Modular concrete construction

The differing perspectives of designers, manufacturers, and contractors in Lebanon

Farook Hamzeh, Omar Abdul Ghani, Mohammad Bassel Saleh Bacha and Yara Abbas

Department of Civil and Environmental Engineering, American University of Beirut, Beirut, Lebanon

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Abstract

Purpose – This study evaluates the enablers and barriers for modular concrete construction in Lebanon. The purpose of this paper is to investigate various factors (time, cost, technical know-how, organizational, sustainability, etc.) and their influence on the choice of the construction method. The paper examines the different assessments of designers, manufacturers, and contractors regarding precast construction in comparison to traditional in-situ methods, and highlights the major differences in their views.

Design/methodology/approach – Structured face-to-face surveys were conducted with top management personnel of precast manufacturers, architectural and engineering firms, and contracting companies in Lebanon. In addition, a case study from the largest precast project in Lebanon was used to provide a deeper understanding of factors encouraging the use of precast concrete, and to highlight major onsite issues associated with its implementation.

Findings – On the one hand, the findings highlight technical, logistical, organizational, and cultural factors that inhibit the use of precast concrete as a construction method. On the other hand, results reveal that cost, time, sustainability, and flexibility factors are the main enablers for increasing the uptake of modular concrete construction.

Originality/value – The main contribution to knowledge is that this study presents different stakeholders' perspectives on precast concrete construction. Moreover, this is the first research addressing precast concrete construction in the Middle East and Lebanon. The results of the study provide valuable global insights and recommendations that may help increase the uptake of precast concrete construction. They can also guide project stakeholders to properly match project characteristics and precast concrete as a construction method.

Keywords Developing countries, Construction, Construction management, Construction systems, Concretes, Construction engineering

Paper type Research paper

1. Introduction and literature review

Precast construction refers to concrete building and structural elements that are cast in molds at a centralized facility, transported to site, and then installed at the intended project (Chan and Hu, 2002). Prefabrication is a manufacturing process that produces component parts for the final facility by integrating a multitude of items either off-site or onsite (Gibb *et al.*, 1999; Testa, 1972). While precast concrete construction offers several environmental, structural, and economical benefits that encourage its application, it is important to understand the barriers hindering the expansion of its use over traditional cast-in-situ methods.

Project duration and the speed of construction are major concerns for owners and developers. This is where precast concrete construction adds value to the process by enabling superstructure work to progress off-site while the foundations are being constructed (Kelly, 2005). The just-in-time and lean philosophies in supplying precast elements at the time of onsite installation has tremendous value in alleviating the space

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constraints for onsite storage and traffic congestion around the worksite (Pheng and Chuan, 2001; Meiling *et al.*, 2012).

Due to their favorable prerequisite conditions, industrialized countries such as the USA have enjoyed a rise in the use of precast concrete and reaped benefits in consequence (Polat, 2008). On the other hand, various challenges are hindering the use and expansion of precast systems in developing countries. These barriers include: the lack of good communication among parties as well as the lack of structural engineers and contractors specialized in precast concrete systems (Polat, 2010). Although off-site concrete construction is present in rapidly developing countries such as China, its benefits are still not fully understood and it has not been employed as much as it should be (Zhai *et al.*, 2014).

Chen *et al.* (2010) state that the hindered-expansion-of-prefabrication problem could be alleviated with better decision making to aid the selection of appropriate construction methods. Several models were developed to aid in the selection process (Murtaza *et al.*, 1993). When discussing the possibility of contractors developing in-house off-site capabilities rather than subcontracting the work out to a manufacturer, Vernikos *et al.* (2013) believe that such a non-traditional organizational rearrangement could result in short-term off-site construction benefits being more easily realized. However, this requires a committed support from top management to develop a clear and transparent system of communication across the various hierarchical levels of the company and to direct more investments toward research and development (R&D) for spurring innovation in this domain (Vernikos *et al.*, 2013). Several variables affect the long-term performance of the precast industry. For example, growth in the construction industry, accurate sales forecasting and production plans, accurate and fast circulation of information about production and orders in the system, government spending, and non-availability of skilled site labor increase the need for off-site fabrication (Nashwan and Richard, 1990). Furthermore, historical accidents on precast construction projects dent the industry's reputation and affects its expansion due to difficulties in overcoming the prejudice surrounding such incidents (Goodier and Gibb, 2005).

Seeing developers as the most influential stakeholder in terms of deciding between on and off-site construction, Mao *et al.* (2013) analyze the barriers to off-site construction from a developer's perspective. The main factors found are: the absence of governmental regulations and incentives, high initial cost, and the dependence on traditional construction methods. Chiang *et al.* (2006) investigate the impact of Hong Kong's government efforts on promoting precast in housing construction. Lachimpadi *et al.* (2012) and Zhang *et al.* (2014) confirm the important role government programs play in the implementation of industrialized building systems by fostering off-site construction via incentives and subsidies, reskilling labor forces, and/or increasing manufacturing capacities to reach a level of mass production that enables the private market to sustain the industry independently.

Pan *et al.* (2012) find it difficult for organizations to identify and recognize the advantages of off-site production given the lack of value-based decision criteria; this is especially true given that "measuring project success or failure is very limited" (Gibb and Isack, 2003). Thus, they provide a three-level decision criteria matrix consisting of more than 50 criteria that were clustered into eight categories. They couple this matrix with a structured decision-making process to aid the house-building construction industry in making more informed value-based construction method decisions. It is worth noting that participant interviewees in their study in the UK, a developed country, believed that the criteria categories of sustainability as well as health and safety were obligatory, and therefore no trade-off could be negotiated. This is mainly due to the increasing concerns, awareness, and strict governmental requirements and regulations in the UK; such factors are lacking in many other developing countries.

With no consensus reached regarding the overall value of precast construction, Lam *et al.* (2007) assess the constructability of various construction systems according to a set of researched constructability factors extracted from industry experts in Hong Kong. Results show that precast systems received the best rating in terms of constructability for almost all elements of a building's structure ranging from structural frames, slabs, roofs, internal walls, and external building envelopes. A similar result was revealed in a study performed by independent consultants in Saudi Arabia. In the study, developers perceived precast construction systems to be better than conventional cast-in-situ concreting or Insulated Concrete Forms construction systems in almost all 14 comparison factors considered (Green Precast, 2013).

