Decision Support Model with Life Cycle Assessment for Building in Design Phase

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Abstract -

The building materials and structural form chosen in design phase not only affect the costs for construction, but also decide the costs for maintenance. However, the large amounts of maintenance costs are not easy to estimate. This article proposes a decision support model adopting life cycle assessment to assist the project owner and architect engineering for selecting an appropriate building structure type and materials is used in design phase via assessment the building's total costs and CO_2 emissions in the periods of build, maintenance, and disposal. The test results of cases show the model is feasible to help owners to decide a properly structural form.

Keywords -

Life Cycle Assessment; Building Information Modelling; Decision Support System

1 Introduction

The costs of a building in design phase mostly are evaluated as only one factor - construction cost. However, the building materials and structural form chosen in design phase not only affect the costs for construction, but also decide the costs for maintenances. Under the trend of buildings management, the researchers pay much attention to life cycle assessment (LCA) of buildings. LCA is a process of evaluating the economic performance of a building over its entire life. [1, 2]

From plan, design, construction, operation, maintenance, demolish, we think about the total costs in different stage. Based upon those considerations, we can step by step achieve the goals - energy saving, litter of building reduce, and environment sustainability. And this study proposes a decision support model adopting life cycle cost assessment concept to assist the project owner and architecture for selecting an appropriate building structure types and materials used in design phase.

2 Literature Review

2.1 Life cycle assessment

Life cycle assessment (LCA) is a technique for assessing various aspects associated with development of a product and its potential impact throughout a product's life from raw material acquisition, processing, manufacturing, use and finally its disposal. [3] It is used to assess systematically the impact of each material and process.

The LCA process has three major phases: production phase, use phase, and the end of life phase. Each of them includes production, transportation, and distribution. The first studies on environmental impacts date from the 1960s and 1970s, focusing on the evaluation or comparison of consumer goods, with only a small contribution to the use phase [4].

In the beginning of the 1980s, the concept of life cycle adopt to study in the construction sector with focusing on the use of (renewable) resources [5]. The LCA concept is extensive applied by researchers in different aspect of construction sector in recent years, such as structure [6], energy consumption and environmental impacts [7, 8, 9, 10], building materials and components [11, 12].

2.2 Building information modelling (BIM)

BIM is currently the most common denomination for a new way of approaching the design, construction and maintenance of buildings. BIM is a digital representation of physical and functional characteristics of a facility [13]. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. Use of BIM goes beyond the planning and design phase of the project, extending throughout the building life cycle, supporting processes including cost management, construction management, project management and facility operation.

The most benefits of applying BIM in design phase are cost reduction and control and time saving by improving productivity, better coordination and reduced error, and rework [14, 15].

3 Decision Support Model with LCA

This study proposes a model which was composed with modules in different phase of building lifecycle. The decision support model is shown in Figure 1.

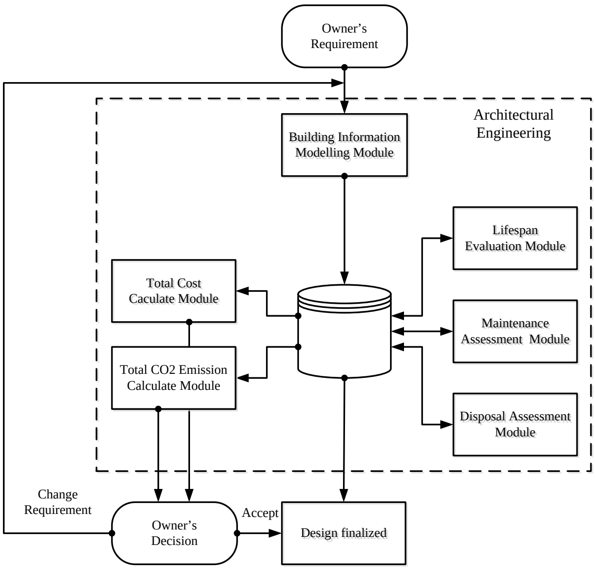

Figure 1. Main structure of decision support model

3.1 Life cycle cost

In this study, the building's life cycle cost in study year y can be defined as below:

$$LCC = C_C \times (1+i)^{y} + \sum_{t=0}^{T}\left[C_M \times (1+e)^{(y_m)} \times (1+i)^{(y-y_m)} \right] \tag{1}$$

while:

C_C -construction cost in year 0.
C_M -maintenance cost in year 0.
y_m -years of performing maintenance incur after construction accomplish.
e -inflation rate.
i -interest rate.
$\sum$ -denotes the summation of all the cost of maintenance.
T -numbers of maintenance incur.

