

Life Cycle Costing of a Detached House in Bangkok, Thailand

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Abstract

In Thailand, the number of residential buildings in the detached house category tends to increase due to increasing consumer demand. This causes economic competition among contractors and customers who would like to construct detached houses. As a result, stakeholders in detached house construction must manage costs to the lowest possible expenses throughout the building life cycle from construction to residential use, replacing maintenance equipment, and eventual demolition. Life cycle costing is growing in popularity, especially in the field of sustainable construction. However, the use of life cycle costing in the construction industry remains restricted and plagued by practical issues. One of the major issues in the widespread use of life cycle costing in the construction stage, use stage, and end-of-life stage is a lack of knowledge of the research methods and usage of life cycle costing. This study describes a research that shows how a detached house's life cycle cost evaluation was undertaken, along with how the life cycle cost variables were defined and applied to advance a life cycle budget for the entire life cycle of a detached house. This research analyzed the life cycle cost of a detached house through a case study in Bangkok by considering diverse expenses, including construction materials, maintenance, labor, electricity, water, and demolition during service life of 50 years for the building. Costs throughout the life cycle of a detached house analyzed over 50 years amount to 4,901,775.21

baht. This sum may be categorized into costs for each stage of a detached house life cycle, to be used in considering detached house project development and consumer decision-making.

Keywords: Life cycle costing, Detached house, Construction, Demolition

1. Introduction

At present, buildings in Thailand tend to increase every year. According to the National Statistical Office [19], the demand for building construction permits varies year to year, with a 19% increase in 2020, as shown in Figure 1. The total residential area is 62,245,131 square meters, divided into the number of residential buildings equal to 38,479,227 square meters and non-residential buildings equal to 23,765,904 square meters. Single-family homes accounted for 26,652,840 square meters, followed by condominiums. The area is 3,819,701 square meters of row houses or townhouses, representing an area of 3,613,197 square meters, accounting for a spot of 2,069,965 square meters of commercial buildings. The residential building site is 1,279,225 square meters and the twin houses are 1,044,299 square meters.

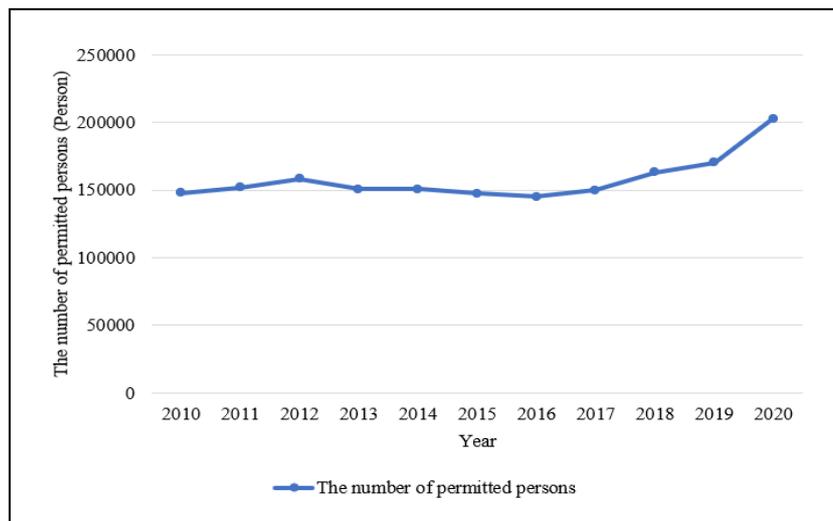


Figure 1: The graph shows the number of people who have received permission to construct buildings from 2010 to 2020.

When considering the construction of residential buildings in the category of detached houses in Bangkok and their vicinities. The construction of residential buildings in the form of houses, classified into 3 types, namely single-detached houses, row houses or townhouses, and twin houses, found that the construction area of detached houses in Bangkok had the highest volume, representing 55.68%, townhouses accounted for 43.65%, and twin houses accounted for 33.21%, as shown in Figure 2.

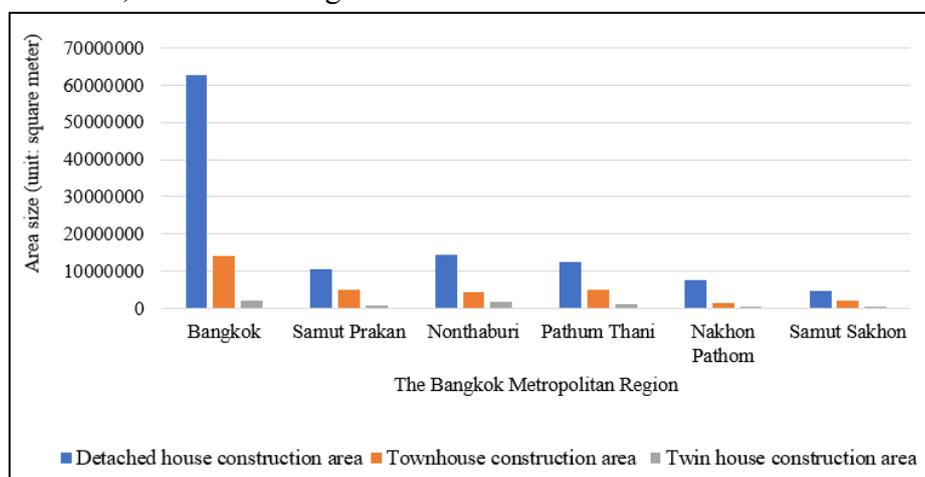


Figure 2: The graph shows the construction area of 3 types of houses: detached houses, townhouses, and twin houses in Bangkok and their vicinities

Therefore, the demand for permission to construct detached houses in Bangkok tends to increase. This causes economic competition among contractors and owners of detached houses. As a result, those involved in the construction of detached houses will have to manage the cost as low as possible throughout the life cycle of the building. It can be divided into 4 phases, including the 1. Production Stage, which is the phase of construction material production. Design to prepare for construction planning and transportation planning in construction 2. The Construction Process Stage is the phase of building construction according to the design, transportation, and installation of equipment according to the design plan of the building. 3. Use Stage refers to a building's period of use. This is the longest phase of the building's life cycle. In addition to the usage period, the building must still be maintained by means of repair and replacement of materials used in the building. The last phrase, 4. End of Life Stage, is the life expectancy of the building. The demolition and transport of these scraps will continue for disposal and recycling [22].

