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Choosing the Best Sustainable Prefabricated Building Systems Using the Analytical Network Process (ANP) Technique

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ABSTRACT

Sustainable prefabricated construction practices are essential for economic and resource management, as the consumption of raw materials in traditional construction is high and affects the country's resources and economy. Sustainable prefabricated building systems in Iraq suffer from a clear weakness in management due to the use of old methods and a lack of focus on important management criteria. This research addresses this issue by modeling the analytical network process (ANP) technique to select the best types of systems. Through a review of the general literature, 80 indicators were identified within 12 relevant categories. These indicators formed the basis of a closed questionnaire distributed to 90 experienced respondents. Three prefabricated construction systems were determined based on the structural composition (bearing wall system, frame system, and box system). The expert questionnaire was analyzed using the Analytical Network Process technique and the Sustainability Index (SI) was found for each system using the Excel program it was found that the best sustainable prefabricated construction system is the box system. This research helps in determining the most important sustainability criteria that contribute to improving the management of sustainable prefabricated construction projects. After studying the research results, it was found that prefabricated construction can contribute to improving construction productivity, increasing speed and quality, reducing pollution, and lowering the cost of housing in Iraq, which suffers from high costs.

1. Introduction

Prefabricated construction is the process of creating buildings or other construction components in a factory or workshop. It is often referred to as off-site fabrication, modular construction, or prefab. After that, the components are delivered to the building or infrastructure project's construction site and integrated there [1]. In previous studies for prefabricated buildings, the terms of "prefabricated" [2], "prefabricated concrete building" [3], "industrialized building" [4, 5], and "off-site construction" [6] have all been used.

The concept of prefabricated housing is not new; it was first introduced in 1875 AD, and at that time, wood was the primary material used to construct cabins. France, Germany, and Sweden achieved significant advancements in this area in the 1920s, while the United States started using prefabricated fabrication based on the usage of concrete, iron, and wood to create mostly residential buildings [7].

Prefabricated construction is considered a sustainable construction method because of has many benefits in terms of cost savings, energy efficiency, and environmental conservation. The application of prefabricated construction

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can reduce construction waste by 50% [8], reduce the consumption of natural resources by 35.82%, reduce health damage by 6.61%, and reduce environmental damage by 3.47% [9]. Transitioning from conventional to sustainable building practices is imperative [10]. Therefore, applying prefabricated construction on a large scale is a future method that contributes to the sustainable development of the construction industry.

Not much effort has been made to identify sustainability criteria that can be applied to manage sustainable prefabricated construction projects [11]. This research aims to identify the most important sustainability criteria to contribute to bridging this gap, in addition to selecting the best types of sustainable prefabricated construction systems. This was done after reviewing previous literature, collecting categories and indicators, and prioritizing them through questionnaires analyzing them using SPSS, and then applying the Analytical Network Process (ANP) technique using Excel to find the Sustainability Index (SI) for the criteria.

2. Literature review

Prefabricated building systems are classified into three types depending on how they bear and transport weights and distribute these weights: frame systems, panel systems (bearing walls), and cell systems (Box systems) [12, 13, 14].

2.1 Frame Systems (FS)

In fundamental design, "frame systems" refer to the structural sub-arrangement [15]. Work is accomplished this way using thresholds (beams) that support weights from floors and ceilings and transmit them to columns [13], as shown in Figure 1. This system is the same as that used in traditional construction. One of the advantages of this type is that the units used are simple in shape and easy to transport and connect [12]. Another advantage of this framework is that it can reduce the on-site construction time for medium-sized buildings (approximately 150-200 square meters) from 12 months to at least 4-5 months (excluding the construction time of each panel in the processing plant) [16]. Among its disadvantages is the difficulty of assembling the frame units due to their large number, in addition to the difficulty of assembling between the frame and the walls.

2.2 Panel Systems (Bearing Walls Systems WS)

It is the ideal prefabrication method for straight, curved, and angular facade applications [13]. It uses structural panels that support the weights in addition to the weight of the unit to do this. The distribution of weight-bearing panels is parallel to the building’s longitudinal or transverse direction, or in both directions [12], as shown in Figure 2. The plate system features a smooth and round edge and a beautiful appearance. Among its advantages, transportation impacts can be reduced to a minimum by installing services, windows, doors, interior wall finishes, and exterior cladding in the factory and stacking them flat. This will allow a larger portion of the building to be moved in one trip. One of its disadvantages is that such types cannot be applied at high altitudes.

2.3 Cells Systems (Box System BS)

The cell is an integrated box in one space with different dimensions according to the intended design, as shown in Figure 3. This cell implicitly contains all other services (from water or electricity pipes, etc.) [12]. The load-bearing spacers (beams) in the cell system, a contemporary design, provide the floors with the necessary vertical support and horizontal stiffness. Ladders, lifting posts, or split outer panels are used to provide the necessary longitudinal dependability. Pile-bearing spacers or facade dividers support connecting elements, such as floors, roofs, and columns [13]. In this system, concrete is one of the materials that is most often used worldwide for building cells. One benefit of this kind is that it is possible to carry the full residential unit from the manufacturer to the location of the work. One of the disadvantages of this type is the difficulty of changing its design because it arrives at the site as an integrated unit.

Figure 1. A model of the frame system [13]

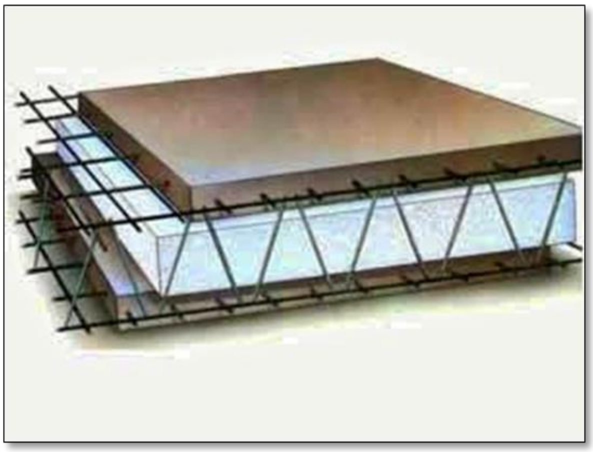

Figure 2. A model of the panel system [13]

Figure 3. A model of the Box system [13]

3. Tools used in research

This research implemented the Analytical Network Process (ANP) technique using the Excel program. Below is a simplified explanation of the methods.

3.1 Analytical Network Process (ANP).

Saaty introduced the Analytic Network Process (ANP) to address decision-making challenges, offering a more flexible approach than the Analytical Hierarchy Process (AHP) [17]. ANP allows for intricate interactions between decision levels, deviating from AHP's rigid hierarchy [18, 19]. ANP's network structure accommodates complex decision models involving various factors, stakeholders, and interdependencies [19]. Unlike AHP's unidirectional hierarchy, ANP permits bidirectional influences, enabling non-linear outcomes in prioritization [20]. ANP's pairwise comparison process aids in prioritizing decision elements within a network framework, enhancing its applicability in real-world decision issues with multifaceted relationships and dependencies [17].

4. Research Methodology

The components of the research methodology are detailed as follows:

4.1 Theoretical Part

Collection of categories and indicators from previous research and studies, literature review, internet and theoretical topics related to sustainability indicators for sustainable prefabricated building systems. The analysis of the literature review resulted in a summary of 80 indicators within 12 categories; three alternatives in prefabricated building systems were identified: bearing wall, frame and box.

4.2 Practical part

In this research, two questionnaires were conducted and their results were approved to select the best system for prefabricated construction based on the Analytical Network Process (ANP) technique and using Excel program as follows.

4.2.1 Closed questionnaire.

The closed questionnaire aims to find the relative importance (arithmetic mean) of sustainability indicators. The questionnaire was conducted according to the five-point Likert scale to determine the relative importance of the criteria, as shown in Appendix A. The questionnaire includes the following steps:

1. The questionnaire was prepared and distributed in the Iraqi governorates (Salah al-Din, Nineveh, Kirkuk, Baghdad, Diyala, Najaf, Erbil, and Sulaymaniyah) to 90 respondents in various engineering specialties and those with experience in this field. Because they did not meet the research criteria, three respondents were excluded.

