

# Con-LCCA V1.0: A Computerized Tool for Analyzing the Life Cycle Cost of Construction Projects.



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**Abstract:** One of the growing terms that are gaining attention in the building construction field is the life cycle costing, especially when it comes to green and sustainable constructions; however, its applications in the construction field are still not widely understood, it is limited and facing practical limitations in the construction market due to the lack of the awareness of its applications and its complexity. The main objective of the study is to create a computerized tool based on a systematic methodology that helps the construction project's managers analyze the life cycle costs of their projects. The study created a systematic thirty years study period life cycle cost analysis methodology based on the different types of costs and the different factors affecting the life cycle cost calculations; the proposed methodology was converted to a computerized VBA tool and examined by applying it to a case study project.

**Keywords:** Building Costs; Life Cycle; Computerized Tool; Cost Analysis; Cost Management

## 1 Introduction

Construction costs can be an illusory as the unhidden top part of an iceberg submerged in water, as seen in Fig. 1, the submerged, hidden base of the iceberg can be more significant and compelling than its top. Future costs can be figured as the submerged part of the iceberg; it can have

the same effect in the building's total costs compared to the initial construction costs [1]. Different types of expenses are needed to keep the building/project working throughout the building's service life such as design fees, construction costs, consumption costs, operational costs, maintenance costs, in addition to disposal or end of life costs [2].

Life cycle cost analysis is an evaluation technique that compares different design alternatives according to its economic performance throughout their lifetime as it reflects the total cost of ownership by calculating the present initial costs required in order to cover and balance all the building's future costs over its lifetime [3].

The main problem facing the application of life cost analysis technique in the construction field is that it is still not widely understood, it is limited and facing practical limitations in the construction market due to the lack of the awareness of its applications in addition to its complexity [4].

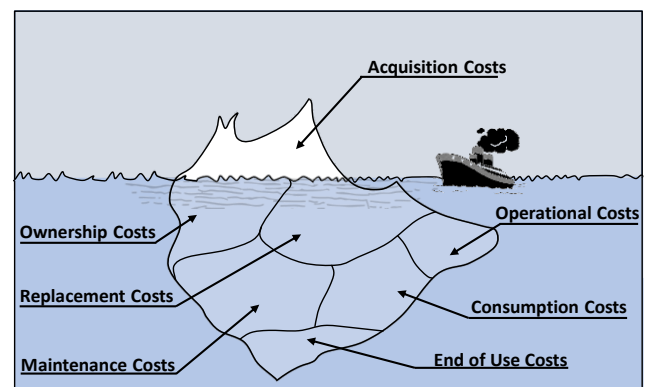


Fig. 1: Life Cycle Cost Iceberg.

According to a study performed in Malaysia, there are many reasons reducing the use of any measurement

Received: 25 September 2022/ Accepted: 2 November 2022

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software in the bill of quantity preparations, as seen in Table 1.

Table 1: Problems of Using Software Tools in Bill of Quantities Preparation [5].

	Problems	Agreement
1	Software Cost	60%
2	Learning Much Procedure	53.3%
3	Hardware Cost	46.7%
4	Lack of Experience	40%
5	Data Security Problems	26.7%
6	Training Issues	13.3%
7	Lack of Flexibility	3.7%
8	Causing Over-Measurement	6.7%

To avoid the problems extracted from Fig. 1 and to encourage using the life cycle costing applications; the main objective of the study is to create an open-source tool that can calculate the life cycle cost alongside with creating typical Microsoft Excel bill of quantities (Same Procedure that is compatible with the nature of the project's cost analysis in the Egyptian market). The tool differs from other Microsoft excel tools that it is designed especially for construction project and according to the inputs, constraints and items categories of construction projects.

## 2 Theoretical Background

### 2.1 Life Cycle Costs (L.C.C.)

The life cycle cost (L.C.C.) is the summation of the expenses needed by an item or system during its life cycle (it is the total cost of ownership) [6]. Life cycle costs can be divided into many types of expenses, beginning with the design costs ending with the disposal value [4]. Some of the main types of costs are as the following:

#### 2.1.1 Initial (Capital) Cost

The capital costs are the initial costs needed for constructing the project, such as the land value and the materials costs [7], and it can include the following:

- **Investment Costs:** It is the amount of money needed in order to study the feasibility of any project by analyzing the market needs compared to the value of the product, in addition to the costs of providing the financial plan for the project. The investment costs also include the cost of opportunity, or in another way, the profits suspended because of using the money in the project, such as the money banking interest [7].

- **Design Costs:** The design costs are the fees required in order to obtain the design drawings of the project, in addition to the shop drawings [9].

- **Advertising Costs:** Advertising Costs are a type of cost that covers any expenses related to promoting the project in any advertisement way such as printable media, radio, television, social media of any other advertisement way.

- **Land Acquisition Costs:** It is all kinds of fees and taxes required and paid in order to own land in addition to the opportunizing costs of this land or in another way, the profit suspended by the project related to the land, as an example the fees of renting the land to another investor [10].

- **Construction Costs:** The construction costs are the summation of the expenses paid in order to construct the building, including the recourses used in the construction process, not including the land costs, including the materials, labors, supervision, equipment, and systems used in the construction process [9]. The construction costs are the most effective category of costs as it has the most significant portion that exceeds fifty percent of the project's total costs. The construction costs are the costs or materials, human resources, and planting implicated in the construction process of the building or the project, including the supervision, and contractor's profit, and any other changes that could happen during the construction time [7].

#### 2.1.2 Operational Costs

Unlike the capital costs, the costs of operations are the costs done after the construction process, such as energy costs, salaries, maintenance costs, replacement costs [11]. The operational costs is the costs paid during the life cycle of the project that is related to the functions of the building and its working performance [8]. The costs of operation can include many categories; some of the main categories are as the following:

- **Ownership Costs:** Which have the regular costs resulted from the ownership of a working project such as the energy and water consumption costs, the security and cleaning staff's fees, the maintenance [7, 2].

- **Maintenance and Replacement Costs:** Which are Annual and intermittent costs associated with the repair of the building, including periodic replacement or planned renovation [2]. They are resulted from the replacement of any item in the project, which mainly includes the equipment replacement costs, painting, and some maintenance issues [12].

- **Occupancy Costs:** It is the costs related to the occupancy of the place, such as the insurance, the renting costs, the costs related to the function of the building, and including the opportunity costs of the use [13].

#### 2.1.3 Salvage Value (Disposal)

It is the total value of the building or the project at the end of the proposed investing time. Usually, this type of

cost has negative value because the building or the land is sold at the end of the project [8]. The salvage value is the worth of the construction, including all its components at the end of the lifetime determined by the life cycle cost analysis tool. These costs are in a negative value as it reduces the summation of the total costs. When comparing alternatives having different study periods, the residual value becomes the main point that affects the comparison [14].

## 2.2 Factors Affecting LCC.

In order to calculate the life cycle cost of a project, some adjustments should be made to the Currency values paid or received at any future time in that project. These adjustments are necessary because the value of money is not constant; what a dollar can buy today is not the same as the past year and would not be the same as the next year [15]. There are two main reasons for the change in the value of money over time, the first one is the inflation as the buying power decreases over time; I need more than a dollar in the future to buy an item with a price of one dollar in the present [16]. The second reason is the earning potential of money relative to time by putting the money in a bank and advancing with its interest, or the potential earning of any alternatives that can make profits with the same money [17]. The main factors affecting the calculation process of the life cycle cost are according to the following:

### 2.2.1 Lifespan

The lifespan is a term referring to the period of time the building or its elements and components satisfies acceptable performance, and it can differ according to many variables [4]. There are different methods for determining the service life; ISO 15868-1 [13] and 15868-2 [18] deals with the lifespan of buildings and building's elements, they provide an approach named "Factors Method" to determine the potential lifespan of buildings and building's elements depending on the available material and technology data [19].

### 2.2.2 Study Period

The study period is the period of time evaluated by the life cycle analysis process [9, 13], Even if the length of the study is not the real lifespan of the project, but it reflects as it is usually shorter than the lifetime. The study period consists of two main phases the construction phase and the service phase [14]. The construction phase is the period of time needed from the start of the feasibility studies of the project passing through the design and construction and ending with the starting of the operation of this project. In

contrast, the service period or the operation period starts at the end of the construction phase and ends with the end of the study or the lifetime [14].