Thus, at each stage of a building's life cycle, there are cost of energy and water are consumed, including the cost of labor and transportation in each process that is different. This led to the use of detached house construction data from Bill of Quantities (BOQ) to be studied to analyze life-cycle costs and to be instrumental in deciding which method to operate with the lowest overall cost [1]. The long-term value of the investment over the entire life cycle of a detached house [34] so that it can be reliably presented and published for investment decision-making.

2. Objective of the Study

To study the Life Cycle Costing (LCC) of a detached house to make investment decisions for constructing a detached house.

3. Methodology

3.1. Life Cycle Costing (LCC)

In this study, the LCC was used as a method of calculating the total cost over the building's lifecycle from cradle to tomb to estimate the building's project cost. All costs incurred from construction, use, maintenance, and the demolition of buildings will be important for project owners to make decisions about the investment project building the detached house at each stage [13]. This study is an amendment from the LCC procedure based on the structure of the EN 16627 standard [21] and covers steps A1–C4 shown in Figure 3, including cost of construction materials, construction, maintenance, replacement, operation, and the end of the service life or demolition.

Therefore, the cost at each stage over the life cycle of a detached house can be described below as follows.

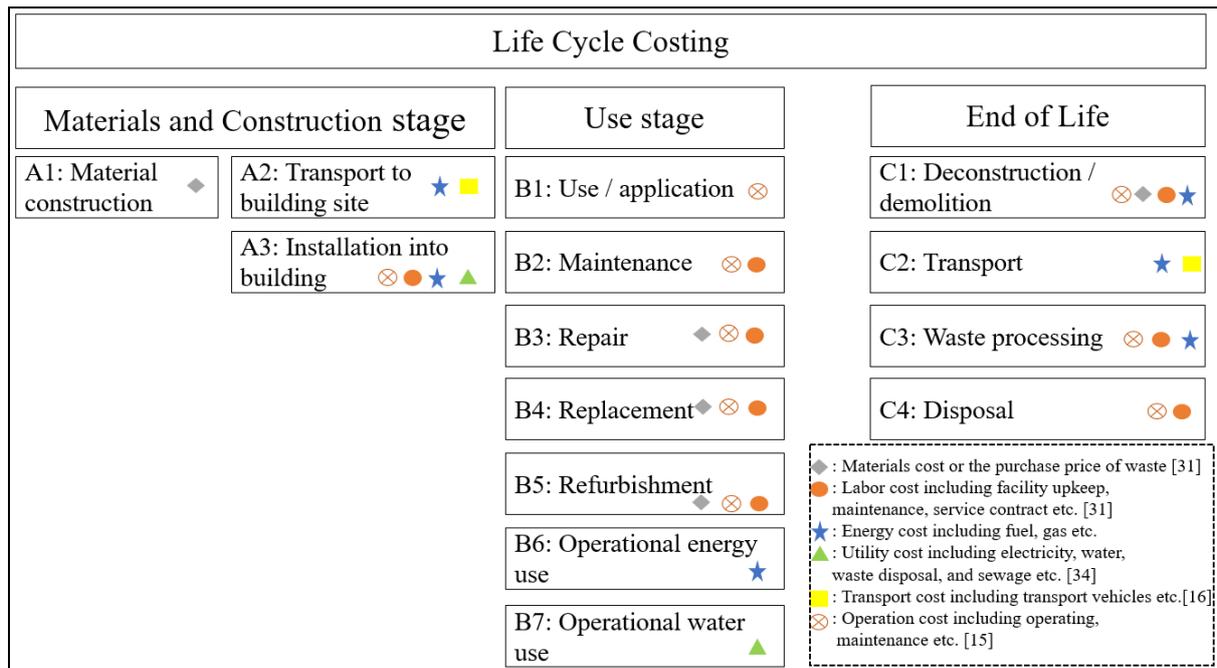


Figure 3: The four life cycle stages modified according to the EN 16627 standard.

3.1.1 Material and Construction stage (A1-A3)

The materials stage means the materials used for building construction, including the architecture being built [31]. For example, concrete, soil, sand, metal, plastic, glass, and land for construction [20]. These materials have different purposes and specific application properties. Therefore, it is the investment phase in the first part of the budget plan [2]. For this study, the cost of building materials was only taken from the BOQ and did not include the cost of the construction material production process. The construction stage means the cost of tools and equipment, including transportation costs, labor costs for the construction and installation of materials and equipment. In addition, it includes overhead costs such as water, electricity, and construction costs, which are covered until the operating costs, taxes (7%), and profit (10%). Therefore, the cost of the construction process is dependent on the contractor who determines and agrees with the owner of the building project.

3.1.2 Use stage (B1-B7)

The use stage refers to the phase of use implementation that includes use, maintenance, repair, and the replacement of damaged component equipment. In terms of costs incurred during the use phase, the costs consist of water, electricity, and liquefied petroleum gas incurred during the period of use. In addition, the cost of maintenance of a detached house has a cost of labor and equipment. In this study, maintenance was performed, including repainting the house with maintenance every 10 years, grouting every 10 years, replacing LED lights every 17 years, and spraying termite protection every 5 years. The different parts of the equipment of a detached house have different lifespans. That depends on the usage behavior as well. Therefore, these maintenance costs will be maintained according to the normal maintenance plan.

3.1.3 End of Life stage (C1-C4)

End of Life refers to a building's end of life or demolition process, which includes labor, energy, landfill disposal, and recycling. Therefore, in this research study, it was found that, from interviews with five contractors for the demolition of detached houses, they were the only material handling managers after the demolition. The research of a detached house construction project in Sweden [22] calculated the cost of this stage and found that costs accounted for 2.5% of the total cost, which was close to the work in this study as well.