2. SPSS is used to verify the consistency of the questionnaire according to Cronbach's alpha values for each category, as shown in Table 1. One of the most commonly used internal consistency (reliability) measures is Cronbach's alpha, especially when having multiple Likert questions in a questionnaire and wanting to determine the measure's reliability [21]. Cronbach's alpha values for this research range from (0.711 to 0.982), on a scale acceptable to very good for each category separately. The alpha value for the questionnaire as a whole is equal to (0.958), which is a very good measure. Cronbach's alpha criteria are shown in Table 2.

3. Using the arithmetic mean equation using SPSS to analyze the results of the closed questionnaire and determine the relative importance of each indicator. Arithmetic mean equation (1) [19, 20].

$$AM = (\sum (Fr \times D))/N \quad \ldots \quad (1)$$

AM: Arithmetic mean

Fr.: Frequency

D: Degree (1, 2, 3, 4, 5)

N: Sample amount

4. After arranging the indicators according to relative importance (arithmetic mean) in descending order from the largest to the smallest, which numbered 80 indicators, the number of indicators was reduced based on the Pareto principle (80/20) %, which stipulates that (20) % of the indicators have an impact of (80) % on sustainability compared to the rest of the other indicators, as (20) % equals (16) indicators only, which are of the most relative importance within eight categories. The shaded indicators in Appendix A have been deleted.

5. The indicators were adapted and arranged into four categories in line with the requirements of pairwise comparisons, as shown in Table 3.

Table 1. Reliability and validity for categories

NO	Categories	No. indicators	Cronbach's alpha
1	Cost	15	0.791
2	Time	7	0.711
3	Quality	8	0.864
4	Occupational safety and health (OHS)	5	0.886
5	Customer requirements	5	0.820
6	Resources Saving	6	0.732
7	Environmental protection	7	0.869
8	Emissions	8	0.801
9	Logistics	5	0.885
10	Construction Productivity	6	0.922
11	Process	5	0.982
12	Information	4	0.869

Table 2. Limits of Cronbach's alpha (ca) [21]

Limits of Cronbach's alpha (ca)	Ranking
ca ≥ 0.9	Very good
$0.8 \leq$ ca < 0.9	Good
$0.7 \leq$ ca < 0.8	Acceptable
$0.6 \leq$ ca < 0.7	Doubtful
$0.5 \leq$ ca < 0.6	Bad
ca < 0.5	Not acceptable

Table 3. Key sustainability categories and indicators

Code	Details	Arithmetic Mean
1	**Occupational Safety and Health (OSH)**	
1.1	Ensuring occupant health	3.517
1.2	Off-site manufacturing implies a reduction in site disruptions	3.483
1.3	Reduced number of on-site accidents	3.471

1.4	Safer working conditions due to controlled environments	3.471
1.5	Safety materials and technologies	3.414
2	**Quality**	
2.1	Quality requirement of workers	3.425
2.2	Aesthetic options	3.402
2.3	Reduction in defects upon completion	3.379
2.4	Construction quality	3.379
3	**Process**	
3.1	Increased speed of construction onsite	3.494
3.2	Integrity and accuracy of design information	3.483
3.3	Management processes through design, manufacturing, and construction	3.448
3.4	Simplified construction process	3.391
4	**Cost**	
4.1	Construction cost	3.621
4.2	Construction technical difficulty	3.425
4.3	Profitability	3.414

4.2.2 Expert Questionnaire

The experts' questionnaire was conducted on the indicators obtained from the closed questionnaire from Table 1. This questionnaire aims to select the best types of sustainable prefabricated building systems. The questionnaire was distributed to 12 experts in the field of prefabricated construction. Table 4 shows the most important information about the experts. After analyzing the questionnaire using SPSS, the relative weights of the indicators for each alternative were obtained. Tables (5, 6, and 7) show the results of the alternatives.

The results were then entered into Excel using the Analytical Network Process (ANP) model to select the best types of the three sustainable prefabricated building systems (load-bearing walls, frame system, and box system).

Table 4. Information about Experts

Occupation	Number of years of professional experience	Academic certificate	Specialization?	Number of years of experience in prefabricated	Place of work (Gove.)
Academic	More than 30	Ph.D.	Project Management	6-10 years	Baghdad
Academic	21-30 years	Ph.D.	Construction	More than 20	Salah Al-din
Design engineer	21-30 years	Ph.D.	Architectural	11-15 years	Nineveh
Academic	More than 30	Ph.D.	Construction	More than 20	Nineveh
Academic	21-30 years	Ph.D.	Environmental engineering	16-20 years	Nineveh
Academic	11-20 years	Master's	Project Management	6-10 years	Kirkuk
Project manager	11-20 years	Higher Diploma	Construction	6-10 years	Salah Al-din
Supervising engineer	11-20 years	Higher Diploma	General Civil	11-15 years	Kirkuk
Contractor	More than 30	Bachelor's	General Civil	6-10 years	Salah Al-din
Project manager	More than 30	Bachelor's	General Civil	16-20 years	Kirkuk
Supervising engineer	11-20 years	Bachelor's	General Civil	11-15 years	Erbil
Implementation engineer	More than 30	Bachelor's	Survey engineering	11-15 years	Najaf

Table 5. The relative importance of the indicators for the First Alternative: Bearing Walls Systems

1	Occupational Safety and Health (OSH) Indicators	Ar. Mean	Std. Deviation	Rank	Level of imp.
1.1	Off-site manufacturing implies a reduction in site disruptions	3.8889	0.6980	1	H
1.2	Ensuring occupant health	3.8148	0.7357	2	H
1.3	Safer working conditions due to controlled environments	3.7037	0.7753	3	H
1.4	Reduced number of on-site accidents	3.6667	0.7338	4	H
1.5	Safety materials and technologies	3.4444	0.6980	5	H
2	**Quality Indicators**	**Ar. Mean**	**Std. Deviation**	**Rank**	**Level of imp.**
2.1	Construction quality	3.7407	0.7642	1	H
2.2	Quality requirement of workers	3.7037	0.8689	2	H
2.3	Reduction in defects upon completion	3.5556	0.7511	3	H
2.4	Aesthetic options	3.3704	0.5649	4	M
3	**Process Indicators**	**Ar. Mean**	**Std. Deviation**	**Rank**	**Level of imp.**
3.1	Increased speed of construction onsite	4.0000	0.9608	1	H
3.2	Integrity and accuracy of design information	3.5926	0.8440	2	H
3.3	Simplified construction process	3.5926	0.9306	3	H
3.4	Management processes through design, manufacturing, and construction	3.4444	0.8006	4	H
4	**Cost Indicators**	**Ar. Mean**	**Std. Deviation**	**Rank**	**Level of imp.**
4.1	Construction cost	3.7407	0.7642	1	H
4.2	Construction technical difficulty	3.4444	0.6980	2	H
4.3	Profitability	2.9630	0.8979	3	M
	Cronbach's alpha= 0.811				

Table 6. relative importance of the indicators for the Second Alternative: Frame Systems

1	Cost Indicators	Ar. Mean	Std. Deviation	Rank	Level of imp.
1.1	Construction cost	3.667	0.620	1	H
1.2	Construction technical difficulty	3.296	0.724	2	H
1.3	Profitability	2.926	0.730	3	M
2	**Quality Indicators**	**Ar. Mean**	**Std. Deviation**	**Rank**	**Level of imp.**
2.1	Construction quality	4.037	0.808	1	H
2.2	Quality requirement of workers	3.741	0.656	2	H
2.3	Reduction in defects upon completion	3.519	0.509	3	H
2.4	Aesthetic options	3.444	0.577	4	H
3	**Occupational Safety and Health (OSH) Indicators**	**Ar. Mean**	**Std. Deviation**	**Rank**	**Level of imp.**
3.1	Ensuring occupant health	3.667	0.620	1	H
3.2	Reduced number of on-site accidents	3.630	0.742	2	H
3.3	Safer working conditions due to controlled environments	3.519	0.753	3	H
3.4	Off-site manufacturing implies a reduction in site disruptions	3.482	0.580	4	H
3.5	Safety materials and technologies	3.370	0.565	5	H
4	**Process Indicators**	**Ar. Mean**	**Std. Deviation**	**Rank**	**Level of imp.**
4.1	Increased speed of construction on-site	3.630	0.839	1	H
4.2	Simplified construction process	3.519	0.580	2	H
4.3	Management processes through design, manufacturing, and construction	3.444	0.641	3	H
4.4	Integrity and accuracy of design information	3.407	0.797	4	H
	Cronbach's alpha= 0.625				

