Zaheraldeen, H., Khoury, H., and Hamzeh, F. (2019). “An AHP Approach for Selecting and Identifying off-site Construction Systems.” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 73-82. DOI: https://doi.org/10.24928/2019/0238. Available at: <www.iglc.net>.

AN AHP APPROACH FOR SELECTING AND IDENTIFYING OFF-SITE CONSTRUCTION SYSTEMS

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ABSTRACT

Many studies have shown the positive impact of applying lean principles in off-site construction. However, limited research have focused on evaluating the attributes associated with those various systems needed to highlight their difference. In fact, off-site systems present different advantages and disadvantages implying a need to evaluate their value maximization in terms of cost, time, quality, etc. when selecting the appropriate off-site system. Although some research studies have attempted to compare off-site against on-site systems, none has performed a comparison among non-volumetric systems (e.g. panelized and natural materials), volumetric systems, and hybrid systems. Therefore, this paper takes the initial steps and presents work targeted towards identifying the optimal off-site systems for a given project by extracting and elaborately analyzing the attributes of the different systems using the Analytical Hierarchy Process technique (AHP). The outcomes of this study will yield standardized policies for properly choosing optimal off-site systems based on lean principles.

KEYWORDS

Lean construction, Off-site construction, Analytical hierarchy process (AHP), Value maximization.

INTRODUCTION

Traditional on-site construction methods have been popular since the end of the 19th century (Mydin et al., 2014; Kamali et al., 2016). These methods are also defined as “site-built” or “conventional” construction and refer to construction being built on site after the design is done and the contractor is awarded the contract. The respective systems had been predominantly built using reinforced concrete frames and are typically divided into two

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groups. The first group is the structural system including cast in-situ columns, beams, slabs and frames. The second one includes bricks and plaster as the non-structural infill material. However, these methods have been witnessing a high level of waste in production, low productivity rates, high costs, poor safety records, poor quality control, and long project durations (Deffense et al., 2011). As a result, off-site construction emerged as an alternative modern method aimed at enhancing the overall traditional process (Vernikos et al., 2013; Howell,1999; Bekdik et al., 2016). Off-site construction is one of the construction strategies that applies the principles of industrialization in the construction projects; in other words it couples construction with manufacturing. It refers to the planning, design, fabrication and assembly of elements of a construction project at off-site factories typically situated at a different location from the jobsite.

After World War II, this technology became one of the major construction methods in many developed countries as it was tested and applied to provide soldier accommodation during the war (Arditi et al., 2000; Ghazilla et al., 2015). However, it didn’t get the full attention of both academia and industry in these developed regions (e.g. United States, Australia, parts of Europe) up until late (Kamali et al., 2016) where engineers have increasingly turned to using the off-site method due to its ability to reap the benefits of automotive manufacturing principles and achieve the lean construction goals of adding value while reducing process and material waste (Howell,1999; Vernikos et al., 2013; Antillón et al., 2014, Bekdik et al., 2016). More specifically, off-site systems allow projects to be delivered with higher value to the users, shorter construction times, lower on-site labor cost, higher safety level through eliminating the on-site risks, higher on-site productivity rates, lower waste production and tighter control of quality (Polat et al., 2005).

Furthermore, many studies tackled the division of the off-site construction into several classifications to assist in understanding the differences among off-site systems. In a study conducted by Švajlenka et al. (2017), the off-site systems were divided into several categories. In short, off-site systems can be classified into different levels according to the product’s manufacturing process (Gibb and Goodier, 2007; Li et al., 2014). As shown in Table 1, the first level, sub-assembly and component manufacturing, involves small-scale elements assembled in the factory environment (e.g. windows). The second level is the non-volumetric manufacturing which defines pre-assembled units that do not enclose a usable space (e.g. the timber panels). On the contrary, the volumetric manufacturing involves pre-assembled units that enclose a usable space. The units are processed inside the factory and do not form a part of the building structure. Finally, the complete manufacturing, also known as the modular construction, involves pre-assembled volumetric units that form the actual structure and fabric of the building. (Gibb, 1999; Goodier and Gibb, 2007).