3.2. Calculation of LCC

The LCC can be used as an economic indicator to evaluate investment in a construction project. The LCC accounts for investment costs, operating costs, transportation costs, energy costs, labor costs, maintenance costs, and the system's residual value. For life cycle cost calculation, these costs are incurred over different time periods, and these future costs are converted to the Present Value (PV) in the cash flow diagram. This can calculate the total cost incurred throughout the building's lifecycle [13] as shown in Eq. (1).

$$LCC = (I + Repl - Res) + (E + W + OM\&R) \quad (1)$$

Where *LCC* is total the LCC in the PV Baht (฿), *I* is the PV of investment cost, *Repl* is the PV of capital replacement costs, *Res* is the PV of residual value (resale, scrap, and salvage value), *E* is the PV of energy cost (liquefied petroleum gas and fuels), *W* is the PV of water supply cost, and *OM&R* is the PV of operating, maintenance, and repair costs, which is non-fuel.

For calculating the various costs in the form of PV incurred during the whole time of this case study, they can be divided into 2 parts or Eq. (2) and (3), as shown below:

Part 1 is the Single Present Value (SPV) refers to the cost that occurs once, as shown in Eq. (2).

$$PV = F_t \cdot \frac{1}{(1 + d)^t} \quad (2)$$

Where *PV* is the present value of future cash, *F_t* is future cash occurring at the end of the year at *t*, and *d* is the discount rate.

Part 2 is the Uniform Present Value (UPV) means that annual expenses incurred can be equal or uneven, as shown in Eq. (3).

$$PV = A_0 \cdot \frac{(1 + d)^n - 1}{d \cdot (1 + d)^t} \quad (3)$$

Where *PV* is the present value of future cash, *A₀* is the cash value that is incurred annually over *n* years, incurred at the end of the year *t*, and *d* is the discount rate.

When the value of future costs is calculated and converted to *PV* using Eq. (2) and (3), the total PV value can be used to calculate the LCC using Eq. (1).

4. Case study description

The study selected a detached house model of the De De Rak Nam 3 project as shown in Figure 4, which is one of the 12 types of energy-saving residential housing projects in the category of detached houses by the Department of the Energy Development of Alternative Energy, Ministry of Energy [9]. The De De Rak Nam 3 Project has the concept of saving energy according to the climate of Thailand. And there is a complete list and price of construction information or BOQ, including the discount rate used to calculate 6% [3] for studying the LCC of the detached house in order to make a decision to invest in building the detached house.



Figure 4: The DEDE Rak Nam 3 detached house project design example

4.1 Material and Construction stage

This detached house has 2 floors and a total area of 365 square meters. The service life of the building is 50 years [12]. This house was modeled after construction in Bangkok, Thailand. The cost of the construction process refers to the cost of the contractor's design and construction. The homeowner is the employer for the construction of a detached house. The detailed construction information is shown in the BOQ document obtained from the manual. The manual contains the cost of construction materials, labor costs, transportation costs, and construction costs (water and electricity costs in construction), which shows the details of construction costs as summarized and shown in Table 1. The value of the land was not included in the study. This depends on location and landholdings with high variation [6].

Table 1 Cost of construction detached house (in Thailand Baht)

No.	List	Detached house						
		Materials			Construction facility fee		Labor cost	Transport cost
		Unit	Quantity	Cost	Electricity and energy consumption	Water supply		
					46,356.73	1,496.79	-	-
A	Structural work category							
A-1	Foundation structure work and pier							
A-1.1	Driven pile (Size I: 15X15 cm. Long 5m)	Ton	23.00	125,580.00			-	3645.96
A-1.2	Piling work	Ton	23.00	-			5,290.00	-
A-1.3	Labor costs (Driven pile) (Unit: L/S is Lump Sum)	L/S	23.00	-			33,350.00	-
A-1.4	Dig the soil	m ³	13.36	-			1,670.00	-
A-1.5	Fill the soil	m ³	4.01	-			396.99	-
A-1.6	Sharp sand	m ³	2.14	970.13			194.74	474.93
A-1.7	Lean concrete (fc' 180 Ksc., Cylinder)	m ³	1.71	3,478.14			680.58	500.00
A-1.8	Concrete (fc' 210 Ksc., Cylinder)	m ³	10.28	23,222.52			4,019.48	500.00
A-1.9	Shutter boards (Thickness 2.5 inch or 0.0635 m.)	m ³	23.10	9,240.00			2,425.50	Free shipping
A-1.10	Labor costs for assembling shutter boards	m ³	33.00	-			3,465.00	
A-1.11	Crutches for fixing framework (Size 1.5× 3 x 1.5 inch.)	m ²	6.93	2,772.00			-	
A-1.12	Reinforced concrete (DB 12 mm. SD 40)	kg.	934.43	15,978.75			3,083.62	148.13
A-1.13	Annealing Wire	kg.	28.03	591.71			-	Free shipping
A-1.14	Nail	kg.	8.25	195.53			-	
A-2	Structural work (Beams, principal post, floor, stairs and dowel rebar)							
A-2.1	Excavation work	m ³	19.57	-			2,446.25	4,343.17
A-2.2	Foundation sand	m ³	1.13	512.26			102.83	250.78
A-2.3	Lean concrete	m ³	0.75	1,525.50			298.50	500.00
A-2.4	Concrete (fc' 210 Ksc., Cylinder)	m ³	38.87	87,807.33			15,198.17	500.00
A-2.5	Concrete (fc' 210 Ksc., Cylinder) mixed with waterproofing agent.	m ³	26.57	64,219.69			10,388.87	500.00
A-2.6	Shutter boards (Thickness 2.5 inch or 0.0635 m.)	m ²	526.72	210,688.00			-	Free shipping
A-2.7	Labor costs for assembling shutter boards	m ²	752.46	-			79,008.30	
A-2.8	Crutches for fixing formwork (Size 1.5× 3 X 1.5 inch) - DB 12 mm. SD 40	m ² kg.	158.02 4,176.16	63,208.00 71,412.34			- 13,781.33	 662.00

Table 1 Cost of construction detached house (in Thailand Baht) (continued)

