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Building a Framework for Managing Sustainable Prefabricated Construction Systems: Using Analytical Network Process

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Abstract

The management of sustainable prefabricated construction projects in Iraq suffers from outdated methods and a lack of focus on important management criteria. This research addresses this issue by developing a framework for managing sustainable prefabricated building systems and choosing the best types of systems. A review of the general literature identified 80 indicators within the 12 relevant categories. These indicators formed the basis of a closed questionnaire distributed to 90 experienced respondents. Three prefabricated building systems were identified based on the structural configuration (bearing wall, frame, and box system). The expert questionnaire for each system was conducted according to the Analytical Network Process (ANP) and using Super Decision Software (SDS). After implementation, a framework was built to manage sustainable prefabricated building systems, and the best system, which is the box system, was chosen. This framework helps improve the management of prefabricated construction projects, increase speed, quality, and pollution, and reduce the cost of housing in Iraq, which suffers from its high cost. There must be attention to prefabricated construction, as the consumption of raw materials in traditional construction is large and affects the country's resources and economy.

Keywords: Analytical Network Process (ANP); Prefabricated build; Prefabricated systems management; Super Decision Software (SDS); Sustainability Criteria

1. Introduction

Since prefabricated buildings are advantageous in terms of quality, speed of assembly, cost, power savings, emissions reductions, and cleaner and safer operating environments, they have been around for decades. It has sparked intense interest in many countries and regions, including Japan, Germany, Malaysia, the UK, Australia, and so on [1]-[7]. Prefabricated buildings are still in their infancy, though, with more parties engaged than cast-in-situ construction, and a host of additional issues are brought on by the lifestyles of geographically scattered work locations [8], [9]. Integrating the disjointed construction processes using appropriate management techniques is crucial [10], [11].

Globally, the construction sector significantly impacts the environment, society, and economy [12],[13]. An excessive percentage of energy intake is constantly present in the industry, significantly impacting sustainable development [14]. Buildings utilize more than 40% of the energy consumed worldwide, according to estimates from the Intergovernmental Panel on Climate Change [15]. In the European Union, buildings are responsible for around 40% of energy consumption and 36% of carbon dioxide emissions [16]. Time overrun in public sector projects has become a global problem, especially in developing countries. When expenditure and duration overruns exceed 100% of the expected expenditure and duration. Timely completion of the project has become a business for all parties involved in the construction sector. Stakeholders are the most affected by time overruns [17]. Transitioning from conventional to sustainable building practices is imperative [18].

This research was based on the following hypotheses: There is a lack of integrated management for prefabricated construction projects in Iraq, it is necessary to resort to prefabricated construction instead of construction on site, as it significantly impacts the depletion and waste of natural resources, and the categories, indicators, and factors for managing sustainable prefabricated construction projects exist. The present study has limitations: The questionnaire was distributed in the Iraqi governorates (Salah al-Din, Nineveh, Kirkuk, Baghdad, Diyala, Najaf, Erbil, and Sulaymaniyah).

2. Literature review

The literature review mainly aims to identify the criteria that must be considered to build an integrated framework for managing sustainable prefabricated building systems. Other related issues were also addressed, such as the types of prefabricated building systems and the methods used to choose the best system. The literature review results were used to (1) build an integrated framework for managing sustainable prefabricated building systems and (2) Develop an ANP-based model for the final selection of the best types of prefabricated building systems using the (SDS).

2.1. Sustainability criteria.

Through a review of the general literature, sustainability criteria relevant to prefabricated construction were collected and presented in Table 1. These criteria form the basis for building the framework and developing the ANP model.

Table 1. Summary of literature on sustainability criteria

No.	Categories	Indicators	References
1	Quality	Quality requirement of workers	[19]
		Construction quality	[19]-[21]
		Industrial linkage development	[19]
		Reduction in defects upon completion	[22]
		The product was tried and tested in the factory.	[23]
		Greater consistency, as the same product types are precisely identical	[23]
		More control of quality, especially about compliance with standards	[23]
2	Occupational Safety and Health (OSH)	Real-time risk and hazard detection and reminder	[21]
		ensuring occupant health	[24]
		Safer working conditions due to controlled environments	[23]-[25]
		Reduced number of on-site accidents	[23], [24]
		safety materials and technologies	[21], [23]
3	Customer requirements	Aesthetic options	[20],[25]
		Accessibility (equitable access, Public access)	[24], 26]
		Cultural heritage	[26]
		Inclusiveness	[26]
		Stakeholder satisfaction	[26]
4	Cost	Construction cost	[19],[20],[22],[27], [28]
		Operation and maintenance cost	[19], [26]
		Construction technical difficulty	[19], [26]
		Policy support (Policy measures taken by the government to promote prefabricated buildings)	[19], [26]
		Risk of investing in prefabricated buildings	[19], [26], [28]
		Cost savings	[20], [26], [28]
		Labor reduction	[20], [25], [26]
		Spending on research, development, and technological change	[26]
		Reserve funds	[26]
		life cycle cost	[21], 2[4], [26]
		Resettling cost of people	[26]
		Rehabilitating cost of the ecosystem	[26]
		Supply chain (It means the suppliers of materials and equipment)	[26]
		Profitability	[21], [26]
		Unsuccessful choice of suppliers and non-competitiveness	[26],[29]
5	Time	Construction time	[20], [22]
		Weather disruption	[20]
		Fewer total number of person-hours worked.	[22], [28]
		Preconstruction speed (e.g., design, planning, and procurement)	[25]