And in the end of lifespan, the building's life cycle cost can be defined as below:

$$LCC = C_C \times (1+i)^{y_e} + \sum_{t=0}^{T}\left[C_M \times (1+e)^{(y_m)} \times (1+i)^{(ye-y_m)} \right] + (C_D - R)\times(1+e)^{(y_e)} \tag{2}$$

while:

C_D -disposal cost in year 0.
R -residual value in year 0.
ye -years of lifespan.

3.2 CO_2 emission

The greenhouse gases (GHGs) produced by humans' daily activities and emission to atmosphere is the main cause of global climatic change. The primary GHGs in the Earth's atmosphere are CO_2, O_3, CH_4, N_2O, CFCs, PFCs, HFCs, HCFCs and SF_6.

In the studies of GHGs emissions of construction activities show that the emissions of CO_2 hold a major part of GHGs [11]. In this study, the CO_2 in buildings life cycle is the topics for discussion. Therefore, the CO_2 emissions in buildings life cycle is one criterion of the alternative decision in this study.

4 Case Study

This study takes 60 years as a building lifespan, and calculates the life cycle cost and estimates the CO_2 emissions in different study year. Life cycle cost is considered under the interest rate 0.017 and the inflation rate 0.0083.

4.1 Structure type

Due to different construction materials of reinforced concrete structure and steel structure, the structural properties, and the lifespan of buildings are different [16]. This study chooses the above-mentioned two types structure building for LCA calculation. For simplicity, the easy form is taken into account only including beam and column.

The building's BIM model shown in Figure 2 is drawn by Autodesk Revit. The dimensions and quantity of two type structure's element of buildings are export by the software and shown in Table 1 and Table 2.

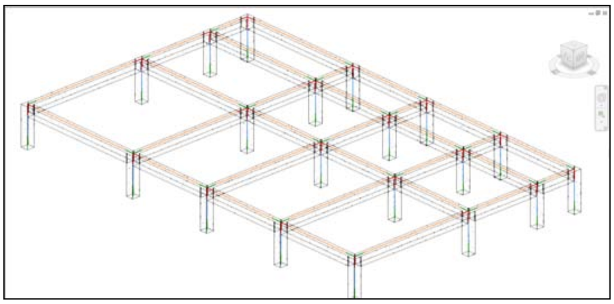

Figure 2. Structure's 3D diagram of case study

Table 1. Dimensions of reinforced concrete structure

Element	Dimensions (mm)				Qty.
	D	W	d	L	
CC1	60	60	5	400	20
CG1	70	50	5	1000	9
CG2	70	50	5	700	12
CG3	70	50	5	600	5
CG4	70	50	5	328	5

Table 2. Elements of steel structure

Element	Dimensions (mm)					Qty.
	H	B	t1	t2	L	
SC1	400	400	13	21	4000	20
SG1	500	200	10	16	10000	9
SG2	500	200	10	16	7000	12
SG3	500	200	10	16	6000	5
SG4	500	200	10	16	3280	5

4.2 Costs

4.2.1 Construction cost

The unit price of construction materials used in case study is evaluated from the local construction market and shown below:

Table 3. Unit cost of construction material

Material	Unit	Price (NTD)
Concrete (210kgf/cm^2)	m^3	2,300
Rebar	tonne	20,000
Formwork	m^2	540
H-Steel	tonne	37,000
Antirust painting	m^2	140

From Table 1, Table 2, and Table 3, the construction costs of different structure types building is calculated and shown in Table 6.

4.2.2 Maintenance cost

The reinforced concrete structure is formed by a combination of concrete and rebar. Due to the neutralization of concrete cover is main cause of corrosion of rebar and damage the structure. This study adopts the action of replace the concrete cover to maintaining the reinforced concrete structure.