One of the major stakeholders' concerns is the performance of precast systems under earthquakes, especially in beam-to-column connections. Analyzing several types of these connections, Yee *et al.* (2011) recommend the avoidance of some (e.g. field welding) while advancing other precast connection types (e.g. Dywidag Ductile Connections) that are capable of withstanding large vigorous earthquake events with minimal structural damage. The recommended connections can be installed on site without the need for developed technologies, and they comply with the economic boundaries of cost.

Modular precast concrete industry is growing slowly in developing countries. The precast concrete industry in Lebanon is less mature than that in developed countries. It emerged in Lebanon as a solution for the increasing demand for reducing construction time. The Gross Domestic Product (GDP) for Lebanon is estimated at $44.35 billion (World Bank, 2013) and the construction industry contributes 4 percent of its GDP (IDAL, 2011). Thus, the size of the construction industry is relatively small when compared to other countries. Consequently, economies of scale are completely different and the factors affecting the use of precast may vary.

The most common precast elements used in the Lebanese market are hollow-core slabs, pre-stressed beams, and pre-stressed slabs. Moreover, the use of such elements, mainly hollow-core slabs, is becoming more popular due to value engineering carried by the contractors to speed up the program. Although some projects have used 3D modular elements, 2D elements comprise the majority of market use. While competition should improve quality and reduce cost, the Lebanese precast market is not in a real competition due to the small capacity of precast suppliers. In fact, some large projects required a combined effort of all suppliers to cover their demand.

While modular concrete provides many advantages compared to the conventional cast-in-situ methods, its use still faces many barriers. Even though some studies have addressed the benefits of precast concrete construction and challenges facing its wide implementation (Arditi *et al.*, 2000; Blismas *et al.*, 2006; Chiang *et al.*, 2006; Jaillon *et al.*, 2009; Polat, 2008, 2010), none has analyzed the perspectives and interests of different project stakeholders. Moreover, no previous studies have investigated the precast concrete industry in Lebanon. In fact, some questions remain unanswered: "How do various project parties, namely architects and engineers (A/Es), contractors, and manufactures, perceive precast concrete in comparison to traditional methods? What are the main barriers and enablers for implementing precast construction at a wider scale in Lebanon?"

In this regard, this study presents the first assessment of the enablers and barriers for implementing off-site construction in Lebanon. The study also analyzes the perspectives of designers, manufacturers, and contractors to formulate a better understanding of the needed matchup between project design and the most suitable construction process; thus, increasing value generated on the project.

2. Research methodology

When investigating the precast concrete industry in Lebanon, no studies have indicated the factors contributing to the growth of this industry, the barriers hindering the wide implementation of this method, or the perspectives of project parties on choosing precast construction as a preferred method of construction. Hence, this paper aims at answering the following research questions:

RQ1. What are the main barriers and enablers for implementing precast construction at a wider scale in Lebanon?

RQ2. How do various project parties, namely, A/Es, contractors, and manufactures, perceive precast concrete in comparison with traditional methods?

RQ3. How can this understanding help increase the uptake of precast construction?

A research design was developed to start with research questions and arrive at explanatory conclusions. It selects and assigns methods of evidence collection to address the research questions. The plan looks at the methods required to answer each question, how and what data to collect, and how to analyze data (Yin, 2003). Research was performed through five main stages: first, assessment of the current literature addressing the implementation of precast concrete methods; second, identification of key areas that need to be analyzed; third, development of structured surveys and pilot testing; fourth, data collection from structured surveys and the case study; and fifth, analysis of the results and formation of conclusions. Figure 1 summarizes the research methodology employed in this study.

In addressing the research questions posed, a methodology combining structured survey analysis and case study analysis was selected. Structured surveys were conducted with experienced professionals from various design, contracting, and precast concrete firms in Lebanon. The paper draws on results from a major case study project in the Lebanese capital, Beirut, where precast concrete from all precast suppliers in Lebanon was used. While survey results represent a cross-sectional view of the nature of precast industry in Lebanon, case study results highlight field issues over a project's life and show a more longitudinal aspect of characteristics of the industry. Using multiple sources of evidence (survey, case study, visits, interviews, photos, etc.) is necessary to develop a process of triangulation where different lines of inquiry converge (Meredith, 1998, Stuart *et al.*, 2002; Yin, 2003).

Research involves some limitations including: survey interpretation, non-generalizability of case study results to the whole industry, limited availability of data and documentation, and bias of interviewees. Hence, several actions were taken to overcome these limitations. The survey was pilot tested to gather feedback and refine the questions. This ensures that the questions match the intended purpose and lowers response bias. Structured surveys were used where data are collected by an interviewer rather than through mailed or online self-administered questionnaire. The interviewer reads the survey questions in the similar manner each time to ensure that each respondent receives a similar interview stimulus as the other respondents. Structured surveys were employed because of the many advantages they offer such as: higher response rate, reduction of interpretation errors, and increased degree of data reliability (Dipboye, 1994; Creswell, 2003; Bryman, 2012; Phellas *et al.*, 2012; Roulin and Bangerter, 2012). Moreover, data from surveys and the case study were compared to results from previous studies to ensure that results are realistic.

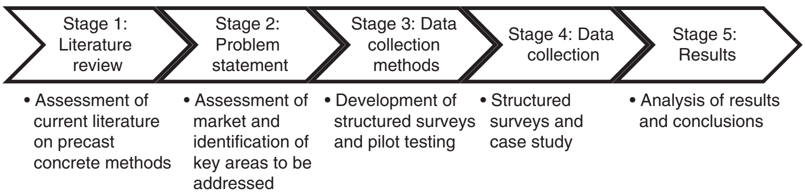

Figure 1.
Research method followed

The survey was developed after Jaillon *et al.* (2009) study and adjusted to meet the Lebanese construction context. It consists of four main sections addressing general information, construction methods and waste minimization, benefits and challenges of the precast concrete industry, and the precast products demanded in Lebanon. The first section includes information about the organization and the interviewee. The second section aims to identify the main decision factors taken into account when choosing a construction method, distinguish the work components considered the most waste producing, and highlight the significance of waste minimization. The purpose of the third section is to determine the benefits and barriers for adopting prefabrication in Lebanon and the importance of each factor that affects the process. The fourth section aims to recognize the precast elements that could be provided by precast suppliers and the level of demand for each type. Data from the structured surveys (30 interviews) were collected using a five-point Likert scale (1 = least important, 2 = less important, 3 = neutral, 4 = important, 5 = very important).