		Manufacturing & delivery speed	[11], [25[,[28]
		Increased speed of construction on-site	[25], [28]
		Guaranteed delivery- more certainty over the program and reduced management time	[28]
6	Resources Saving	Energy consumption	[19],[20],[22],[24],[26]
		Water consumption	[20]-[22],[24],26]
		Formwork consumption	[20]
		Resource consumption	[19], [26]
		Reduction in the use of raw material	[22]
		Material reuse and/or recycling	[21] – [26]
7	Environmental protection	Land use	[24], [26]
		Landscape	[26]
		Climate change and atmosphere	[26]
		Civilized construction method compared with traditional construction.	[19]
		Flexibility/adaptability	[25]
		Cleaner sites due to reduced on-site wet trades (The term 'wet trades' is commonly used in the construction industry to refer to trades that use materials mixed with water, e.g., Blockwork and concrete.)	[28]
		Green design	[21]
8	Emissions	Construction waste	[20] – [26]
		Pollution generation and controls	[19], [20], [26]
		Local air pollution	[26]
		greenhouse gas (GHG) emissions	[21], [24], [26]
		Visual impact	[26]
		Energy and carbon emissions	[21], [22], [26]
		particulates emissions	[24]
		Dust and noise mitigation	[21], [26]
9	Logistics	On-time delivery of components to the site	[11]
		Component quality assurance in the transportation process	[11]
		Tracking of components in the transportation process	[11]
		Reduced transportation	[25]
		Off-site manufacturing implies a reduction in site disruptions	[24], [28]
10	Construction Productivity	Less nagging	[28]
		Automated construction	[21]
		Novel technology integration	[21]
		Equipment requirements	[25]
		Improved productivity from economies of scale	[23]
		Less rework	[23], [25]
11	Process	Simplified construction process	[28]
		Systems can easily be measured and more accurately	[28]
		Performance evaluation system	[21]
		management processes through design, manufacturing, and construction	[25]
		Different prefabricated structure performance comparison	[21]
12	Information	Standardization of information transmission and storage	[11]
		Degree of information sharing	[11]
		Integrity and accuracy of design information	[11]
		Streamlined information flow	[25]

2.2. Sustainable Prefabricated Construction Systems.

After the development of the prefabricated building process after World War II, the technology developed with it in production, in the use of appropriate materials, and even in the design of the units themselves so that each country became a specific system in applying the prefabricated building process depending on the capabilities of that country economically and technically [30],[31]. Regarding their structural design, 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) [31], [32].

2.2.1. Frame systems.

In fundamental design, "frame systems" refers to the structural sub-arrangement [33]. Work is accomplished this way using thresholds that support weights from floors and ceilings and transmit them to columns [32]. This system is the same as that used in traditional construction, and one of the advantages of this type is that the units used are simple in shape and easy to transport and connect [31].

2.2.2. Panel systems (Walls Bearing).

The panel system has a smooth, rounded edge and a beautiful look. It is the perfect prefabrication method for straight, curved, and angled façade applications [32]. To do this, structural panels support the weights in addition to the unit's weight. The distribution of the weight-bearing panels is parallel to the building's longitudinal or transverse direction or in both directions [31].

2.2.3. Cells Systems (Box system).

The load-bearing spacers 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 provide the necessary longitudinal dependability. Pile-bearing spacers or façade dividers support connecting elements like floors, roofs, and columns [32]. The cell is an integrated box in one space with different dimensions according to the intended design. This cell implicitly contains all other services (from water or electricity pipes, etc.) [31].

2.3. Methods used to choose the best system.

This research implemented the Analytical Network Process (ANP) technique using Super Decision Software (SDS). Below is a simplified explanation of the methods.

2.3.1. Analytical Network Process (ANP).

Saaty was the first to introduce ANP to provide a framework for dealing with decision-making issues. Many forecasting and various decision-making issues have been addressed with it since its first appearance. Decision theory is the Analytical Hierarchy Process (AHP), of which ANP is a general form [34]. All potential interactions between criteria may be measured using the ANP model [19], [35]. While AHP models presume a unidirectional hierarchical link between decision levels, ANP permits more intricate interrelationships between the choice levels and does not need this rigid hierarchical structure. Because of this, ANP is more practical than AHP. Because many real-world choice issues include the interaction and dependency of higher-level components of a hierarchy on lower-level elements, they are not amenable to hierarchical structuring. As a result, a network rather than a hierarchy is used to express ANP [36].