Table 7. relative importance of the indicators for the Third Alternative: Box Systems

1	**Cost Indicators**	**Ar. Mean**	**Std. Deviation**	**Rank**	**Level of imp.**
1.1	Construction cost	3.815	0.786	1	H
1.2	Construction technical difficulty	3.630	0.629	2	H
1.3	Profitability	2.963	0.940	3	M
2	**Quality Indicators**	**Ar. Mean**	**Std. Deviation**	**Rank**	**Level of imp.**
2.1	Quality requirement of workers	3.741	0.764	1	H
2.2	Construction quality	3.704	0.823	2	H
2.3	Aesthetic options	3.370	0.792	3	M
2.4	Reduction in defects upon completion	3.370	0.629	4	M
3	**Occupational Safety and Health (OSH) Indicators**	**Ar. Mean**	**Std. Deviation**	**Rank**	**Level of imp.**
3.1	Reduced number of on-site accidents	3.963	0.808	1	H
3.2	Safer working conditions due to controlled environments	3.926	0.829	2	H
3.3	Off-site manufacturing implies a reduction in site disruptions	3.815	0.681	3	H
3.4	Ensuring occupant health	3.778	0.751	4	H
3.5	Safety materials and technologies	3.704	0.669	5	H
4	**Process Indicators**	**Ar. Mean**	**Std. Deviation**	**Rank**	**Level of imp.**
4.1	Increased speed of construction on-site	4.333	0.555	1	V.H
4.2	Simplified construction process	3.593	0.844	2	H
4.3	Integrity and accuracy of design information	3.556	0.641	3	H
4.4	Management processes through design, manufacturing, and construction	3.444	0.751	4	H
	Cronbach's alpha= 0.785				

5. The Application of (ANP) Technique Using the Excel Program

The ANP model is a network model, and its manual calculation is very complicated and needs to be implemented by computer programs. Therefore, this study used an Excel program to calculate the weighted super matrix and super matrix to obtain the self-weights of each element. Figure 4 shows the requirements for finding the Sustainability Index (SI) values based on the Analytical Network Process (ANP) technique, to select the best type of sustainable prefabricated building systems using the Excel program (manual calculations). Figure 5 shows the steps for finding the Sustainability Index (SI) value using Excel.

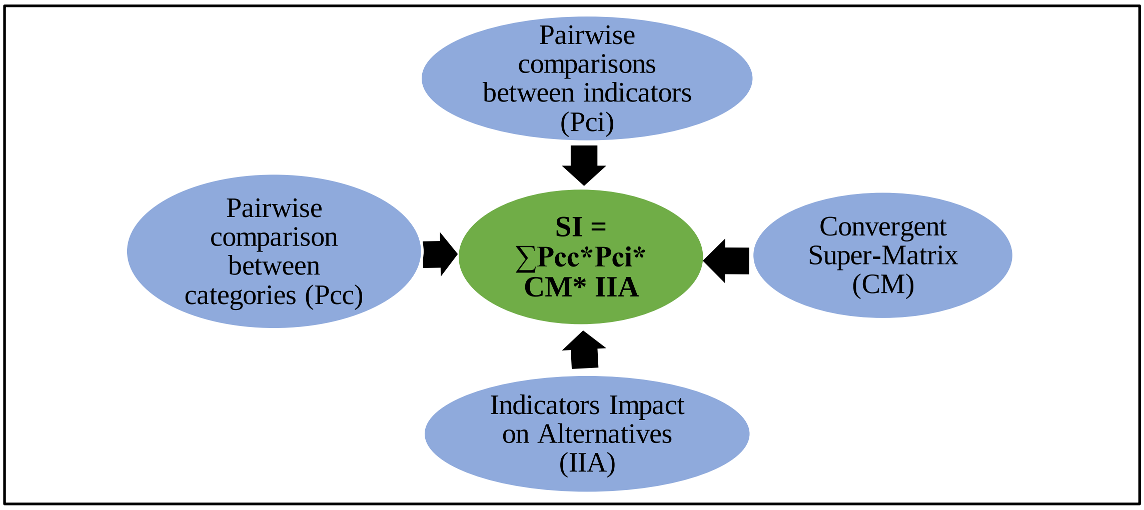

Figure 4. Requirements for finding Sustainability Index (SI) values [Researcher]

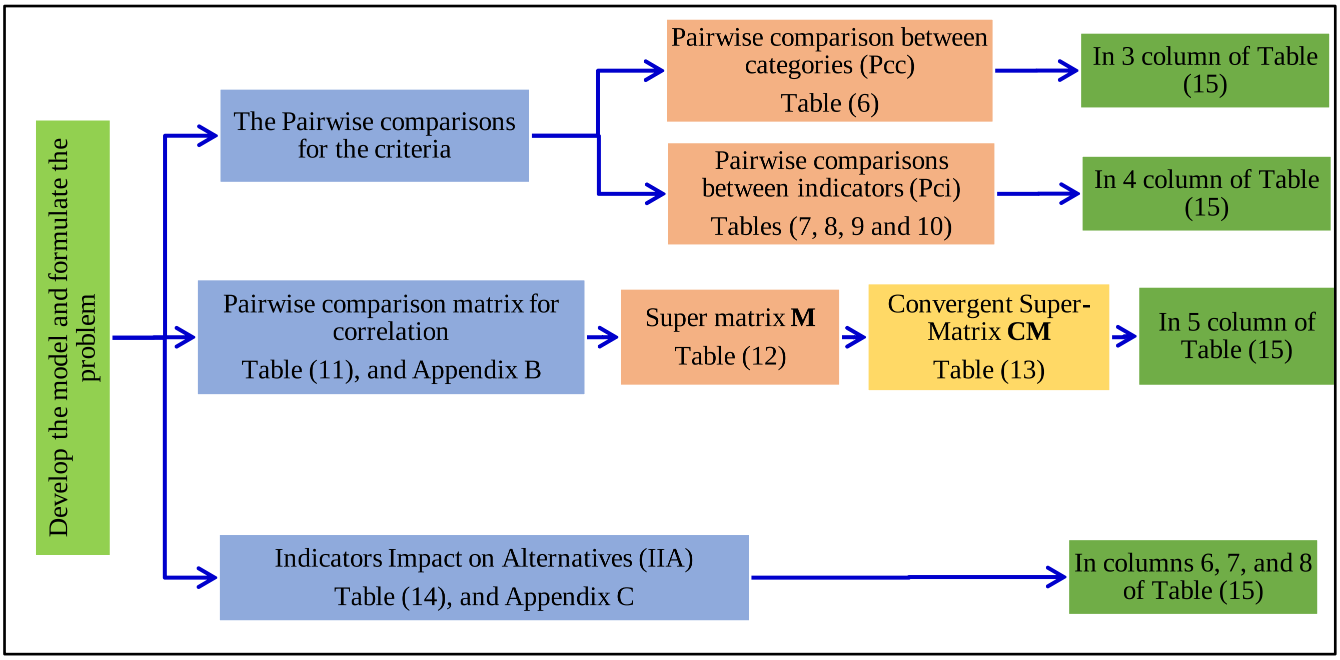

Figure 5. Steps to find the value of the Sustainability Index (SI) using Excel [Researcher]

5.1 Developing the Model and Formulating the Problem

The ANP model has developed based on a review of the literature and previous research and conducting a closed questionnaire with engineers, academics, contractors, etc. This questionnaire contributed to focusing on the critical indicators, so the number of indicators was reduced according to the Pareto theory, which states that 20% of the indicators control 80% of the sustainability of prefabricated construction, as shown in Table 3. The proposed ANP model is classified into three levels (categories, indicators, and alternatives). The categories constitute the highest level of the ANP model, containing four categories: (cost, quality, occupational safety and health, and process). The indicators represent the middle level of the ANP model, consisting of 16 indicators. As for the last level of the model, three types of sustainable prefabricated building systems are identified (bearing wall system, frame system, box system), and the alternatives are named to choose the best alternative among them, as shown in Figure 6.