The survey targets various stakeholders in the precast concrete construction industry in Lebanon including general contractors (GC), A/Es, and precast manufacturers (M). The authors had to secure approval from the companies' management prior to conducting the surveys (collecting data in Lebanon is extremely difficult due to companies' resistance to participating in research). The distributions of the participants according to their position within the firm, the nature of the company they work for, their overall years of experience, and number of employees are summarized in Table I.

Conducting the survey involves a 30-minute structured interview session with each respondent. The interviewer distributes a copy of the survey to the respondent and reads the questions out loud while recording the respondent's answer to each question. Toward the end of the survey, the interviewer asks open ended questions regarding the enablers for increasing the uptake of precast construction in Lebanon. This results in a 5 to 15 minute discussion session. Since the interview results are anonymous, respondents feel free to give their personal opinion thus allowing new ideas to be brought up during the interview and enriching the quality of the data obtained.

The survey included all precast suppliers in Lebanon. Out of the contractors and A/Es pool, the survey addresses those who employ precast construction the most. To identify if those companies fit the purpose, an assessment of contractors and A/Es in the Lebanese construction industry is performed. The authors referred to two lists ranking contractors and A/E firms by the Council for Development and Reconstruction (CDR). The CDR, a public association, produces these lists to classify companies during the bidding and award process for their projects across Lebanon. Thus, the interviews addressed the top contractors and A/E firms in the market who are associated with precast concrete construction in Lebanon.

A case study project was also selected to provide a deeper understanding of project circumstances when employing precast concrete, the factors encouraging the use of precast concrete, and the major onsite issues associated with day to day construction of precast systems. The case study section provides further details about the case study and reasons behind its selection.

Position within the firm		Nature of firm		Years of experience		Number of employees	
White collar (technical)	53%	Contractor	53%	< 5	3%	1-19	0%
Blue collar	0%	Architect /engineer	33%	5-10	10%	20-99	17%
White collar (managerial)	47%	Manufacturer	14%	11-15	30%	100-199	20%
				16-20	7%	> 200	63%
				> 30	50%		

Table I. Distribution of participants in structured interviews

3. Survey results and discussion

Data from structured surveys were collected over more than 18 months into a database. Results were later analyzed using statistical tools in R and Excel. Responses were broken down into six categories: factors impacting the choice of construction methods, ranking precast vs cast-in-situ methods, evaluating the waste minimization associated with precast concrete, assessing benefits of precast concrete, assessing the barriers to precast concrete, and assessing the overall satisfaction with the precast concrete method. Tables II-VII present the full results for each of the six categories and respects the following presentation method:

- Column 1 shows the entries in each category;
- Columns 2 and 3 highlight the mean (μ) and standard deviation (α) for each entry in the survey ($N=30$).
- Column 4 shows the one-sample t-test results for entries in each category compared to the neutral test value of 3 (test the significance of the results).

Table II. Results for the construction methods category

Construction methods	μ	α	p-value for test value $=3$	A/E-GC	p-value	M-GC	p-value	A/E-M	p-value
Familiarity with the construction technology	4.10	0.87	*0.00*	0.81	*0.01*	0.27	0.62	0.55	0.22
On site labor dependence requirements	3.70	0.97	*0.01*	0.17	0.64	0.53	0.34	−0.36	0.59
Construction cost	4.70	0.55	*0.00*	−0.44	*0.05*	0.20	0.36	−0.64	*0.09*
Construction time	4.63	0.45	*0.00*	−0.55	*0.00*	−0.50	*0.00*	−0.05	0.89
Developers requirement	4.20	0.75	*0.00*	0.36	0.21	0.25	0.61	0.11	0.76
Waste reduction	3.51	1.16	*0.01*	−0.75	0.11	−0.43	0.49	−0.32	0.67
Availability of resources	4.00	0.85	*0.00*	−0.22	0.53	−0.13	0.91	−0.09	0.85
Delivery logistics	4.23	0.78	*0.00*	−0.38	0.22	0.55	0.24	−0.93	*0.02*
Constructability in the local market	4.07	0.76	*0.00*	0.61	*0.05*	0.58	0.20	0.02	0.95

Table III. Results for the precast vs cast-in-situ category

Precast vs cast-in-situ	μ	α	p-value for test value $=3$	A/E-GC	p-value	M-GC	p-value	A/E-M	p-value
Reduce overall project cost	4.25	0.94	*0.00*	−0.22	0.57	0.62	0.21	−0.84	0.15
Maximize returns	3.82	0.99	*0.00*	−0.46	0.23	0.77	0.22	−1.23	*0.01*
Site management	3.67	0.76	*0.00*	−0.19	0.54	0.02	0.97	−0.20	0.69
Aesthetic quality	3.34	1.07	*0.06*	−0.60	0.17	−0.10	0.85	−0.50	0.49
Quality of design	3.48	0.93	0.18	−0.47	0.18	0.53	0.31	−1.00	*0.09*
Quality of end product	3.98	0.94	*0.00*	−0.23	0.53	0.63	0.17	−0.86	0.20
Partnership between companies	2.97	0.77	1.00	−0.07	0.88	0.38	0.40	−0.45	0.31
Life cycle of building	3.67	0.97	0.12	−0.15	0.67	1.17	*0.03*	−1.32	*0.04*
Opportunity for standardization	4.19	0.92	*0.00*	0.09	0.81	0.50	0.32	−0.41	0.51
Reduce waste	4.16	0.88	*0.00*	−0.38	0.30	0.30	0.43	−0.68	0.29
Reduce material cost	4.23	0.79	*0.00*	−0.05	0.87	1.13	*0.00*	−1.18	*0.02*
Program progress	4.48	0.63	*0.00*	−0.24	0.37	−0.10	0.78	−0.14	0.72
Ease of maintenance	3.72	1.10	*0.00*	−0.05	0.90	0.40	0.54	−0.45	0.50

- Columns 5, 7, and 9 show the difference in means between the A/Es and the GC, manufacturers (M) and the GCs, and between A/Es and Ms, respectively.
- Columns 6, 8, and 10 present the statistical significance of each difference beyond the 90 percent level.
- All significant results are shown in italic.

