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Developing a Framework for Implementing Green- Lean Construction Techniques

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Abstract: It is known that the traditional construction life cycle produces wastes in time, materials and cost as well as producing polluting materials. The main objective of this study is to propose a framework that integrates the traditional construction techniques with green-lean construction techniques to improve the economic and environmental performance of the construction industry. The study was carried out using Analytical Network Process (ANP) and Zero One Goal Programming (ZOGP). The results suggested an optimum arrangement to reach an effective green-lean framework; this involves a wide range of interventions that could be implemented for moving the traditional construction towards green-lean construction. The study concluded that going green-lean is not necessarily expensive if the right approach is applied. Further, going green-lean can save time and money while keeping staff and buildings clean and safe. Further, the study recommended paying more effort in the design phase to integrate innovative solar and water energy alternatives. It was also recommended to find new value-added activities/ materials to replace non-value ones. In addition to that, analyzing the needed activities in an early start of the project would help releasing the right work at the right time with the right people at an optimum price.

Index Terms— Green techniques, Lean construction, Analytical Network Process, ANP, ZOGP

I INTRODUCTION

Despite management efforts, construction industry faces many issues related to performance, productivity and impact on the environment [1]. The construction industry consumes a significant amount of resources annually, generates significant waste and produces a host of emissions [2] both of which could be decreased using green-lean techniques to meet the estimated budget, time and reduce the negative environmental impacts of construction activities [3].

Currently, 100 million tons of construction waste, including 13 million tons of unused materials, is being generated each year, with only 20% currently capable of being recycled. The majority of this waste ends up in landfill, contributing to further pollution of the biosphere [4].

The construction activities require prudent planning and efficient management. This was assumed due to the high volume of construction activities, the creation of poor-quality products and the harmful environmental impact [3]. Therefore, there is an urgent need to improve efficiency and effectiveness of management strategy during the construction cycle, to smartly balance between time, cost, quality, resources and its influence on the environment. The optimum solution is to achieve high quality with low cost within the time constraints, to use the resources without affecting the environment.

The lean construction process is a derivative of the lean manufacturing process. This has been a concept popularized since the early 1980s in the manufacturing sector. It is concerned with the elimination of waste activities and processes that create no benefit. It is about doing more for less[5].

The lean techniques can help to improve the economic impact of the project and reduce the waste in the construction process where different studies from various countries have illustrated that the wastes in construction field equal approximately 47% of the total construction process [6]. While green techniques mitigate the significant impacts of the construction on the economy, society and environment [7], where, regarding to the World Business Council (WBC) for sustainable development, blocks in the construction consumes 40% of total construction energy [7]

Therefore, this study attempted to provide a better understanding of green -lean techniques and their concepts, which will increase the productivity and reduce waste. As an output, the study suggest a framework which enables integrating the traditional construction process with green- lean construction techniques, to promote the economic and environmental performance of the construction through using Analytical Network Process (ANP) and Zero One Goal Programming (ZOGP) as analytical methods.

II LITERATURE REVIEW

The construction industry has changed all over the world including Gaza Strip over the past years; companies are faced with real issues regarding performance, productivity and the construction impact on the environment. The next paragraphs discuss previous studies, which recommended green building and using lean principles. In additional to that, the paragraphs introduce ANP, ZOGP principles.

Kibert [8] defined green building as “a healthy facility designed and built in a resource efficient manner and using ecologically based principles”. Green principles focus on the environmental issues; they include eco-product design, environmental design, consider re-use principles of design for re-use, re-manufacturing and recyclability, and the use of environmentally friendlier materials [9].

There are many international tools to assess the green performance of the construction and its effect on the environment, for example, Australian Building Greenhouse Rating (ABGR), green star, Leadership in Energy and Environmental Design (LEED) and Life Cycle Assessment (LCA).

The applied green tool in this study is Life Cycle Assessment (LCA) which was defined by Rebitzer, et al. [10] as a green tool that systematically assesses and manages the environmental impact of a product, process, or service through its entire life cycle, from the material and energy used in the raw material extraction and production processes, through acquisition and product use, and continuing to final product disposal.

As for lean, Ohno [11] defined it as a business system with a fundamental objective of eliminating waste, and he defined waste as “anything that does not add value.”. Value-added activities are the ones that the client is interested in paying for, the ones that help converting the product or service to a new product, and the ones that must be done correctly.

Issa [12]defined lean as a new concept in the construction production management. It produces a control tool with the goal of reducing the losses throughout the process. Another definition for lean described by Lim [13] which is attaining a balanced use of works, materials and resources. This allows contractors to minimize costs, decrease the waste in the construction and deliver projects on time.

The lean has five principles, namely: value, Value Stream Map (VSM), flow, pull and perfection. The value emphasized that customer is the main person who is charge of determining the needed value of the project [14]. The value stream map is a well-known used lean tool, which is a technique that analyzes the materials and information through a process flow diagram, taking into consideration the details of the required time, resources, cost that are needed for each step in the process flow.

With regard to the pull principle, Womack and Jones [14], mentioned that pull implies the capability to design and make precisely what the client needs quickly and efficiently. Finally, perfection is defined as to deliver a product which meets the client requirements, with optimum quality without mistakes and defects and within the agreed time.