5.2 The Pairwise Comparisons for the Criteria

A ratio scale ranging from 1 to 9 is used in these comparisons to rate any two objects. A score of 1 indicates that the two components are equally important, whereas a score of 9 denotes that the row component—the element under consideration—dominates the comparison element by a significant margin (column component). If an item's impact is less than that of its comparable item, the score range will be 1 to 1/9, where 1 denotes indifference and 1/9 denotes the column item's overwhelming domination over the item [22]. It is split into the following two sections:

5.2.1 Pairwise Comparison between Categories (Pcc)

After finding the weights of the categories through the experts' questionnaire, pairwise comparisons were made between the categories to determine the relative weight of each category, as shown in Table 8. The results of these comparisons (relative weight) of Pcc are shown in the third column of Table 17.

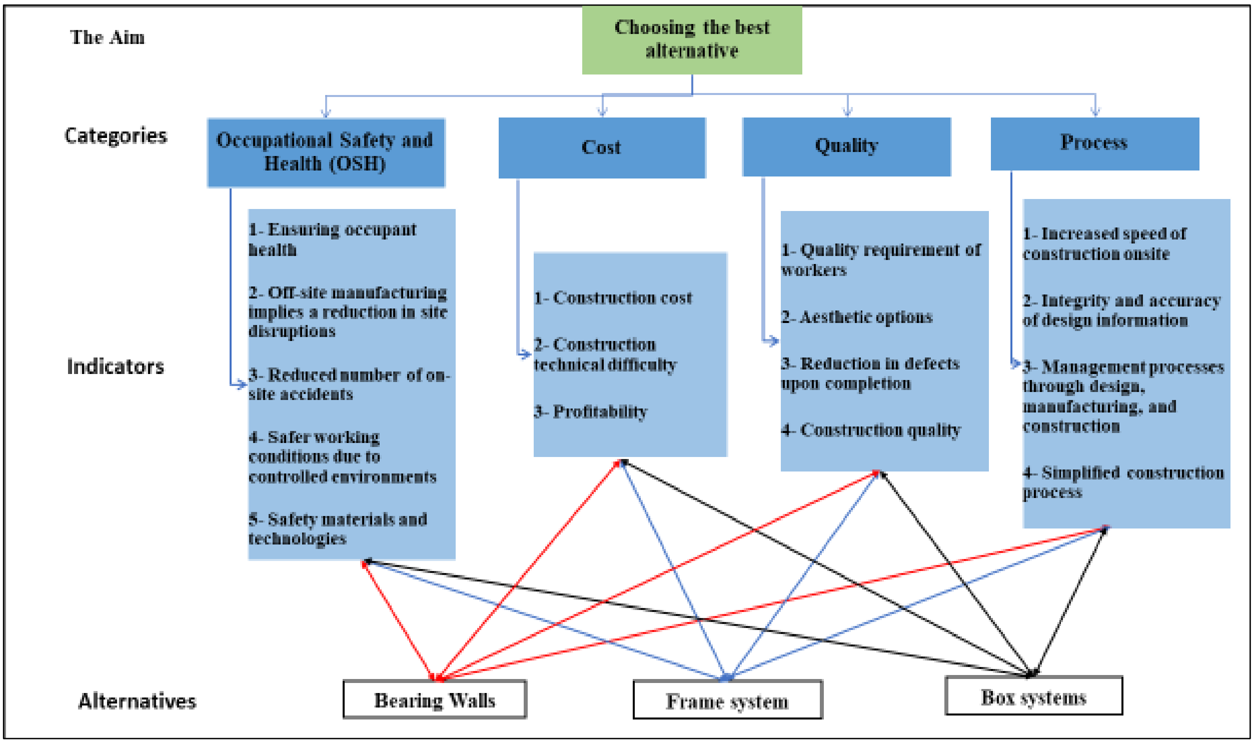

Figure 6. Development of the Analytical Network Process (ANP) model [Researcher]

Table 8: Relative weight for each Category

Categories	Cost	(OSH)	Process	Quality	Average	Rel. Weight
Cost	1	1	2	3	1.75	0.3818
(OSH)	1	1	1	2	1.25	0.2727
Process	1/2	1	1	1	0.875	0.1909
Quality	1/3	1/2	1	1	0.7083	0.1545
				∑ =	4.58	1.0000

5.2.2 Pairwise Comparisons between Indicators (Pci)

In this step, the relative weight of each indicator for the categories is obtained through the pairwise comparison matrix. In this case, four such matrices will be formed, one for each category, as shown in Tables (9, 10, 11 and 12). The results of these comparisons (relative weight) of Pci are shown in the fourth column of Table 17.

Table 9: Relative weight of Cost indicators

Cost indicators	CC	CCT	CP	Average	Rel. Weight
CC	1	1	2	1.333	0.4211
CCT	1	1	1	1.000	0.3158
CP	1/2	1	1	0.833	0.2632
			∑ =	3.167	1.0000

Table 10: Relative weight of Quality indicators

Quality indicators	QRW	QA	QR	QC	Average	Rel. Weight
QRW	1	1	3	4	2.250	0.4202
QA	1	1	2	3	1.750	0.3268
QR	1/3	1/2	1	1	0.708	0.1323

QC	1/4	1/3	1	1	0.646	0.1206
				∑ =	5.354	1.0000

Table 11: Relative weight of Occupational Safety and Health (OHS) indicators

(OHS) indicators	SE	SMD	SR	SSM	SSW	Average	Rel. Weight
SE	1	1	2	3	4	2.200	0.3501
SMD	1	1	1	2	3	1.600	0.2546
SR	1/2	1	1	1	2	1.100	0.1751
SSM	1/3	1/2	1	1	1	0.767	0.1220
SSW	1/4	1/3	1/2	1	1	0.617	0.0981
					∑ =	6.283	1.0000

Table 12: Relative weight of Process indicators

Process indicators	PIS	PIA	PM	PS	Average	Rel. Weight
PIS	1	1	2	3	1.750	0.3818
PIA	1	1	1	2	1.250	0.2727
PM	1/2	1	1	1	0.875	0.1909
PS	1/3	1/2	1	1	0.708	0.1545
				∑ =	4.583	1.0000

5.3 Pairwise Comparison Matrix for Correlation

This step performs pairwise comparisons to capture the relationship between the indicators for each category where the number of matrices is equal to the number of indicators (so if the number of indicators is 4 in the category, the number of matrices will be 4 in each matrix, canceling the effect of one of the indicators). One of these comparisons appears in Table 13. It displays the quality category with the Quality Requirements for Workers (QRW) indicator as the controlling attribute over the other quality indicators. That is when the effect of the QRW indicator is removed from the quality category (its value is zero), the relative weight of the remaining quality indicators is found when compared to each other. In Table 13, the aesthetic options indicator (QA) (0.636) has the maximum impact on the quality category, the Reduction in defects upon completion (QR) indicator has a value of (0.185), and finally, the construction quality (QC) indicator has a value of (0.179), and so on for the rest of the quality indicators. The relative weights of these matrices are used to form a super matrix. The relative weights in Table 13 were used in the fifth column of the super matrix (M) in Table 14. The number of matrices for each category will be equal to the number of indicators for that category, i.e. a total of 16 matrices, which are listed in Appendix B.

5.3.1 Super-Matrix (M) Formation

The super -matrix allows the resolution of the interconnections between the system's elements. It is a partitioned matrix where each submatrix consists of relationships between and within levels, as represented by the decision-maker model. The super-matrix (M) shown in Table 14 displays the results of the relative weights for each of the category indicators. The super-matrix (M) elements were imported from the correlation pairwise comparison matrices in Table 13 and Appendix B. Since there are 16 correlation pairwise comparison matrices, one for each category indicator, there will be 16 non-zero columns in this super-matrix M. Each of the non-zero values in the columns is the relative importance weight for indicators from the correlation pairwise comparison matrices. The results of this matrix are used to find the Convergent Super-Matrix CM in Table 15.