Table 1: Off-site construction categories

	Systems	Example
Off-Site Construction	Sub-Assembly Systems	Windows
	Non-Volumetric Systems	Timber Panels
	Volumetric Systems	Bath Rooms
	Modular Systems	Hotel Rooms

On the other hand, in developing countries like Lebanon and Syria, four off-site categories were identified based on thorough investigation in the regional and local manufacturing market, namely Non-Volumetric Panelized Systems: Non- Volumetric Natural Materials Systems, Volumetric Systems and Hybrid (Panelized-Volumetric) Systems. However, despite the aforementioned advantages, the off-site method is still not widely adopted in these regions, which explains the lack of literature, and does not even follow lean principles whenever employed.

As such, resorting to off-site systems is very important to continually improve current construction methods. However, none of the previous works have selected the optimal off-site construction systems for a given project while considering value maximization and waste minimization. The greatest challenge facing construction practitioners is that of achieving the balance between: (1) the effort expended to predict related benefits and (2) the value provided by the adopted evaluation system (Pasquire et al., 2004) as lean construction principles suggest. Therefore, the objective of this research study is to design a new decision support tool targeted at identifying and selecting the best off-site system for a project at hand while maximizing the value and meeting customer requirements through continuous improvement and waste elimination. This lean decision tool can, in turn, incite practitioners to use off-site systems and better assess them, especially in the Lebanese and Syrian construction sector.

METHODOLOGY

In order to achieve the aforementioned objective, a conceptual three-stage decision model was initially developed using the combined key findings gathered from the literature review and regional data. Figure 1 depicts the proposed model.

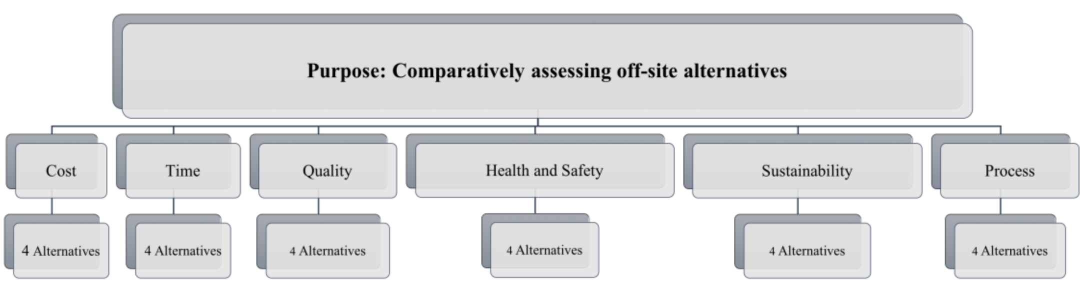

Figure 1: The proposed decision model

The first stage consists of establishing the purpose or goal behind a certain decision; in this case evaluating the importance and comparatively assessing off-site alternatives. The second stage consists of defining the main decision criteria. A wide range of criteria was identified from the literature review in relation to the adoption of off-site construction methods (Pan et al., 2012a). After conducting semi-structured interviews with construction practitioners in Lebanon and Syria, six specific criteria were singled out, namely:

1. Cost: the cost of design, implementation and maintenance.
2. Time: the time of design and implementation.
3. Quality: high quality achieved in erecting the facility and high customers' satisfaction.
4. Health and safety: risk minimization during the construction process.
5. Sustainability: high building energy efficiency and waste minimization.
6. Process: project site access, logistics, and installation planning strategies

The final stage entails delineating the alternative options for each criterion; in this case the four off-site categories adopted in Lebanon and Syria:

1. Non-Volumetric Panelized Systems: These units are produced in the plant then transported to the project site to fit within the assembly into existing structural systems. Examples include wall, floor or roof panels that can be load or non-load-bearing and can be made of light gauge steel, timber, structurally insulated panels (SIPs) or concrete.
2. Non- Volumetric Natural Materials Systems: These units are similar to the panelized systems with one difference: the source of materials. This difference leads to the consideration of natural materials systems that are more environmentally friendly and sustainable than other systems.
3. Volumetric Systems: These units are produced with high quality control then transported to the project site to be assembled through bolting. The structural skeleton of these modules are usually fabricated with concrete, light gauge steel, timber frame, or composite with different external and internal finishes materials.
4. Hybrid Systems: These units (called semi-volumetric units) combine panelized and volumetric technology in the same constructed facility or building. The highly serviced areas of a building (e.g. kitchen, bathroom units, etc.) are constructed as volumetric units while others are built as panelized units.