Thanks to ANP, which makes the pairwise comparison process more general, decision models can be made up of complex networks of decision goals, criteria, stakeholders, alternatives, situations, and other environmental factors that affect how one group's priorities affect those of another. The AHP process involves breaking down the decision problem into a hierarchy of criteria and sub-criteria and then using a pairwise comparison process to assign relative importance to each level of the hierarchy [27]. Unlike the Analytical Network Process (ANP), the core idea of the ANP is that influence need not always travel just downward. Any two components in the network may influence one another, leading to non-linear outcomes in prioritizing possible options [34].

2.3.2. Super Decision Software (SDS).

The Super Decisions, created by Thomas Saaty's team, is the first free educational program that applies the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP). It is created and kept up-to-date under the direction of the Creative Decisions Foundation, which Thomas L. Satie and his wife, Rosanne Whitaker Satie, established in 1996. The Foundation funds research, instruction, and software development related to advanced AHP decision-making techniques [36].

The Super Decisions program is used for dependent and feedback-based decision-making. This program offers capabilities for managing and building AHP and ANP models, making decisions, getting outcomes, and doing sensitivity analysis on those outcomes. Moreover, it enables intricate, hierarchical BOCR models (Benefits, Opportunities, Costs, and Risks). The Super Decisions software makes the calculations automatically without going through cases. It consists of a primary network and subnetworks, each of which might have multiple layers; a subnetwork is connected to a control node in the network above. The ANP model's alternatives are often found in the lowest-level subnetwork. The alternatives ' priorities are combined through the levels of subnetworks to the top network [36].

3. Research Methodology.

Fig. 1 illustrates the components of the research methodology used in this study as follows.