5.3.2 Convergent Super-Matrix M (CM)

The super matrix M must converge to obtain a set of long-term constant weights. For convergence to occur, the sum of each column of the super matrix M must be equal to 1. Therefore, the super matrix M must be raised to the power of (M^k+1), where k is an arbitrarily large number that makes the sum of each column equal to 1, allowing convergence [86]. After many attempts, the convergence of the super matrix (M) in Table 12 reached (M^16), meaning that when the super matrix M is raised to the power of 16, the sum of each column of the matrix equals 1, as required. Table 15 shows the result of the convergent super matrix (CM). The results of the CM matrix are used in the fifth column of Table 17.

Table 13: Pairwise comparison matrix between quality indicators without the QRW indicator

Quality without (QRW)	QA	QR	QC	Average	Rel. Weight
Aesthetic options (QA)	1	3	4	2.667	0.636
Reduction in defects upon completion (QR)	1/3	1	1	0.778	0.185
Construction quality (QC)	1/4	1	1	0.750	0.179
			∑ =	4.194	1.000

5.4 Indicators Impact on Alternatives (IIA)

Pairwise comparisons are made of the relative impact of indicators on each of the three alternatives. The number of these pairwise comparison matrices depends on the number of indicators, which is 16, creating 16 pairwise comparison matrices. Table 16 shows one of these pairwise comparison matrices, showing the extent of the relative impact of the construction cost indicator on each of the three alternatives. The results of this matrix are used in the second row (corresponding to CC) of columns 6, 7, and 8 in Table 17. The remaining pairwise comparison matrices are presented in Appendix C. The results of these matrices are used in columns 6, 7, and 8 of Table 17.

5.5 Calculating the Sustainability Index (SI)

To find the Sustainability Index (SI) for the alternatives: bearing Walls Systems (WS), Frame System (FS), and Box System (BS). Using the following Equation 2 [21] is used:

SI = ∑Pcc × Pci × CM × IIA …. (2)

SI: Sustainability Index

Pcc: Pairwise comparison between categories (Table 8).

Pci: Pairwise comparisons between indicators (Tables 9 - 12).

CM: Convergent Super-Matrix CM in (Table 15).

IIA: Indicators Impact on Alternatives (Table 16 and Appendix C).

Table 17 shows the values of the Sustainability Index (SI) and its normal values. These values are based on the relative weights obtained from the pairwise comparison of categories and indicators, the effect of alternatives on the indicators, and the convergent Super-Matrix.

The values of the third column in Table 17 represent the relative importance of the categories (Pcc) that have been imported from Table 8. The values of the fourth column in Table 17 represent the relative importance of the indicators (Pci) that were imported from Tables (9, 10, 11, and 12). The values of the fifth column in Table 17 represent the relative importance of the pairwise comparison matrix for the correlation of indicators obtained through the convergence super-matrix CM from Table 15.

Table 14: The super-matrix M

	CC	**CCT**	**CP**	**QRW**	**QA**	**QR**	**QC**	**SE**	**SMD**	**SR**	**SSM**	**SSW**	**PIS**	**PIA**	**PM**	**PS**
CC	0	0.5	0.5													
CCT	0.5	0	0.5													
CP	0.5	0.5	0													
QRW				0	0.636	0.462	0.462									
QA				0.636	0	0.369	0.369									
QR				0.185	0.185	0	0.169									
QC				0.179	0.179	0.169	0									
SE								0	0.294	0.294	0.294	0.294				
SMD								0.294	0	0.294	0.294	0.294				
SR								0.294	0.294	0	0.235	0.235				
SSM								0.235	0.235	0.235	0	0.176				
SSW								0.176	0.176	0.176	0.176	0				
PIS													0	0.462	0.462	0.421
PIA													0.462	0	0.369	0.316
PM													0.369	0.369	0	0.263
PS													0.169	0.169	0.169	0

Table 15: Convergent Super-Matrix (CM)

	CC	**CCT**	**CP**	**QRW**	**QA**	**QR**	**QC**	**SE**	**SMD**	**SR**	**SSM**	**SSW**	**PIS**	**PIA**	**PM**	**PS**
CC	0.33	0.33	0.33													
CCT	0.33	0.33	0.33													
CP	0.33	0.33	0.33													
QRW				0.356	0.356	0.356	0.356									
QA				0.339	0.339	0.339	0.339									
QR				0.154	0.154	0.154	0.154									
QC				0.151	0.151	0.151	0.151									
SE								0.23	0.23	0.23	0.23	0.23				
SMD								0.23	0.23	0.23	0.23	0.23				
SR								0.21	0.21	0.21	0.21	0.21				
SSM								0.18	0.18	0.18	0.18	0.18				
SSW								0.15	0.15	0.15	0.15	0.15				
PIS													0.312	0.312	0.312	0.312
PIA													0.285	0.285	0.285	0.285
PM													0.258	0.258	0.258	0.258
PS													0.145	0.145	0.145	0.145

The three columns (sixth, seventh, and eighth) in Table 17, which correspond to alternatives WS, FS, and BS, respectively, are values of the Pairwise comparisons made of the Indicators' Impact on Alternatives (IIA), these values were imported from Table 16 and Appendix C. The last three columns in Table 17 represent the values of the Sustainability Index (SI) for the indicators and alternatives obtained from Equation 2.

For example, the value of the Sustainability Index (SI) corresponding to the WS alternative and the CC indicator in Table 17 is:

$(SI = \sum Pcc \times Pci \times CM \times IIA)$ $(0.3818 \times 0.4211 \times 0.3330 \times 0.3158 = 0.0169)$.

The sum of the SI values of the indicators represents the SI value of the alternative. The SI index and its normal values appear in the last two rows of Table 17.

5.6 Choosing the Best Prefabricated Building Systems

Choosing the best system is based on the normal Sustainability Index (SI) values, for representing the sum of the SI values of the indicators. These results shown in Table (17) indicate that the Alternative the Box System (BS), which has a natural sustainability index SI of (0.3925), represents the highest value among the alternatives. It is followed by alternatives WS (0.3462) and FS (0.2613). These results indicate that the Box System (BS) is the best sustainable prefabricated building system.

5.7 Discussing the Results

The Sustainability Index (SI) values for all categories can be obtained by summing the values of the weights of the indicators for that category, as the values of the categories are affected by their components of the indicators. For the cost category, Alternative BS obtained the highest value, which is (0.0522), followed by Alternative WS, with a value of (0.0429), and finally Alternative FS, with a value of (0.0320). As for the quality category, the FS alternative received the highest value, which is (0.0134), followed by the WS alternative, with a value of (0.0121), and finally the BS alternative, with a value of (0.0117). As for the occupational safety and health category, the WS alternative received the highest value, which is (0.0232), followed by the BS alternative, with a value of (0.0211), and finally the FS alternative, with a value of (0.0134). As for the process category, the BS alternative received the highest value, which is (0.0219), followed by the WS alternative, with a value of (0.0161), and finally the FS alternative, with a value of (0.0124), as shown in Table 17.

From the above, it is found that Alternative BS obtained the highest Sustainability Index (SI) value for both the Cost and Process categories, while Alternative WS obtained the highest SI value for the Occupational Safety and Health category, and Alternative FS obtained the highest SI value for the Quality category. The sustainability index (SI) values of the alternatives can be obtained by summing the sustainability index (SI) values of the categories, as the values of the alternatives are affected by their components of the categories and indicators. Overall, the BS alternative obtained the highest Sustainability Index (SI) value among the three alternatives and is therefore the best type for sustainable prefabricated building systems.