Relationship between green and lean; It is elementary that adopting green techniques lead to sustainability. This is not necessarily a vice versa relationship[15]. Lean production is a systemic approach to meeting customer expectations, whatever they value, by reducing waste. At first glance, lean could only contribute to sustainability, while sustainability is achieved only if the customer values sustainability (Bae, 2008). Many countries gain great benefits from applying lean methods to construction industries. China, as a great construction country, also has advocated the implementation of lean construction technologies in recent years [16] .

The direct relationships between green and lean practice overall and environmental performances are promising. It seems to be great ‘win-win’ opportunities. However, there must be total long-term commitment to green and lean practice to achieve better performance[17].

III METHODOLOGY

A combination of quantitative and qualitative methods are applied in the study. Qualitative data were collected through semi-structured questionnaire with project managers and experts having more than 10 years of experience. The purpose was to understand the advantages of the traditional techniques and to prioritize the criterion that affect the construction process to be analyzed through Analytical Network Process (ANP) and Zero One Goal Programming (ZOGP).

Study strategy: (ANP) and (ZOGP) are used as analytical tools to propose the optimum framework for the integration of the traditional construction with more green- lean techniques.

Questionnaire design: The questionnaire comprised six tables, in which the first table consisted of a pairwise comparison of the main criteria, the second, third, fourth and fifth tables consisted of sub- criteria pairwise comparison and finally the sixth table designed to perform a comparison for feedback connections between these sub-criteria. Figure (1) shows ANP model structure.

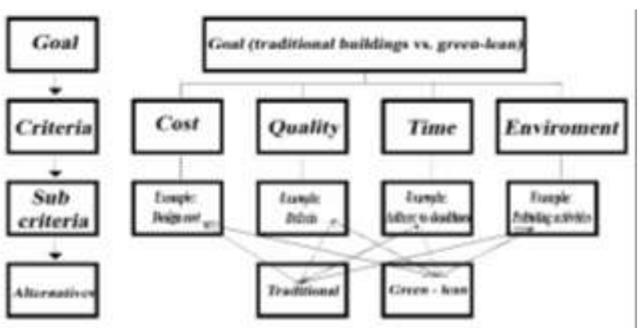

Figure 1 Analytical network analysis framework

Developing framework: Analytical Network Process (ANP) was used to prioritize the sub-criteria that generally affect the construction process, and then Zero One Goal

Programming (ZOGP) was applied to propose a realistic green-lean framework in different scenarios as in Table (1).

Analytical Network Process (ANP) model

It's a multi-criteria decision making tool used to derive relative priority scales of absolute numbers from individual judgments [18]. The advantage of ANP uses the ratio scales to make accurate predictions and wiser decisions.

Table 1 Applied criteria and sub-criteria

Criteria	Environment	Quality	Cost	Time
Sub-criteria	Polluting materials	Material reliability	Design	Time wasters (activities)
	Polluting activities	Customer satisfaction	Material	Project duration
	Water systems	Defects	Labor	Adhere to deadline
	Renewable energy	Concurrent drawings	Machine	
	Renewable materi-al	Material waste	Opera-tional	
	Energy systems	Activities waste		

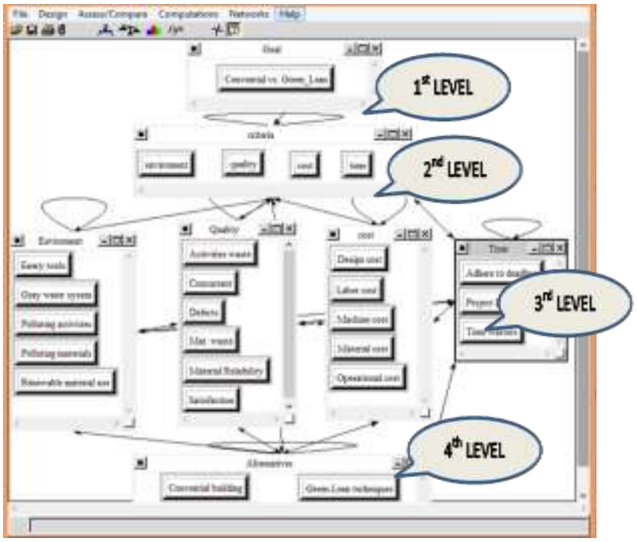

Figure 2 ANP model framework

This model is proven effective in many fields such as predicting sports results, economic fluctuations, business, and different events. The main feature that makes ANP unique is its ability to deal in a systematic manner with feedback and to define precisely the value from a customer's point of view in ratio numerical scale [19].

The ANP method consisted of two parts. The first is to build the hierarchy of criteria, sub-criteria, and alternatives. The second part is to build links and connections between these elements. Then, defining the weight of each element and its rank among other elements (in this study, defining the weights were done based on a specialized questionnaire filled by 10 experts point of view with more than 10 years' experience).

The main idea behind using the ANP approach is not to limit the human creativity into a mathematical shape. Rather, it resembles a natural flow of thinking. ANP provides a mathematical approach that is more effective that the probabilistic approach [20] by using super decision software, which is utilized in the decision-making process with a feedback. ANP consist of clustered network of elements, which are goal, criteria, sub-criteria, and alternatives.

These clusters contain nodes, which are linked together, so that the software could prioritize them. The ANP allows for all possible and potential dependencies [19]. The prioritizing process depends on a series of pairwise comparison between the criteria sub-criteria, and alternative clusters.

The model consists of four levels. The first level is the goal cluster where the goal (traditional vs. green-lean comparison) is determined as a node. The second level is the criteria cluster where four nodes were used (environment, quality, cost and time) as shown in Figure (1).