Therefore, at the heart of this model lie various off-site building categories for which weights are to be allocated with respect to various decision criteria using the Analytic Hierarchy Process (AHP) method. AHP, developed in 1980 by Thomas Saaty, is an advanced, powerful, and flexible tool that provides the ability to calculate the degree of importance for each alternative following pairwise evaluations of the criteria introduced by decision makers (Saaty, 1980). In fact, most researchers recommend the AHP method as a suitable prioritization technique due to its flexibility and simplicity, which leads to enhanced data collection and improvement in the quality of comparisons among the results (Pan et al., 2012b). Moreover, decision makers can easily fill out the survey without having previous knowledge on AHP. It is worth noting that the choosing by advantages (CBA) theory is employed at a later future stage to evaluate the attributes of the chosen off-site methods or systems and is thereby not within the scope of this paper.

As such, the next step involves designing the AHP survey. The survey is divided into three sections: (1) A cover letter to the participant including the invitation, (2) A brief summary of the research topic including the goal of the survey, and chosen criteria and alternatives, and (3) Questions about the type of systems adopted in the interviewed companies, the scale system (Table 2) as introduced by Saaty (1980) and a small example on how two criteria can be evaluated and ranked, and the actual pairwise comparison with respect to the cost, time, quality, health and safety, sustainability and process criteria.

Table 2: The AHP pairwise comparison scale (Saaty, 1980)

Intensity of weight	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objectives
3	Weak/moderate importance of one over another	Experience and judgment slightly favored one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation

The survey was then conducted with a selection of senior construction managers from top off-site builders in the Middle East. More specifically, a total of 20 managers working in 20 different Lebanese and Syrian off-site construction companies responded out of 35 surveys sent, whereby most of them have more than 5 years of experience in this field. The data gathered from the construction managers was basically pairwise comparisons for multiple criteria.

RESULTS AND DISCUSSION

The first part of the third section in the AHP survey has investigated about the decision making process and type of the off-site systems that are used in each company. It was found that off-site companies have chosen the systems according to personal evidence without using any rigorous data. Additionally, it was established that the construction participants have agreed that adopting a decision support tool to choose the optimal off-site systems can potentially shrink the construction waste while expanding the value of this method.

The last part of the survey asked the participants to fill the pairwise comparison with respect to the group of criteria (cost, time, quality, health and safety, sustainability and process). Accordingly, an analysis was conducted to combine the individual comparison judgements from the 20 participants so that a single comparison matrix is produced. This was achieved by computing a geometric average for each response and checking for its consistency. Proper mathematical procedures were then implemented to compute the importance of each criterion relative to the goal and calculate a weight for each off-site option/alternative. Table 3 and Figure 2 present the results of a pairwise comparison of one criterion with respect to the other criteria.

Table 3: The pairwise comparison of one criterion with respect to the other criteria

Criteria	Cost	Time	Quality	Health and Safety	Sustainability	Process
Cost	1	1.530	0.467	0.223	0.346	0.813
Time	0.656	1	0.253	0.172	0.275	0.357
Quality	2.0765	3.739	1	0.625	1.251	1.654
Health and Safety	4.338	5.639	1.426	1	1.795	2.596
Sustainability	2.799	3.641	0.695	0.557	1	1.588
Process	1.229	2.799	0.498	0.385	0.629	1

Figure 2: The pairwise comparison of one criterion with respect to the other criteria

Results reveal that the health and safety, quality, sustainability and process criteria ranked high when compared to the cost one. These results reveal the importance of other criteria in the decision making process, besides cost and time, that are often underrepresented.