Waste minimization	μ	α	*p*-value for test value = 3	A/E-GC	*p*-value	M-GC	*p*-value	A/E-M	*p*-value
Concrete work	3.27	1.07	0.50	−0.74	*0.09*	−0.22	0.62	−0.52	0.13
Formwork	3.85	1.03	*0.00*	−0.71	*0.07*	0.95	0.07	−1.66	*0.00*
Masonry work	3.70	0.97	*0.00*	0.17	0.67	0.53	0.34	−0.36	0.54
Finish work	3.50	0.97	*0.01*	0.08	0.85	0.03	0.95	0.05	0.94
Scaffolding	2.49	1.08	*0.00*	−0.20	0.62	1.05	0.13	−1.25	*0.03*
Hoarding	2.77	0.97	*0.00*	0.57	0.11	1.43	*0.00*	−0.86	0.17
Material handling	2.57	1.19	0.38	0.06	0.90	−0.41	0.56	0.48	0.49
Packaging and protection	3.43	1.20	0.26	0.77	0.12	0.88	0.24	−0.11	0.84

Table IV. Results for the waste minimization category

Benefits	μ	α	*p*-value for test value = 3	A/E-GC	*p*-value	M-GC	*p*-value	A/E-M	*p*-value
Reduction of construction time	4.69	0.50	*0.00*	0.04	0.95	0.47	*0.09*	0.43	0.11
Reduction of design time	3.64	0.89	*0.08*	0.02	0.47	0.73	*0.04*	0.71	*0.00*
Reduction of program time	4.47	0.66	*0.00*	0.09	0.75	0.80	*0.06*	0.71	*0.02*
Reduction of construction waste	4.13	0.95	*0.00*	0.14	0.26	0.75	*0.05*	0.61	0.12
Reduction of material use	4.13	0.59	*0.00*	0.26	0.56	1.40	*0.05*	1.14	0.19
Improved quality control	4.38	0.90	*0.00*	−0.50	0.59	0.68	*0.03*	1.18	0.12
Reduction of labor demand	4.30	0.65	*0.00*	0.56	0.48	0.38	*0.05*	−0.18	0.12
Project cost savings	4.14	0.82	*0.00*	−0.01	0.47	0.63	*0.01*	0.64	*0.00*
Fast return on investment	4.06	0.70	*0.00*	0.05	0.81	1.08	*0.01*	1.04	*0.01*
Improved ease of construction	3.93	0.88	*0.00*	0.27	0.59	0.52	0.68	0.25	1.00
Improved productivity	4.13	0.64	*0.00*	0.20	0.12	0.20	0.35	0.00	0.93
Improved site management and activities	3.92	0.79	*0.00*	−0.05	0.80	1.17	0.28	1.21	0.31
Improved health and safety	3.55	0.94	*0.06*	−0.04	0.45	0.53	0.31	0.57	0.16

Table V. Results for the benefits category

Barriers	μ	α	*p*-value for test value = 3	A/E-GC	*p*-value	M-GC	*p*-value	A/E-M	*p*-value
Conflict with traditional design process	3.21	1.33	*0.03*	0.49	*0.09*	−0.80	*0.06*	−1.29	0.37
Conflict with construction practice	3.14	1.16	*0.03*	0.18	0.90	−1.03	*0.08*	−1.21	*0.03*
Need specification change	3.09	1.06	0.22	0.08	0.30	0.18	0.92	0.11	0.59
Lack of standard components	3.24	1.16	0.29	0.64	0.52	0.07	0.80	−0.57	0.87
Lack of skilled labor	2.76	1.08	1.00	−1.29	*0.04*	−1.50	*0.05*	−0.21	*0.00*
Lack of hoist equipment capacity	3.28	1.28	*0.04*	−0.17	0.55	−1.35	0.18	−1.18	0.11
Lack of on-site storage yard area	3.73	0.99	*0.03*	0.08	0.10	0.68	0.19	0.61	*0.02*
Lack of support from client	2.98	0.87	1.00	−0.56	0.33	−0.13	0.79	0.43	0.77
High overall cost	2.20	0.99	*0.01*	0.56	0.48	−1.12	0.22	−1.68	0.39
Lack of incentives	3.34	1.00	0.48	−0.68	0.78	−0.78	0.27	−0.11	0.30

Table VI. Results for the barriers category

Table VII.
Results for the benefits category

Satisfaction	μ	α	p-value for test value = 3	A/E-GC	p-value	M-GC	p-value	A/E-M	p-value
Overall satisfaction	4.39	0.66	*0.00*	0.18	0.48	1.00	*0.00*	−0.82	*0.05*
Final cost	4.23	0.76	*0.00*	−0.12	0.69	1.07	*0.01*	−1.18	*0.01*
Material cost	4.04	0.82	*0.00*	−0.16	0.61	0.95	*0.00*	−1.11	*0.08*
Design	3.92	1.03	*0.00*	−0.42	0.27	1.40	*0.00*	−1.82	*0.01*
Monitoring production techniques	3.99	0.94	*0.00*	−0.07	0.85	0.70	0.11	−0.77	0.24
Delivery to site	3.81	0.86	*0.00*	0.15	0.64	1.10	*0.02*	−0.95	*0.08*
Reliability of product	4.13	0.91	*0.00*	−0.39	0.27	1.07	*0.00*	−1.45	*0.03*
Reduction in construction time	4.62	0.57	*0.00*	−0.17	0.47	0.47	*0.09*	−0.64	*0.09*
Communication with other stakeholders	3.68	0.86	*0.02*	−0.22	0.50	1.10	*0.04*	−1.32	*0.00*
Reduction of construction waste	4.01	0.91	*0.00*	−0.41	0.25	0.88	*0.02*	−1.30	*0.05*