The third level is the sub-criteria clusters where environment cluster contains polluting materials, polluting activities, efficient water systems, renewable energy, renewable material use and energy system nodes. The quality cluster contains material reliability, customer satisfaction, construction defects, concurrent design drawings (taking into consideration the right design principles and solve the conflicts among the different (architect, civil, mechanical, electrical) specializations in the design phase), material and activities waste nodes. While cost cluster contains design, materials, labor, machines and operational cost nodes. Finally, time cluster contains time wasters, extend the project duration in case of need and adhere to deadline nodes.

The fourth level is the alternative cluster, which contains two nodes, the traditional and green-lean construction alternatives. Figure (2) shows a screenshot for ANP model framework in super decision software.

It is worth mentioning that in order to complete the model, a connection between the nodes must be developed according to the relation between these sub-criteria and nodes. The next step is to insert the average of the expert's responses to the pairwise comparison.

Pairwise comparison process

The prioritizing process depends on a series of pairwise comparison between the criteria, sub-criteria and alternative clusters. The pairwise comparison depends on two questions that were asked during interviewing experts (during the questionnaire filling process) to differentiate between elements. The first question is which criteria is more significant than the other ones. The second question is what is score of this importance? [21].

This process was applied to make tradeoffs among criterion and sub-criteria, the judgments are usually made numerically as a score, which is a reciprocal pairwise comparison in a carefully designed scientific way.

The first step in this phase is to discuss the preliminary questionnaire with a pilot sample by inviting 2 professionals with more than 10 years of experience to identify the criterion that affect the construction process and to develop the final questionnaire design. This helped a lot at the next step of designing the final questionnaire to be answered by 10 different experts.

ANP model was constructed and pairwise comparisons were added to the model based on the experts' responses to calculate the priority of the criteria and sub-criteria. Then analysis of these results, the weights of these criteria and sub-criteria and their relation to each other were obtained.

Table (2) shows the fundamental judgments scale, which was adopted by [19]. In his process, the judgments were first given verbally as indicated in the scale Table (2). The vector of priorities is the principal eigenvector of the matrix. This vector gives the relative priority of the criteria measured on a ratio scale.

Table 2 Fundamental scale [19]

1	Equal importance
3	Moderate importance of one over another
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values
Use reciprocals for inverse comparisons	

The answers of the experts were included in a matrix, and then the following steps were performed as explained in the next example. In the first step, equations in each column are summed up as in Equation (1), a vertical summation was performed for the answers.

$$\begin{array}{cccc} & A & B & C \\ A & 1 & .33 & .5 \\ B & 3 & 1 & 2 \\ C & 2 & .5 & 1 \\ \text{TOTAL} & 6 & 1.83 & 3.5 \end{array} \quad (1)$$

Then, each value is divided by its corresponding total summation to obtain the Equation (2). An illustration of the arithmetic mean calculation was assigned for every horizontal row of this matrix, which is called synthesized matrix.

$$\begin{array}{ccccc} & A & B & C & \text{Arithmetic mean} \\ A & .16 & .18 & .14 & .16 \\ B & .5 & .55 & .57 & .54 \\ C & .33 & .27 & .28 & .30 \\ \text{TOTAL} & & & & 1 \end{array} \quad (2)$$

Third step includes, the arithmetic mean which was obtained for every row in equation (2) and multiplied by the corresponding matrix of Equation (1), as shown in equation (3).

$$.16\begin{bmatrix}1\\3\\2\end{bmatrix} + .54\begin{bmatrix}.33\\1\\.5\end{bmatrix} + .30\begin{bmatrix}.5\\2\\1\end{bmatrix} = \begin{bmatrix}.16\\.49\\.32\end{bmatrix} + \begin{bmatrix}.18\\.54\\.27\end{bmatrix} + \begin{bmatrix}.15\\.60\\.30\end{bmatrix} = \begin{bmatrix}.49\\1.62\\.89\end{bmatrix} \quad (3)$$

In the fourth step, the resulting values were taken from Equation (3) and divide everyone to it's correspond arithmetic mean from Equation (2).

$$(0.49 \div 0.16 = 3.02)..(1.62 \div 0.54 = 3.02)..(0.89 \div 0.30 = 2.98) \quad (4)$$

The fifth step was to calculate lambda (which is a probability distribution used in multivariate hypothesis testing), this process is done by summing up all the values resulting from Equation (4) then dividing it by the total number of the analyzed variables.

$$\lambda_{max} = \frac{3.02+3.02+2.98}{3.0} = 3.01 \quad (5)$$

In the sixth step, consistency index was calculated. This was carried out by subtracting the total number of the values from lambda then divide it by (n-1).

$$Consistency\ Index\ (CI) = \frac{\lambda max - n}{n-1} = \frac{3.01-3}{3-1} = .0041 \quad (6)$$

The final step was to calculate the consistency ratio as shown in equation (7). The result must be less than 0.1 for an acceptable consistency level.

$$Consistency\ Ratio = \frac{Consistency\ Index\ (CI)}{Ratio\ Index\ (RI)} = \frac{.0041}{.58} = .007 < .1 \quad (7)$$

The study model consists of four criteria, namely: cost, quality, duration and environment aspects and 19 sub-criteria as shown in Table 3.