Table 4 and Figure 3 depict comparison results considering the cost criterion. It can be noticed that the participants prefer the panelized system over others when the decision is based on cost. On the other hand, the natural materials system was the least preferred.

Table 4: The pairwise comparison matrix with respect to the cost criterion

Alternatives	Panelized System	Natural Materials System	Volumetric System	Hybrid System
Panelized System	1	2.747	1.329	1.845
Natural materials System	0.364	1	0.757	0.993
Volumetric System	0.752	1.369	1	2.132
Hybrid System	0.542	0.970	0.469	1

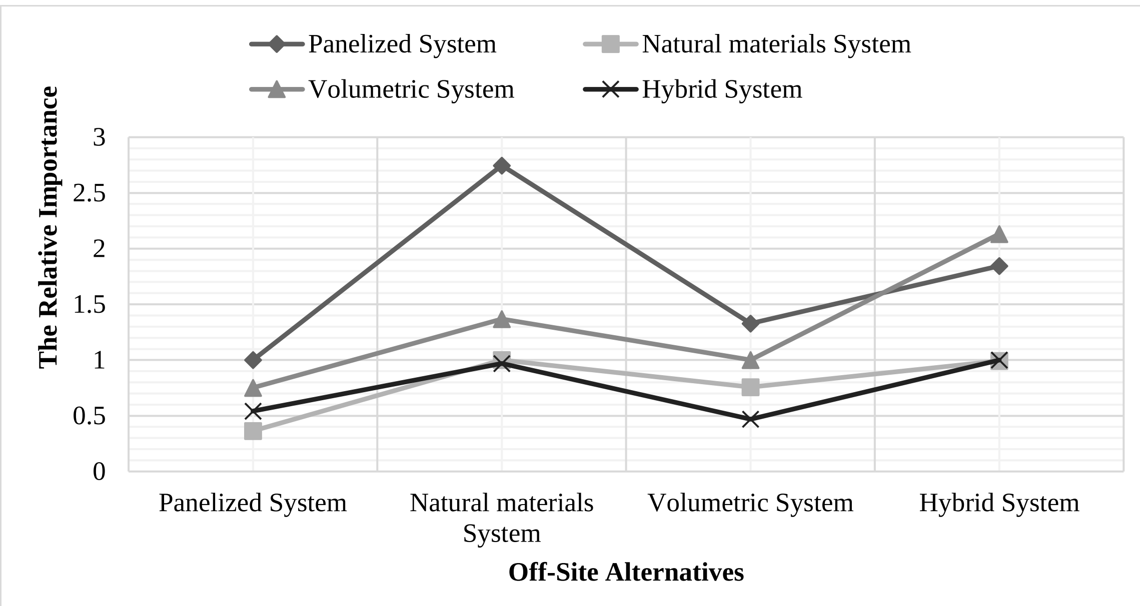

Figure 3: The pairwise comparison results with respect to the cost criterion

Other pairwise comparison results with respect to the time, quality, health and safety, sustainability and process criteria were also analyzed.

Another analysis was conducted to calculate the weighted average rating for each decision alternative. This rating helps in selecting the suitable off-site system based on the participant's objective. Table 5 and Figure 4 depict respective results.

Table 5: The weighted average rating for each decision alternative

Criteria	**Cost**	**Time**	**Quality**	**Health and Safety**	**Sustainability**	**Process**	**Weighted Average Rating**
Alternatives	0.085	0.054	0.209	0.334	0.194	0.123	
Panelized System	0.379	0.285	0.175	0.188	0.253	0.241	**22.56 %**
Natural Materials System	0.169	0.060	0.108	0.213	0.2178	0.066	**16.20 %**
Volumetric System	0.286	0.355	0.384	0.333	0.266	0.339	**32.86 %**
Hybrid System	0.166	0.299	0.333	0.266	0.264	0.354	**28.38 %**
Sum	1	1	1	1	1	1	**100 %**

