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LIFE CYCLE COST ANALYSIS OF LIGHT STEEL FRAMED BUILDINGS WITH CEMENT-BASED WALLS AND FLOORS

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Abstract: Cold-Formed Steel (CFS) framing systems have emerged as an efficient alternative to traditional building construction systems in low and mid-rise residential and office buildings. The current literature on life cycle cost analysis focus on traditional construction systems using timber, reinforced concrete or hot-rolled steel. However, the literature fails to address the potential environmental benefits of off-site construction, particularly the reduced environmental impact and the savings in embodied energy resulting from waste reduction and the improved efficiency of material usage. In addition, comparisons between different systems are done on basis of construction cost mainly. A Life cycle costs analysis emerges as a better indicator of the value for money and prolonged effects, taking into consideration the construction cost, the usage cost over the service life of the building, and the end of life costs. This research performs life cycle cost analysis of CFS buildings with cement-based boards sheathed walls and thin reinforced concrete slabs floors. The analysis identifies the cost proportion of each stage and compares life cycle cost of different building material and construction systems alternatives. Life cycle cost is evaluated including the costs of construction, operations, maintenance and disposal, less any residual value. The research compares between different system alternatives, namely; CFS framing, reinforced concrete framing, and hot rolled steel framing. The analysis is applied to a real-life building where the calculations are projected and compared for the three systems under study. The calculations proved CFS to be a highly competitive option with optimized construction and recycle/reuse cost.

1 INTRODUCTION

The decisions taken proactively during the design stage largely impacts the life cycle impacts of the building from environmental and cost perspectives. Due to the complexity and ambiguity of early decisions, decision-makers tend to defer critical decisions to later when details about the building are more identifiable. Alternatively, the construction industry, especially in Egypt, tend to be sedentary; relying on well-established construction decisions regarding structural systems with not much area for renewal. Cold-formed steel Framing Systems (CFS) have been introduced to the construction industry as a cost and time effective alternative to traditional construction method such as hot-rolled steel or reinforced concrete skeletons. CFS has proven to be more cost and time effective during construction, in addition to being a cleaner alternative. The criteria upon which CFS is being compared to traditional methods only consider initial costs or construction cost. Life Cycle Cost Analysis (LCCA) has proven to be a better measure for the sustainability of different buildings. This paper uses LCCA for early stage decision-making to assist in system selection for low and mid-rise residential and office buildings.

2 BACKGROUND

In recent years societies have begun to re-evaluate their built environment with the objective of achieving higher performance. In 2015, the international community adopted a set of 17 goals as a part of a new global agenda for sustainable development, (United Nation 2015). Among these goals are: Goal 11: Building sustainable communities and Goal 12: Achieving sustainable consumption and production. In order to achieve these goals; the building construction industry must fully consider the importance of balancing the three pillars of sustainability: economic, environmental, and social constraints when considering material selection, building structural systems, and long-term function of the building. It is necessary to explore the latest construction technologies and create innovative building systems that have the potential to bring high-performance affordable buildings within reach of new markets, particularly in developing regions. Beyond being affordable, these systems should be flexible enough to suit local climate, site conditions, cultural and living habits, and spatial standards. Innovative construction solutions also should reduce or eliminate errors due to the lack of skilled personnel on the site, and ideally should be assembled with simple tools and be erectable with minimum machinery. CFS emerges as an innovative and cost-efficient solution, adhering to most of the criteria specified for new sustainable buildings. The most common traditional construction systems used with low and mid-rise residential and office buildings are Reinforced Concrete (RC) skeletons or Structural Steel (SS) framing. In both cases; floors are made of cast-in-situ reinforced concrete slab and walls are made of cement bricks. Wood framing is offered as an option in some countries where the price is competitive. Cold-Formed Steel (CFS) framing systems have proven to be a worthy alternative to traditional systems. Potential advantages of such light steel framing systems include the high degree of dimensional exactness of the members, high strength-to-weight ratio of the members, high recycled content, and ease of construction. These qualities have led cold-formed steel studs and tracks to be an efficient alternative to traditional construction systems. Assessing building design alternatives that satisfy the sustainability constraints in a project with a focus on optimizing the economic performance is best done using Life Cycle Cost Analysis (LCCA). LCCA is defined as a “technique which enables comparative cost assessment to be made over a specified period of time, taking into account all relevant economic factors, both in terms of initial cost and future operational cost", (ISO 2017). LCCA considers all costs associated with life cycle building stages: Initial costs, operational costs, replacement costs, and, end of life cost including any residual value (disposal, resale, and salvage value). LCCA is especially useful when the available construction alternatives fulfill the same performance requirements but differ with respect to costs associated with different stages of the building life. In which case, a life cycle analysis of the two systems will reveal the preferable method with the least life cycle cost and the maximum net profit. LCCA should best be applied early in the design stage to allow decision makers to obtain a deeper understanding of long-term design strategies and to optimize product efficiency and lifetime cost of ownership. LCC is carried out for one of two primary reasons: (i) to predict a cash flow needed to construct a budget, or (ii) to carry out an option appraisal to help the decision maker decide which option is preferable in cost terms. LCC option appraisal calculations may be done either: (i) to assess options at various points through the development of the project to ensure that the selected option represents the best value for money. Options may vary from strategic estate options to single component options, or(ii) to inform a tender appraisal exercise where tenders submitted include information on costs post-completion of construction. LCC estimates are typically performed during design development or post-occupation to determine whether an alternative specification or scope of work is worthwhile. It can take place at the component level, system level, element level, cluster level, single asset (system) level, or, multiple asset level. The framework developed in this study is applied at the whole building level (system level) to assess different construction system alternatives with respect to their life cycle cost.