No.	Work category/activities/components	Detached house					
		Materials			Construction facility fee	Labor cost	Transport cost
		Unit	Quantity	Cost	Electricity and energy consumption	Water supply	
A-2.9	Reinforced concrete						
	- RB 6 mm. SR 24	kg.	669.01	12,289.71		2,742.94	106.05
	- RB 9 mm. SR 24	kg.	3,587.50	62,924.75		14,708.75	568.69
	- DB 12 mm. SD 40	kg.	4,176.16	71,412.34		13,781.33	662.00
A-2.10	Annealing Wire	kg.	252.37	5,327.53		-	Free shipping
A-2.11	Nail	kg.	188.11	4,458.21		-	
A-2.12	Precast concrete slabs work						
	- Precast concrete slabs flat sheet type width 0.35 m., thickness 0.05 m. (Safety load 150 kg. /sq.m.)	m ²	127.50	28,050.00		7,650.00	1,414.80
	- Overlay concrete (Topping) fc' 210 Ksc. (Cylinder), thickness 0.05 m.	m ³	6.38	14,412.42		2,494.58	1,415.91
	- RB 6 mm. SR 24	kg.	356.64	6,551.48		1,462.22	56.53
	- RB 9 mm. SR 24 (Additional roof@ 0.20 m.)	kg.	27.23	477.61		111.64	4.32
A-2.13	Termite control system (Pipe system and solution)	m ²	170.00	20,400.00		-	Free shipping
A-3	Structural work (Roof)						
A-3.1	Concrete fc' 210 Ksc. (Cylinder)	m ³	12.20	27,559.80		4,770.20	500.00
A-3.2	Shutter boards	m ²	101.44	40,576.00		-	Free shipping
A-3.3	Labor costs for assembling shutter boards	m ²	144.92	-		15,216.60	
A-3.4	Crutches for fixing formwork (Size 1.5× 3 inch.)	m ²	30.43	12,172.00		-	
A-3.5	Reinforced concrete						
	- RB 6 mm. SR 24	kg.	24.17	444.00		99.10	3.83
	- RB 9 mm. SR 24	kg.	562.87	10,339.92		2,307.77	89.23
	- DB 12 mm. SD 40	kg.	1,060.28	18,130.79		3,498.92	168.08
A-3.6	Annealing Wire	kg.	49.42	1,042.76		-	Free shipping
A-3.7	Nail	kg.	36.23	858.65		-	
A-3.8	Structural steel (Roof structure)						
	- Square Tube 100 x 100 x 3.2 mm.	kg.	165.65	2,998.27		2,319.10	
	- Rectangular Tube 150 x 50 x 3.2 mm.	kg.	232.29	4,204.45		3,252.06	36.82
	- Rectangular Tube 125 x 50 x 3.2 mm.	kg.	379.13	6,862.25		5,307.82	60.10
	- Rectangular Tube 100 x 50 x 3.2 mm.	kg.	3,385.13	61,270.85		47,391.82	536.61
	- Rectangular Tube 75 x 38 x 3.2 mm.	kg.	2,213.56	40,065.44		30,989.84	350.89
	- Light Lip Channel 150 x 50 x 20 x 3.2 mm.	kg.	1,967.16	35,605.60		27,540.24	311.83
	- Plate 10 mm.	m ²	52.99	1,414.30		495.46	Free shipping
	- Rust-proof paint of TOA or equivalent	m ²	427.61	23,946.16		14,966.35	

Table 1 Cost of construction detached house (in Thailand Baht) (continued)

No.	Work category/activities/components	Detached house					
		Materials			Construction facility fee	Labor cost	Transport cost
		Unit	Quantity	Cost	Electricity and energy consumption		
B	Architecture work category						
B-1	Floor decoration						
B-1.1	F1 – Tile finish, size 24'' × 24''	m ²	125.80	44,030.00		31,450.00	Free shipping
B-1.2	F3 – Wood-patterned tile finish 24'' × 24''	m ²	33.90	10,170.00		8,475.00	
B-1.3	F4 – Ceramic tile finish 12'' × 12''	m ²	27.90	7,812.00		5,022.00	
B-1.4	F5 – Smooth cement (Parking) thickness 15 mm.	m ²	87.50	1,750.00		2,625.00	
B-1.5	PVC Hardwood baseboard ½''×4'' x 2 m. (Lower floor)	m.	52.00	3,120.00		2,340.00	
B-2	Construction material and wall decoration						
B-2.1	Lightweight concrete wall size 1 layer	m ²	385.40	77,080.00		30,832.00	
B-2.2	Finish mortar plaster interior wall	m ²	344.00	15,480.00		27,520.00	
B-2.3	Finish mortar plaster exterior wall	m ²	286.20	12,879.00		22,896.00	
B-2.4	Post and lintel size 0.10 × 0.10 m.	m.	215.00	15,050.00		10,750.00	
B-2.5	Pole corner bead	m.	300.00	7,500.00		10,500.00	
B-2.6	W4-tiled wall size 12''× 12'' high to attic ceiling	m ²	60.00	16,800.00		10,800.00	
	White-wash	m ²	60.00	3,600.00		4,200.00	
B-2.7	Other						
	- Stucco cornices	m.	65.00	7,150.00		4,550.00	
B-2.8	The wall is covered with a smart board.	m ²	170.00	17,000.00		17,000.00	
B-3	Ceiling decoration						
B-3.1	C2 – Moisture resistant gypsum board ceiling, thickness 9 mm., plastered with galvanized steel frame @ 0.60x0.60m. + insulation	m ²	81.65	41,641.50		-	
B-3.2	3'' thick glass fiber with aluminum foil cladding						
B-3.2	C1 – Gypsum board ceiling, thickness 9 mm., conventional type, galvanized steel frame @ 0.60x0.60m. + 3-inch-thick glass wool insulation with aluminum foil cladding.	m ²	124.60	59,808.00		-	
B-3.3	C3 – Ceiling of Elephant Brand Smart Board, thickness 4 mm., galvanized steel frame C-Line C75 No. 24@0.60m. + 3 inches thick glass wool insulation with aluminum foil cladding.	m ²	261.90	98,212.50		-	
B-4	Paint work						
B-4.1	Interior paint	m ²	344.00	9,288.00		9,976.00	
B-4.2	Exterior paint	m ²	286.20	8,586.00		8,299.80	

Table 1 Cost of construction detached house (in Thailand Baht) (continued)