The study period selection depends on many circumstances, such as the lifespan of the alternatives, the owner's priorities, and the market requirements [14, 20]. The owner or the project's team leader can determine it; in most cases, it can range between fifteen and twenty-five years [20], more extended periods may be concerned, especially for large scale projects. In this study, the study period will be limited (standardized) to thirty years based on the construction project's larger life span, so that the output of different alternatives can be compared.

### 2.2.3 Inflation Rate

The inflation rate is an economic term; Craig A. Langston defines it as the rate in the increase of prices of goods and services due to the change in time [16]. The main reason for inflation is the increase in population with the same resources, in order to balance the forces of supply and demand, the prices have to be raised. The inflation is divided into two types, the general inflation, which is the behavior of general prices to rise over time, and the specific inflation (escalation) that is related to certain goods or services [7].

The value money today is not equivalent to the money in the future, and it cannot be compared or added to it unless it is adjusted to calculate this value of today's money in the future. The inflation rate is the change in the rate of the value of money over time. The decrease of the purchasing power of money over time is the inflation, in order to evaluate alternatives of any project; the inflation should be included in the analysis to get accurate results and chose the optimum solution [17, 13].

Since the costs and profits over the life cycle of any project are affected by the inflation rate, it is essential to calculate it; there are two terms used describing the inflation rate, the general inflation and (average)specific inflation, the average inflation rate can be calculated by the following formula [13, 7]:

$$f = \left[ \frac{cost_n}{cost_0} \right]^{\frac{1}{n}} - 1 \quad (1)$$

Where  $f$  is the inflation rate (escalation rate),  $cost_n$  is the cost at a time,  $cost_0$  are the costs at a different time, while  $n$  is the periods between the two costs (usually years). There are two types of economic analysis in order to estimate the effects of inflation. The actual dollar analysis system. Where the cash flows, value is adjusted in order to calculate the present value of future cash flows by

applying the general inflation rate in addition to calculating and applying the interest rates too. The other type is the constant dollar analysis, which assumes that the purchasing power is independent of time in addition to calculating and applying the interest rates too [7].

Fig. 2 shows the historical inflation rate in Egypt in the past sixty years; we can conclude from the trendline that the expected inflation rate for a thirty-year study period is around 15%.

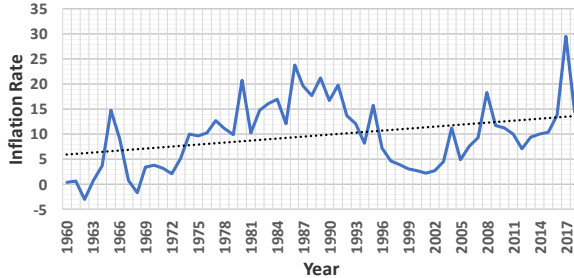


Fig. 2: Historic Inflation Rate in Egypt [21].

#### 2.2.4 Discount Rates

The discount rate is the interest rate that can reflect the time value of money for the investor [13, 17]. For example, if the investor has two choices of receiving an amount of money in the present or receiving a higher amount of money in the future, the discount is the adjustment made in order to choose which option is more profitable [14]. There are two types of discount rates; the first type is the real discount rate, which does not calculate the inflation rate within it. In comparison, the second type, which is more accurate, is the nominal discount rates [14]. The nominal discount rate includes in its calculations the inflation rate. The first type is more straightforward in calculations as it excludes the complexity of calculating the inflation rates.

In the construction industry, for more accuracy, we can assume that the discount rate is the interest rate while putting in mind the inflation rate of each good or service in any future expectations of costs.

#### 2.2.5 Interest Rates

The interest is the cost of casting money aside for a period. Therefore, it can be the extra money paid to the bank in order to take a loan or the amount of money that resulted from the profit of investing an amount of money in a bank [17]. The interest rate is usually said to be an annual rate unless a different period is mentioned; as an example, if the interest rate of a bank is 7%, then the annual percentage rate of the increase of money is 7%.

There is a brief daily life example to understand the concept of interest better if a customer wants to buy a car,

the bank gives him a loan that is equivalent to the car price  $P$ . The customer pays back the money to the bank in the form of premiums that is equivalent to the loan in addition to the interest (bank's profit) at the end of the period agreed. The most common interest type for measuring the discount rates in projects is the compound interest as the project total life span is always more than just one year, the compound interest is the interest earned on another interest. So if the interest of money left in a bank was 7% annually, and the money stayed at the bank for two years then the interest would be 7% of the money for the first year and for the second year, it will be 7% of the summation of money and interest at the end of the first year, and it can be measure according to the following formula [7]:

$$A_n = P(1 + i)^n \quad (2)$$

Where:

- $A_n$ : is total or compound amount at the end of the nth interest period (e.g., a year).
- $P$ : is the principal amount (i.e., borrowed).
- $n$ : is the total number of interest periods (e.g., years).
- $i$ : is the interest rate per specified period.

Fig. 3 shows the historic deposit interest rate in Egypt in the past forty years; we can conclude from the trendline that the expected interest rate for a thirty-year study period is around 8.5%.

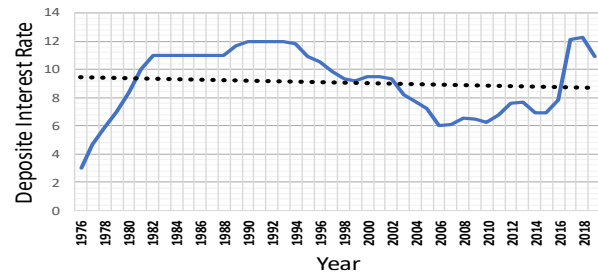


Fig. 3: Historic Deposit Interest Rate in Egypt [22].

#### 2.2.6 Present Worth (Value)

In order to add the initial costs to future costs, we must determine and adjust the value of these future costs within the present time. Tim Mearig defines the present value as it is the time value of any present, past, or future at a certain point (present time) [14]. To adjust the value of money in the present time, we use the discount rate and the time in which the costs are being paid or earned in addition to the amount of money with the same concept of the compound interest shown before [18, 13, 7]. No adjustments are made to the initial costs since they are at the present time already to the present value will be

equivalent to the present cost, which is given.

For calculating the total life cycle costs of a building, Alphonse Dell Isola proposed the present worth method that depends on converting all the future and the initial costs into their present worth by adjusting it using the discount rate. After making the adjustments, all the project costs are being added to compare the alternatives selecting the life cycle cost optimum alternative [23].

### 3 Martial and Methods

The main idea of the proposed life cycle cost measuring tool is to follow systemized procedures in order to calculate the present value of all expected future expenses of the residential project different elements (Bill of Quantity Item), Fig. 4 summarizes the procedures as the following:

- Determining the Project Items: the cost estimator should determine and classify the project items into its category in order to analyze the different costs for each category.
- Determining the Market Value of Different Costs for each Item: In this stage, the cost estimator should determine the contemporary market cost for the different activities such as construction, maintenance, replacement, consumption and disposal, that should be done at any stage of the project's life cycle to each of the items.
- Determining the Timing of Each Expense: At this stage, the cost estimator will determine the timing by wish each type of expense for each item will have to be paid during the project's study duration. The costs determined in this stage will not be the real costs that need to be paid in the future but contemporary market values of it.

• Estimating the Future Worth of Each Expense: After determining the timing of each activity in the, and today's market value of each activity in the previous stage, we can estimate the real future cash flow worth by determining the expected inflation rates for each item and calculating the future worth using the inflation equations, we can create a time plan showing the different cash flow items.

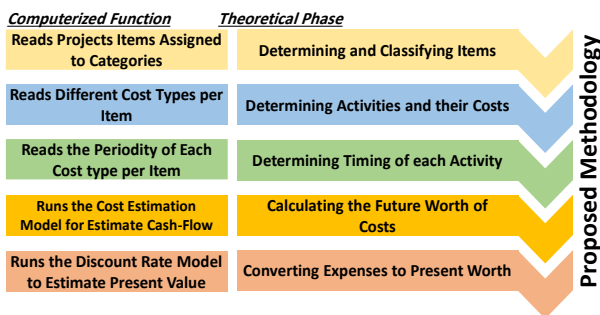


Fig. 4: Proposed Life Cycle Cost Measuring Procedure.

• Estimating the Present Worth of Each Item: By calculating the discount value of time using the compound interest equations, at this stage, we can calculate the present worth as it is the time value of any present, past, or future at a certain point (present time).

The tool depends on the present worth method to calculate the total expected life cycle cost of the project; the present worth method depends on converting all the future and the initial costs into their present worth by adjusting it using the discount rate. After making the adjustments, all the project costs are being added to compare the alternatives selecting the life cycle cost optimum alternative [23].

