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# Life Cycle Cost Analysis for Conventional and Sustainable Slabs in Iraq

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**Abstract** Sustainable development is the key strategy behind the success of developed countries. Energy conservation for protecting the environment and economy is only possible through sustainable housing methods. Sustainable Panels in different houses of Iraq can be one of the ways to promote sustainable development and less damage to the environment in the Country. In order to assess the best sustainable house paneling, Environmental and Economic Life Cycle Analysis (LCCA) was used to collect the data, and later, using SPSS, the values were calculated to see which panel could be the best option. The results of the study indicated that Bubble Deck Panel was the best suitable option according to the questionnaire approach, and the ICF panel is the best option according to LCCA. Hence the conclusion is that for the betterment of the economy, and environment, Bubble and ICF panels are best suitable for eco-economic buildings in Iraq.

**Keywords:** Cost analysis, economic, conventional, and sustainable slab

## 1 Introduction

Value Engineering is a set of advanced and explicit commitment actions aimed at determining the optimal value of both short- and long-term investments. The first and most important task for architects is to design the building, which was initially used in manufacturing during World War II. Is the purpose of construction to demonstrate enjoyment and employment? Isn't it true that no organization spaces make programming easier for the user? The customer expects an architect to design a structure that meets their practical and aesthetic requirements [1]. The second source of concern, and the primary emphasis of the contractors, is the construction of a structure. How will the structure be built? What about the rest of the construction costs? For the estimated construction expenses, the customer estimates that a contractor will be able to construct completing structure.

Value analysis began in the 1942s, during World War II when the demands of life and work led businesses to seek other options. In the United States, Harry Erlicher and Miles Lawrence of the General Electric Company were the pioneers in developing a system of methodologies known as value analysis, which, when applied to industrial operations, resulted in significant advances that occurred deliberately rather than by chance [2]. Value engineering and stimulation judgments were introduced into construction contracts, as well as Naval Engineering in driving and facilities. [3]. In 1972, value and engineering studies are required as part of construction management services in both public and private contracts in the United States. Life cycle cost (LCC) is defined total cost decreases dollar owning and running, maintenance, and disposal of a building or construction system in overtime" [4], [5]

The value engineering idea divides opportunities into two categories: cost reduction vs feature improvement, and so provides a structured framework for identifying opportunities. As a result, "in this circumstance, value engineering is Organized application of both technical knowledge and common sense that objectives to find and eliminate superfluous costs while offering the best overall

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value to project owners. [6]. The life-cycle cost analysis (LCCA) approach is an economic valuation method that calculates the overall cost of owning and operating a facility over time. [7]. Concrete is one of the most widely used construction materials. In buildings, the development in modern science and technology has proven the use of the traditional method of pouring slabs with reinforced concrete. it is unfavorable because of less durable and unsuitable on buildings in terms of high weights, limited insulation ability [8]. The current environmental challenges in the world It led to a search for alternative materials by using sustainable materials and cost-effectiveness and the development of new materials and innovative technologies for better and cheaper alternatives [9]. The number of sustainable structures continues to double every three times and responsible for 24 of the total construction activities [10]

Nevertheless, there are several obstacles to overcome while selecting whether or not to carry out a sustainable building project. Higher perceived construction costs, a lack of political incentives, a lack of market demand, a lack of public awareness, the perception that green is only for high-end projects, an unproven business case due to the split between capital and operating costs, a lack of trained or educated eco-friendly building professionals, and difficulties in obtaining capital are all examples [11]. Plastic (bubble) and Polystyrene are alternative eco-friendly materials used in concrete. It is lightweight aesthetically attractive, saving co2 emissions [12-17].

In this study, Life Cycle Costs (LCC) for each system were investigated for all, the total cost of a slab system taking into consideration initial cost, operational cost, maintenance cost, and replacement cost. that acquires great importance as it gives high confidence to the structural designer and constructors and building specialists in choosing the appropriate type of slab. And since the issue of thermal insulation is of paramount importance in the construction of residential buildings in Iraq, as its climate is hot, dry, summer, and cold rainy winter, Thus, it is important to know the environmental impact of each type.

## 2 Objective

This research has three goals that comply with sustainability main aspect;

a- Environmental as it will provide a good alternative slab with less impact on the environment by keeping the natural resource used in less manner.

b-Social as it will provide the best alternative to improve the people who interact with the building.

c-Economical as it will provide the local market with the accurate value with each alternative to maintaining a positive long-term impact for the operating company.

## 3 Case studies

### 3.1 Manuscript preparing

In this project five types of slabs with ten alternatives criteria taking to compare and chose the best. Two methods have been used in this project to evaluate the alternative. The first one LCCA depends on the determination of the present worth of future costs with time in the life span. Defines present value as "the time-equivalent value of past, present or future cash flows as of the beginning of the base year." [18]

The time period is the difference between the time of primary costs and the time of future costs. Initial costs are incurred at the beginning of the study period at Year 0, the base year. Between Year 1 and Year 25, future costs can be acquired at any time.

The difference between the time of primary costs and the time of future costs is the time period. The initial costs are incurred in Year 0, the base year, at the start of the study period. Thus, Between Year 1 and Year 25, future costs can be incurred at any time. Slabs were taken as (Flat Slab Normal, ICF slab, Bubble slabs or Voided biaxial slabs, Joist slab ribbed & waffle, Hollow-core core slab). The entire description and cost of materials for the alternative slab as shown in **Table1.** The equation (1) is used to calculate the present value of future one-time costs. Likewise, equation (2) is used to calculate the present value of future recurring costs.