3.1 Choice of construction methods

Results from this section of the survey, as summarized in Table II, reveal interesting angles describing the status of precast construction in Lebanon and how different specialists perceive its added value. When compared to contractors and precast manufacturers, A/Es have a lower appreciation of precast concrete as a method that reduces time, cost, and waste on a construction project. Moreover, A/Es seem to be less aware of the importance of "delivery logistics" than contractors and manufacturers. Results in columns 4, 6, and 8 show the variability of results across A/Es, contractors, and manufacturers. For example, the results clearly show that contractors and manufacturers rank "delivery logistics" and "waste reduction" higher than the A/Es do. Such results indicate that the A/Es preference for construction methods might not favor precast concrete at all times. It is strange that A/Es appear to be more familiar with the precast concrete method (average score of 4.55) than contractors are (3.73) and that contractors have a lower confidence in precast constructability (3.67) in the local market.

3.2 Ranking precast vs cast-in-situ methods

This category of questions compares precast to cast-in-situ methods as summarized in Table III. Examining the results shows a wide variability of opinions regarding the efficacy of the precast method. For example, A/Es rank "reduction of overall project cost" and "maximize returns" much lower than contractors and manufactures do as they do not see a clear cost benefit for this method. On the one hand, all separate parties graded the "aesthetic quality" of precast concrete as low. On the other hand, they all agree that precast concrete can help with the overall construction program, thus giving "program progress" a high grade. One alarming result is that of "partnership between companies" where all three stakeholders have a pessimistic view regarding the potential for the precast concrete method to improve project collaborations and partnerships. This result also reflects the non-collaborative nature of the industry in Lebanon. Results also show the wide discrepancy in opinions regarding "quality of end product" and "reduce material cost" where manufacturers rank these entries much higher than contractors and A/Es do.

3.3 Evaluation of waste minimization

This category addresses the prospects of waste minimization when employing precast concrete as a construction method. Results summarized in Table IV show that A/Es do not place high scores for the potential of precast concrete to generate savings on "concrete work", "formwork", and "scaffolding". Moreover, A/Es underappreciate the waste minimization potential of precast concrete. However, all three various specialists (A/Es, contractors, and manufacturers) agree that precast concrete would require a lot of material handling.

3.4 Benefits of precast concrete

This category examines the overall benefits of precast concrete. Results shown in Table V indicate that all parties agree on the benefits of precast concrete construction especially its impact on "improved site management and activities" and "improved health and safety". The specialists' opinions vary regarding "improved quality" and "project cost savings" where A/Es rank the former very low and manufacturers rank the latter very high. However, the biggest discrepancy between specialists' assessment of the benefits of precast concrete is in the "reduction of design time" and "reduction of construction waste" where A/Es grade them much lower than other specialists do.

3.5 Barriers to adoption of precast concrete

This section of the survey addresses the barriers to precast construction and the results are summarized in Table VI. While A/Es and contractors regard "conflict with construction practice" and "lack of hoist equipment capacity" as major barriers to precast concrete construction, manufacturers do not consider these factors as barriers. Moreover, A/Es consider "lack of skilled labor" as a major barrier for the uptake of precast in Lebanon while manufacturers have an opposing perception. It is interesting that all parties do not consider the "high overall cost" as a barrier for the uptake of precast concrete in Lebanon.

3.6 Satisfaction with the precast concrete method

This category presents an assessment of the overall satisfaction with precast concrete as the results shown in Table VII. Respondents are satisfied with the precast method giving the average result for "overall satisfaction" a grade of 4.39 out of 5.0. All parties are satisfied with the "Reduction in construction time" as it is graded the highest entry with an average of 4.62. On the other hand, "communication with other members of the project team" ranks lowest with an average of 3.68. The biggest disagreement in the satisfaction category was in "design" where A/Es rank it the lowest as they do not seem satisfied with the design of precast concrete projects.

4. Case study

4.1 Description

The Beirut City Center (BCC) project was used as a case study as mentioned in Section 2. It comprises the construction of a seven-floor shopping center with a 25,000 m^2 (around 270,000 ft^2) of footprint area, 164,000 m^2 (around 1,800,000 ft^2) of total built up area, and a total cost of USD170 million. The case study was carefully selected for the following reasons: it is a mega fast-track project, located in a metropolitan area with several logistical constraints, employs international building standards, uses huge amounts of precast units, and employs all the precast manufactures/suppliers functioning in Lebanon.

The BCC mall obtained the LEED pre-certification for the silver rating based on the US Green Building Council LEED sustainability scheme. One of the sustainability matters that were tackled was reducing the waste generated during construction by recycling, reusing, or donating waste materials (EcoConsulting, 2010).

The case study research involved collecting/investigating project records (e.g. quantities, cost figures, production rates, working zones, chronological events, project progress photos, etc.), interviewing six specialists who were involved in design and construction, visiting manufacturers' facilities who supplied precast units to the project, and comparing the data obtained from the case study project to survey responses.

To formulate a better understanding of the nature of precast concrete manufacturers supplying the project, all precast suppliers' factories were visited to assess the design technology used, products, plant technology, logistics, and production conditions. As Table VIII shows, the precast concrete industry is still developing in Lebanon and faces major obstacles in terms of logistics, technology, and skill level of the workforce.