Table 16: the relative impact of the construction cost indicator on the alternatives

Construction Cost (CC)	Box systems (BS)	Walls systems (WS)	Frame systems (FS)	Average	Rel. Weight
Box systems (BS)	1	1	2	1.333	0.4211
Walls systems (WS)	1	1	1	1.000	0.3158

Frame systems (FS)	1/2	1	1	0.833	0.2632
			∑ =	3.167	1.000

Table 17: Weighted values of alternatives (Sustainability Index SI)

Categories	Indicators	Pcc	Pci	CM	Indicators Impact on Alternatives (IIA)			Value (SI) for each alternative		
					WS	FS	BS	WS	FS	BS
Cost (C)	**CC**	0.3818	0.4211	0.3330	0.3158	0.2632	0.4211	0.0169	0.0141	0.0225
	CCT	0.3818	0.3158	0.3330	0.3692	0.1692	0.4615	0.0148	0.0068	0.0185
	CP	0.3818	0.2632	0.3330	0.3333	0.3333	0.3333	0.0112	0.0112	0.0112
							∑=	**0.0429**	**0.0320**	**0.0522**
Quality (Q)	**QC**	0.1545	0.4202	0.1510	0.2632	0.4211	0.3158	0.0026	0.0041	0.0031
	QRW	0.1545	0.3268	0.3560	0.3333	0.3333	0.3333	0.0060	0.0060	0.0060
	QR	0.1545	0.1323	0.1538	0.4615	0.3692	0.1692	0.0015	0.0012	0.0005
	QA	0.1545	0.1206	0.3390	0.3333	0.3333	0.3333	0.0021	0.0021	0.0021
							∑=	**0.0121**	**0.0134**	**0.0117**
Occupational Safety and Health (OSH)	**SMD**	0.2727	0.2546	0.2270	0.4211	0.2632	0.3158	0.0066	0.0041	0.0050
	SE	0.2727	0.3501	0.2270	0.4211	0.2632	0.3158	0.0091	0.0057	0.0068
	SSW	0.2727	0.0981	0.1500	0.3158	0.2632	0.4211	0.0013	0.0011	0.0017
	SR	0.2727	0.1751	0.2120	0.3692	0.1692	0.4615	0.0037	0.0017	0.0047
	SSM	0.2727	0.1220	0.1840	0.3974	0.1258	0.4768	0.0024	0.0008	0.0029
							∑=	**0.0232**	**0.0134**	**0.0211**
Process (P)	**PIS**	0.1909	0.3818	0.3120	0.2308	0.2154	0.5538	0.0052	0.0049	0.0126
	PIA	0.1909	0.2727	0.2850	0.4211	0.2632	0.3158	0.0062	0.0039	0.0047
	PS	0.1909	0.1909	0.1450	0.4000	0.2000	0.4000	0.0021	0.0011	0.0021
	PM	0.1909	0.1545	0.2580	0.3333	0.3333	0.3333	0.0025	0.0025	0.0025
							∑=	**0.0161**	**0.0124**	**0.0219**
Sustainability Index (SI)								**0.0944**	**0.0712**	**0.1070**
Normalized Sustainability Index (SI)								**0.3462**	**0.2613**	**0.3925**

6. Conclusions

Through reviewing previous literature and field visits to prefabricated construction projects in Iraq, the researcher found that the biggest problem lies in the presence of a clear weakness in the management of prefabricated construction projects and the failure to specify criteria for evaluating the sustainability of prefabricated construction projects.

In this research, three alternatives for sustainable prefabricated building systems based on structural composition (bearing wall system, frame system, and box system) were identified to apply the Excel program to the ANP model.

The most important categories used to sustain prefabricated construction projects are cost, time, quality, occupational safety and health, customer requirements, resource-saving, environmental protection, emissions, logistics services, construction productivity, process, and information. The most important indicators that affect the sustainability of prefabricated construction projects are 80 indicators distributed into 12 categories: the construction cost indicator received the highest value (3.621), followed by the indicator ensuring occupant health in the second place (3.517), and the third place is for the increased speed of construction on site with a value of (3.494). The last place is for the particulate emissions indicator, which obtained the lowest value (2.276).

After studying the research results, it was found that prefabricated construction can contribute to improving construction productivity, increasing speed and quality, reducing pollution, saving resources, and preserving the environment. It can also contribute to reducing the cost of housing.

After analyzing the results of the experts' questionnaire, the best type of prefabricated building system in terms of structural configuration was chosen, which is the Box system.

The ANP model by the Excel program, accurate results can be obtained, but with great effort because the model is networked and its calculations are complex.

7. Recommendations

Attention should be increased to prefabricated construction, as the consumption of raw materials in traditional construction greatly affects the country's resources and economy. Therefore, the future of prefabricated construction can be viewed as an improvement for existing and new economies.

This approach helps decision-makers identify factors that enhance the sustainability of prefabricated construction systems to focus on and grow in the future.

It is possible to use the Super Decision Software (SDS) program based on Analytical Network Process (ANP) technology, as it has proven its effectiveness in accelerating the analysis and decision-making process, which distinguishes it from the analysis and traditional decision-making methods.

Conflict of Interest

The authors confirm that there is no conflict of interest resulting from the publication of this article.

Author's Contribution Statement

Author Mohammed Saleh Khalaf: Proposed the research problem, developed the theory, and performed the calculations.

Author Maysoon Abdullah Mansour: Validation of analytical methods and supervision of the results of this work. The authors discussed the results and contributed to the final manuscript.

References

[1] VICTORIAN BUSINESS SUPPLY CHAIN DIRECTORY. (2019). PREFABRICATED CONSTRUCTION IN VICTORIA. Retrieved from email: construction@ecodev.vic.gov.au

[2] Liu, J., Shen, G. Q., Mao, C., Li, Z., & Li, K. (2016). Life-cycle energy analysis of prefabricated building components: an input-output-based hybrid model. Journal of Cleaner Production, 112, 2198-2207.

[3] Kale, S., & Arditi, D. (2006). Diffusion of ISO 9000 certification in the precast concrete industry. Construction Management and Economics, 24(5), 485-495.

[4] Jonsson, H., & Rudberg, M. (2014). Classification of production systems for industrialized building: a production strategy perspective. Construction Management and Economics, 32(1-2), 1-17.

[5] Meiling, J. H., Sandberg, M., & Johnsson, H. (2013). A study of a plan-do-check-act method used in less industrialized activities: two cases from industrialized housebuilding. Construction Management and Economics, 32(1-2), 1-17.

[6] Pan, W., Gibb, A. G. F., & Dainty, A. R. J. (2008). Leading UK housebuilders' utilization of offsite construction methods. Building Research & Information, 36(1), 56-67.

[7] M. Mohee and H. Khaleel, "Study of performance efficiency of prefabricated construction, applied research on the building of the Civil Engineering Department - Tikrit University," Diyala Journal of Engineering Sciences, vol. 4, no. 2, pp. 1-22, 2021. Available: https://djes.info/index.php/djes/article/view/581/537.

[8] Hu, X., & Chong, H.-Y. (2019). Environmental sustainability of off-site manufacturing: A literature review. Engineering, Construction and Architectural Management, 1-21.

[9] Cao, X., Li, X., Zhu, Y., & Zhang, Z. (2015). A comparative study of environmental performance between prefabricated and traditional residential buildings in China. Journal of Cleaner Production, 109, 131-143. http://doi.org/10.1016/j.jclepro.2015.04.120

[10] A. J. Mohammed, "Evaluation of time overruns and time management techniques in road construction projects in Erbil city," Journal of Engineering and Sustainable Development, vol. 27, no. 4, pp. 499-510, 2023. DOI: 10.31272/jeasd.27.4.7.

[11] N. F. Ali and M. A. Mansor, "An Integrated Framework for Measuring Construction Building Project Performance Success," Master's thesis, Tikrit University, Department of Civil

Engineering, College of Engineering, 2021. DOI: 10.1063/5.0123472.

[12] Mohee, M., & Khaleel, H. (2021). Study of performance efficiency of prefabricated construction, applied research on the building of the Civil Engineering Department - Tikrit University. Diyala Journal of Engineering Sciences, 4(2), 1-22. Retrieved from https://djes.info/index.php/djes/article/view/581/537

[13] Baghchesaraei, A., Vatan Kaptan, M., & Reza Baghchesaraei, O. (2015). Using Prefabrication Systems in Building Construction. International Journal of Applied Engineering Research, 10(24), 44258-44262. Retrieved from Research India Publications.

[14] البناء الجاهز في العراق. (1984). دراسة أنظمة البناء المستخدمة في مشاريع الإسكان المنفذة عن طريق الشركات الأجنبية. وزارة التخطيط/ هيئة تخطيط التشييد والإسكان والخدمات/ خطة بحوث الوزارة دراسة رقم -١٤١.

[15] Koskela, L., Howell, G., Ballard, G., & Tommelein, I. (2002). The Foundations of Lean Construction. In Design and Construction. Taylor and Francis, Oxford, UK, pp. 16. [CrossRef]

[16] Limthongtang, R. (2005). Comparison between prefabrication construction and normal construction (Master's thesis). Chulalongkorn University, Bangkok, Thailand.