No.	Work category/activities/components	Detached house					
		Materials			Construction facility fee	Labor cost	Transport cost
		Unit	Quantity	Cost	Electricity and energy consumption	Water supply	
B-4.3	Interior ceiling paint	m ²	206.25	6,187.50		6,187.50	
B-4.4	Exterior ceiling paint	m ²	261.90	9,166.50		9,428.40	
B-4.5	Eave wood color, over the eaves (material + strength)	m.	90.30	3,160.50		2,257.50	Free shipping
B-4.6		m.	90.30	2,709.00		1,806.00	
B-4.7	Oil paint on the bottom of the hardwood ½"x4" Scaffolding	(L/S)	1.00	3,000.00			
B-5	Door-window and equipment work (as specified in form GG-0.03)						
B-5.1	Door work (including wooden door color)						
B5.1.1	Door 1	Set	1.00	9,840.00			
B5.1.2	Door 2	Set	2.00	95,000.00			
B5.1.3	Door 3	Set	1.00	30,000.00			
B5.1.4	Door 4	Set	2.00	20,500.00			
B5.1.5	Door 5	Set	3.00	14,400.00			
B5.1.6	Door 6	Set	1.00	20,500.00			
B5.1.7	Door 7	Set	3.00	9,000.00			
B5.1.8	Door 8	Set	2.00	9,600.00			
B5.1.9	Door 9	Set	2.00	15,600.00			
B-5.2	Window work						
B-5.2.1	Window 1	Set	2.00	4,025.00			
B-5.2.2	Window 2	Set	2.00	1,500.00			
B-6	Sanitary ware work						
B-6.1	Toilet 1	Set	1.00				
B-6.1.1	Flush toilet	Set	1.00	4,628.00			
B-6.1.2	Rinsing hose with stop valve	Set	1.00	150.00			
B-6.1.3	Toilet paper holder	Set	1.00	94.00			
B-6.1.4	Basin	Set	1.00	2,440.00			
B-6.1.5	Single Basin Faucet	Set	1.00	934.60			
B-6.1.6	Clothes rack	Set	1.00	300.0			
B-6.1.7	Shelf	Set	1.00	315.00			
B-6.1.8	Floor drain strainer with odor trap with filter cap	Set	1.00	231.00			
B-6.1.9	Mirror, thickness 3 mm.	Set	1.00	350.00			
B-6.1.10	Washbasin navel	Set	1.00	172.20			
B-6.1.11	Chromium duct	Set	1.00	90.00			
B-6.1.12	Water pipe	Set	1.00	570.00			

Table 1 Cost of construction detached house (in Thailand Baht) (continued)

No.	Work category/activities/components	Detached house					
		Materials			Construction facility fee	Labor cost	Transport cost
		Unit	Quantity	Cost	Electricity and energy consumption	Water supply	
B-6.1.13	Others						
	- Chrome plated faucet ERA ½"	Set	1.00	145.00			
	- Red handle field tap with rubber hose holder.	Set	1.00	145.00		Free shipping	
B-6.2	Toilet 2						
B-6.2.1	Flush toilet	Set	1.00	4,628.00			
B-6.2.2	Rinsing hose with stop valve	Set	1.00	150.00			
B-6.2.3	Toilet paper holder	Set	1.00	94.00			
B-6.2.4	Basin	Set	1.00	2,440.00			
B-6.2.5	Single Basin Faucet	Set	1.00	834.60			
B-6.2.6	Hand shower set with hook	Set	1.00	670.00			
B-6.2.7	Clothes rack	Set	1.00	300.00			
B-6.2.8	Dish soap	Set	1.00	94.00			
B-6.2.9	Shelf	Set	1.00	315.00			
B-6.2.10	Floor drain strainer with odor trap with filter cap	Set	2.00	462.00			
B-6.2.11	Mirror, thickness 3 mm.	Set	1.00	350.00			
B-6.2.12	Washbasin navel	Set	1.00	172.20			
B-6.2.13	Chromium duct	Set	1.00	90.00			
B-6.2.14	Water pipe	Set	1.00	570.00			
B-6.3	Toilet 3	Set	1.00				
B-6.3.1	Flush toilet	Set	1.00	4,628.00			
B-6.3.2	Rinsing hose with stop valve	Set	1.00	150.00			
B-6.3.3	Toilet paper holder	Set	1.00	94.00			
B-6.3.4	Basin	Set	1.00	2,440.00			
B-6.3.5	Single Basin Faucet	Set	1.00	834.60			
B-6.3.6	Hand shower set with hook	Set	1.00	670.00			
B-6.3.7	Clothes rack	Set	1.00	300.00			
B-6.3.8	Dish soap	Set	1.00	94.00			
B-6.3.9	Shelf	Set	2.00	315.00			
B-6.3.10	Floor drain strainer with odor trap with filter cap	Set	1.00	462.00			
B-6.3.11	Mirror, thickness 3 mm.	Set	1.00	350.00			
B-6.3.12	Washbasin navel	Set	1.00	172.20			
B-6.3.13	Chromium duct	Set	1.00	90.00			
B-6.3.14	Water pipe	Set	1.00	570.00			

Table 1 Cost of construction detached house (in Thailand Baht) (continued)