Pairwise comparison was added to the questionnaire panel. All the responses of the experts were inserted in an excel sheet to calculate the average of the answers, which creates super matrix and then inserted in data entry panel.

Table 3 Criteria and sub criteria

Criteria	Sub criteria
Cost	Design cost
	Materials cost
	Operational cost
	Labor cost
	Machine cost
Quality	Reliability of the used material
	Customer satisfaction
	Construction defects
	Concurrent drawings relationship
	Material waste
	Activities waste

Time	Time wasters
	Project duration
	Adhere to deadline
Environment	Polluting materials
	Polluting activities
	Water systems
	Renewable energy tools
	Renewable material use

Zero One Goal Programming (ZOGP)

The Analytical Network Process (ANP) is the first analyzing tool applied in this study, the next paragraphs discuss the next applied tool which is Weighted Zero One Goal Programming (ZOGP) using the LINDO program, in which more constraints were added to make the model more dynamic and realistic.

Lindo platform is designed solely for solving optimization problems, whether they are linear, integer, and non-linear etc. Its applications are, but not limited to, business and governmental issues. This optimization process helps in getting the optimum value of profit, production, or even happiness. This is through getting the best utilization of funds, time, and labor (LINDO Systems, Inc., 2010).
The weights results of ANP were fed into Lindo program as coefficients for the objective function of the main model. Several scenarios were suggested to simulate real construction cases where one of the five cost sub-criteria (the operation, design, labor, machine and material) cost is fixed or all the sub-criteria were fixed as in real construction process.

Table (4) shows that every sub-criteria is linked to a variable that indicates its condition whether it is minimized or maximized.

Table 4 The variable definition

	Criteria	Condition	Sign
X1	Operation cost	Minimize	-
X2	Machine cost	Minimize	-
X3	Material cost	Minimize	-
X4	Design cost	Minimize	-
X5	Labor cost	Minimize	-
X6	Renewable material	Maximize	+
X7	Energy systems	Maximize	+
X8	Polluting materials	Minimize	-
X9	Polluting activities	Minimize	-
X10	Water systems	Maximize	+
X11	Concurrent design drawings	Maximize	+
X12	Activities waste	Minimize	-
X13	Materials waste	Minimize	-
X14	Construction defects	Minimize	-
X15	Customer satisfaction	Maximize	+
X16	Materials reliability	Maximize	+
X17	Adhere to deadline	Maximize	+
X18	Project duration	Minimize	-
X19	Time wasters in construction	Minimize	-

The formulation of the ZOGP

The obtained weights from ANP are set as coefficients for objective function that should be maximized or minimized as shown in Table (4). The maximization process was assigned a positive sign while the minimization process was assigned a negative sign. The objective function was subject to the environment, quality, cost and time constraints. The detailed formulations are given the next paragraphs.

Objective function Minimize $\sum w_j d_i^+ + w_j d_i^-$

Subject to:

1. $X_j + d_j^+ - d_j^- = 0$ j = 6, 7, ……19
2. $\sum_{j=19}^{6} Yj = B$ B= 5,6, ……19

Where

- " X_j " represents the integer variables of the sub-criteria except the corresponding fixed sub-criteria given in table (4).
- "j" is the assumed index value of the sub criteria except the fixed sub-criteria correspond to the given in table (4).
- "dj+, dj-" = the positive and negative deviation variables of the sub-criteria except the excluded fix ones which are being analyzed in the scenario depending on its corresponding condition in Table(4), j= 1,2,….19 except fixed sub-criteria.
- Where " Y_j " represents the variables of the sub-criteria except the corresponding fixed sub-criteria given in table (4).
- "B" represents the number of the sub-criteria that were required to work from 1 to 19, where "b" is the control point that prioritizes the sub-criteria in order to give the logical framework that was targeted in this study.

The five cost sub-criterion (the operation, design, labor, machine and material) were assigned a fixed value to determine the priority of the other sub-criterion and analyze the influence on the sub-criterion order which to be implemented in the green-lean framework.

IV Result and Analysis

A Main criteria weights

This study analyzes the construction performance from four different aspects that formulate the main criteria (environmental, quality, cost and time) criteria. Every criteria contain many sub-criteria. Through the analysis, a study of the relation between these sub-criteria and their influence on each other were discussed and analyzed using analytical network process (ANP) as shown in the next paragraphs.

Results indicated that the environmental criteria is the most significant criteria that should be taken into consideration with a weight of 0.34. Quality and cost criteria weights are 0.27 and 0.21 respectively. Finally, the time criteria weighed 0.18 as shown in Table (5), which indicates that there is a tendency from the experts to encourage promoting traditional construction to be greener and to pay more effort on the environmental side of the project and the high quality of the production, even if it is little higher than in the cost.

Table 5 Main criteria weights

	Normal value	Limit super matrix
Environmental criteria	0.342	0.055
Quality criteria	0.271	0.043
Cost criteria	0.208	0.033
Time criteria	0.178	0.028
Total	1	

B Sub criteria weights

1. Weights of environment sub-criteria

The environmental criteria weighs 0.34, which indicates that it is significant to adopt new changes and make the construction process more sustainable. This would surely affect the construction environment .Table (6) shows the weights of the environment sub criterion.

Table 6 Environment sub-criteria weights

	Normal value	Limit super matrix
Renewable material use	0.301	0.068
Energy systems	0.260	0.059
Polluting materials	0.211	0.048
Polluting activities	0.128	0.029
Water systems	0.099	0.022
Total	1	

The results indicate that renewable material is an important sub-criterion weighs 0.068 as shown in Table (6). This spot the lights on the effects of the energy consumption of the building and its performance with respect to the environment.