3 METHODOLOGY

The methodology used in this research is based on the four-phase structure of LCCA given in (ISO 2006a) and (ISO 2006b). The assessment includes: (i) goals and scope definition, (ii) Life Cycle Inventory (LCI), (iii) Life Cycle Assessment (LCA), and (iv) interpretation. More specifically, (ISO 2017) and (RICS 2016) cover the main principles, processes, calculations and definitions for life cycle costing.
The core process of LCCA comprise the following steps, (Langdon 2007):

1. Define the *objective* of the proposed LCCA

2. Identify the *key parameters*, analysis requirements
3. Identify design alternatives to be evaluated.
4. Assembly of cost and performance data
5. Carry out analysis
6. Interpret and report results

3.1 Objective

The objective of the study is to calculate and compare between the projected life cycle cost of alternative building construction systems used in Egypt to assist in the decision-making process. Ideally, this analysis should be carried out during the early stages of scheme design when decisions on the primary construction system are made. At this stage it is unlikely that any detailed design work will have been undertaken beyond initial feasibility studies. Therefore, the analysis will be carried out using benchmark data and broad assessment of future costs.

3.2 Key Parameters

The key parameters included in the analysis are the basic cost components. The total cost of the building during its service life from cradle to grave is the sum of the individual costs of the following components:

i. *Construction costs:* include the material, labor, equipment cost and contractor's profit.
ii. *Usage costs:* include *Operation costs* incurred in running the building in addition to the *Maintenance costs* incurred in ensuring the continued specified functional performance of the building is maintained.
iii. *End of life costs:* include demolition, waste collection and transportation to landfills, in addition to end of life incomes resulting from the residual values of the building items that can be reused or recycled.

It is highly unlikely that the operation and maintenance costs will be much affected by the type of building construction system.

3.2.1 Cost components

The system boundary for the analysis follows the guidelines stated in (EN 15978 2011).As shown in Figure 1, the life cycle of a building does not necessarily stop at stage C (end-of-life). The building itself or the materials can be re-used or recycled. The goal of the information in module D is to describe potential benefits and impacts related to future recycling or reuse.