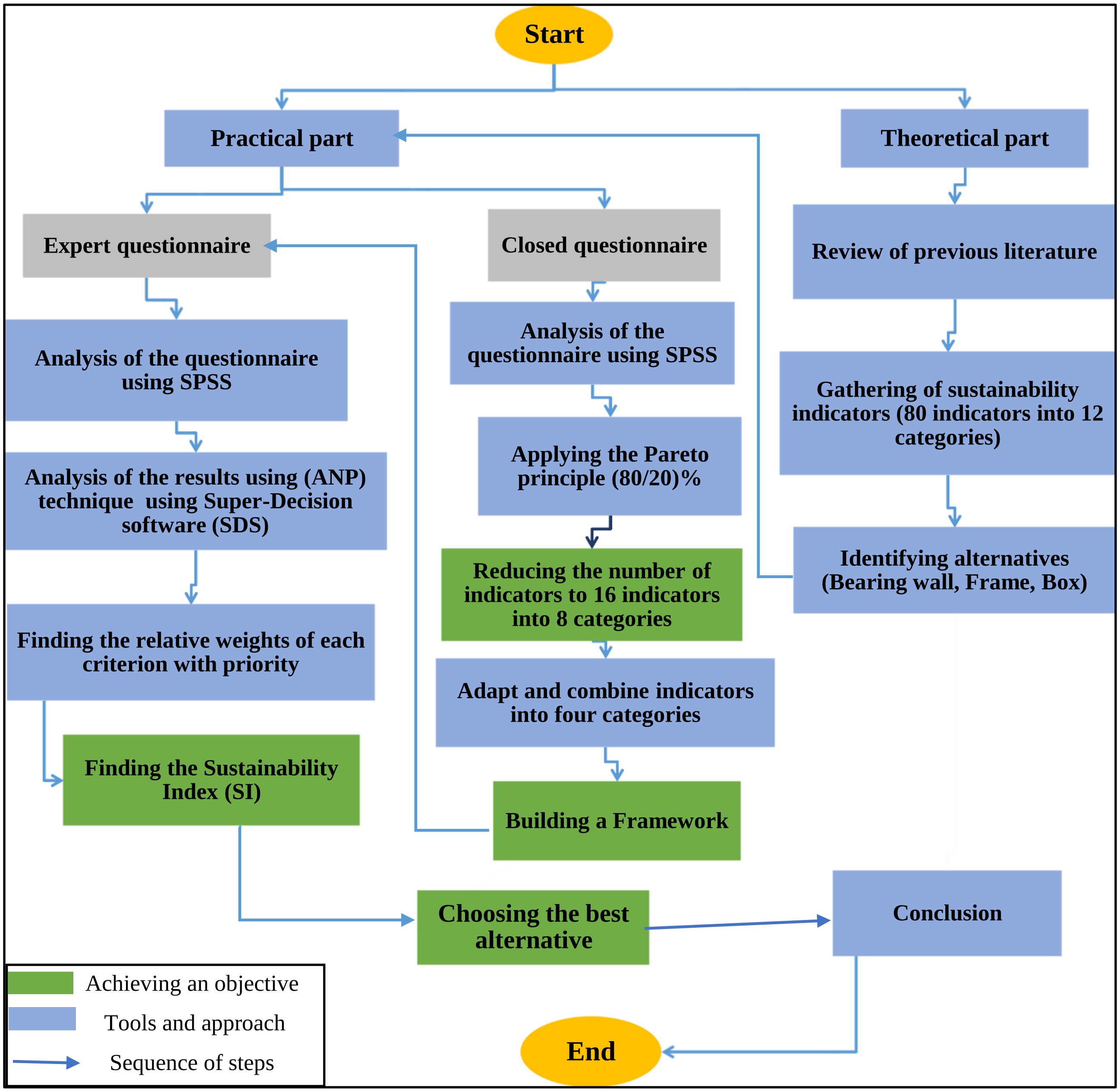


Figure 1. Components of the Research Methodology

3.1. Theoretical part.

Collect categories and indicators from previous research and studies and review the literature, the Internet, and theoretical topics related to sustainability indicators for managing sustainable prefabricated construction projects. An analysis of the literature review yielded a summary of 12 categories and 80 indicators; three alternatives were identified in prefabricated building systems: Bearing Wall, Frame, and Box.

3.2 Practical part.

In this research, two questionnaires were conducted, and their results were approved to build a framework for managing sustainable prefabricated building systems, choosing the best system according to (ANP) technique, and using (SDS) software as follows.

3.2.1 Closed questionnaire.

The closed questionnaire aims to build a framework for managing sustainable prefabricated building systems through sustainability standards. The questionnaire was conducted using a five-point Likert scale to find 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 disciplines and those with experience

in this field. Three respondents were excluded for not meeting the search criteria.

2. Use the arithmetic mean equation using SPSS to analyze the closed questionnaire results and determine each indicator's relative importance. Arithmetic average equation [29], [37].

$$\mathbf{AM} = \frac{\sum(\boldsymbol{Fr} \times \boldsymbol{D})}{\boldsymbol{N}}$$

AM: Arithmetic Mean

Fr.: Frequency

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

N: Sample amount

3. After applying the Pareto principle (80/20) % according to the relative importance of the indicators, it was summarized into eight categories and 16 indicators.
4. The indicators were adapted and arranged into four categories in line with the requirements for pairwise comparisons.
5. Building a framework for managing sustainable prefabricated construction projects.

3.2.2 Expert questionnaire

This questionnaire aims to find the best types of sustainable prefabricated building systems. Includes the following:

1. After building a framework of categories and indicators through the closed questionnaire, this framework was used to find the Sustainability Index (SI) through an expert questionnaire.
2. The questionnaire was prepared and distributed to 12 experts in the field of prefabricated construction.
3. The questionnaire results were analyzed using SPSS to find the relative weights of the indicators for each alternative.
4. The Analytical Network Process (ANP) technique was applied using Super Decision Software (SDS) to find the Sustainability Index (SI).
5. Using the sustainability index values to find the best alternative among the three alternatives.

4. Results and Discussion.

The results of this research are divided into two parts: (1) building a framework for managing sustainable prefabricated building systems and (2) choosing the best system for sustainable prefabricated construction, as follows:

4.1 Building a Framework.

The questionnaire was analyzed using SPSS to obtain the relative importance of the indicators, as shown in Table 2: The cost category is an example of the rest of the categories. After applying the Pareto theory (80/20) %, which states that 20% of the indicators affect 80% of the sustainability of prefabricated building systems, and according to the relative importance of the indicators, they were summarized into 8 categories and 16 indicators, As shown in Appendix B. Based on the previous literature review, the indicators were adapted and arranged into four categories in line with the requirements for pairwise comparisons to obtain the framework, as shown in Table 3, which was subsequently used in the expert questionnaire.

Table 2. The relative importance of indicators for the cost category

No	Cost Indicators	Ar. Mean	Std. Deviation	Rank	Level of imp.
1	Construction cost	3.6207	0.7028	1	H
2	Construction technical difficulty	3.4253	0.8440	2	H
3	Profitability	3.4138	0.9469	3	H
4	Operation and maintenance cost	3.1494	0.8426	4	M
5	Labor reduction	3.1264	0.9860	5	M
6	Life cycle cost	3.1264	0.8997	6	M
7	Cost savings	3.0115	0.9213	7	M
8	Competitiveness	3.0000	1.1102	8	M
9	Spending on research, development, and technological change	2.8721	1.0824	9	M
10	Supply chain	2.8621	0.8650	10	M
11	Resettling cost of people	2.8276	0.9049	11	M
12	Rehabilitating cost of the ecosystem	2.8161	0.9945	12	M
13	Reserve funds	2.7816	0.8684	13	M
14	Risk of investing in prefabricated buildings	2.6667	1.0192	14	M
15	Policy support	2.3793	1.1538	15	L
	Cronbach's alpha= 0.791				