When it comes to the energy systems sub-criteria, the results show that appropriate energy systems (photovoltaic, thermal, biomass and wind) weigh 0.058, which means that this sub-criteria should highly be taken into consideration, especially that developing country suffers from energy problems and an increase in the pollution, poor resources of energy and inefficient use of them [22].

The reason behind this high rank can be attributed to the absence of fossil fuel resources. Palestine imports all it needs of petroleum products from Israeli market and about 92% of electrical energy from the Israeli Electric Corporation (IEC). Indigenous energy resources are quite limited to solar energy for photovoltaic and thermal applications (mainly for water heating), and biomass (wood and agricultural waste) for cooking and heating in rural areas, while the potential of wind energy is relatively small but not yet utilized in Palestine.

2. Weights of cost sub-criteria

The study analyzed many cost sub criterion that influence the proposed framework in order to integrate the traditional construction with green-lean techniques as shown in Table (7). The budget of the project imposes many serious limitations, for example, the area of the building, types of the used materials in the project, types of equipment, which significantly affect the decision whether to use green-lean techniques or not, as it needs a higher initial cost.

Table 7 Cost sub criteria weights

Cost sub-criteria	Normal value	Limit super matrix
Operational cost	0.306	0.043
Machine cost	0.260	0.037
Material cost	0.172	0.024
Design cost	0.129	0.018
Labor cost	0.132	0.019
Total	1	

The operational cost sub-criteria ranked as the first cost sub-criteria with a weight of 0.043. The operational cost is the biggest cost during the life cycle of the building. So, studying carefully the value that the customer wants to achieve in the final product, will help the designer to prepare the building in the design phase for these values with the least possible cost savings and high ability to predict and control the expected defects on the projects, which minimize the total cost of the project. Changes initiated by the client and end-user together with errors and omissions in contract documentation were found to be the primary causes of rework and increasing the operational cost [23].

Machine cost sub-criteria ranks as the second with a weight of 0.036, this high rank can be justified by the fact that machines save time, money and give a sequence reliable performance.

3. Weights of quality sub-criteria

The quality sub-criterion (such as concurrent design drawings, activity waste, material waste, construction defects, customer satisfaction and reliability of the used material) were analyzed. The results showed that solving contradictions between the concurrent drawings in the design phase before moving to the next step – the real implementation – has the highest rank with a weight of 0.044. This was followed by decreasing the waste in the construction activities with a weight of 0.042 as shown in Table (8).

Table 8 Quality sub criteria weights

Quality sub-criteria	Normal value	Limit super matrix
Concurrent drawings	0.248	0.045
Activities waste	0.230	0.042
Material waste	0.224	0.040
Defects	0.116	0.021
Satisfaction	0.103	0.019
Material reliability	0.077	0.014
Total	1	

The concurrent drawings sub-criteria, has the highest weight of 0.044. This attributed to the fact that solving the contradictions between the drawings (architect, civil, mechanical, and electrical) in the design phase, will highly minimize the defects of the drawings and their implementation, which will directly affect the cost and duration of the construction project.

4. Weights of time sub-criteria

The construction projects rarely ends at the scheduled time. Therefore, there is a need to improve efficiency and effectiveness of the management strategy to smartly balance between time, cost, quality, resources and their influence on the environment. Table (9) presents the weights of time sub criteria.

Table 9 Time sub criteria weights

Time sub-criteria	Normal value	Limit super matrix
Adhere to deadline	0.615	0.080
Project duration	0.238	0.031
Time wasters	0.147	0.019
Total	1	

The results show that meeting the deadline is the most important time sub-criteria with a weight of 0.080. This could be justified due to many reasons, for example, the construction penalty payment and resources overload in case of delay.

Comparison of Alternatives

Results showed that for the green-lean alternative, the environment criteria has the highest rank as it weighed 0.33. The second highest rank was the quality criteria which weighed 0.27, followed by the time criteria with a weight of 0.23 and cost criteria comes in the last rank with a weight of 0.17 as shown in Table (10).

On the other hand, for the traditional alternative, time criteria has the highest rank with a weight of 0.35, cost criteria is in the second rank and weighs 0.32 as shown in Table (10) . The quality is in the third rank with a weight of 0.19, while the environmental criteria is in the lowest rank showed a weight of 0.13.

Table 10 Alternatives performance with respect to the main criteria

Main criteria	Green – lean	Traditional
Environment criteria	0.33	0.13
Quality criteria	0.27	0.19
Time criteria	0.23	0.35
Cost criteria	0.17	0.32

The next paragraphs compare the performance of the two alternatives (traditional vs. green-lean) in the construction process as shown in Figure (4). With respect to the environment criteria of the green-lean alternative, the renewable materials sub-criteria have the weight of 0.197 while in the traditional alternative weighs 0.145. For the energy system sub-criteria (photovoltaic, thermal, biomass and wind), the green-lean has a weight of 0.206 while the traditional alternative weighs 0.227.

For the polluting materials, activities and efficient water systems (using gray water system, wastewater treatment and conservation) indicated the same weight of 0.199 in the green-lean alternative; the case is different in traditional alternative for the same sub- criterion with weights of 0.264, 0.20 and 0.164 respectively as shown in Figure (3).