Whole life cost (WLC)																	
Life cycle cost (LCC)																	**Supplementary information**
Material Production			**Construction**		**Use stage**							**End-of-life**					**Benefits beyond the system boundary**
A1	A2	A3	A4	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**		**D**
Raw Materials supply	Transport	Manufacturing	Transport	**Construction**	**Use stage**	**Maintenance**	**Repair**	**Replacement**	**Refurbishment**	**Operational energy use**	**Opertional water use**	**Deconstruction/Demolition**	**Transport**	**Waste processing**	**Disposal**		**Reuse/Recycling**

Figure 1: Building life cycle stages and cost components (adapted from (EN 15978 2011))

3.2.1.1 Usage costs

The operational costs incurred in the use stage comprise the costs of energy for space and water heating, lighting, cooking and domestic appliances as well as the costs for water and waste water treatment in addition to maintenance costs.

a) Energy cost

The cost of energy includes the cost of electricity and natural gas needed for household uses such as lighting, appliances and air conditioning (heating/cooling). In the design stage this cost can be calculated using average consumption rates for each building type based on historical data and survey of similar buildings. The following average electricity consumption rates can be used at the early design stage:

- Residential buildings: 100 kWh/m^2/year
- Office buildings: 160 kWh/m^2/year
- Commercial buildings: 350 kWh/m^2/year

More exact values can be estimated at the detailed design stage using available energy simulation software, e.g., DesignBuilder (DesignBuilder software). The cost of electricity can then be calculated using the current electricity price in Egypt as shown in Table 1 (CAPMAS 2018). Similarly, the cost of natural gas needed for household uses can be calculated based on an average natural gas consumption of 4 m^3/m^2/year and applying the current natural gas prices in Egypt shown in Table 1.

Table 1: Current Energy Prices in Egypt

Electricity				Natural Gas	
Residential		Commercial		Residential & Commercial	
Consumption (kWh)	Price (US $/kwh)	Consumption (kWh)	Price (US $/kwh)	Consumption (m^3)	Price (US $/m^3)
0 - 200	0.020	0 - 100	0.031	0 - 30	0.097
201 - 350	0.0389	101 - 250	0.055	30 - 60	0.139
351 - 650	0.050	251 - 600	0.064	> 60	0.167
651 - 1000	0.075	601 - 1000	0.081		
➢ 1000	0.081	➢ 1000	0.083		

b) Water and waste water cost

The average water consumption in Egypt is 0.25 m^3/person/day. Assuming an occupation density of 20 m^2/person, the average water consumption per square meter each year is calculated as 4.563 m^3/m^2/year. The cost of water consumption can then be calculated using the current prices of water and waste water treatment in Egypt as shown in Table 2.

Table 2 : Current Prices of water and waste water treatment in Egypt

Residential		Commercial	
Consumption (m^3)	Price (US $/m^3)	Consumption (m^3)	Price (US $/m^3)
0 - 10	0.036	all	0.200
11 - 20	0.089		
21 - 30	0.125		
30 - 40	0.153		
0 > 40	0.175		
Add 75 % for Waste water treatment		Add 98 % for Waste water treatment	

c) Maintenance cost

Maintenance costs during the service life of the building include cost of labor, materials, energy and transportation associated with the replacement of windows, doors and floor covering. In this study, the maintenance cost was assumed equal to 2 % of the initial construction costs based on studies performed by (Arja 2009 and Kehily 2011).

3.2.1.2 Construction cost

Construction costs comprise the production and transport costs of the construction materials as well as labor and energy costs for the construction, in addition to the contractor's profits. These costs can be calculated from the used material quantities and the current construction costs. Building Information

Modeling (BIM) can be used to calculate the quantities required for each alternative as follows, Abu-Hamd (2016):

1- Develop the 3D model for each alternative.
2- The structural analysis/design tool linked to the BIM software is then used to perform the structural design considering the appropriate geometric, loading, material and design code requirements.
3- The material quantities needed are calculated using the BIM 5D tool link the BIM software tool used.
4- The quantities are used to calculate the initial construction cost of each alternative using the current construction costs of building components.

3.2.1.3 End of life cost

Different building components have different end of life scenarios according to their reuse/recycle potentials. These scenarios vary from complete demolition to reuse/resale of part or all the building. The end-of-life costs includes costs of demolition, waste collection and transport to landfills. In addition, some revenue exists from selling the construction waste for reuse and/or recycling for which the system should be credited. The economic aspects of sustainability require the development of waste management techniques for minimization of demolition costs and maximization of reuse or recycle costs. Concrete members and brick walls have the least re-use/recycle value while the potentials for reuse/recycle of steel members is very high. Based on the current practices obtained from survey of building construction companies,

Table 3 shows the proposed end of life scenarios for common building components. Accordingly, the end of life costs associated with these scenarios are shown in Table 4.