Fig. 5 shows the main procedures of the present worth technique, as the procedures depend on two main steps, the cost estimation step, and the present value modification step as the following:

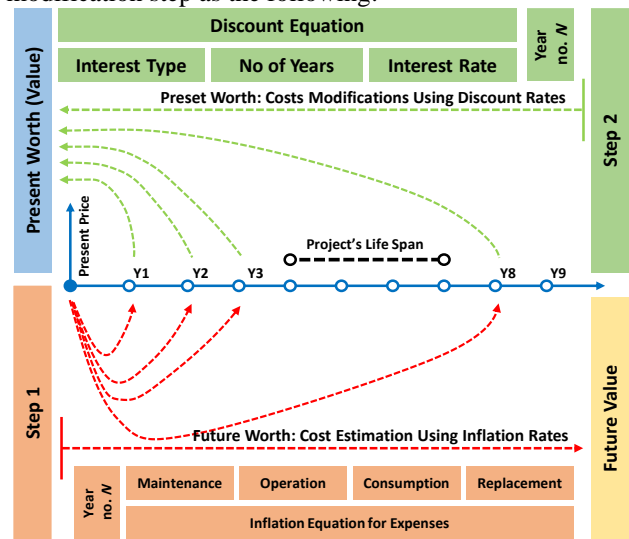


Fig. 5: Present Worth Method Technique.

• Cost Estimation Step: Calculating the future worth of each expense after determining the year of applying each activity in the, and today's market value of each activity in the previous stage, we can calculate the real future cash flow worth by determining the expected inflation rates for each item and calculating the future worth using the inflation equations.

• Present Worth Modification Step: Which is the step of adjusting the future values estimated in the previous step by calculating the discount value of time using the compound interest equations in order to calculate the present worth as it is the time value of any present, past, or future at a certain point (present time).

The main idea of the research is to convert these two steps into a systematic computerized process that can be converted into a software that can help designers and contractors in Egypt to apply the LCCA. Process.

### 3.1 Determining Project's Items

In this stage the cost estimator should determine and classify the project items into its category as presented before, in order to analyze the different costs for each category, the leading residential project's items were classified into six main categories as the following:

- **Structural Works Items:** Which are the items related to the main structural activities in the construction process, such as concrete works, excavation works, and brickworks.
- **Architectural Works Items:** Which are the items related to the main Architectural and Finishing activities in the construction process, such as painting works, furnishing works, and doors installations.
- **Plumbing Works Items:** Which are the items related to the main plumbing activities in the construction process, such as water supply piping systems.
- **Mechanical Works Items:** Which are the items related to the main Mechanical activities in the construction process, such as elevators and air conditioning works.
- **Electrical Works Items:** Which are the items related to the main Mechanical activities in the construction process, such as elevators and air conditioning works.
- **Site Works Items:** Which are the items related to site works.
- **Consumption Items:** Which are the items related to future consumption in the building, such as electricity consumption or water consumption.

Table 2: Example of Determining Project's Items.

Item (ii)	Discipline	Description	Quantity (Qk)
Plaster	Architectural Works	Supply and paint for interiors according to manufacturer instructions and recommended system from Jotun/Scib ; Work include all materials and accessories required to complete according to drawings and specification. Type, color and samples shall be submitted by the contractor and approved by the engineer	100 M2
I1	D1	.....	Q1
I2	D2	.....	Q2
I3	D3	.....	Q3
I4	D4	.....	Q4
.	.	.....	.
.	.	.....	.
ii	Di	.....	Qk

Table 2 shows an example for a table representing the output data expected from the phase of determining the project items, including the items, the quantities of each item, the discipline of the item, and the description of each item. Where:

- $I_i$ : is the title of the item  $i$ .
- $D_i$ : is the discipline of the item  $i$ .
- $Q_i$ : is the quantity of the item no  $i$ .

### 3.2 Determining Market Cost Value for Different Items

In this stage, the cost estimator should determine the contemporary market cost for the different activities such

as construction, maintenance, replacement, disposal, and consumption that should be done at any stage of the project's life cycle to each of the items.

Table 3 shows an example of a table representing the output data expected from the phase of determining the market value of different costs for each item. The primary output data in this phase is as the following:

- **Maintenance Outputs:** Two main outputs related to the maintenance of each item should be provided as the following:
  - **Maintenance Interval:** This is the interval time by which the item should be maintained, the regular annual maintenance is excluded from this variable.
  - **Maintenance Cost:** This is the cost required for maintaining the item.
- **Annual Operation Costs:** Which are the costs that should regularly be paid each year to keep the building working, including consumption and annual maintenance costs.
- **Replacement Outputs:** Two main outputs related to the replacement of each item should be provided as the following:
  - **Life Span:** Which is the life span of each item by which at its end it should be replaced.
  - **Replacement Costs:** Which are the costs that should be paid at the end of the life span of the item to replace it with a newer one.
- **Salvage (Disposal) Cost:** Which is the worth of the item all its components at the end of the study period determined by the cost analysis.

Table 3: Example of Determining Market Values of Costs Table.

ID	Item (ii)	Maintenance		Annual Operation	Replacement		Salvage
		Cost	Interval	Cost	Cost	Life Span	
1	Ceramic Tiles	20	Every 2 Years	5	130	10 Years	20
2	Land Acquisition	0	0	120,000	0	0	-5,000,000
3	I3						
4	I4						
5	I5						
.	.						
i	ii						

### 3.3 Determining Payment Time for Expenses

At this stage, the cost estimator will determine the timing by which each type of expense for each item will have to be paid during the project's study duration. The costs determined in this stage will not be the real costs that need to be paid in the future but the contemporary market values of it.

Table 4 shows an example for a table representing the output data expected from the phase of Determining the

Timing of Each of the Expenses for each item.  
 where:

- $I_i$ : is the title of the item  $i$ .
- $C_i$ : is the initial unit cost for the item  $i$ .
- $Q_i$ : is the quantity of the item no  $i$ .
- $C_{i,N}$ : is summation of today's market value of all the expected unit costs of the expenses needed by the item  $i$  in the year  $N$ , such as operational and maintenance expenses that were calculated in the previous phase, Where the year  $N$  is the  $n^{\text{th}}$  year after operating the project.
- $S_i$ : is today's market unit cost value of the salvage (disposal) value of the item  $i$  at the end of the study, where it can be in a negative value if the item is going to worth money and can be sold, and a positive value if the item cannot be sold and needs effort for disposal.

The initial cost of the item can be calculated according to using the initial unit cost and the quantity of the item according to the following formula:

$$\text{Initial Cost of item } i = Q_i \times C_i \quad (3)$$

Where:

- $C_i$ : is the initial unit cost for the item  $i$ .
- $Q_i$ : is the quantity of the item no  $i$ .

Table 4: Example for Expenses Timing Determination Table.

ID	Item (I)	Discipline	Description	Quantity (Qi)	Unit Cost (Ci)	Initial Cost (Qi x Ci)	Year						Year N	Year N+1	Year N+2	Last Year	Salvage (Si)
							Year 1	Year 2	Year 3	Year 4	Year 5	Year 6					
1	I1	D1	Q1	C1	Q1 x C1	C1.1	C1.2	C1.3	C1.4	C1.5	C1.6	C1.7	C1.N	.	.	.	S1
2	I2	D2	Q2	C2	Q2 x C2	C2.1	C2.2	C2.3	C2.4	C2.5	C2.6	C2.7	C2.N	.	.	.	S2
3	I3	D3	Q3	C3	Q3 x C3	C3.1	C3.2	C3.3	C3.4	C3.5	C3.6	C3.7	C3.N	.	.	.	S3
4	I4	D4	Q4	C4	Q4 x C4	C4.1	C4.2	C4.3	C4.4	C4.5	C4.6	C4.7	C4.N	.	.	.	S4
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
i	Ii	Di	Qi	Ci	Qi x Ci	Ci.1	Ci.2	Ci.3	Ci.4	Ci.5	Ci.6	Ci.7	Ci.N	.	.	.	Si

### 3.4 Calculating the Future Worth of Expenses

After determining the year of applying each activity in the, and today's market value of each activity in the previous stage, we can calculate the real future cash flow worth by determining the expected inflation rates for each item and calculating the future worth using the inflation equations; we can create a time plan showing the different cash flow items for the project.

