.

Ragin, C. C. (2009). "Qualitative comparative analysis Using fuzzy sets (fsQCA)." *Configurational Comparative Analysis*, B. Rihoux and C. C. Ragin, eds., Sage, 87–122.

Tam, V. W. Y., Tam, C. M., Zeng, S. X., and Ng, W. C. Y. (2007). "Towards adoption of prefabrication in construction." *Building and Environment*, Elsevier, 42, 3642–3654.

Zhai, X., Reed, R., and Mills, A. (2014). "Factors impeding the offsite production of housing construction in China: an investigation of current practice." *Construction Management and Economics*, Taylor & Francis, 32, 40–52.

Zhang, X., Skitmore, M., and Peng, Y. (2014). "Exploring the challenges to industrialized residential building in China." *Habitat International*, Elsevier, 41, 176–184.