[17] A. C- igˇdem Ko¨nea, and T. Bu¨keb, "An Analytical Network Process (ANP) evaluation of alternative fuels for electricity generation in Turkey" Elsevier Journal Energy Policy 35 5220–5228, April 2007. DOI:10.1016/j.enpol.2007.05.014

[18] L. Xie, Y. Chen, B. Xia, and Ch. Hua, "Importance-Performance Analysis of Prefabricated Building Sustainability: A Case Study of Guangzhou," Journal of Hindawi Advances in Civil Engineering, Volume 2020, Article ID 8839118, p. 17, 2020. https://doi.org/10.1155/2020/8839118.

[19] H. Guo, W. Qiao, and Y. Zheng, "Effectiveness evaluation of financing platform operation of buildings energy saving transformation using ANP-fuzzy in China: an empirical study," Sustainability, vol. 12, no. 7, p. 2826, April 2020. https://doi.org/10.3390/su12072826

[20] T. L. Saaty, "Applications of Analytic Network Process in Entertainment 1," Iranian Journal of Operations Research Vol. 1, No. 2, 2009, pp.41-55. University of Pittsburgh. [Ref.]

[21] Caruana, M., Hackenbruch, S. N., Grech, V., and Farrugia, R., "Inconsistency in the Application of Glasgow Coma Scale in Pediatric Patients," Medical Principles and Practice: International Journal of the Kuwait University, Health Science Centre, vol. 33, no. 1, pp. 41-46, 2023. [Online]. Available: http://dx.doi.org/10.1159/000534797

[22] Jharkharia, S., & Shankar, R. (2007). Selection of logistics service provider: An analytic network process (ANP) approach. Omega, 35(3), 274-289. https://doi.org/10.1016/j.omega.2005.06.005

Appendix – A (Closed Questionnaire form)

The indicators are arranged in descending order of their relative importance according to Pareto principle (20%)

No	Indicators	Ar. Mean
1	Construction cost	3.621
2	Ensuring occupant health	3.517
3	Increased speed of construction onsite	3.494
4	Off-site manufacturing implies a reduction in site disruptions	3.483
5	Integrity and accuracy of design information	3.483
6	Reduced number of on-site accidents	3.471
7	safety materials and technologies	3.471
8	Management processes through design, manufacturing, and construction	3.448
9	Construction technical difficulty	3.425
10	Quality requirement of workers	3.425
11	Profitability	3.414
12	Safer working conditions due to controlled environments	3.414
13	Aesthetic options	3.402
14	Simplified construction process	3.391
15	Construction quality	3.379
16	Reduction in defects upon completion	3.379
17	Guaranteed delivery- more certainty over the programmer and reduced management time	3.368
18	Systems can easily be measured and more accurately	3.368
19	Different prefabricated structure performance comparison	3.368
20	Streamlined information flow	3.368
21	Stakeholder satisfaction	3.356
22	Performance evaluation system	3.356

23	On-time delivery of components to the site	3.333
24	Less nagging	3.333
25	Equipment requirements	3.322
26	Accessibility (equitable access, Public access)	3.310
27	Civilized construction method compared with traditional construction.	3.310
28	Control of quality especially with regards to compliance with standards	3.299
29	Cleaner sites due to reduced number of on-site wet trades	3.299
30	Component quality assurance in transportation process	3.287
31	Tracking of components in the transportation process	3.264
32	Reduction in use of raw material	3.230
33	Product (building components) tried and tested in factory.	3.207
34	Resource-saving benefits from prefabricated buildings	3.195
35	Climate change and atmosphere	3.195
36	Greater consistency, as same product types are exactly identical;	3.172
37	Flexibility/adaptability	3.172
38	Improved productivity from economies of scale	3.172
39	Degree of information sharing	3.161
40	Standardization of information transmission and storage, Although the possibility Distortion of information in transmission	3.161
41	Operation and maintenance cost	3.149
42	Real-time risks and hazards detection and reminder	3.149
43	Preconstruction speed	3.138
44	Labor reduction (The amount of labors used on site)	3.126
45	Life cycle cost	3.126
46	Manufacturing & delivery speed	3.126
47	Green design	3.103
48	Less rework	3.103
49	Fewer total number of man-hours worked	3.092
50	Land use	3.081
51	Energy consumption	3.069
52	Water consumption	3.069
53	Novel technology integration	3.069
54	Inclusiveness	3.058
55	Formwork consumption	3.058
56	Reduced transportation	3.046
57	Cost savings	3.012
58	Competitiveness	3.000
59	Automated construction	2.977
60	Material reuse and/or recycling	2.954
61	Landscape	2.954
62	Industrial linkage development	2.943
63	Construction time	2.920
64	Expenditure in R&D, technology change	2.872
65	Supply chain	2.862
66	Resettling cost of people	2.828
67	Rehabilitating cost of ecosystem	2.816
68	Reserve funds	2.782
69	Weather disruption	2.724
70	Risk of investing in prefabricated buildings	2.667
71	Dust and noise mitigation	2.644
72	Cultural heritage	2.598
73	Pollution generation and controls	2.575
74	Visual impact	2.391
75	Policy support	2.379
76	Local air pollution	2.368
77	Greenhouse gases (GHG) emissions	2.356
78	Construction waste	2.322
79	Energy and carbon emissions	2.287

80	Particulates emissions	2.276

Appendix – B (Pairwise comparison matrix for correlation)

Pairwise comparison matrix for correlation between Cost indicators

			8	7			
		Cost without CC	**CCT**	**CP**		**Average**	**Rel. Weight**
H	8	**CCT**	1	1		1	0.500
H	7	**CP**	1	1		1	0.500
					∑=	2	1
			8	7			
		Cost without CCT	**CC**	**CP**		**Average**	**Rel. Weight**
H	8	**CC**	1	1		1	0.500
H	7	**CP**	1	1		1	0.500
					∑=	2	1
			8	7			
		Cost without CP	**CC**	**CCT**		**Average**	**Rel. Weight**
H	8	**CC**	1	1		1	0.500
H	7	**CCT**	1	1		1	0.500
					∑=	2	1

Pairwise comparison matrix for correlation between Quality indicators

			8	5	4		
		Quality without QRW	**QA**	**QR**	**QC**	**Average**	**Rel. Weight**
H	8	**QA**	1	3	4	2.667	0.636
M	5	**QR**	1/3	1	1	0.778	0.185
M	4	**QC**	1/4	1	1	0.750	0.179
					∑=	4.194	1.000
			8	5	4		
		Quality without QA	**QRW**	**QR**	**QC**	**Average**	**Rel. Weight**
H	8	**QRW**	1	3	4	2.667	0.636
M	5	**QR**	1/3	1	1	0.778	0.185
M	4	**QC**	1/4	1	1	0.750	0.179
					∑=	4.194	1.000
			8	7	5		
		Quality without QR	**QRW**	**QA**	**QC**	**Average**	**Rel. Weight**
H	8	**QRW**	1	1	3	1.667	0.462
H	7	**QA**	1	1	2	1.333	0.369
M	5	**QC**	1/3	1/2	1	0.611	0.169
					∑=	3.611	1.000
			8	7	5		
		Quality without QC	**QRW**	**QA**	**QR**	**Average**	**Rel. Weight**
H	8	**QRW**	1	1	3	1.667	0.462
H	7	**QA**	1	1	2	1.333	0.369
M	5	**QR**	1/3	1/2	1	0.611	0.169
					∑=	3.611	1.000

Pairwise comparison matrix for correlation between safety indicators

			8	8	7	6			
		Safety without SE	**SMD**	**SR**	**SSM**	**SSW**		**Average**	**Rel. Weight**
H	8	**SMD**	1	1	1	2		1.25	0.294
H	8	**SR**	1	1	1	2		1.25	0.294
H	7	**SSM**	1	1	1	1		1.00	0.235
H	6	**SSW**	1/2	1/2	1	1		0.75	0.176
							∑=	4.25	1.000
			8	8	7	6			