**Table 1** Cost of materials

| Slab / Criteria | Flat slab Normal | ICF SLAB | Bubble slabs Or Voided biaxial slabs | Joist slab ribbed & waffle | Hollow-core slab |
|---|---|---|---|---|---|
| **Size (m2)** | 1*1 | 1*1 | 1*1 | 1*1 | 1*1 |
| **The size of the material occupied in m3** | 1 | 0.78 | 0.62 | 1 | 0.77 |
| **Curing** | 1.00 | 1 | 1.00 | 1.00 | 1.00 |
| **Cement** | 40 | 31 | 24 | 40 | 31.00 |
| **Water** | 6 | 6 | 6.00 | 6 | 6.00 |
| **Sand** | 11 | 10 | 7 | 11 | 10.00 |
| **Gravel** | 8 | 7 | 5.00 | 8 | 6.00 |
| **Steel rebar** | 120.00 | 96 | 117.00 | 120.00 | 90.00 |
| **Steel/wood Frame** | 20.00 | 20 | 20.00 | 20.00 | 20.00 |
| **glue/** | 10 | 11 | 12.00 | 10 | 10.00 |

| | | | | | |
|---|---|---|---|---|---|
| **additional materials (polystyrene, waste plastic )** | | | | | |
| **Labor** | 25 | 25 | 25.00 | 25 | 25.00 |
| **TOTAL cost** | 241.00 | 207 | 217.00 | 241.00 | 199.00 |

The second one, the data from the questionnaires were analyzed descriptive tools such as frequencies, percentage, and mean values by using SPSS with below Criteria's which are used in this study are:

1-Sound Insulation
2-Fire Insulation
3-Heat Insulation
4-Aesthetics
5-Weight
6-Anti Humidity (water Proofing)
7-Environmental sustainability
8- Safety in Use
9-Quality
10- Installation

This study included the descriptive analysis of the availability of the study variables and their dimensions at the site of the study, and according to the answers of the sample individuals to the questionnaire, through some directional descriptive statistical methods represented by frequency distributions, percentages, arithmetic means, standard deviations, the trend of answers, and relative importance.

The arrangement of Criteria is based on their relative importance. Verification of the test of normal distribution of the data: to verify the integrity of the data and prove that it is free from fake associations, we used the Kolmogorov - Smirnov scale, which may negatively affect the results, as well as to prove that the data are distributed normally, and the statistical analysis has proven that the data of all variables are distributed normally through the test. The hypothesis that (the data are distributed normally if the significant value of the Kolmogorov-Smirnov test is greater than 0.05 and vice versa), confirms the ability of the explanatory variable (independent) to explain the responsive variable (dependent) as in **Tables 2 and 3.**

**Table 2** Tests of Normality variables

| variables | Kolmogorov-Smirnov[a] | | |
|---|---|---|---|
| | Statistic | df | Sig. |
| Flat slab | .097 | 66 | .200* |
| ICF SLAB | .102 | 66 | .085 |
| Bubble deck slab | .109 | 66 | .048 |
| waffle slab or two-way joist slab | .082 | 66 | .200* |
| Hollow-core slab | .112 | 66 | .060 |

**Table 3** Classification of the study sample response level categories based on the arithmetic mean [19]

| Categories | level |
|---|---|
| 1 + 0.79 = 1.79 | Bad |
| 1.80+ 0.79 = 2.59 | Weak |
| 2.60 + 0.79 = 3.39 | Medium |
| 3.40 + 0.79 = 4.19 | Good |
| 4.20 + 0.79 ~ 5 | Excellent |

## 4 Methodology of calculation LCCA of Value of a Product

### 4.1 Identifying Economic Criteria

- Economic approaches constant dollars
- Project life cycle 25 years
- Discount (interest) rate 10 %
- Present time occupancy date
- In Flatiron ignored
- Cost growth 0%
- Cash flow end of year

### 4.2 Life Cycle Cost Analysis (LCCA)

A LCCA can be applied in a variety of manners without affecting the results of the hypotheses that shape. Primary Formula for Determining Life-Cycle Cost as illustrated in equation (3).

$$LCC = I + Repl + Res + E + OM\&R + O \qquad (3)$$

Given the many techniques for performing an LCCA, the basic steps for completing an LCCA for this study are listed below.

### 4. 2.1 Initial Investment Costs

The first stage in completing the LCCA of a project alternative is to define all of the alternative's initial investment costs. Initial investment costs are those that will be incurred before the facility is occupied.

### 4. 2.2 Operation Costs

The second step in completing the LCCA for the alternatives is to define all of the alternative's future operational expenses. The operating expenses are the annual costs associated with the facility's operation, excluding repair and maintenance costs. The majority of these expenses are for building utilities and custodial services. Prior to being added to the LCCA total, all process costs must be discounted to present value. Operating costs that are not directly tied to the building, such as the cost of office materials, should normally be removed from the LCCA.

### 4. 2.3 Maintenance & Repair Costs

The third phase in the LCCA of a project alternative is to define all of the alternative's future maintenance and repair costs. Maintenance and repair expenditures have been consolidated in the department's LCCA spreadsheet for ease of use. It should be noted that there is a distinction between the two costs Some maintenance fees are incurred once a year, while others are incurred less frequently. Because repair expenditures are unplanned by definition, it is difficult to estimate when they will occur. Maintenance and repair costs should be treated as annual costs for simplicity's convenience. Prior to being added to the LCCA total, all maintenance and repair costs must be reduced to their present value.

### 4.2. Replacement Costs

The fourth step in the LCCA process is to define all of the alternative's future replacement costs. The estimated expenditures for the building of the primary components of the system required to keep the facility functioning are known as replacement costs. Prior to being added to the LCCA total, all replacement costs must be reduced to their present value. The cost of replacing a building system or component that has reached the end of its useful life is the most common source of replacement costs.

### 4. 2.5 Residual Value

The residual value of the alternative is the fifth step in completing the LCCA for the alternatives. The net worth of a building slab at the end of the LCCA research period is known as residual value. This is the only cost category in an LCCA where a negative number, which lowers the cost, is permissible. When evaluating options that have investigated the various life expectancies, the residual value of the facility or building system is of particular importance.