Cover with antirust paint is generally used to prevent the steel rusting; this study adopts painting action to maintaining the steel structure. Table 4 shows the maintenance cost of two type structure.

Table 4. Unit cost of maintenance

Item	Unit	Price (NTD)
Covering remove	m^2	1,000
1:3 cement finish	m^2	530
Coating cement paint	m^2	120
Waste transfer	m^3	4,000
Antirust paint	m^2	140

4.2.3 Disposal cost

When a building reaches a predetermined lifespan, the building must be demolished. The following table presents the disposal cost of two different type structures in this study.

Table 5. Unit cost of disposal

Item	Unit	Price (NTD)
Demolishing and transfer (waste)	m^3	2,000
Transfer (steel)	tonner	2,000

4.2.4 Residual value

After the demolition of buildings, the used rebar can be sold as scrap, the unit price adopted in this study is 6,000 NTD/tonne, the used H-steel may reuse so the unit price adopted in this study is 9,000 NTD/tonne.

Table 6. Expenditure and income in building's life cycle

Structure type	Reinforced concrete	Steel
Construction cost (NTD)	2,230,237	2,382,444
Maintenance cost (NTD)	330,119	15,624
Disposal cost (NTD)	275,444	73,831
Residual value (NTD)	552,255	332,237

4.3 CO_2 Emissions

From Table 7 and Table 8 shows the CO_2 emissions (including transfer) in building's life cycle.

Table 7. Unit CO_2 emissions of construction material

Item	Unit	CO_2(kg)
Concrete (210kgf/cm^2)	m^3	253.68
Rebar	tonne	964.75
Formwork	m^2	2.18
H-Steel	tonne	982.16

Table 8. Unit CO_2 emissions of maintenance

Item	Unit	CO_2(kg)
1:3 cement finish	m^2	5.66
Coating cement paint	m^2	0.27
Antirust paint	m^2	0.27

4.4 Parameters in Revit components

For processing the LCA in design phase, the Revit components used in case study not only have the basic geometric and material parameters but also contain the aforementioned costs and CO_2 emissions parameters. Table 9 shows the parameters of CC1 column in case study.

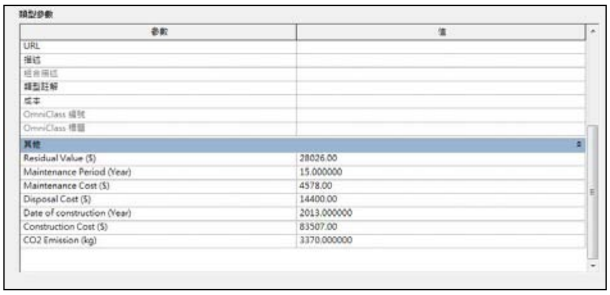

Figure3. Parameters of CC1 column

4.5 Perform LCA

This study takes 60 years for a building's lifespan, and calculates total lifecycle cost from construction cost, maintenance cost, disposal cost. With compound interest form, we compute the final cost within period. The figure represents the relationship between time and cost.

4.5.1 Scenario 1

Assumed the two structure type of buildings were not performed any maintenance activity in whole lifespan, the LCC value is shown as Figure 4. The total CO_2 emissions are 117,005 kg for reinforced concrete structure and 362,527 kg for steel structure.