Table 3. Framework components

Code	Details
1	**Occupational Safety and Health (OSH)**
1.1	Ensuring occupant health
1.2	Off-site manufacturing implies a reduction in site disruptions
1.3	Reduced number of on-site accidents
1.4	Safer working conditions due to controlled environments
1.5	Safety materials and technologies
2	**Quality**
2.1	Quality requirement of workers
2.2	Aesthetic options
2.3	Reduction in defects upon completion
2.4	Construction quality
3	**Process**
3.1	Increased speed of construction on-site
3.2	Integrity and accuracy of design information
3.3	Management processes through design, manufacturing, and construction
3.4	Simplified construction process
4	**Cost**
4.1	Construction cost
4.2	Construction technical difficulty
4.3	Profitability

4.2 Choose the best prefabricated building systems.

To choose the best-prefabricated building systems, the following was done:

4.2.1 Expert questionnaire.

An expert questionnaire was conducted on the indicators obtained after building the framework from Table 3. This method was chosen instead of other methods because of the more accurate results it provides about the types of prefabricated building systems. This is due to the selection of people with experience in this field, unlike other methods not limited to people with high expertise. 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 critical 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 Super Decision Software using the Analytical Network Process (ANP) model to select the best types of three sustainable prefabricated building systems (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 three alternatives

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 on-site	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. The relative importance of the indicators for the alternatives

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. The relative importance of the indicators for the alternatives

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					

4.2.2 The stage of entering criteria weights into the Super Decision Software.

The best sustainable prefabricated building systems are selected through the Super Decision Software version 3.2 application according to the following steps:

(I) creating a decision structure

The steps listed below, as seen in Fig. 2, make up the framework for selecting the best alternatives:

1- Objective: Choose the best alternative.

2- Main Criteria: four categories (Cost, Quality, Safety, and Process).

3- Sub-Criteria: There are many Sub-Criteria (indicators) in each category, which include:

- Group A: Three nodes represent cost indicators.
- Group B: Four nodes representing quality indicators.
- Group C: Five nodes make up the safety indications.
- Group D: Four nodes representing process indicators.

4- There are three nodes in the alternative set.

5- Feedback and dependencies: the connections and options for exchange between alternatives and groups.

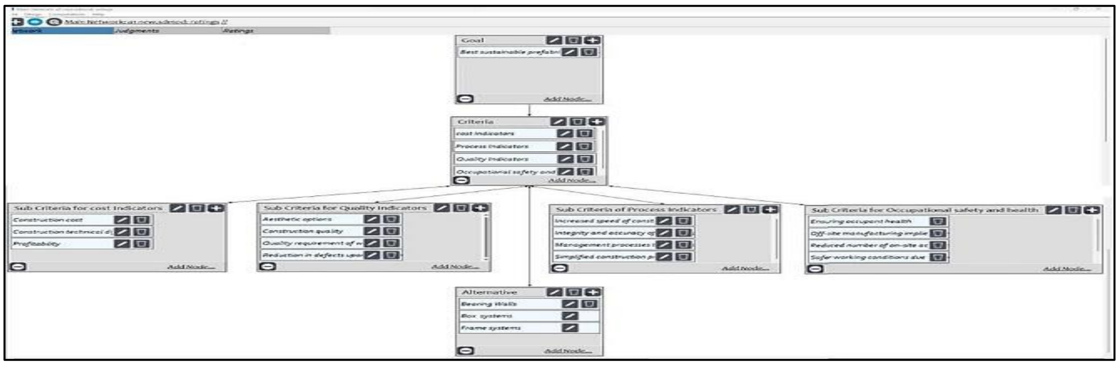


Figure 2. ANP network model in the Super Decision Software

(II) Finding relative weights by pairwise comparisons

To determine the relative weights of each sub-criterion within the main criterion, the pairings were compared across the assessment criteria listed in Table 3. As shown in Fig. 3, these comparisons use a ratio scale of 1 to 9 to compare any two criterion weight items when compared within the same group with each proposed alternative. As shown in Fig. 4, relative weights for each criterion should be obtained with priority.