### 4.2.6 Finalize LCCA

Once all relevant costs have been determined and discounted to present value, the total life cycle cost of the project alternative can be calculated. A summary of the results should be written after this has been completed for all potential project alternatives. The results was displayed as in **Tables 4-9 .**

## 5- Results and Discussion

Some significant results were obtained, these results indicated the reasonable choices to consider when designing and constructing in line with the best value obtained from all the alternatives discussed in this project as below:

**Fig. 1** illustrate that ICF and bubble slab has a lower cost by around 14% than the others. In comparison between ICF system and Flat slab, it’s clear that ICF has lower cost due to for many reasons such as used waste materials (polystyrene) reduce the volume of concrete in the roof about 27%, the lightweight blocks mean the slab is installed easier and faster. In addition, ICF slabs also facilitate making the structure incredibly energy efficient. The slabs are also effective sound insulators, lowering the chance of noise entering or escaping the building. A Bubbled slab system is the slab in which some amount of concrete is replaced by the recycled plastic balls which reduce the self-weight of the slab, void formers in the middle of a Flat slab eliminates 35% of a slab self-weight removing constraints of high dead loads and short spans and this reduces concrete and thus reduces costs. Furthermore, reduce $CO_2$ emission and embedded energy.

While the results showed that hollow core slab less cost than Flat slab about 6% and the waffle slab cost closer to the Flat slab, although there are differences in the quantity of concrete and reinforcement between the waffle and Flat slab systems, where the waffle system has one-way reinforcement, while the Flat slab has two-way. Also, the volume of concrete used, waffle or joist slab demanded lower volume of concrete than in Flat slab, consequently, the cost will be less since the volume is lower. Therefore, the cost will depend on the design and thickness of waffle beams to take into account reducing the quantities of concrete.

**Fig. 2 and 3** showed that the total Lifecycle Cost (Present Worth) different by the system. ICF and bubble slab lower cost than Flat slab by 13% and 10 % respectively. Hollow-core slab lower cost than Flat slab about 5%. In the hollow slabs, despite the concrete size being less due to the presence of the voids, the requirements of the manpower to fix the voids on formwork and demand technical expertise, therefore, may increase the costs.

This means that although there is a convergence in the life-cycle cost of the alternatives, the results showed that the ICF and Buble slab systems were a lower life-cycle-cost analysis.

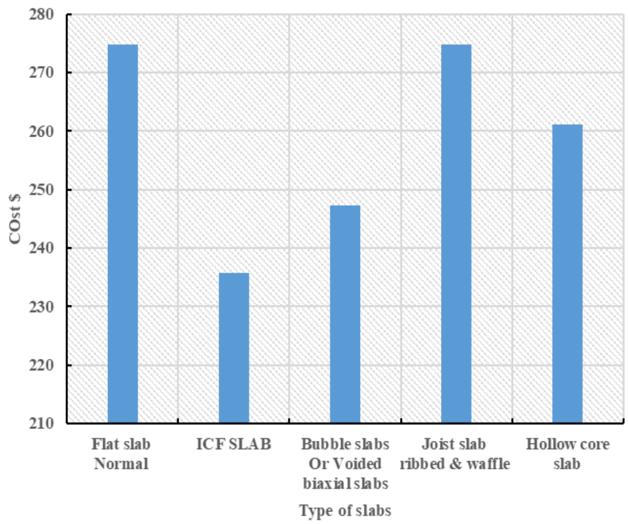


**Fig. 1** Total Initial Cost

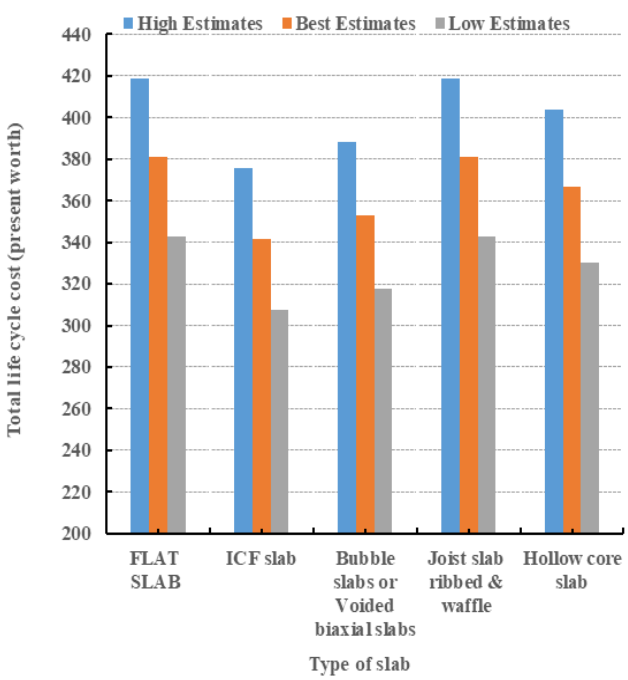


**Fig. 2** Total Life Cycle Cost (Present Worth)

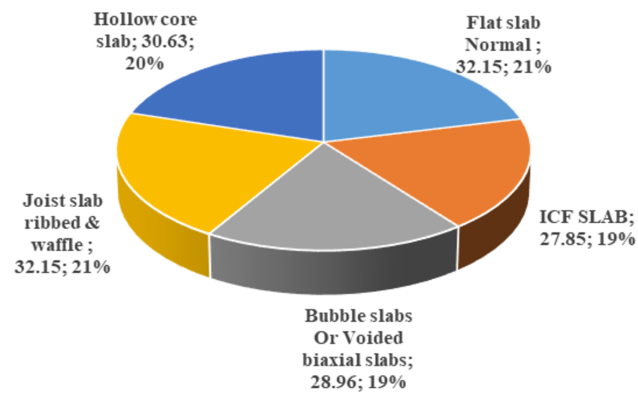


**Fig. 3** Total Life Cycle Cost (Annualized) Per Year

As in **Table 10.** and **Fig. 4**, the descriptive statistics and relative importance of Flat slab showed the quality has the higher importance and equal to 65.326% with a trend (Medium) where the mean is equal to 3.2663 and standard deviation equal to 0.50343 Because it is used more traditionally in construction than other types In terms of ease of use and installation. As for of ICF slab system, the installation and lightweight has the higher importance and are equal to 71.172% with a trend (Good) where the mean is equal to 3.5586 and standard deviation equal to 0.47878, this is due to faster completion time, less weight, and less reinforcement.