Table 3: End of life scenarios for building components

Building component	Demolition/ Dismantling	% Landfill	% Recycle	% Reuse
Brick Wall	Demolition	100%	0	0
Concrete members	Demolition	100%	0	0
Reinforcing steel	Dismantling	0	100%	0
Structural steel members	Dismantling	0	20%	80%
Cold formed steel members	Dismantling	0	20%	80%
Fibercement Boards	Dismantling	30%	0	70%

Table 4 : End of life costs of building components

Building component	UOM	Demolition/ Dismantling $/Unit	Landfill cost $/Unit	Recycle value Option A $/Unit	Reuse value Option B $/Unit
Brick Wall	m^2	1.65	0.4	0.00	0.00
Concrete members	m^3	25	2.20	0.00	0.00
Reinforcing steel	ton	56	0.00	277	0.00
Structural steel members	ton	275	0.00	333	1110
Cold formed steel members	ton	250	0.00	333	1110
Fibercement Boards	m^2	1.50	0.40	0.00	1.10

3.3 Design Alternative

This study covers construction systems used in residential and office buildings in Egypt with focus on low and mid-rise buildings. The most common traditional construction systems used with these buildings are:

1- *RC skeleton* for floor slabs, beams and columns combined with brick walls.
2- *Structural steel framing* for beams and columns combined with RC floor slabs and brick walls.
3- *Cold formed steel Framing* for walls and floors combined with light RC floor slabs and wall sheathing. The common types of wall sheathing are Oriented Stranded Boards (OSB), Gypsum Boards (GB) and Fibercement Boards (FCB).

3.4 Period of analysis

The period of analysis for life cycle costing is usually taken equal to the service life of the building. ISO 15686-5 recommends the estimated service life should not be less than the design life which should not exceed 100 years. Most of the LCCA available in the literature use a service life of 50 to 60 years. In this study the service life over which life cycle costing is analyzed is taken equal to 60 years.

3.5 Method of economic evaluation

To compare alternative options with differing costs and timing on a comparable basis, costs need to be brought to a common basis. This is the process of discounting future costs to the base date using the present value evaluation method. Future costs are discounted using Eq. (1) to present value using an appropriate discount rate which is usually taken equal the interest rate (i):

[1] $DPV = FC / (1 + i)^n$

Where DPC = discounted present value, FC = future cost spent at year (n) and i = interest rate. The variation of the annual interest rate in Egypt is shown in Figure 2 (CAPMAS 2018) for the period 2009 to 2018 with an average of 12.945 %.
Due to inflation; future costs exceed the present costs according to the Equation 2:

[2] $FC = PC*(1 + f)^n$

Where PC = present cost, FC = future cost spent at year (n) and f = inflation rate. The variation of the annual inflation rate in Egypt is shown in Figure 2 for the period 2007 to 2017 with an average of 10.113 % (CAPMAS 2018).