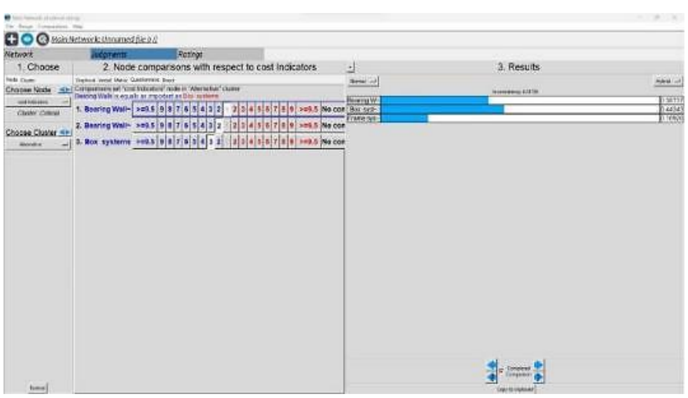
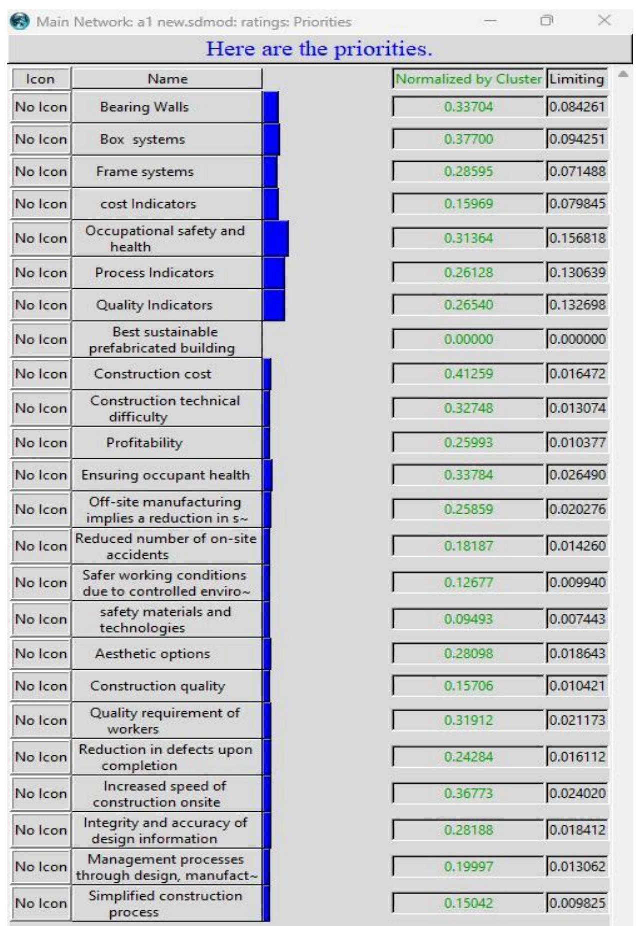


Figure 3. Pairwise Comparison of Cost Indicators with Alternatives



Main Network: a1 new.sdmod: ratings: Priorities

Here are the priorities.

Icon	Name	Normalized by Cluster	Limiting
No Icon	Bearing Walls	0.33704	0.084261
No Icon	Box systems	0.37700	0.094251
No Icon	Frame systems	0.28595	0.071488
No Icon	cost Indicators	0.15969	0.079845
No Icon	Occupational safety and health	0.31364	0.156818
No Icon	Process Indicators	0.26128	0.130639
No Icon	Quality Indicators	0.26540	0.132698
No Icon	Best sustainable prefabricated building	0.00000	0.000000
No Icon	Construction cost	0.41259	0.016472
No Icon	Construction technical difficulty	0.32748	0.013074
No Icon	Profitability	0.25993	0.010377
No Icon	Ensuring occupant health	0.33784	0.026490
No Icon	Off-site manufacturing implies a reduction in s~	0.25859	0.020276
No Icon	Reduced number of on-site accidents	0.18187	0.014260
No Icon	Safer working conditions due to controlled enviro~	0.12677	0.009940
No Icon	safety materials and technologies	0.09493	0.007443
No Icon	Aesthetic options	0.28098	0.018643
No Icon	Construction quality	0.15706	0.010421
No Icon	Quality requirement of workers	0.31912	0.021173
No Icon	Reduction in defects upon completion	0.24284	0.016112
No Icon	Increased speed of construction onsite	0.36773	0.024020
No Icon	Integrity and accuracy of design information	0.28188	0.018412
No Icon	Management processes through design, manufact~	0.19997	0.013062
No Icon	Simplified construction process	0.15042	0.009825

Figure 4. Relative weights of Criteria with Priorities

(III) Determining the Super Matrix.
Following pairwise comparisons, as shown in Fig. 5, a super-matrix is generated to show the links between criteria and options according to their respective weights.

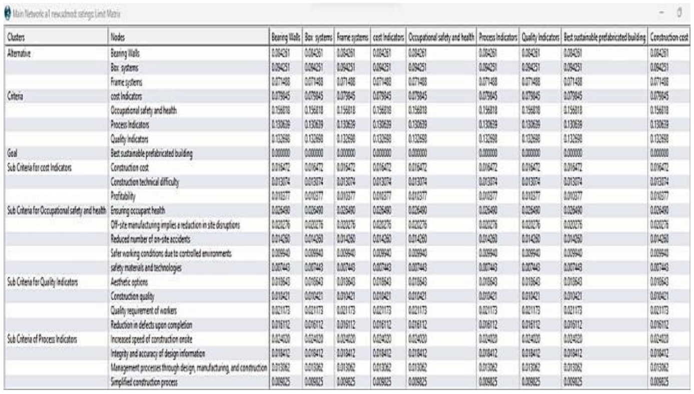


Figure 5. Super Matrix for Alternatives and Criteria (by SDS)

(IV) The stage of choosing the best sustainable prefabricated building systems. Once the relative weights of each criterion have been determined, the optimal alternative is found by combining the relative weights of the criteria and the alternatives. The alternative (Box systems) received a percentage of 37.7%, followed by the alternative (Bearing Walls) with 33.7%, and finally, the alternative (Frame system) with 28.6%, as shown in Fig. 6.