At the same time, for Bubble deck slab system showed that the aesthetics have the higher importance and equal to 71.208% with a trend (Good) where the mean is equal to 3.5604 and the standard deviation equal to 0.52348 because it makes significant assistance to reducing environmental impact because it's more usage of waste materials and fewer emissions resulting from construction.

Furthermore, for the waffle slab or two-way joist slab presented the aesthetics have the higher importance and equal to 71.704% with a trend) Good) where the mean is equal to 3.5852 and standard deviation equal to 0.54244. Some people find the waffle pattern aesthetically pleasing because it is used for larger span slabs or floors and used when there is a limited requirement for a number of columns and used on longer spans and with heavier loads. They provide good structural stability along with an aesthetic appearance. Therefore, it is constructed for hospitals, halls with space, airports, temples, etc.

Finally, the results for the Hollow-core slab showed that heat insulation has the higher importance and is equal to 72.094% with a trend (Good) where the mean is equal to 3.6047and standard deviation equal to 0.55408, which means the presence of voids, it will create an air space that helps reduce sound transmission and against airborne and decrease noise from the external environment.

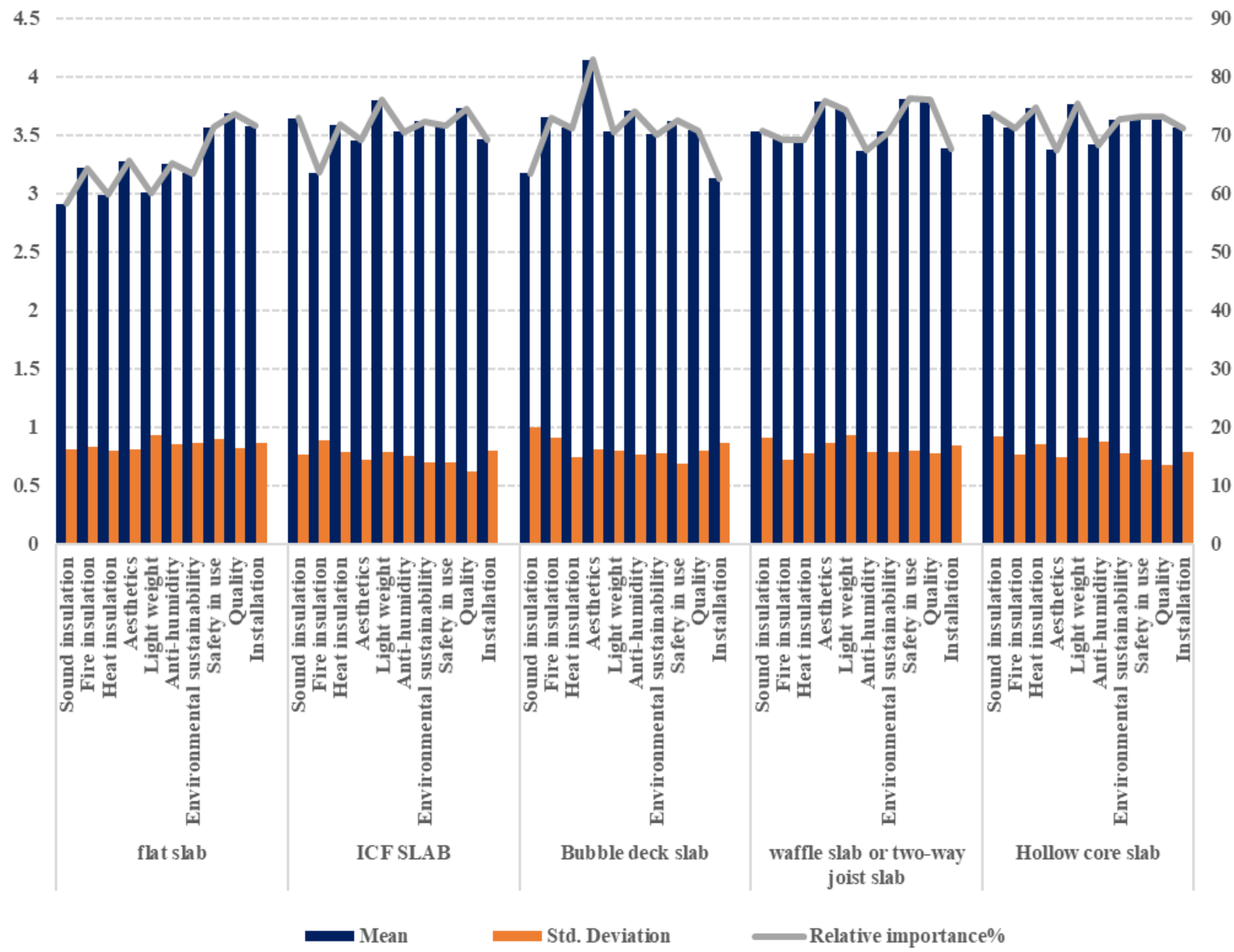


**Fig. 4** The descriptive statistics and Relative importance

## 6- Conclusion

The analysis made allows us to conclude that the condition for the development of the new economy in the countries in transition differs to a large extent. In Iraq, we did this study because the slabs represent one of the important elements for the residential and public buildings, alternative Slabs for Iraq is the ICF slab, as it has the lowest total life cycle cost of present worth $ 235.75 for environmental impact and CO2 emission so, it concluded that ICF and bubble slab systems represent the better alternative for the commonly used concrete slab, therefore, one cubic meter and has the biggest number among other alternatives in the total maximum weight in the evaluation. In addition, ICF and bubble slab systems have the lowest and this makes the choice of the best alternative slabs of these buildings an urgent need. Therefore, according to LCCA and weighted evaluation calculation, we found the best alt

it's preferable to adopted for slab design and construction buildings.