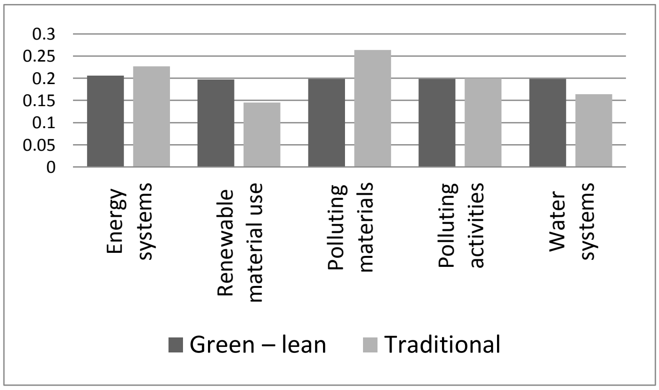

Figure 4 Alternative performance with respect to environment

For the quality criteria, it was obvious that green-lean focuses on decreasing the non-value adding activities and materials, so it was not strange that decreasing the material waste in green-lean had the highest weight of 0.184 in the quality criteria. Furthermore, decreasing these sub-criteria was also very important in the traditional alternative, with a weight of 0.161 as shown in Figure (4). This can be explained by the fact that decreasing the waste would directly guarantee a decrease in the total cost of the project, an increase in its quality and a decrease in the total project duration.

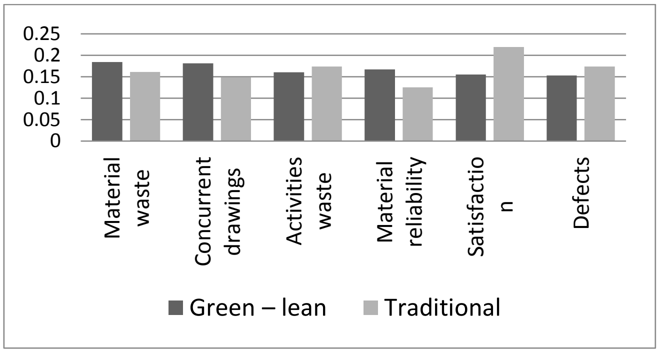

Figure 5 Alternatives performance with respect to quality sub-criteria

As for cost sub-criteria, operational cost showed the highest rank; it weighed 0.283 in the green-lean alternative, while it had the lowest rank and weighed 0.121 in the traditional alternative as shown in Figure (5).

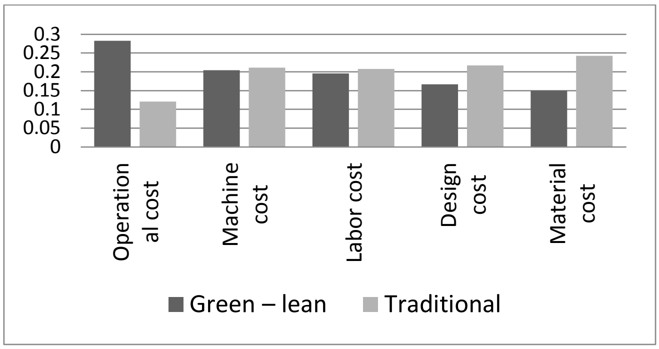

Figure 6 Alternatives performance with respect to cost sub-criteria

As for the time sub-criteria, weights were close for adherence to deadline sub-criteria, in both alternatives green-lean and traditional, had the highest rank with a weight of 0.341 as shown in Figure (6).

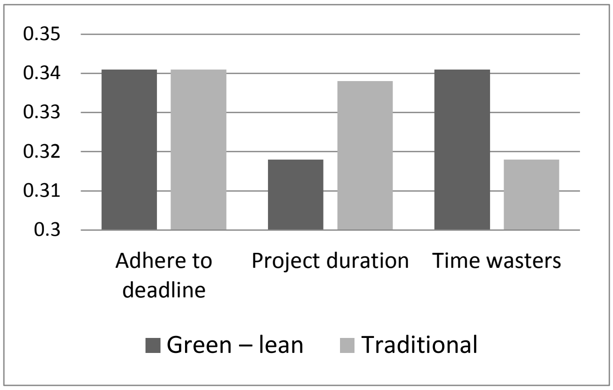

Figure 7 Alternatives performance with respect to time sub-criteria

D Sensitivity analysis

In order to gain more insights into the problem and develop the model to be more dynamic, sensitivity analysis was performed for the main criteria, which are environment, quality, cost, and time. Figure (7) shows the trend of the traditional and green-lean construction. It indicates that the increase in the parameter value α (the horizontal axis) increases the performance of green-lean and decreases the performance of the traditional alternative as in equation (8).

$$\text{Parameter value} = \alpha * \text{alternative (1)} + (1-\alpha) \text{ alternative (2)} \quad (8)$$

Where, alternative 1: (green – lean alternative), alternative 2: (traditional/ conventional alternative) and (α) is a parameter value computed by super decision program base on the weighs of each sub-criterion.