The precast elements used in the project are predominantly hollow-core slabs and precast beams. While three types of hollow-core slabs of different thicknesses were used in order to account for three loading criteria, various sizes of precast beams were employed depending on the weight that the tower cranes can handle. The precast concrete system, comprising hollow-core slabs, precast beams, and concrete topping, was employed on approximately 83 percent of the horizontal area (excluding the raft foundation). To cater for the huge amount of precast elements, the project required the collaboration of all precast concrete suppliers in Lebanon to meet the demand. Although this required extensive planning and logistics, all parties (owner, engineer, and contractors) acknowledged that the precast system employed has delivered substantial savings in time (faster construction time of structural members allowed the finishing trades to start sooner) and resources (due to savings in scaffolding/ formwork material and in manpower). These results coincide with the survey results where the Lebanese contractors, A/Es, and manufacturers gave the precast concrete method a mean of 4.69 and 4.13 on reduction of construction time and reduction of construction waste, respectively. This empathizes the appeal to employ this method on projects requiring fast-track and sustainable approaches.

4.2 Implementation challenges

Contractors who were building the BCC project faced several problems during the installation of precast elements including: logistics, technical issues, and construction coordination concerns.

Logistical issues were mainly related to the limited capacity of lifting cranes and road transportation in Lebanon. For example, the huge size of precast beams obliged the contractors to build precast beams in three sections to facilitate installation. Moreover, transporting precast elements on Lebanese roads remains a challenge due to the hilly nature of the country (roads with steep grades) and the narrow roads. One specialist attributes the lack of heavy lifting cranes to the size of the construction industry that features a small number of large projects and a low overall demand (e.g. absence of large housing projects) for precast construction. Survey results from A/Es and contractors highlight "lack of hoisting capacity" and "lack of onsite storage areas" as barriers to precast construction, whereas manufacturers tend to regard those factors as non-deciding factors.

Table VIII. Assessment of precast concrete industry suppliers in Lebanon

Category	Details	Assessment
Design technology	The majority still design in 2D, only one manufacturer employs 3D	Developing
Products	Mainly 2D elements, two suppliers started manufacturing 3D elements	Developing
Plant technology	Plants employ semi-automatic forms with some computerized controls	Developing
Logistics	Plants employ automatic movement of panels within the plant using gantry cranes	Developing
Production Conditions	Plants' safety, organization, layout, work conditions, and ergonomics, are mediocre at best	Developing

Technical issues emanate from the limited local knowledge of precast systems where Lebanon has only a small group of specialized engineers and skilled laborers who are capable of providing solutions to site issues. These issues, which created bottlenecks during the BBC's construction, are not desirable especially on fast-track projects. Results from the structured survey indicate that only A/Es consider the lack of skilled labor and specialists as barriers to precast construction. This highlights a false sense of confidence on the part of contractors and manufacturers.

The majority of problems encountered on BCC were related to construction coordination. For example, the long spans of hollow-core slabs demanded an excessive camber which resulted in having thinner finishing thicknesses. Accordingly, such thicknesses were not enough to accommodate electromechanical first fix elements required beneath floor tiles. Moreover, the thickness of the bottom web (27 mm) was not enough for installing under-soffit bolts that support mechanical services. Moreover, the fast-track nature of the project demanded changes to the location of service penetrations through the slab. However, concrete coring in hollow-core slabs is very difficult due to the proximity of openings to tensioned cables, which endangers the integrity of these elements. Coordination-related issues were strongly highlighted by the survey results where "communication with other members of the construction team" was given the lowest score among all entries in the satisfaction category. This calls for more collaborative agreements that foster a stronger sense of ownership and partnering among project stakeholders.

Quality of the supplied precast elements imposed some challenges of its own. Due to variability in the length of precast hollow-core slabs, the shorter ones did not have the necessary embedment for self-support and consequently required temporary scaffolding during installation (especially adjacent to precast beams which were supposed to act as supports). This variability also impacted the sizes of joints that sometimes remained visible and were hence esthetically non-pleasing to owners. Survey results show a mean of 3.37, 3.49, and 4.0 for aesthetic quality, quality of design, and quality of the end product, respectively. This will resonate with the A/Es low ranking for the quality of precast concrete.

5. Conclusions

The study examines the enablers and barriers for the uptake of precast concrete construction in Lebanon. Results from structured interviews and from a case study project highlight technical, aesthetic, logistical, organizational, and cultural factors as barriers, whereas they identify cost, time, sustainability, and flexibility factors as enablers for precast concrete construction in Lebanon.

Technical issues that hinder precast construction in Lebanon are: lack of skilled labor and design/engineering specialists, unfamiliarity with the system and lack of construction specialists in this area, seismic requirements that sometimes do not favor non-monolithic joints between precast elements for tall buildings specifically, difficulty in introducing changes (e.g. coring) to precast concrete structures especially in fast-track projects where construction proceeds before the overall design is complete, and maintenance required for sealants and joints in precast structure due to the aggressive climate where temperatures can vary from 35 degrees Celsius in summer to subzero in winter.

Logistics play a central role in enabling the use of the precast concrete technology. In Lebanon, several logistical issues may impede the use of precast concrete construction such as: unavailability of large cranes that can handle large precast units, site accessibility problems for large trucks and trains, lack of trucks with enough capacity to carry large precast elements, and transportation issues related to narrow and steep roads that inhibit transporting precast elements, mainly during the rainy season.

Aesthetics play a role in the choice of the construction method. Several aesthetic requirements do not favor the use of precast concrete including: the choice of variable grids in the design of buildings, the need for drop beams that are disliked by A/Es, the lack of knowledge in designing aesthetically pleasant precast concrete structures, the unsightly joint lines between precast elements, and the lack of confidence from A/Es in the ability of contractors and manufacturers in delivering high quality structures (e.g. tolerances, joints, etc.). Therefore, the authors of this study encourage designers to adopt more innovative designs that incorporate precast concrete while maintaining an aesthetically appealing structure.

Organizational and cultural factors can also influence the success of precast concrete construction, namely: lack of collaborative mentality in the construction industry, poor communication between project participants, and lack of collaborative contracts or incentives that foster collaboration between several parties on a construction project. Moreover, the Lebanese government is far from introducing any subsidies or incentives for precast construction.