**Table 4** Present Worth computation for alternative

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ***Life Cycle Cost Analysis*** | | | | | | |
| | | | | | | **Present Worth (PW) Computation** | | | | | | |
| **Location: Iraq** | | | **Flat slab Normal** | | **ICF SLAB** | | **Bubble slabs Or Voided biaxial slabs** | | **Joist slab ribbed & waffle** | | **Hollow core slab** | |
| **Subject : Life cycle cost analysis for conventional and sustainable slab types in Iraq** | | | **System** | | **System** | | **System** | | **System** | | **System** | |
| **Description : concrete Slab** | | | | | | | | | | | | |
| **Discount rate 10%** | **0.1** | | | | | | | | | | | |
| **INITIAL COSTS** | | | | | | | | | | | | |
| | **Quantity** (Cubic.m) | **Unit Price** (S) | **Est.** | **PW** | **Est.** | **PW** | **Est.** | **PW** | **Est.** | **PW** | **Est.** | **PW** |
| Alternative 1 | 1 | 274.850 | 274.850 | 274.850 | | | | | | | | |
| Alternative 2 | 1 | 235.750 | | | 235.750 | 235.750 | | | | | | |
| Alternative 3 | 1 | 247.250 | | | | | 247.250 | 247.250 | | | | |
| Alternative 4 | 1 | 274.850 | | | | | | | 274.850 | 274.850 | | |
| Alternative 5 | 1 | 261.050 | | | | | | | | | 261.05 | 261.05 |
| Total Initial Cost | | | | 274.850 | | 235.750 | | 247.250 | | 274.850 | | 261.05 |
| Initial Cost PW Savings(Compared to A1) | | | | | | | | | | | | |
| **REPLACEMENT COST** | | | | | | | | | | | | |
| Description | Year | PP factor | | | | | | | | | | |
| Slab Painting | 3 | 0.3112 | 1.030 | 2.796 | 1.030 | 2.796 | 1.030 | 2.796 | 2.731 | 2.796 | 1.030 | 2.796 |
| Slab coat | 10 | 0.0678 | 1.080 | 0.577 | 1.080 | 0.609 | 1.080 | 0.609 | 1.080 | 0.609 | 1.080 | 0.609 |
| major repairs | 15 | | | | | | | | | | | |
| Slab protection | 3 | | | | | | | | | | | |
| Restoration | 5 | | | | | | | | | | | |
| Energ consumption | 10 | | | | | | | | | | | |
| Total Replacement /Salvage Costs | | | | 3.3728 | | 3.4047 | | 3.4047 | | 3.4047 | | 3.4047 |
| **ANNUAL COSTS** | | | | | | | | | | | | |
| Description | | PW | | | | | | | | | | |
| Surface Cleaning | | 9.0770 | 1.500 | 13.616 | 1.500 | 13.616 | 1.350 | 12.254 | 1.500 | 13.616 | 1.500 | 13.616 |
| Surface protection | | 9.0770 | | | | | | | | | | |
| Total Annual Cost(PW) | | | | 13.616 | | 13.616 | | 12.254 | | 13.616 | | 13.616 |
| **Total Life CycleCost (Present Worth)** | | | | 291.8383 | | 252.7703 | | 262.9087 | | 291.8703 | | 278.0703 |
| Life Cycle Saving(Compared to Alt.1) | | | | | | | | | | | | |
| Discounted Payback(Compared to Alt.1) | | | | 3.24264821 | Never | 2.808558537 | 0.00 | 2.92120791 | 0.00 | 3.24300298 | Never | 3.08966965 |
| **Total Life CycleCost (Annualized)** | | | 32.15 | Per Year | 27.85 | Per Year | 28.96 | Per Year | 32.15 | Per Year | 30.63 | Per Year |

**Table 5** Normal LCCA High, best and low estimates Alternative1(Flat slab Normal)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Present Worth (PW) Computation** | | | | | | | | | |
| **Location: Iraq** | | | **High Estimates** | | **Best Estimates** | | **Low Estimates** | | |
| **Subject :Life cycle cost analysis for conventional and sustainable slab types in Iraq** | | | **(+10%)** | | | | **(-10%)** | | |
| **Description : Alternative concrete slab** | | | | | | | | | |
| **Discount rate 10%** | **0.1** | | | | | | | | |
| **Alternative1 : Flat slab /normal** | | | | | | | | | |
| **INITIAL COSTS** | | | | | | | | | |
| | Quantity (cu.m) | Unit Price Best Est. (S) | **Est.** | **PW** | **Est.** | **PW** | **Est.** | **PW** | |
| Curing | 1 | 5 | 5.5 | 5.5 | 5 | 5 | 4.5 | 4.5 | |
| mortar(cement, sand & gravel) | 1 | 59 | 64.9 | 64.9 | 59 | 59 | 53.1 | 53.1 | |
| Steel rebar | 1 | 120 | 132 | 132 | 120 | 120 | 108 | 108 | |
| Steel/wood Frame | 1 | 20 | 22 | 22 | 20 | 20 | 18 | 18 | |
| glue/ additional materials | 1 | 10 | 11 | 11 | 10 | 10 | 9 | 9 | |
| Labor | 1 | 25 | 27.5 | 27.5 | 25 | 25 | 22.5 | 22.5 | |
| General Condition, OH & P (15%) | | | 39.435 | 39.435 | 35.85 | 35.85 | 32.265 | 32.265 | |
| Total Initial Cost | | | | 302.335 | | 274.850 | | 247.365 | |
| Initial Cost PW Difference(Compared to High Est) | | | | | | 27.485 | | 54.970 | |
| **REPLACEMENT COST** | | | | | | | | | |
| Description | Year | PW factor | | | | | | | |
| Restoration | 3 | 0.7513 | 1.133 | 0.85 | 1.03 | 0.774 | 0.927 | 0.696 | |
| Coating/protection | 4 | 0.6830 | 1.188 | 0.81 | 1.08 | 0.738 | 0.972 | 0.664 | |
| Total Replacement /Salvage Costs | | | | 1.6627 | | 1.5115 | | 1.3604 | |
| **ANNUAL COSTS** | | | | | | | | | |
| Description | | PW | | | | | | | |
| Surface Cleaning | | 9.0770 | 1.650 | 14.977116 | 1.500 | 13.616 | 1.350 | 12.254 | |
| Surface Protection | | 9.0770 | 11.000 | 99.84744 | 10.000 | 90.770 | 9.000 | 81.693 | |
| Total Annual Cost(PW) | | | | 114.82456 | | 104.386 | | 93.947 | |
| **Total Life Cycle Cost (Present Worth)** | | | | 418.822 | | 380.747 | | 342.673 | |
| Life Cycle PW Difference(Compared to High Est.) | | | | | | 38.075 | | 76.149 | |