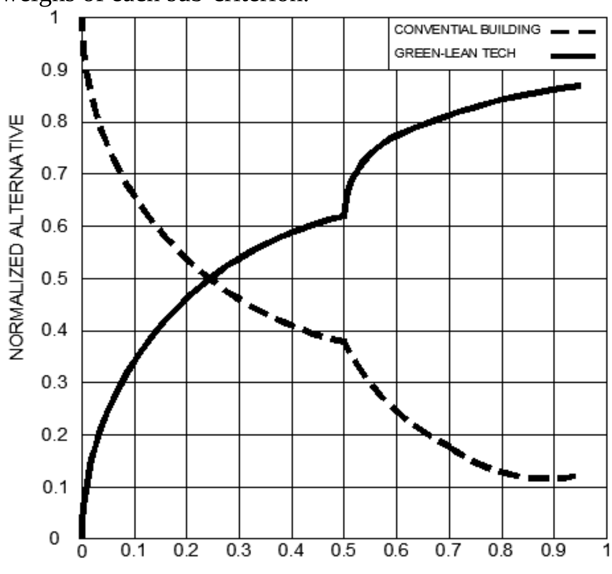

Figure 8 Sensitivity analysis of the alternatives performance

α

Alternative performance (the vertical axis) represents numerically the integrated relation between the two alternatives and the sub-criteria. This means that at the start of the project, there are two situations in front of the decision maker. Whether to accept or not any of the criteria and sub-criteria into consideration.

A. When the decision maker doesn't implement the green – lean criteria and sub-criteria, then α * alternative (1) = 0, the parameter value of green –lean alternative is zero and the traditional alternative (1- α) alternative (2) = is at the highest value =1. This also means that the green-lean alternative is at the lowest value zero as shown in Figure (9). As more sub-criteria are being taken into consideration, the preference of the traditional practices decreases, while the green-lean preference increases. It's worth mentioning that α is the percentage of the sub-criteria includes overall scenario.

B. As the demand for fulfillment of more green – lean sub-criterion increases (horizontal axis -parameter value), the traditional alternative fails in satisfying the sub-criteria in an optimum value as the green- lean does. The traditional normalized value decreases, while the green–lean increases, when considering more sub- criterion.

C. When the decision maker does implement all the green – lean criteria and sub-criteria, then the parameter value is approximately 0.88, while the traditional alternative is approximately 0.12. It is obvious from Figure (7) that neither the green – lean trend can reach the value 1 nor the tradition fall to a zero value.

E Suggested framework using Zero- One Goal Programming

ZOGP determines near optimum and realistic frameworks in different scenarios. The model considered all the goals simultaneously by forming an achievement function that minimizes the total weighted deviation from all the goals stated in the model. The weights reflected the decision makers' preferences regarding the relative importance of each goal. The main idea of the ZOGP model is to answer the question of "what is the near optimum framework to work on, for a given amount of cost?"

The framework assigned the five cost sub-criterion (operational, machine, material, design and labor costs) fixed values to determine the priority of the other sub-criteria in ZOGP model, the sub-criterion were ranked according to their contribution to the total objective function value as shown in Figure (8).

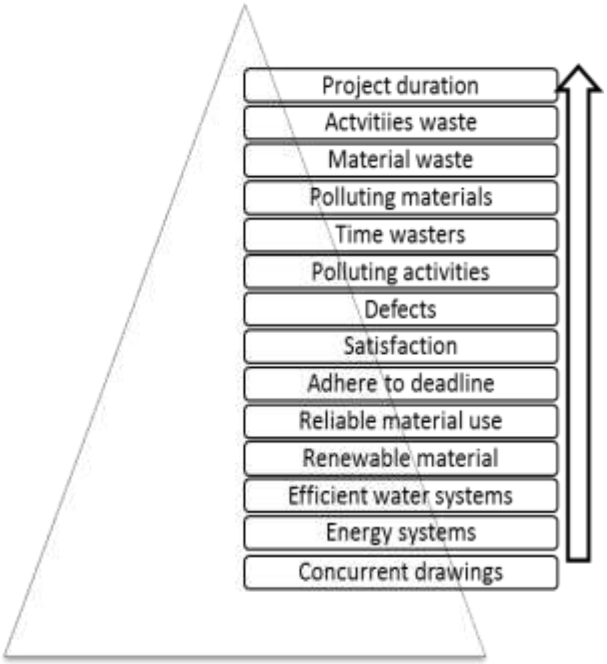

Figure 9 Framework for the First scenario

It is worth mentioning that the objective function remains consistent as more sub-criterion are added till eight sub-criterion. This means, for example, if the decision maker decided to use just one sub-criteria to improve his work, or if he use 8 sub-criteria (concurrent drawings, increase the energy systems, efficient water use, renewable material, reliable material use, adhere to deadline, satisfaction, reduce defects), he will get the same objective function value and the same result. However, including more sub-criterion will increase the objective function value as shown in Figure (9). Beyond the eighth criteria, the total cost of the project would increase more than the one in the traditional construction. It would be recommended to implement the next sub-criteria as in Figure (9), however, the initial cost would increase gradually.

This situation would encourage the decision maker to expand his promoting plan to be more green-lean without adding cost or penalty. Beyond the eighth sub-criteria, the objective function value starts to increase.