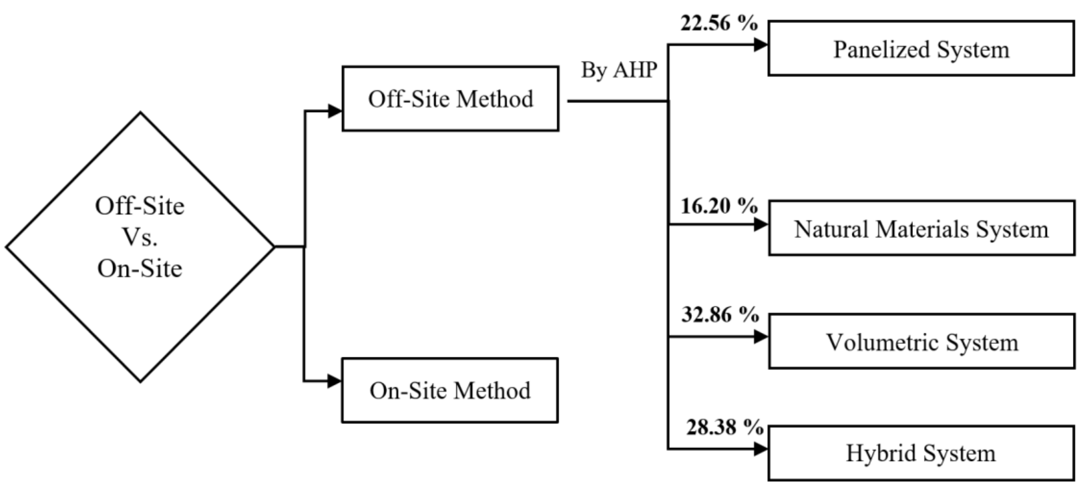

Figure 4: The decision tree for selecting from the four off-site systems

Results reveal that participants in Lebanon and Syria prefer to opt for the volumetric systems (rating about 32.86%) as opposed to other systems such as natural materials systems (16.20), panelized systems (22.56), or hybrid systems (28.36).

CONCLUSION, RECOMMENDATIONS AND FUTURE WORK

Most construction practitioners consider that opting for any off-site method is risky and needs careful attention. Therefore, this research effort took the initial steps and aimed at providing a decision support tool to aid practitioners in identifying and selecting the optimal off-site methods given a certain project and based upon various factors (e.g. cost, time, waste, quality, health, safety etc.). The AHP technique was used and results from the survey revealed the benefits of each system with respect to the factors tested. Moreover, the AHP survey shows the need for optimally selecting off-site methods to drive more value into the construction process.

To increase value in future off-site projects, a shift in the decision making process is needed and a lean thinking approach should be applied. Off-site practitioners are encouraged to invest in the lean philosophy (e.g., Waste Minimization and Continuous Improvement) to decrease the non-value adding tasks when adopting off-site methods and to reduce cost and time, increase quality and safety, and deliver a sustainable building. Additionally, they should enhance communication among project stakeholders during the decision making process to explore different attributes of off-site systems. Using the proposed decision support tool while taking into account the various criteria will result in choosing the most convenient off-site system.

More importantly, the improvement suggestions for the off-site construction are parallel with the lean spirit of incremental improvement while encouraging the use of this technology (i.e. Off-site Construction). Therefore, practitioners working in off-site construction should align the project objectives to consider various customer requirements. Finally, the proposed study is not only limited to construction buildings in Lebanon and Syria but can be also applied elsewhere once the goal, criteria and alternatives are identified.

Further work is needed to study other off-site categories such as Sub-Assemble Systems, and Light Weight Facades, and the effect of other factors or constraints on the decision making process.

ACKNOWLEDGEMENTS

The presented work is supported by the AUB's University Research Board (URB) through Grant# 103604. Any opinions, findings, conclusions, and recommendations expressed by the authors in this paper do not necessarily reflect the views of URB. The authors would like as well to thank all the off-site construction companies who participated in the AHP survey.

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