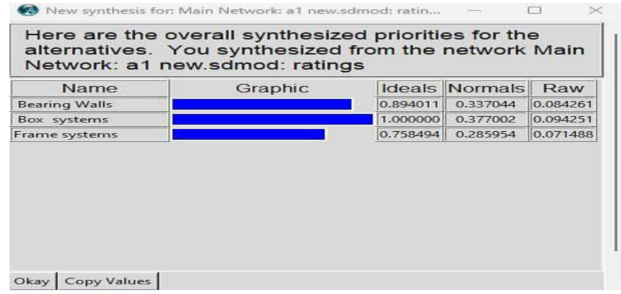


Figure 6. Results Synthesize between Criteria and Alternatives (by SDS)

5. A framework for managing sustainable prefabricated building systems

After obtaining the results of the closed and expert questionnaires, an integrated framework was obtained for managing sustainable prefabricated building systems, as shown in Fig. 7.

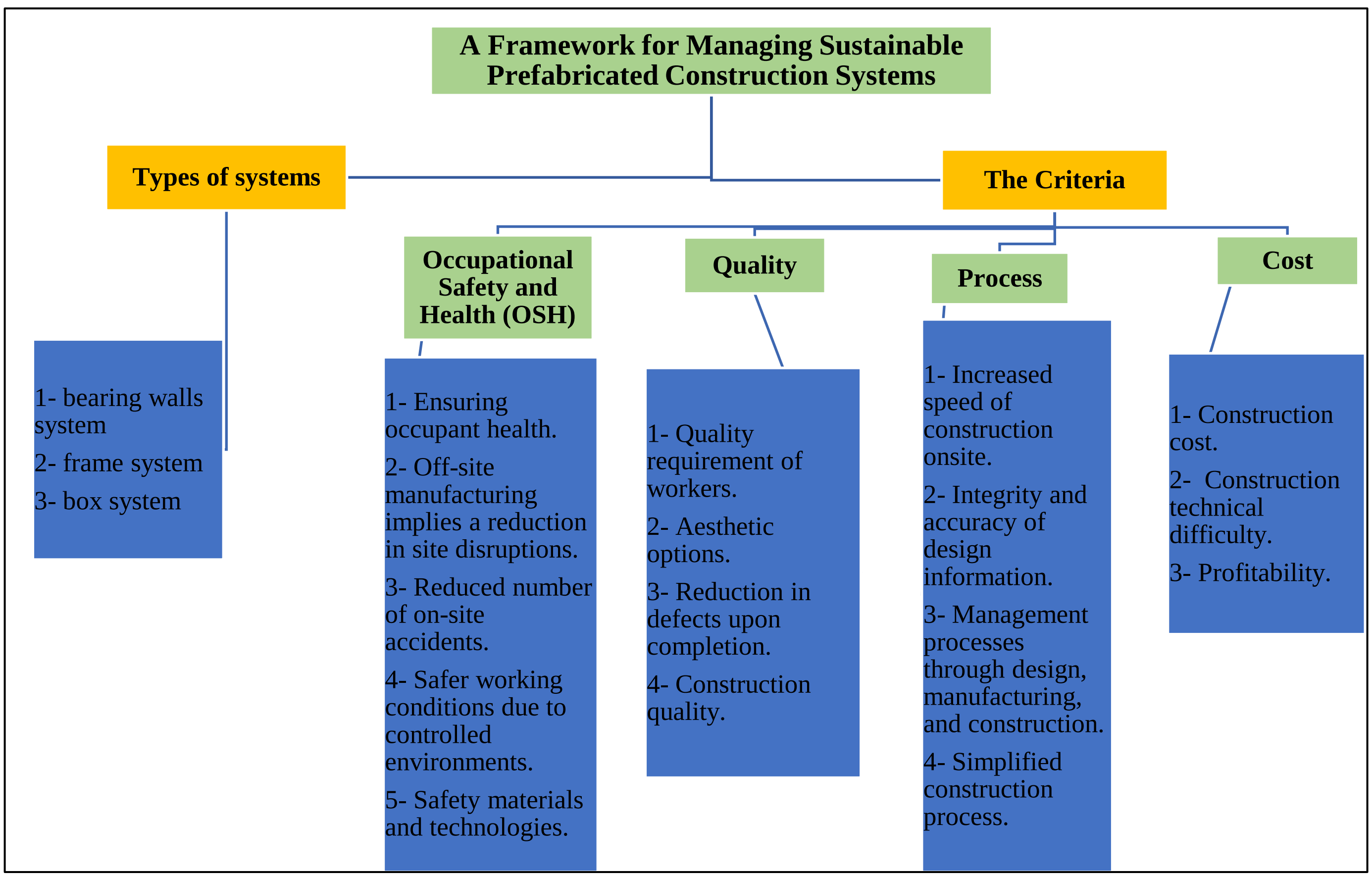


Figure 7 The final framework for Managing Sustainable Prefabricated Construction Systems

6. Conclusions

This research built an integrated framework for managing sustainable prefabricated building systems based on the most relevant sustainability standards. This framework helps improve prefabricated building productivity, increase speed and quality, reduce cost and pollution, etc. It can also contribute to reducing the cost of housing in Iraq, which suffers from its high cost.

Three alternatives for sustainable prefabricated building systems based on structural configuration (load-bearing wall system, frame system, and box system) are identified for applying Super Decision Software (SDS) to the ANP model.

After implementation, the best of the three alternatives, the box system, was chosen. SDS has proven effective in accelerating analysis and decision-making, distinguishing it from traditional decision-making methods. By using ANP technology through the Super Decision program, objective and accurate results can be achieved, and the mutual influences between alternatives can be calculated. This choice allows for determining the best structural configuration methods in prefabricated construction.

There should be increased interest in 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 to existing and new economies. This approach helps decision-makers identify factors that enhance the sustainability of prefabricated building systems to focus on and grow in the future.

Conflict of interest

The authors attest that no conflict of interest results from this article's publication.

Author Contribution Statement

Muhammad Saleh Khalaf proposed the research problem, developed the theory, and performed the calculations.

Maysoon Abdullah Mansour: Verify analytical methods and supervise the results of this work.

Both authors discussed the results and contributed to the final manuscript.

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Appendix – A (Closed Questionnaire form)

Part One:

Specific to identifying information for the honorable respondent:

1- Profession (Designer, implementation engineer, project manager, supervisor, contractor, academic, others)?

2- The department you work for?

3- Number of years of professional experience?

4- Academic certificate?

5- Specialization?

6- What types of projects did you contribute to the implementation of?

7- How familiar are you with prefabricated construction:

- What type of work is in the prefabricated buildings (e.g., academic knowledge only, implementation, supervision, design, etc.)?