Table 5 shows an example for a table representing the output data expected from the phase of calculating the future worth of each expense; we can calculate the future worth of each unit expense according to the inflation equation as the following:

$$F_{i,N} = C_{i,N} \times (1 + f_i)^N \quad (4)$$

Where:

- $F_{i,N}$ : is the future unit worth of expenses of the item  $i$  at the year  $N$ .
- $C_{i,N}$ : is summation of today's market value of all the expected unit costs of the expenses needed by the item  $i$  in the year  $N$ , such as operational and maintenance expenses that were calculated in the previous phase, Where the year  $N$  is the  $n^{\text{th}}$  year after operating the project.
- $f_i$ : is the expected inflation rate for the item  $i$ .

And with the same procedure, we can calculate the expected salvage according to the following equation

$$FS_i = S_i \times (1 + f_i)^{\text{Study Period}} \quad (5)$$

Where:

- $FS_i$ : is the future worth of the salvage of the item  $i$ .
- $S_i$ : is today's market unit cost value of the salvage.

Table 5: Future Worth of Each Expense Calculation Table.

ID	Item (I)	Future Worth (Cash Flow)										Year N	Year N+1	Year N+2	Future worth of Salvage (FSi)	
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10					
1	I1	F1.1	F1.2	F1.3	F1.4	F1.5	F1.6	F1.7	F1.8	F1.9	F1.10	F1.N	.	.	.	FS1
2	I2	F2.1	F2.2	F2.3	F2.4	F2.5	F2.6	F2.7	F2.8	F2.9	F2.10	F2.N	.	.	.	FS2
3	I3	F3.1	F3.2	F3.3	F3.4	F3.5	F3.6	F3.7	F3.8	F3.9	F3.10	F3.N	.	.	.	FS3
4	I4	F4.1	F4.2	F4.3	F4.4	F4.5	F4.6	F4.7	F4.8	F4.9	F4.10	F4.N	.	.	.	FS4
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i	Ii	Fi.1	Fi.2	Fi.3	Fi.4	Fi.5	Fi.6	Fi.7	Fi.8	Fi.9	Fi.10	Fi.N	.	.	.	FSi

### 3.4 Calculating the Present Worth

By calculating the discount value of time using the compound interest equations, at this stage, we can calculate the present worth as it is the time value of any present, past, or future at a certain point (present time) by converting the future values obtained in the previous stage into present values.

In order to add the initial costs to future costs, we must determine and adjust the value of these future costs within the present time

Table 6 shows an example for a table representing the output data expected from the phase of calculating the Present Worth of Each Item; we can calculate the present worth of each unit expense according to the discount compound interest equation as the following:

$$P_{i,N} = \frac{F_{i,N}}{(1 + D_i)^N} = \frac{C_{i,N} \times (1 + f_i)^N}{(1 + D_i)^N} \quad (6)$$

In order to add the initial costs to future costs, we must determine and adjust the value of these future costs within the present time

Table 6: Example for Present Worth of Calculation Table.

ID	Item (ii)	Present Worth										Future worth of Salvage (PSi)
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year N	
1	I1	P1.1	P1.2	P1.3	P1.4	P1.5	P1.6	P1.7	P1.8	P1.9	P1.N	PS1
2	I2	P2.1	P2.2	P2.3	P2.4	P2.5	P2.6	P2.7	P2.8	P2.9	P2.N	PS2
3	I3	P3.1	P3.2	P3.3	P3.4	P3.5	P3.6	P3.7	P3.8	P3.9	P3.N	PS3
4	I4	P4.1	P4.2	P4.3	P4.4	P4.5	P4.6	P4.7	P4.8	P4.9	P4.N	PS4
i	Ii	Pi.1	Pi.2	Pi.3	Pi.4	Pi.5	Pi.6	Pi.7	Pi.8	Pi.9	Pi.N	PSi

Where:

- $P_{i,N}$ : is the present unit worth of the expenses of the item  $i$  at the year  $N$ .
- $F_{i,N}$ : is the future unit worth of the item  $i$  at the year  $N$ .
- $D_i$ : is the expected discount rate for the item  $i$ .
- $C_{i,N}$ : is the summation of today's market value of all the expected unit costs of the expenses needed by the item  $i$  in the year  $N$ , such as operational and maintenance expenses that were calculated in the previous phase, Where the year  $N$  is the nth year after operating the project.
- $f_i$ : is the expected inflation rate for the item  $i$ , the reason for taking in place more than the inflation rate, is that some items that depend on salaries, may not have the same inflation rate as the items that depend on materials.

The study will be limited to the first thirty years of the age of the residential project. Therefore, the study period will be replaced in the equations by number 30 in order to control the study variables.

The summation of the unit present values of each item multiplied by its quantity will be equal to the present value of all future costs for a study period of thirty years as the following:

$$PV \text{ of } FV = Q_i \times \sum_{i=1}^{N=30} \frac{C_{i,N} \times (1+f_i)^N}{(1+D_i)^N} \quad (7)$$

The summation of the unit present values of each item's salvage value by its quantity will be equal to the present value of all future Salvages for a study period of thirty years as the following:

$$\begin{aligned} \text{Present Value of Salvage} &= Q_i \times PS_i \\ &= Q_i \times \frac{FS_i}{(1+D_i)^{30}} = Q_i \times \frac{S_i \times (1+f_i)^{30}}{(1+D_i)^{30}} \quad (8) \end{aligned}$$

After calculating the present worth of each for each item, we can calculate the total life cycle cost of the project as the following:

$$LCC = \text{Initial Costs} + PV \text{ of Future Costs} + \text{Salvage PV} \quad (9)$$

So that it can be calculated according to the following formula:

$$LCC = Q_i \times \left( C_1 + \left( \sum_{i=1}^N \sum_{N=1}^{N=30} \frac{C_{i,N} \times (1+f_i)^N}{(1+D_i)^N} \right) + \frac{S_i \times (1+f_i)^{30}}{(1+D_i)^{30}} \right) \quad (10)$$

Where:

- $LCC$ : is the total present value of all the life cycle costs of the studied project.
- $Q_i$ : is the quantity of the item no  $i$ .
- $C_i$ : is the initial unit cost for the item  $i$ .
- $C_{i,N}$ : is the summation of today's market value of all the expected unit costs of the expenses needed by the item  $i$  in the year  $N$ , such as operational and maintenance expenses that were calculated in the previous phase, Where the year  $N$  is the nth year after operating the project.
- $f_i$ : is the expected inflation rate for the item  $i$ .
- $D_i$ : is the expected discount rate for the item  $i$ .
- $S_i$ : is today's market unit cost value of the salvage (disposal) value.

#### 4 Con-LCCA Tool Construction

The main purpose of this part is to convert the proposed methodology into a systematic computerized process that (a software) that can help designers and contractors in Egypt to apply the LCCA. Process

The main idea of the ResiLCCA 1.0 tool is to computerize the proposed life cycle cost evaluation model for measuring the life cycle cost of the project's design alternative. The proposed computerized tool uses a script written code integrated with a macro-enabled Microsoft Excel sheet using Visual Basic for Applications (VBA) for excel.

##### 4.1 Workflow

The proposed tool simulates the manual procedure of applying the proposed tool in a computerized form the main workflow consists of three successive subfunctions or steps as the following:

###### 4.1.1 Subfunction "F1"

As seen in Fig. 6 the first subfunction in the tool reads the different inputs required for the calculation process and makes the following functions:



• Assigning Operational Costs: The function assigns estimated operational costs for all the years of the project's

calculate the total present worth of the life cycle cost of the analyzed design alternative.

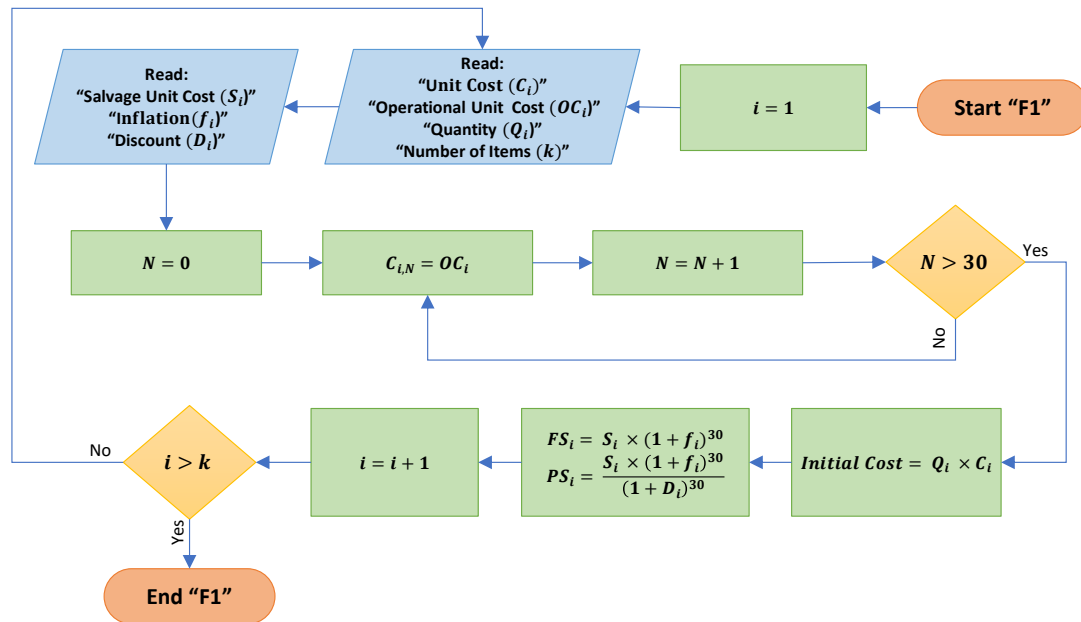


Fig. 6: Subfunction "F1" Workflow

life span.