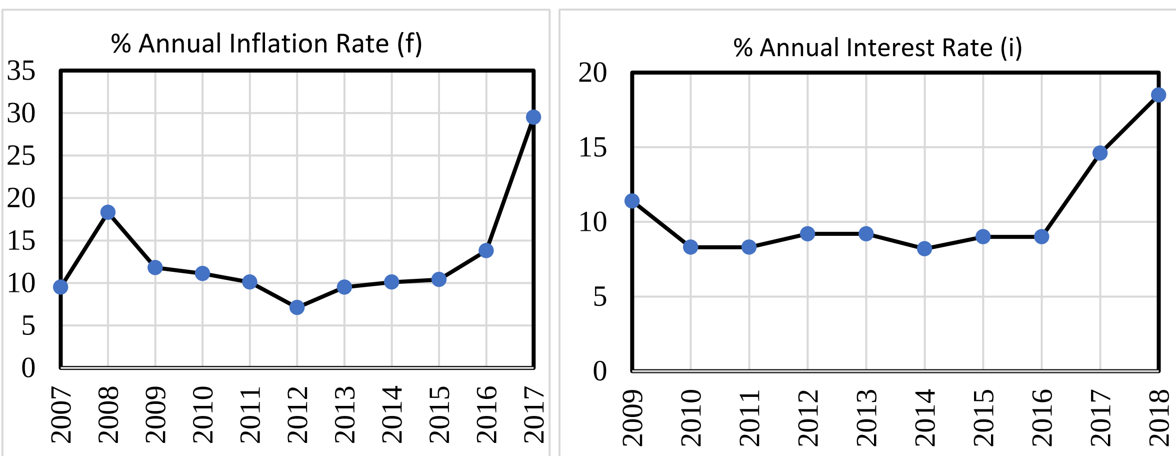


Figure 2 : Variation of Inflation rate and interest rate in Egypt (CAPMAS, 2018)

Accordingly, the discounted present value DPV of a single payment FC at the end of year y is calculated from Equation 3.

[3] $DPV_1 = PC * \{(1+f)^y/(1+i)^y\}$

Similarly, the discounted present value DPV_n of a yearly payment FC at the end of each year (y) of n years is shown in Equation (4):

[4] $DPV_n = PC * \sum_{y=1}^{n}\{(1+f)^y/(1+i)^y\}$

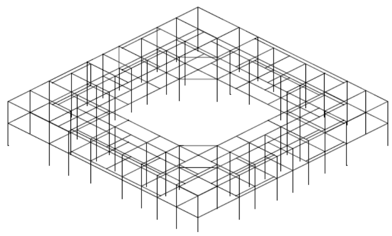
4 APPLICATION

4.1 Building description

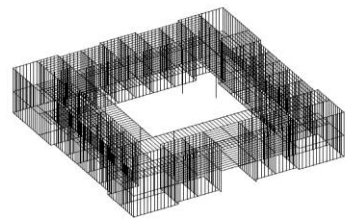
The LCCA methodology presented was applied to a university student center built at Cairo University in 2017. The outer dimensions of the building are 35860 mm*35860 mm in plan with an open court having dimensions of 20540 mm*20540 mm. The building has two floors with height 3.5 meters each. As stated in the design alternatives section, three construction systems shall be investigated:
1- *RC skeleton* for floor slabs, beams and columns combined with brick walls,
2- *Structural steel framing* for beams and columns combined with RC floor slabs and brick walls, and
3- *Cold formed steel Framing* for walls and floors combined with fiber-cement floor slabs and walls.

4.2 Construction costs

A 3D BIM model of the building was constructed based on the architectural design requirements. The structural model was then imported to the STAAD PRO® software to perform the structural analysis and design for the selected design alternatives as stated in section 3.2.1.2. The developed structural models are shown in Figure a for the RC and SS framing and in Figure b for the CFS framing.



(a) RC and SS Framing



(b) CFS Framing

Figure 4: Structural Models

The resulting material quantities were extracted for the model and used to calculate the initial cost of construction as shown in Table 5. Figure 5 shows the comparison of the construction costs among the three systems. The RC framing system and the CFS framing system have nearly the same initial construction cost and the SS framing system has the highest cost at 21 % higher than the two other systems.