No.	Work category/activities/components	Detached house					
		Materials			Construction facility fee	Labor cost	Transport cost
		Unit	Quantity	Cost	Electricity and energy consumption	Water supply	
B-7	Roof work						
B-7.1.1	- Corrugated roof tile, small corrugated, 54x120 cm.	Sheets	823.00	34,566.00			
B-7.1.8	- Other equipment	L/S	1.00	10,000.00			Free shipping
B-8	Stairs work						
B-8.1	ST1 (Main stair)						
	- baby lying on the stairs	Part	14.00	7,560.00			
	- Staircase	m ²	1.25	587.50			
	- Prefabricated wooden wall cornice ½"x4"	m.	16.40	1,148.00		12,000.00	
	- Labor cost for installing stairs	(L/S)	1.00	-			
	- Plastering and paint work under the stairs	(L/S)	1.00	2,500.00			
	- Adjust the cement sand steps	(L/S)	1.00	3,500.00			
	- Handrail	m.	12.35	1,800.00			
B-9	Miscellaneous work						
B-9.1	Sunshade						
B-9.1.1	Sunshade 1	Set	7.00	14,000.00			
B-9.1.2	Sunshade 2	Set	5.00	55,000.00			
B-9.1.3	Sunshade 3	Set	2.00	16,875.00			
B-9.1.4	Sunshade 4	Set	1.00	8,575.00			
B-9.2	Guard rail						
B-9.2.1	Balcony railing 1	Set	7.00	15,750.00			
B-9.2.2	Balcony railing 2	Set	3.00	12,379.50			
B-9.2.3	Balcony railing 3	Set	8.00	86,400.00			
B-9.2.4	Balcony railing 4	Set	1.00	2,025.00			
B-9.2.5	Balcony railing 5	Set	1.00	7,425.00			
C	Electrical System Category						
C-1	Sub-panel, Circuit Breaker and electric meter	Set	1.00	1,465.00		110.00	
	- CONSUMER UNIT (CU) 14 circuits	Set	1.00	1,100.00		110.00	
	- Molded Case Circuit Breaker (MCCB) 2P,100AT/100AF, Ics 10 KA	Set	6.00	660.00		660.00	
	- Miniature Circuit Breaker (MCB) 1P,16AT	Set	4.00	5,800.00		440.00	
	-RCBO 1P,16AT (6kA, 30mA)	Set	2.00	2,900.00		220.00	
	-RCBO 1P,20AT (6kA, 10mA)	Set	1.00	800.00		200.00	
	-Ground wire, size 5/8 inches, length 2.4 meters	Set	1.00	1,900.00		400.00	
	-Ready-made pond 30X40X40 cm.	Set	1.00	1,465.00		110.00	

Table 1 Cost of construction detached house (in Thailand Baht) (continued)

No.	Work category/activities/components	Detached house						
		Materials			Construction facility fee		Labor cost	Transport cost
		Unit	Quantity	Cost	Electricity and energy consumption	Water supply		
C-2	Wires and conduits							
	-IEC01 (THW) 35 SQ.MM. (MAIN FEEDER)	m.	50.00	5,615.50		1,500.00	Free shipping	
	-IEC01 (THW) 10 SQ.MM. (GROUND MAIN FEEDER)	m.	15.00	521.40		240.00		
	-IEC01 (THW) 4 SQ.MM.	m.	370.00	4,488.10		3,700.00		
	-IEC01 (THW) 2.5 SQ.MM.	m.	959.00	7,710.36		6,713.00		
	-NYY 2.5 -1C SQ.MM.	m.	30.00	617.70		360.00		
	-NYY 1.5 -1C SQ.MM.	m.	30.00	528.90		300.00		
	-COAXIAL RG6	m.	40.00	192.00		120.00		
	-TIEV 0.65-4C	m.	20.00	187.00		120.00		
	-VCT 2C-2.5 SQ.MM.	m.	66.00	2,574.00		792.00		
	-DIA. 1 ¼ inch HDPE-PN6	m.	10.00	160.00		190.00		
	-DIA. 1-inch HDPE-PN6	m.	15.00	330.00		270.00		
	-DIA. 2 inches uPVC	m.	25.00	1,932.00		875.00		
	-DIA. ¾ in. uPVC	m.	13.00	235.95		299.00		
	-DIA. ½ inch uPVC	m.	558.00	7,834.32		11,160.00		
	-Flexible Metal DIA. ½ inch pipe	m.	66.00	290.40		726.00		
	-Fitting Accessories	Collectively	1.00	-		6,058.00		
C-3	Electric lamp							
	-Round ceiling lamp using COMPACT LED lamp 2X13W/ E27	Set	6.00	2,520.00		66.00		
	-Lamp DOWNLIGHT 4-6 inches using - COMPACT LED 13W/ E27 cap	Set	21.00	5,250.00		2,415.00		
	-Lamp DOWNLIGHT 4-6 inches, use COMPACT LED 13W/E27 (insect-proof) lamp	Set	10.00	2,500.00		1,150.00		
	-Ceiling lamp T8 LED 18W/Lamp type G13	Set	8.00	2,560.00		920.00		
	-Ceiling lamp T8 LED 18W/G13 cap type (Insect proof)	Set	1.00	320.00		115.00		
	-COMPACT LED bulb 13W/ E27 cap	Set	43.00	5,160.00				
	-T8 LED lamp 18W/Lamp type G13	Set	9.00	1,980.00				
C-4	Switch and socket							
	-1-way electrical switch	Set	29.00	870.00		2,320.00		
	-2-way electrical switch	Set	2.00	112.00		170.00		
	-1 switch cover with accessories	Set	9.00	198.00				
	-2 switch covers with accessories	Set	6.00	132.00				

Table 1 Cost of construction detached house (in Thailand Baht) (continued)

No.	Work category/activities/components	Detached house					
		Materials			Construction facility fee	Labor cost	Transport cost
		Unit	Quantity	Cost	Electricity and energy consumption	Water supply	
	-3 switch covers with accessories	Set	2.00	44.00			
	-4 switch covers with accessories	Set	2.00	44.00			Free shipping
	-Electrical socket type double socket 16 A. 250 V.	Set	17.00	2,210.00		1,530.00	
	-Electrical socket type double socket 16 A. 250 V. (waterproof)	Set	3.00	390.00		345.00	
	-2 electrical socket covers with accessories	Set	17.00	374.00			
	-Cover for 2 electrical sockets with accessories (waterproof type)	Set	3.00	66.00			
C-5	Other (MTV, TEL, Doorbell)						
	TV OUTLET	Set	4.00	1,200.00		360.00	
	TAB OFF	Set	4.00	1,320.00		360.00	
	SPLITTER 4-way	Set	1.00	950.00		115.00	
	LINE AMP	Set	4.00	560.00		360.00	
	TELEPHONE OUTLET	Set	2.00	400.00		180.00	
	Wall bell	Set	1.00	300.00		80.00	
	Wall bell switch, fence post, waterproof type	Set	1.00	200.00		80.00	
D	Waterworks and Sanitation						
D-1	Water supply pipe system	m.	2.50	24.95			
	Size ½ inches (Normal Size)	m.	46.50	585.44		75.00	
	Size ¾ inches (Normal Size)	Collectively	1.00	61.03		1,395.00	
	Couplings and pipe fittings	Set	1.00	105.00		18.31	
	Hose Bibb (Size ½ inch)	Set	6.00	1,584.00		100.00	
	Water valve (Gate Valve)	Set	1.00	1,135.00		900.00	
	Water Meter	Set	1.00	155.00		100.00	
	½" field tap	Set	1.00	11,600.00		50.00	
	Automatic water pump 250 W	Set	1.00	4,590.00		3,480.00	
	1,500 liters prefabricated above ground water tank	Collectively	1.00	1,916.00		1,377.00	
	Couplings and pipe fittings	Pillar	4.00	1,808.00		575.07	
	P.C. PILE 0.12x0.12x6.00 m.	Pillar	4.00			2,192.00	
	Cutting pile head	m.	2.50	22.65		1,600.00	
	Coarse sand, compacted underside	m ³	0.05	101.70		4.55	
	Lean concrete	m ³	0.05	118.35		19.90	500.00
	Structural concrete 280 ksc. (Cylindrical)	m ³	0.05	80.00		21.80	500.00
	General wood, 50% off	m ²	0.20	24.95		26.60	Free shipping