• Calculates the Initial Costs: The function calculates the initial costs of each item by multiplying the quantity of the item by its unit cost.

• Calculating the Different Salvage Values: The function calculates the expected future worth of the salvage for each item using the inflation equation and calculates the present worth of the salvage using the discount equation.

4.1.2 Subfunction "F2"

As seen in **Error! Reference source not found.** the first subfunction in the tool reads the different inputs required for the calculation process and makes the following functions:

- Assigning Replacement Costs to different years according to the life span of each item.
- Assigning Replacement Costs to different years according to the life span of each item.

4.1.3 Subfunction "F3"

As we can see in Fig. 9 that the third subfunction in the tool reads the different inputs required for the calculation process and makes the following functions:

- Calculate the Present Worth of future Costs: The Function uses a loop to sum the present worth of all
- Calculate the Total Life Cycle Cost: The function sums up the present worth of the future costs, the present worth of the salvage value, and the initial cost in order to

• Calculate the Required Cash-Flow for Different Years: The Functions sum up the required cash flow of each item in every year of the study period of the project to create a cash flow table.

4.2 Interface

The tool's interface consists of nine main parts, as seen in Fig. 8, each part performs a function as the following:

- General Information Part: Which contains input boxes related to the project's primary information, such as the project name and area.
- Items Information Part: in order to add an item to the tool, the user should add the general information about the item such as the item's name, description, quantity, unit, unit price.
- Future Costs Part: in order to add an item to the tool, the user should add the information related to future costs in this input part, such as the item's life span, salvage value, maintenance cost.
- Actions Part: This part allows the user to take several actions such as adding, deleting, and editing items, in addition to creating different types of reports and exiting the tool.
- Screen Part: It shows information about the added items.

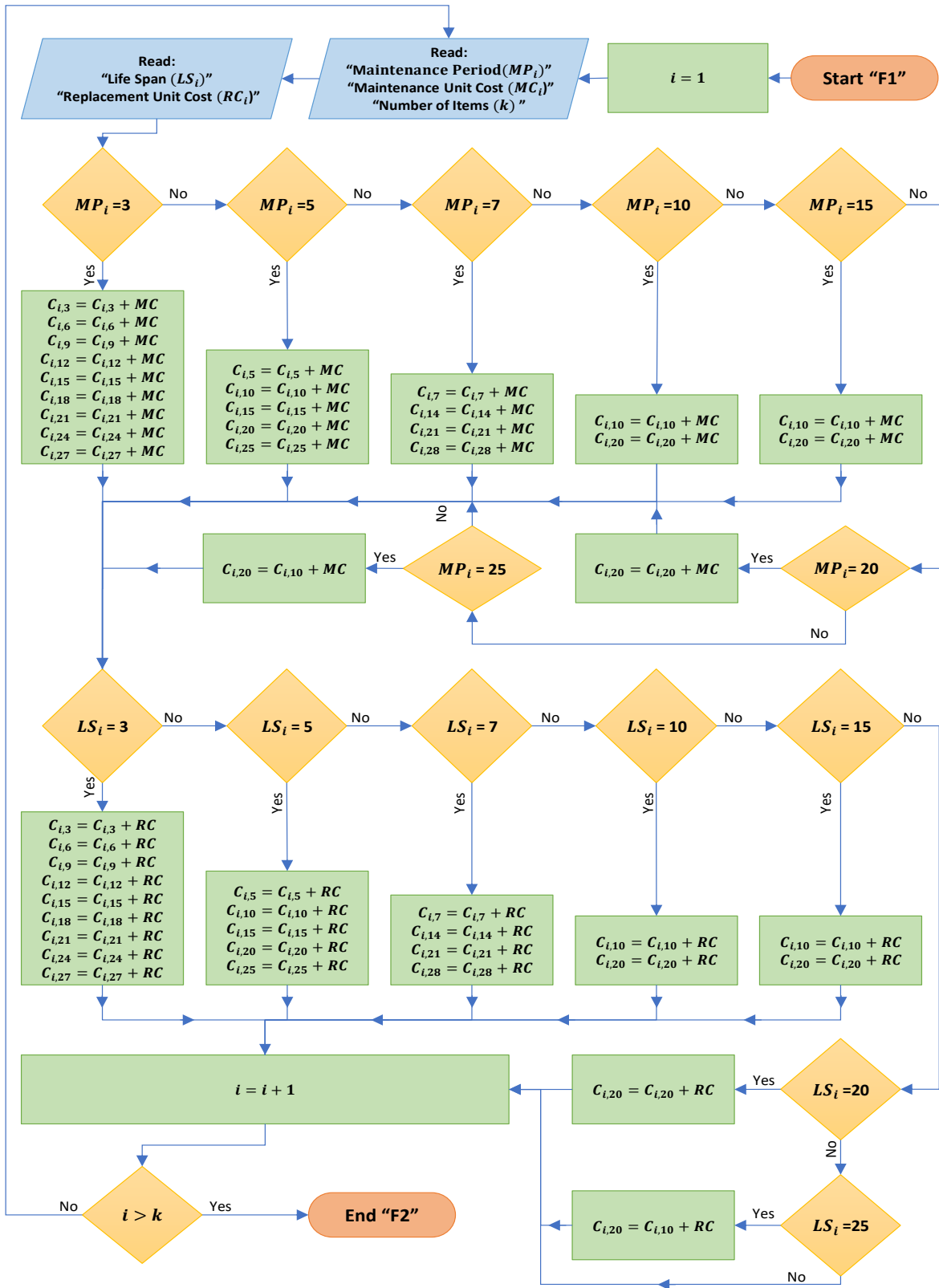


Fig. 7: Subfunction "F2" Workflow

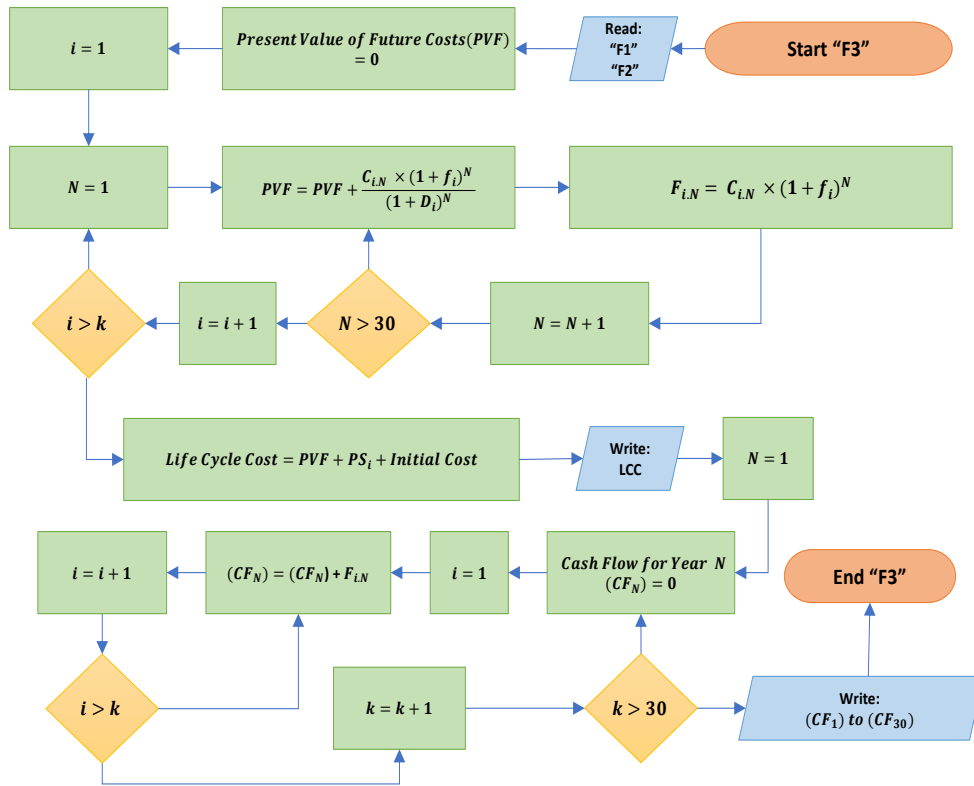


Fig. 9: Subfunction "F3" Workflow

### Items Information Part

Item Name:  Description:

Quantity:  Unit:

Unit Price:  Inflation:  Discount:

Life Span:  Discipline:  Type:

Maintenance Period:  Maintenance Cost:  Salvage:

Annual Operating:  Replacement Cost:

### Project Information Part

Project Title:

Location:

Area:

Alternative No:

### Future Costs Part

### Items Screen

ID	Item	Discipline	Type	Description	QTY	Unit	Unit Pr
2	Electric Consumpt	Consumption	Commissioning	Annual Electric Co	24000	kWH	0
3	ACOUSTICAL PAN	Architectural Work	Supply and install	Supply and install	248	M2	336
4	ALUMINUM CLADE	Architectural Work	Supply and install	Supply and install	0	M2	1337.
5	ALUMINUM CLADE	Architectural Work	Supply and install	Supply and install	0	M2	1337.
6	BACK PAINTED GL	Architectural Work	Supply and install	Supply and install	7	M2	1287.
7	GIPSUM BOARD #	Architectural Work	Supply and install	Supply and install	298	M2	171.6
8	INTERIOR PAINTS	Architectural Work	Supply and install	Supply and paint f	365	M2	-42.9
9	PANTRY CABINET	Architectural Work	Supply and install	Supply and install	4.5	M2	2788.
10	Plaster for interna	Architectural Work	Supply and install	Supply and apply i	581	Each	71.5
11	POLYMER MODIFI	Architectural Work	Supply and install	Supply and apply i	15	M2	100.1
12	PORCELAIN & CEF	Architectural Work	Supply and install	Supply and install	336	M2	343.3
13	RECEPTION COUN	Architectural Work	Supply and install	Supply and install	1	L.M	9867
14	Single hinged tem	Architectural Work	Supply and install	Supply and fix gla	3	Each	6999.6
15	Wooden Door size	Architectural Work	Supply and install	Supply and fix wo	4	Each	5362.1
16	Wooden Door size	Architectural Work	Supply and install	Supply and fix wo	3	Each	6077.1
17	DEMOLISHING WC	Structural Works	Supply and install	Demolish and dum	10	M2	71.5
18	UNIT MASONRY F	Structural Works	Supply and install	Supply and install	108	M2	107.3

### Actions Part

Fig. 8: Cons-LCCA Tool Interface

When choosing to edit a previously added item, a pop-up screen is activated, as seen in Fig. 8 that allows the user to change the inputs of the item and confirm editing.

### Items Editing Screen

Fig. 10: Cons-LCCA Items Editing Screen

To ensure calculations validity, a pop-up error message appears for any missing or wrong input data notifying the user with the nature of the problem seen in Fig. 11.

### Pop-Up Error Message

Fig. 11: Pop-Up Error Message Screen.

### 4.3 Tool's Output

The tool creates two main outputs, the first one is a detailed bill of quantity report, and the other output, which is the main objective of the tool is a detailed life cycle cost analysis report. The tool sends the items data to a bill of quantity excel sheet so that the user can integrate user the file separately as a bill of quantities file to save time. Fig. 12 shows a sample bill of quantity reports produced by the tool. Microsoft Excel software was chosen because most of the construction firms use it for constructing their quotations and bill of quantities sheets.

ConsLCCA Life Cycle Costing Tool		Journal Information					
Project: Administrative Building							
ID	Item	Discipline	Description	Quantity	Unit	Unit Price	Total Price
3	ACOUSTICAL PANEL CEILING	Architectural Works	Supply and install Mineral fiber suspended ceiling tiles, type: Ultima size 600x600 mm from Armstrong, with 12.5 mm thick, white color, work include suspended system 6mm silhouette profile from Armstrong, all accessories and any material or activity required to finish the work. For Offices & Meeting Rooms	248	M2	\$ 336.00	\$83,328.00
5	ALUMINUM CLADDING For Main Facade ( White Color )	Architectural Works	Supply and install aluminum cladding ( alcopanel ) for facade 4 mm thick , price include aluminum sub framing ,Metal angles, stickers and all needed accessories to complete the work (RATE ONLY)	0	M2	1337.1	\$0.00
6	BACK PAINTED GLASS	Architectural Works	Supply and install Back Painted Glass Behind Reception Counter	7	M2	1287.0	\$9,009.00
7	GYPSUM BOARD ASSEMBLIES	Architectural Works	Supply and install gypsum board suspended ceilings (Knauf or equivalent), 12.5 mm thick, work include suspended system, all decorative shapes, light houses, all required upstand panels as per detail drawings, all accessories and any material or activity required to finish the work. Shop drawings and samples shall be submitted by the contractor and approved by the engineer.	298	M2	171.6	\$51,136.80
8	INTERIOR PAINTING	Architectural Works	Supply and paint for interiors according to manufacturer instructions and recommended system from Jotun/Scib ; Work include all materials and accessories required to complete according to drawings and specification. Type, color and samples shall be submitted by the contractor and approved by the engineer.	365	M2	42.9	\$15,658.50
9	PANTRY CABINET	Architectural Works	Supply and install pantry cabinet Height 1.5 m, corian counter top measured separately.	4.5	M2	\$ 2,788.50	\$12,548.25
10	Plaster for internal walls	Architectural Works	Supply and apply cement plaster, with fine finish over cement splashing coat includes angles beads, wire mesh on all joints, patching works to complete according to drawings.	581	Each	71.5	\$41,541.50
11	POLYMER MODIFIED CEMENT WATERPROOFING	Architectural Works	Supply and apply cement waterproofing with MASTERSEAL 599 from BASF, the rate will include surface preparation, all materials, mixing and application in accordance with manufacturer's instructions.	15	M2	100.1	\$1,501.50
12	PORCELAIN & CERAMIC FLOORING	Architectural Works	Supply and install gray Porcelain Floor tiles 60x60 cm . 20 mm thick, automatic cut with zero joint.	336	M2	343.3	\$115,348.80
13	RECEPTION COUNTER	Architectural Works	Supply and install Reception Counter including drawer unit Dim. (2.20 m x Depth 0.70 m x Height 1.10 m )	1	LM	9867	\$9,867.00
14	Single hinged tempered clear glass door 10 mm thick, size 800x2200 mm.	Architectural Works	Supply and fix glass doors shown on door schedule, rate includes polyurethane sealants and all work according to drawings and specification. Colors and samples shall be submitted by the contractor and approved by the engineer.	3	Each	6999.9	\$20,999.70
15	Wooden Door size 700x2200 mm,Alum Single hinged door for Toilets	Architectural Works	Supply and fix wood doors and frames as shown on door schedule,rate includes paint, sealants, accessories from rashdan or hanemik and all work according to drawings and specification. Colors and samples shall be submitted by the contractor and approved by the engineer.	4	Each	\$ 5,362.50	\$21,450.00

Fig. 12: Sample Output Bill of Quantities Page.