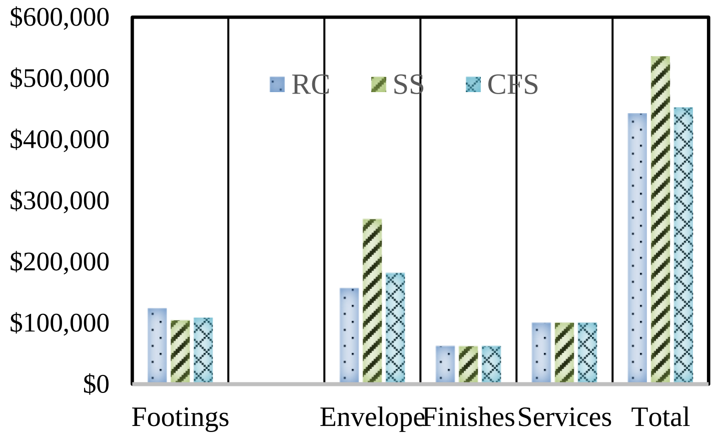


Figure 5: Comparison of Construction Costs

Table 5: Construction cost calculations

	ELEMENT	unit	Unit cost	RC Framing		SS Framing		CFS Framing	
				Quantity	cost	Quantity	Cost	Quantity	Cost
1	**SUBSTRUCTURE**		US$						
1.1.1	Excavation	m3	2.78	1350	3750.0	1350	3750.0	1350	3750.0
1.1.2	Plain Concrete Footings	m3	83.33	76.904	6408.7	48.328	4027.3	29.956	2496.3
1.1.3	RC footings	m3	250.00	217.02	54255.0	152.46	38115.0	159.1	39775.0
1.1.4	Insulation	m2	2.78	1000	2777.8	600	1666.7	2000	5555.6
1.1.5	Back filling	m3	6.67	1056	7040.0	1150	7666.7	1160	7733.3
1.1.6	RC Slab on grade	m2	55.56	885	49166.7	885	49166.7	885	49166.7
	Substructure			S	123398.1		104392.3		108476.9
2	**SUPERSTRUCTURE**								
2.1	RC floors	m3	277.78	230.1	63916.7	230.1	63916.7	0	0.0
2.2	RC beams and columns	m3	277.78	211.7	58805.6	0	0.0	0	0.0
2.3	Metal deck for floors	m^2	11.11	0	0.0	0	0.0	0	0.0
2.4	Structural steel framing	ton	1555.56	0	0.0	110.291	171563.8	0	0.0
2.5	CFS framing	ton	1666.67	0	0.0	0	0.0	54.352	90586.7
2.6	Brick walls + Mortar	m^2	16.67	2037	33950.0	2037	33950.0	0	0.0
2.7	40 mm FCB floor panels	m^2	19.44	0	0.0	0	0.0	1770	34416.7
2.8	10 mm FCB wall	m^2	13.89	0	0.0	0	0.0	4074	56583.3
	Superstructure			S	156672.2		269430.4		181586.7
3	**FINISHES**								
3.1	Wall Finishes	m^2	5.56	4074	22633.3	4074	22633.3	4074	22633.3
3.2	Floor Finishes	m^2	16.67	1770	29500.0	1770	29500.0	1770	29500.0
3.3	Ceiling Finishes	m^2	5.56	1770	9833.3	1770	9833.3	1770	9833.3
	Finishes				61966.7		61966.7		61966.7
4	**SERVICES**		0.00						
4.1	Plumping	SUM	22222.22	1	22222.2	1	22222.2	1	22222.2
4.2	Electrical Installations	SUM	77777.78	1	77777.8	1	77777.8	1	77777.8
	Services		100000.00		100000.0		100000.0		100000.0
	Total construction cost				442037.0		535789.4		452030.2

4.3 Usage cost

The usage cost for electricity and natural gas needed for household uses such as lighting, appliances and air conditioning (heating/cooling) are calculated based on the information compiled and presented in section 3.2.1.1 and is presented in Table 6.

Table 6 : Usage cost for the selected case study

	Kwh/m2/yr	Kwh/yr	Price/Kwh	$/year	60 years	i	f	PV
Electricity	350	619,500	$0.083	$51,419	$3,085,110			$1.526,465
	m^3/m^2/yr	m^3/yr						
Natural gas	60	7080	$0.17	$1204	$72,216	12.945	10.113	$35,612
	m^3/m^2/yr	m^3/year						
Water and waste water	9.03474	15,991.5	0.39	$6,333	$379,958			$192,578

4.4 Maintenance costs

Maintenance costs were calculated as 2% of the construction cost shown in Table 5 as: $8,841 for RC framing, $10,716 for SS framing, and, $9,041 for CFS framing.