		Safety without SMD	SE	SR	SSM	SSW	Average	Rel. Weight
H	8	**SE**	1	1	1	2	1.25	0.294
H	8	**SR**	1	1	1	2	1.25	0.294
H	7	**SSM**	1	1	1	1	1.00	0.235
H	6	**SSW**	1/2	1/2	1	1	0.75	0.176
						∑=	4.25	1.000
			8	8	7	6		
		Safety without SR	**SE**	**SMD**	**SSM**	**SSW**	**Average**	**Rel. Weight**
H	8	**SE**	1	1	1	2	1.25	0.294
H	8	**SMD**	1	1	1	2	1.25	0.294
H	7	**SSM**	1	1	1	1	1.00	0.235
H	6	**SSW**	1/2	1/2	1	1	0.75	0.176
						∑=	4.25	1.000
			8	8	7	6		
		Safety without SSM	**SE**	**SMD**	**SR**	**SSW**	**Average**	**Rel. Weight**
H	8	**SE**	1	1	1	2	1.25	0.294
H	8	**SMD**	1	1	1	2	1.25	0.294
H	7	**SR**	1	1	1	1	1.00	0.235
H	6	**SSW**	1/2	1/2	1	1	0.75	0.176
						∑=	4.25	1.000
			8	8	7	6		
		Safety without SSW	**SE**	**SMD**	**SR**	**SSM**	**Average**	**Rel. Weight**
H	8	**SE**	1	1	1	2	1.25	0.294
H	8	**SMD**	1	1	1	2	1.25	0.294
H	7	**SR**	1	1	1	1	1.00	0.235
H	6	**SSM**	1/2	1/2	1	1	0.75	0.176
						∑=	4.25	1.000

Pairwise comparison matrix for correlation between Process indicators

			8	7	5			
		Process without PIS	**PIA**	**PM**	**PS**		**Average**	**Rel. Weight**
H	8	**PIA**	1	1	3		1.667	0.462
H	7	**PM**	1	1	2		1.333	0.369
M	5	**PS**	1/3	1/2	1		0.611	0.169
						∑=	3.611	1.000
			8	7	5			
		Process without PIA	**PIS**	**PM**	**PS**		**Average**	**Rel. Weight**
H	8	**PIS**	1	1	3		1.667	0.462
H	7	**PM**	1	1	2		1.333	0.369
M	5	**PS**	1/3	1/2	1		0.611	0.169
						∑=	3.611	1.000
			8	7	5			
		Process without PM	**PIS**	**PIA**	**PS**		**Average**	**Rel. Weight**
H	8	**PIS**	1	1	3		1.667	0.462
H	7	**PIA**	1	1	2		1.333	0.369
M	5	**PS**	1/3	1/2	1		0.611	0.169
						∑=	3.611	1.000
			8	7	6			
		Process without PS	**PIS**	**PIA**	**PM**		**Average**	**Rel. Weight**
H	8	**PIS**	1	1	2		1.333	0.421
H	7	**PIA**	1	1	1		1.000	0.316
H	6	**PM**	1/2	1	1		0.833	0.263
						∑=	3.167	1.000

Appendix – C (Indicators Impact on Alternatives (IIA)

The relative impact of the Cost indicators on the alternatives

			8	7	6		
		Construction Cost	**BS**	**WS**	**FS**	**Average**	**Rel. Weight**
H	8	**Box systems**	1	1	2	1.333	0.421
H	7	**Walls systems**	1	1	1	1.000	0.316
H	6	**Frame systems**	1/2	1	1	0.833	0.263
					∑=	3.167	1
			8	7	5		
		CCT	**BS**	**WS**	**FS**	**Average**	**Rel. Weight**
H	8	**Box systems**	1	1	3	1.667	0.462
H	7	**Walls systems**	1	1	2	1.333	0.369
M	5	**Frame systems**	1/3	1/2	1	0.611	0.169
					∑=	3.611	1
			5	5	4		
		CP	**BS**	**WS**	**FS**	**Average**	**Rel. Weight**
M	5	**Box systems**	1	1	1	1.000	0.333
M	5	**Walls systems**	1	1	1	1.000	0.333
M	4	**Frame systems**	1	1	1	1.000	0.333
					∑=	3.000	1

The relative impact of the Quality indicators on the alternatives

			8	7	6		
		QC	**FS**	**BS**	**WS**	**Average**	**Rel. Weight**
H	8	**Frame systems**	1	1	2	1.333	0.421
H	7	**Box systems**	1	1	1	1.000	0.316
H	6	**Walls systems**	1/2	1	1	0.833	0.263
					∑=	3.167	1
			8	8	7		
		QRW	**FS**	**BS**	**WS**	**Average**	**Rel. Weight**
H	8	**Frame systems**	1	1	1	1.000	0.333
H	8	**Box systems**	1	1	1	1.000	0.333
H	7	**Walls systems**	1	1	1	1.000	0.333
					∑=	3.000	1
			8	7	5		
		QR	**WS**	**FS**	**BS**	**Average**	**Rel. Weight**
H	8	**Walls systems**	1	1	3	1.667	0.462
H	7	**Frame systems**	1	1	2	1.333	0.369
M	5	**Box systems**	1/3	1/2	1	0.611	0.169
					∑=	3.611	1
			6	5	5		
		QA	**FS**	**WS**	**BS**	**Average**	**Rel. Weight**
H	6	**Frame systems**	1	1	1	1.000	0.333
M	5	**Walls systems**	1	1	1	1.000	0.333
M	5	**Box systems**	1	1	1	1.000	0.333
					∑=	3.000	1

The relative impact of the Safety indicators on the alternatives

			8	7	6		
		SMD	**WS**	**BS**	**FS**	**Average**	**Rel. Weight**
H	8	**Walls systems**	1	1	2	1.333	0.421
H	7	**Box systems**	1	1	1	1.000	0.316
H	6	**Frame systems**	1/2	1	1	0.833	0.263
					∑=	3.167	1

			8	7	6			
		SE	**WS**	**BS**	**FS**		**Average**	**Rel. Weight**
H	8	**Walls systems**	1	1	2		1.333	0.421
H	7	**Box systems**	1	1	1		1.000	0.316
H	6	**Frame systems**	1/2	1	1		0.833	0.263
						∑=	3.167	1
			8	7	6			
		SSW	**BS**	**WS**	**FS**		**Average**	**Rel. Weight**
H	8	**Box systems**	1	1	2		1.333	0.421
H	7	**Walls systems**	1	1	1		1.000	0.316
H	6	**Frame systems**	1/2	1	1		0.833	0.263
						∑=	3.167	1
			8	7	6			
		SR	**BS**	**WS**	**FS**		**Average**	**Rel. Weight**
H	8	**Box systems**	1	1	2		1.333	0.421
H	7	**Walls systems**	1	1	1		1.000	0.316
H	6	**Frame systems**	1/2	1	1		0.833	0.263
						∑=	3.167	1
			8	7	4			
		SSM	**BS**	**WS**	**FS**		**Average**	**Rel. Weight**
H	8	**Box systems**	1	1	4		2.000	0.477
H	7	**Walls systems**	1	1	3		1.667	0.397
M	4	**Frame systems**	1/4	1/3	1		0.528	0.126
						∑=	4.194	1

The relative impact of the Process indicators on the alternatives

			9	7	6			
		PIS	**BS**	**WS**	**FS**		**Average**	**Rel. Weight**
V.H	9	**Box systems**	1	2	3		2.000	0.554
H	7	**Walls systems**	1/2	1	1		0.833	0.231
H	6	**Frame systems**	1/3	1	1		0.778	0.215
						∑=	3.611	1
			8	7	6			
		PIA	**WS**	**BS**	**FS**		**Average**	**Rel. Weight**
H	8	**Walls systems**	1	1	2		1.333	0.421
H	7	**Box systems**	1	1	1		1.000	0.316
H	6	**Frame systems**	1/2	1	1		0.833	0.263
						∑=	3.167	1
			8	8	6			
		PS	**WS**	**BS**	**FS**		**Average**	**Rel. Weight**
H	8	**Walls systems**	1	1	2		1.333	0.400
H	8	**Box systems**	1	1	2		1.333	0.400
H	6	**Frame systems**	1/2	1/2	1		0.667	0.200
						∑=	3.333	1
			8	8	7			
		PM	**WS**	**BS**	**FS**		**Average**	**Rel. Weight**
H	8	**Walls systems**	1	1	1		1.000	0.333
H	8	**Box systems**	1	1	1		1.000	0.333
H	8	**Frame systems**	1	1	1		1.000	0.333
						∑=	3.000	1