Commercial issues might sway the choice between precast construction and other methods. Cost is usually a major factor in owner's decision. The study findings indicate that the cost of precast concrete construction is not a barrier as highlighted by the low score (2.20) on "high overall cost". However, while contractors and manufacturers report huge cost savings when employing precast concrete, A/Es seem more skeptical about these savings. Therefore, further local studies are required to show that long term facility cost could be reduced despite the relative increase in initial construction cost. Some builders believe that even if the direct cost of precast concrete might be higher, the speed of delivery and time savings on the project's schedule amply compensate for the cost and save money overall. However, some specialists argue that even though precast concrete can save on construction schedule, time has a lower importance on some commercial projects due to lack of customers who readily occupy the finished buildings.

Moreover, some technical factors might favor the use of precast construction such as having precast elements not interfering with the main structure (e.g. columns, shear walls, and foundations). This factor enables precast construction especially when contractors look for alternative construction methods during value engineering and often sways the owner's decision toward adoption.

Other enabling factors for precast concrete include sustainability concerns that usually encourage the use of precast concrete. In fact, the majority of project parties surveyed perceive it as a strong contributor to sustainable construction in terms of reducing waste, materials, and processes.

In a nutshell, several factors favor precast construction such as cost, time, sustainability, and flexibility, while other factors inhibit its wide application in Lebanon such as technical, logistical, organizational, and cultural aspects. Future research should focus on developing decision support models for the Lebanese industry for comparing precast construction to traditional methods. These models can help decision makers to identify the crucial decision making factors and constraints for a certain project. A tool can be established as a formal framework for decision-making support and feasibility analysis based upon various factors. Moreover, these efforts are required to offset the negative perception of off-site construction by presenting more transparent information and comparisons with other traditional methods (e.g. cost, time, waste, quality, etc.) for the decision makers in the process.

References

Arditi, D., Ergin, U. and Gunhan, S. (2000), "Factors affecting the use of precast concrete systems", *Journal of Architectural Engineering*, Vol. 6 No. 3, pp. 79-86.

Blismas, N., Pasquire, C. and Gibb, A. (2006), "Benefit evaluation for off-site production in construction", *Construction Management and Economics*, Vol. 24 No. 2, pp. 121-130.

Bryman, A. (2012), *Social Research Methods*, Oxford University Press, Oxford.

Chan, W.T. and Hu, H. (2002), "Constraint programming approach to precast production scheduling", *Journal of Construction Engineering and Management*, Vol. 128 No. 6, pp. 513-521.

Chen, Y., Okudan, G. and Riley, D. (2010), "Decision support for construction method selection in concrete buildings: prefabrication adoption and optimization", *Automation in Construction*, Vol. 19 No. 6, pp. 665-675.

Chiang, Y.-H., Chan, E.H.-W. and Lok, L.K.-L. (2006), "Prefabrication and barriers to entry – a case study of public housing and institutional buildings in Hong Kong", *Habitat International*, Vol. 30 No. 3, pp. 482-499.

Creswell, J.W. (2003), *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 2nd ed., Sage, Thousand Oaks, CA.

Dipboye, R.L. (1994), "Structured and unstructured selection interviews: beyond the job-fit model", *Research in Personnel and Human Resources Management*, Vol. 12, pp. 79-123.

EcoConsulting (2010), "Beirut city centre", available at: http://ecoconsulting.net/www/bcc.htm (accessed July 14, 2016).

Gibb, A.G.F. and Isack, F. (2003), "Re-engineering through preassembly: client expectations and drivers", *Building Research and Information*, Vol. 31 No. 2, pp. 146-160.

Gibb, A.G., Groak, S., Sparksman, W.G. and Neale, R.H. (1999), "Standardisation and pre-assembly-adding value to construction projects", London Report No. 176, Construction Industry Research and Information Association (CIRIA), p. 220.

Goodier, C.I. and Gibb, A.G.F. (2005), "The offsite market in the UK – a new opportunity for precast?", in Borghoff, M., Gottschalg, A. and Mehl, R. (Eds), *Proceedings of the 18th BIBM International Congress and Exhibition*, RAI Congress Centre, Amsterdam, pp. 34-35.

Green Precast (2013), "KSA Construction Systems Evaluation", Green Precast Systems Summary Report, Riyadh.

IDAL (2011), "Lebanon in figures, the investment development authority of Lebanon", available at: http://investinlebanon.gov.lb/en/lebanon_at_a_glance/lebanon_in_figures (accessed July 14, 2016).

Jaillon, I., Poon, C.S. and Chiang, Y.H. (2009), "Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong", *Waste Management*, Vol. 29 No. 1, pp. 309-320.

Kelly, P. (2005), "Precast concrete in stadia", *Concrete-London-Concrete Society*, Vol. 39 No. 7, pp. 10-13.

Lachimpadi, S.K., Pereira, J.J., Taha, M.R. and Mokhtar, M. (2012), "Construction waste minimisation comparing conventional and precast construction (Mixed System and IBS) methods in high-rise buildings: a Malaysia case study", *Resources, Conservation and Recycling*, Vol. 63, pp. 96-103.

Lam, P., Chan, A., Wong, F. and Wong, F. (2007), "Constructability rankings of construction systems based on the analytical hierarchy Process", *Journal of Architectural Engineering*, Vol. 13 No. 1, pp. 36-43.

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*, Vol. 31 No. 3, pp. 1943-5479.

Meiling, J., Backlund, F. and Johnsson, H. (2012), "Managing for continuous improvement in off-site construction", *Engineering, Construction and Architectural Management*, Vol. 19 No. 2, pp. 141-158.

Meredith, J. (1998), "Building operations management theory through case and field research", *Journal of Operations Management*, Vol. 16 No. 4, pp. 441-454.

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*, Vol. 119 No. 1, pp. 115-130.

Nashwan, N.D. and Richard, H.N. (1990), "A survey of current production planning practices in the precast concrete industry", *Construction Management and Economics*, Vol. 8 No. 4, pp. 365-383.

Pan, W., Dainty, A.R.J. and Gibb, A.G. (2012), "Establishing and weighting decision criteria for building system selection in housing construction", *Journal of Construction Engineering and Management*, Vol. 138 No. 11, pp. 1239-1250.