- Number of Years of experience in the implementation of prefabricated construction?

8- Place of work (city and the province)?

The second part:

The axes below represent the categories and indicators that affect the importance and performance of the prefabricated construction project. It is required to indicate the relative importance of each indicator in the axes and according to your experiences. Taking into account that the indicators are specific, measurable, achievable, linked to performance, and time-related. Based on the theoretical review, 80 indicators within 12 categories affect the sustainability of prefabricated construction projects. The questionnaire aims to know the relative importance of the categories and indicators that affect the management of sustainable prefabricated building projects.

Note: - The answer is in digital form as shown below

- The number (**1**) represents the choice of......(**Very low**)
- The number (**2**) represents the choice of ......(**Low**)
- The number (**3**) represents the choice of …(**Medium**)
- The number (**4**) represents the choice of.........(**High**)
- The number (**5**) represents the choice of ....(**Very high**)

Appendix – B (Pareto principle (20/80) %)

Applying the Pareto theory (80/20) %, which states that 20% of indicators affect 80% of the sustainability of prefabricated building systems. Since the number of indicators is 80, 20% of them equal only 16 indicators. After analyzing the closed questionnaire using SPSS, the indicators will be arranged according to relative importance, descending from largest to smallest, and the most important indicators will be taken, as shown in Table 8.

Table 8 The indicators are arranged in descending order of their relative importance.

No	Indicators	Ar. Mean
1	Construction cost	3.621
2	Ensuring occupant health	3.517
3	Increased speed of construction on-site	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 regard to compliance with standards	3.299
No	**Indicators**	**Ar. Mean**
29	Cleaner sites due to a reduced number of on-site wet trades	3.299
30	Component quality assurance in the transportation process	3.287
31	Tracking of components in the transportation process	3.264
32	Reduction in the use of raw material	3.230
33	Product (building components) tried and tested in the factory.	3.207
34	Resource-saving benefits from prefabricated buildings	3.195
35	Climate change and atmosphere	3.195
36	Greater consistency, as the 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 of Distortion of information in transmission	3.161
41	Operation and maintenance cost	3.149
42	Real-time risk and hazard 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 person-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 the 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 gas (GHG) emissions	2.356
78	Construction waste	2.322
79	Energy and carbon emissions	2.287
80	Particulates emissions	2.276