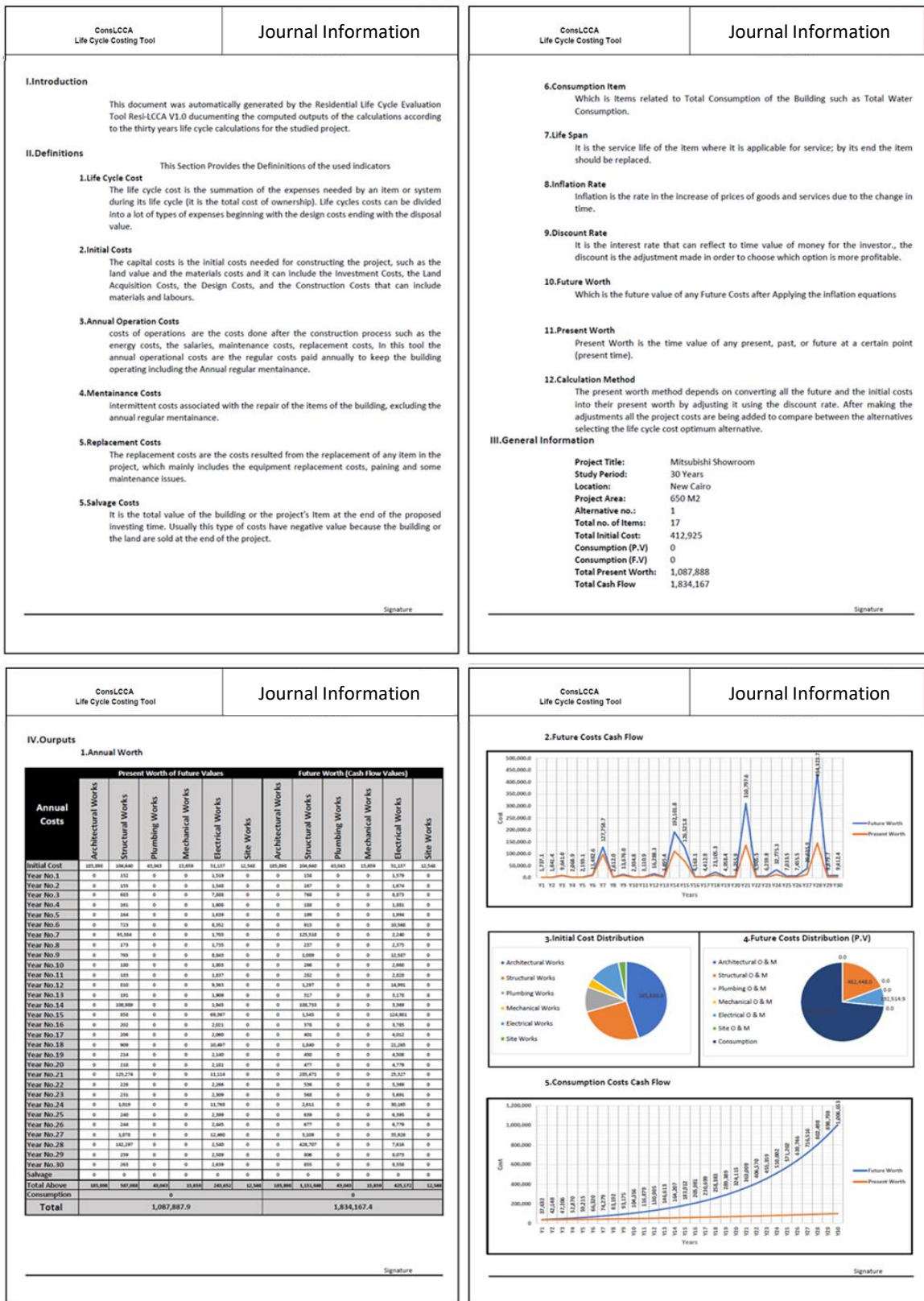
The LCCA analysis output report as seen in **Error! Reference source not found.** consists of five main parts, the introduction part, the main definitions part, the general information part, the output part, and the signature part as the following:

Introduction Part: Which provides an introduction about the nature of the report.

• Definitions Part: Which presents the main definitions related to the output of the research, the definitions are related to two main fields, the types of costs and the calculation factors affecting life cycle costs.

○ General Information Part: Which summarize the general information inputs and Outputs of the project as the following:

- Project Title
- Study Period
- Location
- Alternative Number
- Total Number of Items
- Different Costs quantities: Such as the initial costs, life cycle costs, total project's life cycle cash flow, and consumption costs.



- **Output Part:** Which presents a summary of the calculation process, it consists of five main parts:
  - **Annual Worth Tables:** Which shows the future and the present worth for every discipline in each year in the study period of the project.
  - **Future Worth Chart:** This shows a chart representing the project's annual cash flow distribution along its thirty years study period; it also shows the present value of the future expected cash flow.
  - **Initial Costs Distribution Charts:** Which is a chart analyzing the share of each of the six main disciplines of the project (architectural works, structural works, plumbing works, electrical working, mechanical works, and site work) in the project's initial costs.
  - **Future Costs Distribution Charts:** Which is a chart analyzing the share of each of the six main disciplines of the project (architectural works, structural works, plumbing works, electrical working, mechanical works, site work, and consumption) in the project's expected future costs.
  - **Consumption Cash Flow Chart:** Which shows a chart representing the consumption annual cash flow distribution along its thirty years study period, the consumption includes all types of consumption along the building's life span such as electricity consumption, water consumption, and natural gas consumption, it also shows the present value of the future expected consumption cash flow.
  - **Signature Part:** This allows the user to sign the printed-out document for further processes.

## 5 Case Study

The proposed LCCA tool has been experimented by using it to calculate the life cycle costs of the head department of the Egyptian administrative control authority building in the Sixth of October city in Egypt. The project land area is 10,000 square meters; it consists, as seen in Fig. 14 of three floors, including the ground floor in addition to a basement floor and some storage and service rooms on the roof.



Fig. 14: The Selected Case Study Project.

The building was constructed in 2015; it has a reinforced concrete structure, granite, and stone exterior cladding finishes, the interior finishes use the conventional materials used in most of the Egyptian administrative buildings such as marble, granite, ceramic tiles, wood flooring, ordinary paints, and wallpapers. No green or sustainable characteristics were found in the building.

### 5.1 Inputs

Ninety-two different items had been inserted with their unit costs and quantities in the Con-LCCA tool, including the land price, the electric consumption, the different discipline items such as the structural, architectural, plumbing, mechanical, and electrical items. The interest rate was set to 8.5%, and the inflation rate was set to 15%, as discussed earlier in the study.

#### 5.1.1 Limitations

The future costs variable was only inserted into the architectural finishing items, the consumption, and the land acquisition costs.

#### 5.1.2 Annual Consumption Calculations

Table 7 shows the electric Consumption calculation for the different building equipment for each space.

Table 7: Expected Annual Electricity Consumption.

Area / System	Equipment	QTY	Consumption (Watt)	Consumption Rate	Working Hours Daily	Working Days / Year	Total Annual Consumption (kWh)
<b>Offices</b>	Desktop Computer	240	250	1	8.5	231	<b>117810</b>
	Phone Charger	240	7.5	1	3	231	<b>1247</b>
	Additional socket	240	100	1	2	231	<b>11088</b>
<b>Library</b>	Desktop Computer	5	250	1	8.5	231	<b>2454</b>
	Phone Charger	240	7.5	1	3	231	<b>1247</b>
<b>Restaurant</b>	Laptop	5	70	1	4	231	<b>323</b>
	Additional Socket	5	100	1	4	231	<b>462</b>
	Refrigerator	3	1200	0.6	24	365	<b>18922</b>
<b>Kitchen</b>	Oven	2	3000	1	3	231	<b>4158</b>
	Microwave	3	1500	1	1	231	<b>1040</b>
	Cooker	2	3000	1	3	231	<b>4158</b>
	Additional Socket	3	100	1	2	231	<b>139</b>
	Dishwasher	2	1200	1	5	231	<b>2772</b>
	Desktop computer	16	250	1	8.5	231	<b>7854</b>
<b>Copy Center</b>	Printer	16	250	1	2	231	<b>1848</b>
	Scanner	8	250	1	2	231	<b>924</b>
	Additional Socket	8	100	1	2	231	<b>370</b>
<b>Reference desks</b>	Desktop computer	3	250	1	8.5	231	<b>1473</b>
	Additional Socket	3	100	1	2	231	<b>139</b>
<b>Meeting rooms</b>	Laptop	6	70	1	4	231	<b>388</b>
	Data Show	2	300	1	3	231	<b>416</b>
	Additional socket	15	100	1	2	231	<b>693</b>
<b>Bathrooms</b>	Dryer	35	1500	1	0.5	231	<b>6064</b>
	Additional socket	35	100	1	2	231	<b>1617</b>
<b>Reception</b>	Additional socket	15	100	1	2	231	<b>693</b>
<b>V.I.P. halls</b>	Additional socket	10	100	1	2	231	<b>462</b>
<b>Services</b>	Additional socket	30	100	1	2	365	<b>2190</b>