4.5 End of life cost

The end of life cost is calculated for all the three systems with respect to the overall material quantity, demolition/dismantling cost, landfill (if required), recycle value (if applicable), and, reuse value whenever applicable. The calculations are presented in Table 7, Table 8 and, Table 9 for RC framing systems, SS framing systems, and, CFS framing systems respectively.

Table 7: End of life cost for RC Framing

Building Component	Unit	Quantity	Demolition/ Dismantling $/unit	Landfill cost $/unit	Recycle value $/unit	Reuse value $/unit
Brick Wall	m2	2,037	3,361	815	0.00	0.00
Concrete members	m3	913	22,818	2,008	0.00	0.00
Reinforcing steel	ton	84	4,680	0.00	23,152	0.00
Structural steel members	ton	0.00	0.00	0.00	0.00	0.00
Cold formed steel members	ton	0.00	0.00	0.00	0.00	0.00
Fibercement floor panels	m2	0.00	0.00	0.00	0.00	0.00
Fibercement wall panels	m2	0.00	0.00	0.00	0.00	0.00
			30,859.74	**2,822.79**	**23,152.21**	**0.00**

Table 8 End of life cost for SS Framing

Building Component	Unit	Quantity	Demolition/ Dismantling $/Unit	Landfill cost $/Unit	Recycle value $/Unit	Reuse value $/Unit
Brick Wall	m2	2,037	3,361	815	0.00	0.00
Concrete members	m3	608	15,197	1,337	0.00	0.00
Reinforcing steel	ton	56	3,134	0.00	15,500	0.00
Structural steel members	ton	110	30,330	0.00	36,727	122,423
Cold formed steel members	ton	0	0.00	0.00	0.00	0.00
Fibercement floor panels	m2	0	0.00	0.00	0.00	0.00
Fibercement wall panels	m2	0.00	0.00	0.00	0.00	0.00
			52,021.81	**2,152.15**	**52,226.72**	**122,423.01**

Table 9 : End of life cost for CFS Framing

Building Component	Unit	Quantity	Demolition/ Dismantling $/unit	Landfill cost $/unit	Recycle value $/unit	Reuse value $/unit
Brick Wall	m2	0.00	0.00	0.00	0.00	0.00
Concrete members	m3	366	9,151	805	0.00	0.00
Reinforcing steel	ton	34	1,882	0.00	9,310	0.00
Structural steel members	ton	0.00	0.00	0.00	0.00	0.00
Cold formed steel members	ton	54	13,588	0.00	18,099	60,331
Fibercement floor panels	m2	1,770	2,655	708	0.00	1,947
Fibercement wall panels	m2	4,074	6,111	1,630	0.00	4,481
			33,387	**3,142**	**27,409**	**66,759**

The SS framing has the highest dismantling cost as well as the highest recycle/reuse cost among the three systems. The reuse value for RC frame is none, and the only recyclable value in RC frames are the reinforcement bars within. The dismantling value for the CFS is close to the RC frames and approximately 35% less than the SS frames.

5 CONCLUSION

In this research, the LCCA methodology was applied to to calculate and compare between the projected life cycle cost of alternative building construction systems used in Egypt using benchmark data to assist in the structural system decision-making process. The main key parameters considered were the construction cost, usage cost and end of life cost. Detailed calculation for the key parameters is provided using data from the presented case study. The cost calculations extend beyond the building end of life to include supplementary information of capability to reuse/recycle. Different structural systems are studies; namely; RC skeleton, Structural steel framing for beams and columns combined with RC floor slabs and brick walls, and, Cold formed steel Framing for walls and floors. The analysis period is taken to be 60 years in compliance with the available literature and recommendations. The following conclusions can be stated:

1. RC framing and CFS framing have nearly equal construction costs while the construction cost of SS framing system is 21.2 % more.
2. End of life (EOL) revenues are highest for the SS framing system, followed by the CFS system, and lastly, the RC system.
3. The total life cycle cost is nearly the same for RC framing system and CFS framing system, while the life cycle cost of SS framing system is 5.2 % more.
4. When the system is credited for the revenue resulting from early rent and recycling/reuse of some building components after disposal, the total whole life cycle cost of the CFS framing becomes the least with the SS framing costing 9.3 % more and the RC framing costing 19.4 % more.

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