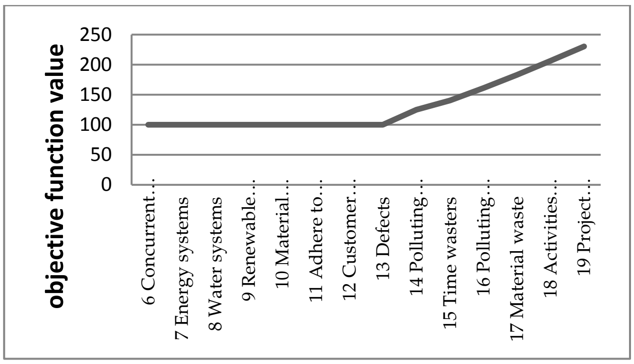

Figure 10 Relation between sub-criterion rank and objective

Effect of fixing cost sub-criteria on the objective function

For fixed cost X_1, X_2, X_3, X_5 cases, Figure (10) shows that the objective function remains consistent for the first eight sub-criterion and would not affect the regular construction cost. This encourages the decision maker to promote the construction process based on at least 8 sub-criteria which are satisfactory, material reliability, adhere to deadline, concurrent drawings, water systems, energy systems and renewable material. If the decision maker takes these sub-criteria into consideration, a wide range of modifications will appear in the construction process and tangible effects would be felt.

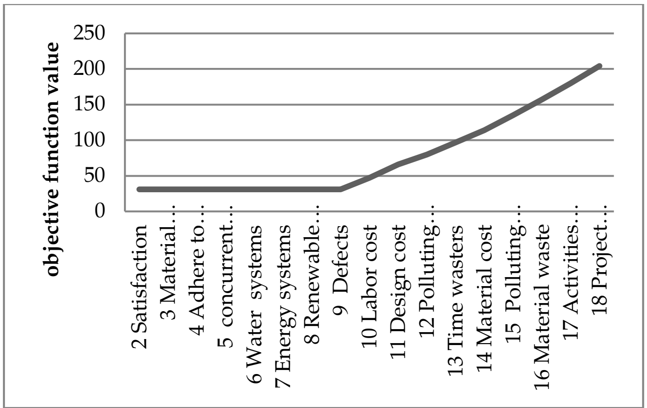

Figure 11 Relation between sub-criterion rank and objective function where all cost sub-criterion are fixed

V Conclusions and Recommendations

The overall goal of this study was to propose an integrated green -lean framework to improve the performance, efficiency and greenness of construction processes during the construction phase. In order to accomplish this goal, several techniques for green-lean construction were discussed as follows.

When simulating a real construction project, it is usual to have a fixed value for the project cost (the operation, design, labor, machine and material).This affect the ranking of the sub-criterion (which is concluded from the literatures and modified by experts with more than 10 years' experience).

In the resulting framework, taking into consideration the right design principles and solve the conflicts among the different (architect, civil, mechanical, electrical) specializations in the design phase were in the first rank as the most critical sub-criteria to insure the smooth flow in the construction process thus affecting the project duration and cost.

Energy system (for example, installing photovoltaic solar cells, replacing regular windows with double-glazed ones, replacing incandescent bulbs with compact fluorescent light bulbs) comes in the second rank. Then, the use of efficient water systems like gray water reuse should also be considered at an early stage of the project. These two sub-criterion are classified as green techniques in addition to renewable material use and reuse of the material in the site.

Renewable material ranked fourth, for example, using green cake block will reduce the harmful effect of the traditional block on the environment. This sub-criteria is strongly related to the next sub-criteria in the fifth rank, which is the reliability of the used material mainly if it is used for the first time in construction.

Adherence to deadline sub-criteria comes in the sixth rank, almost all the projects delayed and do not respect the scheduled time plan, this forces the contractor to pay a delay penalty and affect the value that the owner tries to accomplish. Lean concept concentrates on the idea that the project must be studied precisely to come up with a detailed implementation plan to guarantee the ability to finish the project on time.

Satisfaction sub-criteria is in the seventh rank; it is taken into consideration during the design process, so it is anticipated that the satisfaction would be guaranteed in the construction phase. Defects sub-criteria is in the eighth rank, which might appear due the lack of experience of the labor, misunderstanding in the design drawings, inclement weather or accidents and all these must be considered and be prepared for from the early start of the project.

The current study recommended paying more effort in the design phase to give the designer the optimum duration to improve the designs and integrate it periodically with innovative solar and water energy alternatives. Dhingra, et al. [9]. At the very beginning, planning with the environment in mind cannot be postponed from the design process or considered a luxury in lean thinking. On the other hand, applying green would be beneficial as it is automatically constrained with economic aspects. When thinking sustainable, applying lean cannot be separated from applying green. This means that understanding economic, environmental, and social aspects are inevitable to correctly apply sustainability.

It was also recommended to find new value-added activities/ materials to replace non-value ones. For example, replacing the Portland cement blocks with more-friendly blocks like green cake blocks which made from recycled rubble and ash. Also, to use Polystyrene (PS) foam as sustainable isolation material that replaces asphalts. The asphalts, during the burning process, asphalt vapor does not condense all at once, so the workers are exposed not only to asphalt fumes but also to vapor's. Many studies show that the cancer risk increases among the workers who expose to asphalt vapors (Wess, 2005). While polystyrene foam does not need special handling or consideration, there is no dust during installation and use, no chemical binders and safe for consumers - no exposure to harmful substances during service life.

It is also recommended to use modern analyzing tools, mainly in the design phase to study the environmental impact of the construction and promote it in the early start with innovative alternatives like shading elements, panels and skylight and water treatment strategies. It is not essential to use expensive tools to grantee the thermal satisfaction, for example, it could be done with simple modification in the ventilation, orientation and location of the building.

Furthermore, analyzing the needed activities in an early start of the project would help to release the right work at the right time with the right people at an optimum price.

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