Others	LCDs	10	300	1	6	231	<b>4158</b>
Lighting System	2 Fluorescent Lighting Unit	1227	30	1	12	231	<b>102037</b>
	60*60 Fluorescent Lighting Unit	766	60	1	12	231	<b>127401</b>
	Outdoor Lighting Unit	82	300	1	12	231	<b>68191</b>
	Spotlight Unit	1314	60	1	12	231	<b>218544</b>
	Entrance Up-light Spots Unit	37	60	1	12	231	<b>6154</b>
	Roof Up-light Spots Unit	54	60	1	12	231	<b>8981</b>
	Indirect Lighting Units	637	60	1	12	231	<b>105946</b>
Light Current Systems	CCTV	1	1800	1	24	365	<b>15768</b>
	Data Network	1	400	1	24	365	<b>3504</b>
	Fire Alarm Network	1	1400	1	24	365	<b>12264</b>
Air Conditioning Systems	Split Units	16	1200	0.6	24	365	<b>100915</b>
	Fan Coil Units	251	100	1	12	231	<b>69577</b>
	Chilled water System	1	-	-	-	-	<b>132000</b>
	Centralized System	1	-	-	-	-	<b>240000</b>
E.W.H	Water Heater	25	4500	0.15	24	231	<b>93555</b>
Elevators	Elevator 1 (1.4*1.5)	7	450	1	4	231	<b>2911</b>
	Elevator 2 (1.4*3.00)	1	900	1	4	231	<b>832</b>
<b>Total</b>							<b>1503688 kWh / Year</b>
<b>Total + 15%</b>							<b>1729242 kWh / Year</b>

The inflation rate of electric and consumption set to 10% instead of 15% for the other items because the Egyptian government announced in 2015 a long-term plan for the electric consumption rates. The same procedure was conducted to the water consumption of as seen in Table 8.

Table 8: Expected Annual Water Usage.

Expected Daily No. of Users in the Building				
	<b>Males</b>			<b>360</b>
	<b>Females</b>			<b>240</b>
Equipment	Usage	Quantity	Users	Daily Usage (Liters)
Wash Basin	8.3 Liter/Min	2.5 Mins	600	12450
Males Toilets	7.6 Liter/Flush	1 Flush	360	2736
Urinals	5.7 Liter/Flush	2 Flushes	360	4104
Females Toilets	7.6 Liter/Flush	3 Flush	240	5472
Kitchens	8.3 Liter/Min	120 Min	3	2988
Irrigation	25 Liter/M2	598 M2	-	14950
<b>Total Daily Usage</b>				<b>42700 Liters</b>
<b>Total Annual Usage</b>				<b>10436 Cubic Meters</b>
<b>Total Annual + 15%</b>				<b>12005 Cubic Meters</b>

A percentage of 15% was added to the expected water and electricity consumption to cover any unpredicted usage.

### 5.2 Outputs

The construction cost of the architectural items was 38% of the total construction cost of the project, which was EGP 61,290,733, Fig. 15 shows the distribution of the initial costs of the project as extracted from the Cons-LCCA tool.

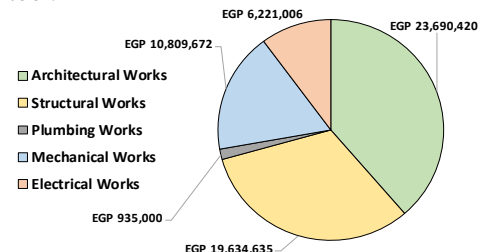


Fig. 15: Distribution of Initial Costs

The tool has shown the importance of considering analyzing the life cycle costs of projects like the present value of the future costs for the architectural finishing items for the case study project were found to be nearly three times the value of the initial construction costs.

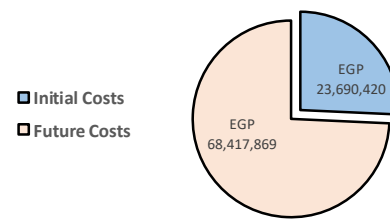


Fig. 16: Present Value of Architectural Costs.

Fig. 17 shows the effect of the end of the lifespan of some items on the future expenses as we can see that the annual expenses rise in a periodic shape every five years due to the end of life of some items and major periodic maintenance, while in the twentieth year it rises because of the replacement of different elements. We can see the effect of inflation on the difference between the present values and future cash flow values.

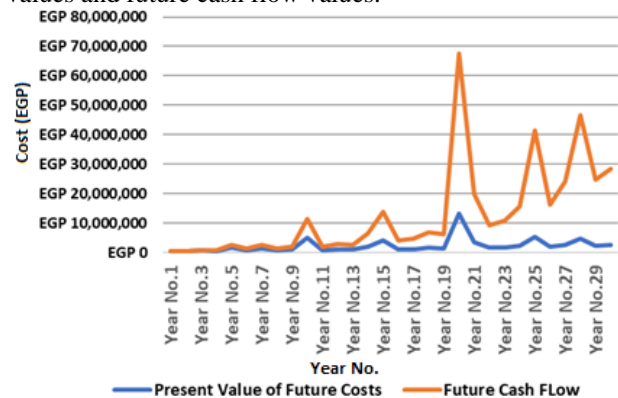


Fig. 17: Future and Present Values of Annual Architectural Expenses.

The total expected present value of the consumption in the thirty years study period is EGP 68,763,780 which is larger than the construction costs of the whole project; this takes us to the importance of saving water and energy. Fig. 18 sows the annual expected consumption expenses according to the output report of the Cons-LCCA tool.

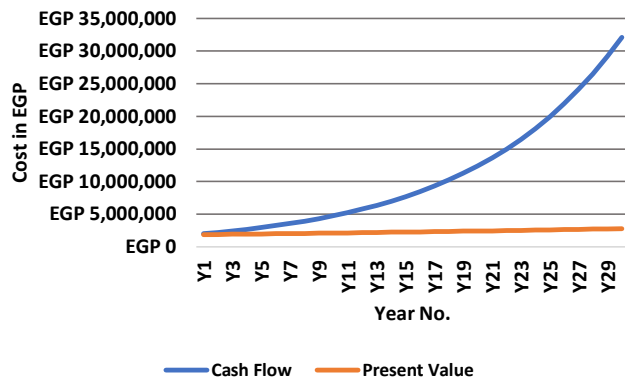


Fig. 18: Annual Present Values vs. Annual Future Cash Flow of Consumption costs.

## 7 Discussion

The study aimed to create an open-source Microsoft Excel tool that is compatible with the bill of quantity creating models in the Egyptian market, the created tool can benefit the stakeholders of the construction industry as seen in Fig. 20.

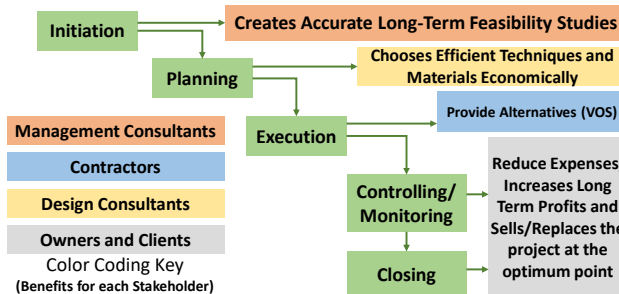


Fig. 20: Tools Benefits for Different Stakeholder.

The main Limitation of the Tool was that the suggested study period is 30-years according to the average life cycle cost analysis study period for construction projects.

The suggested tool has been validated by applying it on a case-study project and by analyzing the outcomes some main points were found:

- Architectural and Structural items Costs sum up to 75% of the total construction project's costs.
- Initial Costs is illusionary as it is less than 30% of the total life cycle costs.

- Annual Maintenance and replacement costs raised in certain years on a periodic basis due to the replacement of major items.

## 6 Conclusion

Life cycle cost analysis technique is an effective tool for evaluating long period expenses considering changes in price due to inflation; the technique has been explained in a theoretical way in many literature resources; however, its practical application is still limited due to some difficulties such as the complicity of the calculation process and the high cost of the software and the hardware for quantifying the project's items automatically.

The study explained the theoretical background of the life cycle cost analysis highlighting the different types of future costs and expenses in addition to the main factors affecting the life cycle cost calculation process.

The study has created an easy-to-use computerized tool that links the bill of quantities of projects to its life cycle cost indicators and creates a full detailed life cycle cost analysis report based on systematic procedures constructed depending on the available literature review.

The constructed tool was experimented by applying it on a case study project, and the results have highlighted the importance of the life cycle costing as an evaluation technique for choosing the best design alternative due to the importance considering the future costs as well as the construction costs

The case study project has shown that it is imperative to consider the green and sustainable building concept for minimizing the energy and water consumption as the consumption costs of construction projects through its lifespan can be higher than its initial construction costs, same as choosing durable and recyclable materials as the future costs of maintenance and replacement of the architectural components as an example through-out the building's life span can be triple the construction costs of those components.

## References

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