**Table 6** ICF slab LCCA

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Present Worth (PW) Computation** | | | | | | | | | |
| **Location: Iraq** | | | **High Estimates** | | **Best Estimates** | | **Low Estimates** | | |
| **Subject :Life cycle cost analysis for conventional and sustainable slab types in Iraq** | | | **(+10%)** | | | | **(-10%)** | | |
| **Description : Alternative concrete slab** | | | | | | | | | |
| **Discount rate 10%** | **0.1** | | | | | | | | |
| **Alternative2 : ICF slab** | | | | | | | | | |
| **INITIAL COSTS** | | | | | | | | | |
| | Quantity (cu.m) | Unit Price Best Est. (S) | **Est.** | **PW** | **Est.** | **PW** | **Est.** | **PW** | |
| Curing | 1 | 5 | 5.5 | 5.5 | 5 | 5 | 4.5 | 4.5 | |
| mortar(cement, sand & gravel) | 1 | 48 | 52.8 | 52.8 | 48 | 48 | 43.2 | 43.2 | |
| Steel rebar | 1 | 96 | 105.6 | 105.6 | 96 | 96 | 86.4 | 86.4 | |
| Steel/wood Frame | 1 | 20 | 22 | 22 | 20 | 20 | 18 | 18 | |
| glue/ additional materials | 1 | 11 | 12.1 | 12.1 | 11 | 11 | 9.9 | 9.9 | |
| Labor | 1 | 25 | 27.5 | 27.5 | 25 | 25 | 22.5 | 22.5 | |
| General Condition, OH & P (15%) | | | 33.825 | 33.825 | 30.75 | 30.75 | 27.675 | 27.675 | |
| Total Initial Cost | | | | 259.325 | | 235.750 | | 212.175 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Initial Cost PW Difference(Compared to High Est) | | | | | | 23.575 | | 47.150 |
| **REPLACEMENT COSts** | | | | | | | | |
| Description | Year | PW factor | | | | | | |
| Restoration | 3 | 0.7513 | 1.133 | 0.85 | 1.03 | 0.774 | 0.927 | 0.696 |
| Coating/protection | 4 | 0.6830 | 1.188 | 0.81 | 1.08 | 0.738 | 0.972 | 0.664 |
| Total Replacement /Salvage Costs | | | | 1.6627 | | 1.5115 | | 1.3604 |
| **ANNUAL COSTS** | | | | | | | | |
| Description | | PW | | | | | | |
| Surface Cleaning | | 9.0770 | 1.650 | 14.977116 | 1.500 | 13.616 | 1.350 | 12.254 |
| Surface Protection | | 9.0770 | 11.000 | 99.84744 | 10.000 | 90.770 | 9.000 | 81.693 |
| Total Annual Cost(PW) | | | | 114.82456 | | 104.386 | | 93.947 |
| **Total Life CycleCost (Present Worth)** | | | | 375.812 | | 341.647 | | 307.483 |
| Life Cycle PW Difference(Compared to High Est.) | | | | | | 34.165 | | 68.329 |

**Table 7** Bubble slabs or Voided biaxial slabs LCCA

| **Present Worth (PW) Computation** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Location: Iraq** | | | **High Estimates** | | **Best Estimates** | | **Low Estimates** | |
| **Subject :Life cycle cost analysis for conventional and sustainable slab types in Iraq** | | | **(+10%)** | | | | **(-10%)** | |
| **Description : Alternative concrete slab** | | | | | | | | |
| **Discount rate 10%** | **0.1** | | | | | | | |
| **Alternative3 : : Bubble slabs or Voided biaxial slabs** | | | | | | | | |
| **INITIAL COSTS** | | | | | | | | |
| | Quantity (cu.m) | Unit Price Best Est. (S) | **Est.** | **PW** | **Est.** | **PW** | **Est.** | **PW** |
| Curing | 1 | 5 | 5.5 | 5.5 | 5 | 5 | 4.5 | 4.5 |
| mortar(cement, sand & gravel) | 1 | 36 | 39.6 | 39.6 | 36 | 36 | 32.4 | 32.4 |
| Steel rebar | 1 | 117 | 128.7 | 128.7 | 117 | 117 | 105.3 | 105.3 |
| Steel/wood Frame | 1 | 20 | 22 | 22 | 20 | 20 | 18 | 18 |
| glue/ additional materials | 1 | 12 | 13.2 | 13.2 | 12 | 12 | 10.8 | 10.8 |
| Labor | 1 | 25 | 27.5 | 27.5 | 25 | 25 | 22.5 | 22.5 |
| General Condition, OH & P (15%) | | | 35.475 | 35.475 | 32.25 | 32.25 | 29.025 | 29.025 |
| Total Initial Cost | | | | 271.975 | | 247.250 | | 222.525 |
| Initial Cost PW Difference(Compared to High Est) | | | | | | 24.725 | | 49.450 |
| **REPLACEMENT COSTS** | | | | | | | | |
| Description | Year | PW factor | | | | | | |
| Restoration | 3 | 0.7513 | 1.133 | 0.85 | 1.03 | 0.774 | 0.927 | 0.696 |
| Coating/protection | 4 | 0.6830 | 1.188 | 0.81 | 1.08 | 0.738 | 0.972 | 0.664 |
| Total Replacement /Salvage Costs | | | | 1.6627 | | 1.5115 | | 1.3604 |
| **ANNUAL COSTS** | | | | | | | | |
| Description | | PW | | | | | | |
| Surface Cleaning | | 9.0770 | 1.650 | 14.977116 | 1.500 | 13.616 | 1.350 | 12.254 |
| Surface Protection | | 9.0770 | 11.000 | 99.84744 | 10.000 | 90.770 | 9.000 | 81.693 |
| Total Annual Cost(PW) | | | | 114.82456 | | 104.386 | | 93.947 |
| **Total Life Cycle Cost (Present Worth)** | | | | 388.462 | | 353.147 | | 317.833 |
| Life Cycle PW Difference(Compared to High Est.) | | | | | | 35.315 | | 70.629 |