Table 1 Cost of construction detached house (in Thailand Baht) (continued)

No.	Work category/activities/components	Detached house					Transport cost	
		Materials			Construction facility fee			Labor cost
		Unit	Quantity	Cost	Electricity and energy consumption	Water supply		
D-2	Sewer system waste water and sewage							
	PVC pipe, quality class 8.5, according to TIS standards 17-2523						Free shipping	
	- Size 2 inches	m.	25.30	1,081.58				
	- Size 4 inches	m.	21.60	3,283.20		1,012.00		
	-Couplings and pipe fittings	Collectively	1.00	436.48		2,160.00		
	-Septic tank, buried in the soil, size 1,200 liters	Set	1.00	4,790.00		130.94		
	-FD	Set	5.00	1,000.00		1,437.00		
	Septic tank receiving structure							
	-P.C. PILE 0.12x0.12x6.00 m.	Pillar	4.00	1,809.84		2,192.00		
	-Cutting pile head	Pillar	4.00	-		1,600.00		
	-Excavation work	m ³	1.20	-		118.80		
	-Coarse sand, compacted foundation	m ³	0.05	22.67		4.55		
	-Lean concrete	m ³	0.05	101.70		19.90	500.00	
	-Structural concrete 280 ksc. (Cylindrical)	m ³	0.05	118.35		21.80	500.00	
	-General wood, 50% off	m ³	0.20	80.00		26.60	Free shipping	
D-3	Air duct work							
	PVC pipe, quality class 8.5, according to TIS standards 17-2523							
	- Size 2 inches	m.	13.50	577.13		540.00		
	Couplings and pipe fittings	Collectively	1.00	57.71		17.31		
D-4	Building's rainwater drainage system							
	PVC pipe, quality class 8.5, according to TIS standards 17-2523							
	Size 2 inches	m.	27.80	1,188.45		2,224.00		
D-5	Drainage system work around the area							
	Cement pipe Ø 0.20 m.	m.	83.00	9,960.00		3,984.00		
	Ready-made cement wastewater pond 0.40 x 0.40 m.	Set	11.00	8,433.37		1,100.00		
	Garbage trap	Set	1.00	800.00		150.00		
	Grease trap installed under the sink	Set	1.00	2,900.00		200.00		
	Grease trap 28 liters	Set	1.00	3,700.00		200.00		
	Excavation work	m ³	3.00	-		297.00		
	Trap	Set	1.00	766.67		100.00		
	Total cost (include operation profit 10% and VAT 7%)			2,719,873.55	43,324.05	1,398.86	797,877.59	23,157.40

4.2 Use stage

The cost of use in the process of using a detached house is considered from the point of view of the user, consisting of the cost of using it for basic home appliances for Thai people [35]. The cost of electricity consists of a water pump, an air conditioner, a water heater, 98 fluorescent lights, a refrigerator, and a television. The average power consumption of electrical appliances depends on the area of the room. number of users or residents) Therefore, the average consumption of electrical appliances from [24] and [5] was referenced to calculate the electricity cost of the Metropolitan Electricity Authority [17] is shown in Eq. (4), (6), (7) and (8). The number of utilization units of air conditioners Eq. (5) [11] and water supply costs (Residence type) from Eq. (9) refer to the Metropolitan Waterworks Authority [18], including the energy costs of households in Bangkok, namely households gas the National Statistical Office [1] is shown in Table 2. And maintenance, repairing and replacement value of this detached house is shown in Table 3.

Customer used energy (kWh or Unit/Month)

$$= \frac{\text{Electric power} \times \text{Period of use} \times 30 \text{ days}}{1000} \quad (4)$$

Where the unit of electric power is Watt (W), and the electricity usage period of each electrical appliance (Hour/day).

In addition, to calculate the quantity consumption of air conditioners, there is a specific calculation formula as follows.

Quantity consumption of air conditioner (Unit/Month)

$$= \frac{\text{Cooling capacity/SEER}}{1000} \times \text{Period time of use} \times 30 \text{ days} \quad (5)$$

Where the unit of cooling capacity is BTU (British Thermal Unit), SEER is the Seasonal Energy Efficiency Ratio (Unit: BTU/hour/Watt), and the unit of period time in use is hours per day.

Next, when we know the total number of electrical units in the house. Therefore, the base electricity tariff (Baht) of the residential buildings in this study can be calculated using residential service on progressive and service charges as specified by the Metropolitan Electricity Authority.

$$F_t \text{ (Baht)} = \text{Total customer used energy} \times F_t \quad (6)$$

Where F_t (Float time) is the cost (Baht/unit) of generating electricity that the utility cannot control, such as fuel prices, inflation, foreign exchange rates, etc.

$$\text{VAT 7\% (Baht)} = (\text{Base electricity tariff} + F_t) \times 7\% \quad (7)$$

Where VAT is a tax that electricity users must pay as well, which will be charged according to Thai law at 7%.

$$\text{Electricity bill (Baht)} = \text{Base electricity bill} + F_t + \text{VAT (7\%)} \quad (8)$$

Where the electricity bill is the net cost that electricity consumers must pay, which includes base electricity, F_t , and VAT7%.

$$\begin{aligned} \text{Water tariffs (Baht)} \\ = (\text{Volume of water} \times \text{Water price}) + \text{Service charge} + \text{VAT (7\%)} \end{aligned} \quad (9)$$

Where the unit of volume water in use is cubic meters (cu.m.), the unit of water price is Baht per cu.m., the unit of service charge is Baht per month and depends on water meter size, with VAT at 7% following Thai law.