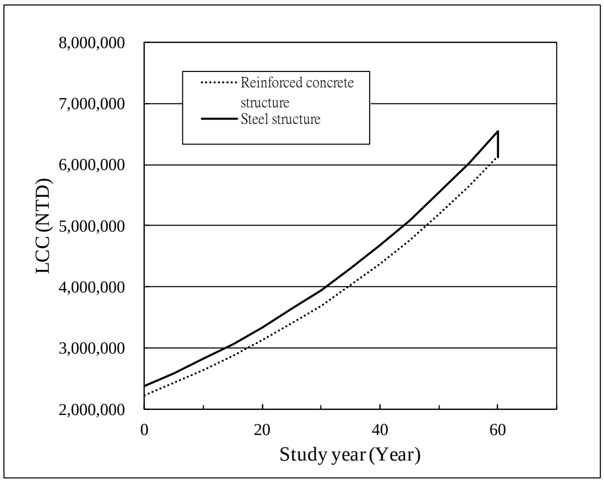

Figure 4. LCC of case study - scenario 1

4.5.2 Scenario 2

Due to the neutralization phenomenon of the covering of concrete will damaged the rebar of reinforced concrete structure. So a new building in the same form will be constructed in the half of 60 years. The building of steel structure takes maintaining action every 10 years to keep the quality of the building and all services in a safe condition in 60 years. The LCC value is shown as Figure 5, and the total CO_2 emissions are 117,630 kg for reinforced concrete structure and 362,667 kg for steel structure.

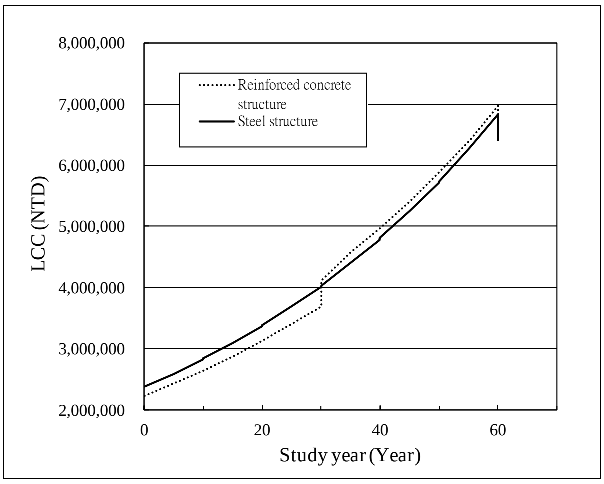

Figure 5. LCC of case study - scenario 2

4.5.3 Scenario 3

The neutralization phenomenon of the covering of concrete has damaged the rebar of reinforced concrete structure. The owner of the building decides to construct a same form new building in the half of 60 years, and dispose the damaged building at same time. The building of steel structure takes maintaining action every 10 years to keep the quality of the building and all services in a safe condition in 60 years. The LCC value is shown as Figure 6, and the total CO_2 emissions are 234,010 kg for reinforced concrete structure and 362,667 kg for steel structure.

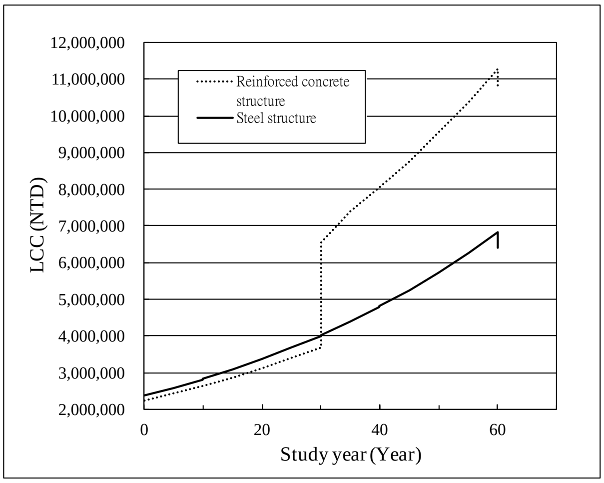

Figure 6. LCC of case study - scenario 3

5 Conclusions

Building maintains are seriously considered in design phase. This study proposes a decision support model with life cycle assessment to help the project owners to select an appropriate building structure type and materials is used in design phase.

This study only tests a model with simple structure including beams and columns. But those results are acceptable for project's owner, designers, and constructors. Based on the results of scenarios can conclude that it is not proper to select structure type only by construction cost.

In scenario 1, although the maintenance costs is not considered, the disposal costs and the residual value will have a significant impact on the LCA value. A good design can prevent to waste more resources if taking into consideration the demolitions and reuse of materials.

In scenario 2, the LCA value of lowest construction cost alternative may be not lowest under considering the maintenance costs, disposal costs and residual value.

In scenario 3 show that, maintenance activities is necessary, because in the same total lifespan condition, the LCA value of rebuilt will higher.

Since CO_2 emissions variation with structure form and maintenance, the decision makers should trade-off between total CO_2 emissions and LCC value to select a proper alternative.

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