**Table 8** Joist slab ribbed & waffle LCCA

| **Present Worth (PW) Computation** | | | |
|---|---|---|---|
| **Location: Iraq** | **High Estimates** | **Best Estimates** | **Low Estimates** |
| **Subject :Life cycle cost analysis for conventional and sustainable slab types in Iraq** | **(+10%)** | | **(-10%)** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Description : Alternative concrete slab** | | | | | | | | |
| **Discount rate 10%** | **0.1** | | | | | | | |
| **Alternative1 : Joist slab ribbed & waffle** | | | | | | | | |
| **INITIAL COSTS** | | | | | | | | |
| | Quantity (cu.m) | Unit Price Best Est. (S) | **Est.** | **PW** | **Est.** | **PW** | **Est.** | **PW** |
| Curing | 1 | 5 | 5.5 | 5.5 | 5 | 5 | 4.5 | 4.5 |
| mortar(cement, sand & gravel) | 1 | 59 | 64.9 | 64.9 | 59 | 59 | 53.1 | 53.1 |
| Steel rebar | 1 | 120 | 132 | 132 | 120 | 120 | 108 | 108 |
| Steel/wood Frame | 1 | 20 | 22 | 22 | 20 | 20 | 18 | 18 |
| glue/ additional materials | 1 | 10 | 11 | 11 | 10 | 10 | 9 | 9 |
| Labor | 1 | 25 | 27.5 | 27.5 | 25 | 25 | 22.5 | 22.5 |
| General Condition, OH & P (15%) | | | 39.435 | 39.435 | 35.85 | 35.85 | 32.265 | 32.265 |
| Total Initial Cost | | | | 302.335 | | 274.850 | | 247.365 |
| Initial Cost PW Difference(Compared to High Est) | | | | | | 27.485 | | 54.970 |
| **REPLACEMENT COST** | | | | | | | | |
| Description | Year | PW factor | | | | | | |
| Restoration | 3 | 0.7513 | 1.133 | 0.85 | 1.03 | 0.774 | 0.927 | 0.696 |
| Coating/protection | 4 | 0.6830 | 1.188 | 0.81 | 1.08 | 0.738 | 0.972 | 0.664 |
| Total Replacement /Salvage Costs | | | | 1.6627 | | 1.5115 | | 1.3604 |
| **ANNUAL COSTS** | | | | | | | | |
| Description | | PW | | | | | | |
| Surface Cleaning | | 9.0770 | 1.650 | 14.977116 | 1.500 | 13.616 | 1.350 | 12.254 |
| Surface Protection | | 9.0770 | 11.000 | 99.84744 | 10.000 | 90.770 | 9.000 | 81.693 |
| Total Annual Cost(PW) | | | | 114.82456 | | 104.386 | | 93.947 |
| **Total Life Cycle Cost (Present Worth)** | | | | 418.822 | | 380.747 | | 342.673 |
| Life Cycle PW Difference(Compared to High Est.) | | | | | | 38.075 | | 76.149 |

**Table 9** Hollow-core slab LCCA

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Present Worth (PW) Computation** | | | | | | | | |
| **Location: Iraq** | | | **High Estimates** | | **Best Estimates** | | **Low Estimates** | |
| **Subject :Life cycle cost analysis for conventional and sustainable slab types in Iraq** | | | **(+10%)** | | | | **(-10%)** | |
| **Description : Alternative concrete slab** | | | | | | | | |
| **Discount rate 10%** | **0.1** | | | | | | | |
| **Alternative5 : Hollow core slab** | | | | | | | | |
| **INITIAL COST** | | | | | | | | |
| | Quantity (cu.m) | Unit Price Best Est. (S) | **Est.** | **PW** | **Est.** | **PW** | **Est.** | **PW** |
| Curing | 1 | 5 | 5.5 | 5.5 | 5 | 5 | 4.5 | 4.5 |
| mortar(cement, sand & gravel) | 1 | 47 | 51.7 | 51.7 | 47 | 47 | 42.3 | 42.3 |
| Steel rebar | 1 | 120 | 132 | 132 | 120 | 120 | 108 | 108 |
| Steel/wood Frame | 1 | 20 | 22 | 22 | 20 | 20 | 18 | 18 |
| glue/ additional materials | 1 | 10 | 11 | 11 | 10 | 10 | 9 | 9 |
| Labor | 1 | 25 | 27.5 | 27.5 | 25 | 25 | 22.5 | 22.5 |
| General Condition, OH & P (15%) | | | 37.455 | 37.455 | 34.05 | 34.05 | 30.645 | 30.645 |
| Total Initial Cost | | | | 287.155 | | 261.050 | | 234.945 |
| Initial Cost PW Difference(Compared to High Est) | | | | | | 26.105 | | 52.210 |
| **REPLACEMENT COST** | | | | | | | | |
| Description | Year | PW factor | | | | | | |
| Restoration | 3 | 0.7513 | 1.133 | 0.85 | 1.03 | 0.774 | 0.927 | 0.696 |
| Coating/protection | 4 | 0.6830 | 1.188 | 0.81 | 1.08 | 0.738 | 0.972 | 0.664 |
| Total Replacement /Salvage Costs | | | | 1.6627 | | 1.5115 | | 1.3604 |
| **ANNUAL COSTS** | | | | | | | | |
| Description | | PW | | | | | | |
| Surface Cleaning | | 9.0770 | 1.650 | 14.977116 | 1.500 | 13.616 | 1.350 | 12.254 |
| Surface Protection | | 9.0770 | 11.000 | 99.84744 | 10.000 | 90.770 | 9.000 | 81.693 |
| Total Annual Cost(PW) | | | | 114.82456 | | 104.386 | | 93.947 |
| **Total Life Cycle Cost (Present Worth)** | | | | 403.642 | | 366.947 | | 330.253 |
| Life Cycle PW Difference(Compared to High Est.) | | | | | | 36.695 | | 73.389 |