Phellas, C.N., Bloch, A. and Seale, C. (2012), "Structured methods: interviews, questionnaires and observation", in Seal, C. (Ed.), *Researching Society and Culture*, 3rd ed., Sage Publications, London, pp. 181-205.

Pheng, L.S. and Chuan, C.J. (2001), "Just-in-time management of precast concrete components", *Journal of Construction Engineering and Management*, Vol. 127 No. 6, pp. 494-501.

Polat, G. (2008), "Factors affecting the use of precast concrete systems in the United States", *Journal of Construction Engineering and Management*, Vol. 134 No. 3, pp. 169-178.

Polat, G. (2010), "Precast concrete systems in developing vs. industrialized countries", *Journal of Civil Engineering and Management*, Vol. 16 No. 1, pp. 85-94.

Roulin, N. and Bangerter, A. (2012), "Understanding the academic–practitioner gap for Structured interviews: 'behavioral' interviews diffuse, 'structured' interviews do not", *International Journal of Selection and Assessment*, Vol. 20 No. 2, pp. 149-158.

Stuart, I., McCutcheon, D., Handfield, R., McLachlin, R. and Samson, D. (2002), "Effective case research in operations management: a process perspective", *Journal of Operations Management*, Vo. 20 No. 5, pp. 419-433.

Testa, C. (1972), *The Industrialization of Building*, Van Nostrand Reinhold, New York, NY, p. 199.

Vernikos, V.K., Goodier, C.I., Nelson, R. and Robery, P.C. (2013), "Implementing an offsite construction strategy: a UK contracting organisation case study", in Smith, S.D. and Ahiaga-Dagbui, D.D. (Eds), *Proceedings of the 29th Annual Association of Researchers in Construction Management (ARCOM) Conference, Reading*, pp. 667-677.

World Bank (2013), "Data-Lebanon", available at: http://data.worldbank.org/country/lebanon (accessed July 14, 2016).

Yee, P.T.L., Bin Adnan, A., Mirasa, A.K. and Abdul Rahman, A.B. (2011), "Performance of IBS precast concrete beam-column connections under earthquake effects: a literature review", *American Journal of Engineering and Applied Sciences*, Vol. 4 No. 1, pp. 93-101.

Yin, R.K. (2003), *Case Study Research- Design and Methods*, 3rd ed., Sage Publications, Thousand Oaks, CA, 181pp.

Zhai, X., Reed, R. and Mills, A. (2014), "Addressing sustainable challenges in China", *Smart and Sustainable Built Environment*, Vol. 3 No. 3, pp. 261-274.

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

Further reading

Alfred, A.Y. (2001a), "Structural and economic benefits of precast concrete technology", *PCI Journal*, Vol. 26 No. 3, pp. 34-42.

Alfred, A.Y. (2001b), "Social and environmental benefits of precast concrete technology", *PCI Journal*, Vol. 26 No. 3, pp. 14-19.

Goulding, J.S., Pour Rahimian, F., Arif, M. and Sharp, M.D. (2015), "New offsite production and business models in construction: priorities for the future research agenda", *Architectural Engineering and Design Management*, Vol. 11 No. 3, pp. 163-184.

Mezher, T. and Tawil, W. (1998), "Causes of delays in the construction industry in Lebanon", *Engineering, Construction, and Architectural Management*, Vol. 5 No. 3, pp. 252-260.

Tam, V., Tam, C., Zeng, S. and Ng, W. (2007), "Towards adoption of prefabrication in construction", *Building and Environment*, Vol. 42 No. 10, pp. 3642-3654.

About the authors

Dr Farook Hamzeh has been an Assistant Professor in Civil and Environmental Engineering at the American University of Beirut (AUB) since 2011. He earned his Bachelor Degree in Civil Engineering from the AUB in 1997 and later a Masters in Engineering Management in 2000. Dr Hamzeh then received a Masters Degreee in Engineering Project Management from the UC-Berkeley in 2006. He earned his PhD Degree in Civil and Environmental Engineering (Engineering Project Management emphasis) from the University of California (UC), Berkeley in 2009. He became an Assistant Professor at Colorado State University between 2009 and 2011. Dr Hamzeh has worked for more than seven years in the construction industry in Lebanon, Qatar, Dubai, and the USA on several mega projects. These include the \$1.7 Billion Cathedral Hill Hospital in San Francisco, the 333 m high Rose Rotana Hotel in Dubai, Losail motor-bike racetrack in Qatar, Olympic Tower in Qatar, Al-Amal Oncology Hospital in Qatar, Serail 1374 Building in downtown Beirut, and Sibline Cement factory 2nd production line in Lebanon. Throughout his career, Dr Hamzeh has developed a passion for improving construction processes to increase productivity, raise customer value, and reduce process waste. This passion has fueled his research in the areas of lean construction, process improvement, production planning, BIM, simulation, and supply chain management. Dr Farook Hamzeh is the corresponding author and can be contacted at: fh35@aub.edu.lb

Omar Abdul Ghani received the Bachelor's Degree in Civil and Environmental Engineering from the American University of Beirut and a Master's Degree in Civil Engineering from the University of Ottawa. He is currently a Project Engineer with Bird Construction – Canada. Omar has more than four years of construction experience in Oman and Canada working on several infrastructure and oil & gas projects, ranging in size from \$7M to \$60M.

Mohammad Bassel Saleh Bacha received the Bachelor's Degree in Civil and Environmental Engineering from the American University of Beirut and the Masters of Science Degree in Civil Engineering focusing on Engineering & Project Management from the University of California at Berkeley. Bassel worked for two years as a Research Assistant in Construction Management, interned as a Structural Engineer, and even experienced teaching at UC, Berkeley. Following his passion for construction, Bassel joined Bechtel after graduation in Houston, TX as a Construction Engineer and later moved to KSA where he is now working as a Field Engineer on the Riyadh Metro Project.

Yara Abbas is a Graduate of the American University of Beirut. After receiving her Bachelors of Civil and Environmental Engineering Degree, she pursued a Master's Degree with a focus on Construction Management. She has co-authored with Dr Farook Hamzeh several papers related to construction management, integrated project delivery, building information modeling, and modular construction.