**Table10** The descriptive statistics and Relative importance of type slabs

| Type | Criteria | Mean | Std. Deviation | Relative importance% | Trend |
|---|---|---|---|---|---|
| Flat slab | Sound insulation | 2.9112 | 0.80795 | 58.224 | Medium |
| | Fire insulation | 3.2189 | 0.83416 | 64.378 | Medium |
| | Heat insulation | 2.9882 | 0.8017 | 59.764 | Medium |
| | Aesthetics | 3.2781 | 0.80891 | 65.562 | Medium |
| | Light weight | 3.0059 | 0.92901 | 60.118 | Medium |
| | Anti-humidity | 3.2544 | 0.85933 | 65.088 | Medium |
| | Environmental sustainability | 3.1716 | 0.86611 | 63.432 | Medium |
| | Safety in use | 3.568 | 0.89797 | 71.36 | Good |
| | Quality | 3.6864 | 0.81788 | 73.728 | Good |
| | Installation | 3.5799 | 0.86317 | 71.598 | Good |
| ICF SLAB | Sound insulation | 3.645 | 0.76648 | 72.9 | Good |
| | Fire insulation | 3.1775 | 0.88194 | 63.55 | Medium |
| | Heat insulation | 3.5917 | 0.78992 | 71.834 | Good |
| | Aesthetics | 3.4556 | 0.72341 | 69.112 | Good |
| | Light weight | 3.7988 | 0.78361 | 75.976 | Good |
| | Anti-humidity | 3.5266 | 0.74853 | 70.532 | Good |
| | Environmental sustainability | 3.6154 | 0.69864 | 72.308 | Good |
| | Safety in use | 3.5858 | 0.69439 | 71.716 | Good |
| | Quality | 3.7278 | 0.62431 | 74.556 | Good |
| | Installation | 3.4615 | 0.79433 | 69.23 | Good |
| Bubble deck slab | Sound insulation | 3.1716 | 0.9941 | 63.432 | Medium |
| | Fire insulation | 3.6509 | 0.90765 | 73.018 | Good |
| | Heat insulation | 3.5621 | 0.73839 | 71.242 | Good |
| | Aesthetics | 4.1479 | 0.81395 | 82.958 | Good |
| | Light weight | 3.5266 | 0.80227 | 70.532 | Good |
| | Anti-humidity | 3.7041 | 0.76067 | 74.082 | Good |
| | Environmental sustainability | 3.5089 | 0.7801 | 70.178 | Good |
| | Safety in use | 3.6213 | 0.68904 | 72.426 | Good |
| | Quality | 3.5385 | 0.79433 | 70.77 | Good |
| | Installation | 3.1299 | 0.86848 | 62.598 | Medium |
| waffle slab or two-way joist slab | Sound insulation | 3.5325 | 0.90656 | 70.65 | Good |
| | Fire insulation | 3.4615 | 0.72375 | 69.23 | Good |
| | Heat insulation | 3.4615 | 0.77152 | 69.23 | Good |
| | Aesthetics | 3.787 | 0.86027 | 75.74 | Good |
| | Light weight | 3.716 | 0.9334 | 74.32 | Good |
| | Anti-humidity | 3.3669 | 0.78397 | 67.338 | Good |
| | Environmental sustainability | 3.5266 | 0.78729 | 70.532 | Good |
| | Safety in use | 3.8107 | 0.80156 | 76.214 | Good |
| | Quality | 3.8047 | 0.77366 | 76.094 | Good |
| | Installation | 3.3846 | 0.83808 | 67.692 | Good |
| Hollow core slab | Sound insulation | 3.6805 | 0.92178 | 73.61 | Good |
| | Fire insulation | 3.5621 | 0.76219 | 71.242 | Good |
| | Heat insulation | 3.7337 | 0.84873 | 74.674 | Good |
| | Aesthetics | 3.3728 | 0.74608 | 67.456 | Good |
| | Light weight | 3.7692 | 0.91287 | 75.384 | Good |
| | Anti-humidity | 3.4201 | 0.87686 | 68.402 | Good |
| | Environmental sustainability | 3.6331 | 0.77634 | 72.662 | Good |
| | Safety in use | 3.6568 | 0.72414 | 73.136 | Good |
| | Quality | 3.6568 | 0.6818 | 73.136 | Good |
| | Installation | 3.5621 | 0.79282 | 71.242 | Good |

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## Notations

| | |
|---|---|
| **PV :** | Present Value |
| **At :** | Amount of one-time cost at a time t |
| **A0 :** | Amount of recurring cost |
| **d :** | Real Discount Rate |
| **t :** | Time (Represent as the number of years) |
| **LCC:** | Total life-cycle cost in present value (PV) dollars of a given alternative |
| **I:** | Initial cost |
| **Repl:** | PV capital replacement costs |
| **Res:** | PV residual value (resale value, salvage value) fewer disposal costs |
| **l:** | Desired useful life in years of the building or system |
| **E:** | Total energy cost (PV) |
| **W:** | Total water costs (P) |
| **OM&R:** | Total operating, maintenance, and repair costs (PV) |
| **O:** | Total other costs, if any—contract administration costs, financing costs, employee salaries and benefits, and so forth (PV). |