Table 3 The annual and lifetime of electricity, energy, and, utilities cost in the use stage

No.	Electricity/energy/utilities source	Annual cost (Baht/year)	Life time cost (Baht)
1.	Electricity	63,568.18	1,001,955.27
2.	Energy costs (Household Gas) [25]	636.00	10,024.57
Total electricity and energy cost		64,204.18	1,011,979.84
3.	Water supply	5,229.73	261,486.60
Total utilities cost		5,229.73	82,430.51
Total all		69,433.91	1,094,410.35

Table 4 The annual and lifetime of maintenance, repairing and replacement costs in the use stage

No	Maintenance, repairing and replacement activity	Lifetime of materials (Year)	Cost (Baht/time)	Life time cost (Baht)
1.	Sealant	10 [27]	1,710.00	2,044.82
2.	House paint			
	- Indoor	10 [8]	19,264.00	23,035.89
	- Outdoor	10 [8]	16,885.80	20,192.04
3.	Injecting anti-termite solution	5	20,400.00	57,042.48
4.	LED lamps 13W and 18W	17	20,290.40	10,333.90
Total maintenance and repairing costs				112,649.13

4.3 End of life stage

The cost of the end-of-life stage, which is the final stage that covers deactivation, the layoff of construction and maintenance, and demolition. This level was assessed through interviews with five building and house demolition contractors. It was found that the average demolition cost was 310 Baht per square meter. All costs associated with the end of life include demolition, labor costs, transportation costs, and the cost of dismantling waste management shown in Table 5. The total cost of demolition of detached houses is approximately 113,150 Baht. Incorporating guidelines for waste management from demolition, there is a determination of the amount of waste from the demolition of houses from the inspection of BOQ documents. The transport distance to the landfill/recycling is 40 kilometers by 6-wheel trucks [33].

Table 5 The costs in the end of life stage

Description of cost	Cost (Baht/ m^2)	Total cost (365 m^2)	Remark
Demolition (include labor, energy, transport)	310	113,150.00	Interview with 5 companies of building and house demolition contractors and average demolition costs.
Total cost		113,150.00	

Suggestions for the cost of the demolition process include that the demolition company will sell the demolition waste to the scrap metal purchase company for recycling. In this case, the study did not consider the cost of waste management and assumed that all demolition waste was directed to the demolition waste management process. So, except for scrap metal from demolition, the demolition company will be sold to scrap metal purchase companies for recycling. The amount received is 131,054.07 baht, thus becoming the revenue of the demolition company and cannot be deducted from the cost of the demolition process.

From calculating the cost over the life cycle of a detached house over a period of 50 years. It was found that the construction stage amounted to 3,585,631.45 baht, the use stage cost 1,207,059.48 baht, and the end of life stage demolition cost 113,150.00 baht, as shown in Table 6, and the proportion of costs in each step of the detached house in Figure 5.

Table 6 The summary life cycle costing of the detached house over lifetime 50 years

Life cycle stage		Life time cost (Baht)
Construction	Materials	2,719,873.55
	Labor	797,877.59
	Transport	23,157.40
	Construction facility fee	44,722.91
	Construction total	3,585,631.45
Use	Electricity	1,001,955.27
	Energy cost (Household gas)	10,024.57
	Water supply	82,430.51
	Maintenance, repairing and replacement	112,649.13
	Use total	1,207,059.48
End of life	Demolition	113,150.00
	Total	4,905,840.93

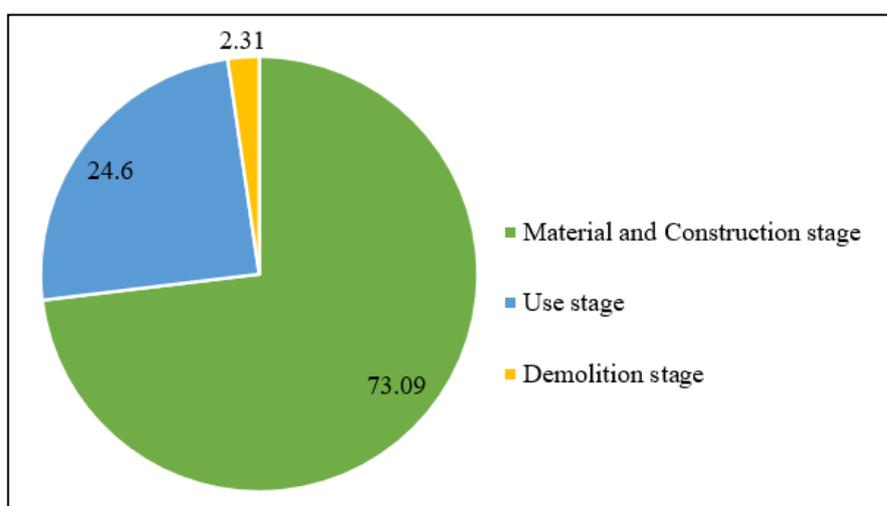


Figure 5: The proportion of total life cycle cost (3 stages) of a detached house over 50 years.

5. Conclusions

The detached house case study's overall life cycle cost analysis was compiled from the De De Rak Nam 3 project model, and Microsoft Excel was used as a tool to assess the LCC of the detached house, including materials and construction stage, use stage, and demolition stage. These future costs are converted to present value (PV) in cash flows. It was found that the cost over the life of 50 years at a discount rate of 6% per year amounted to 4,905,840.93 Baht. Subsequently, when considering the main cost of the materials and construction stage accounted for 73.09%, mainly because the value of construction materials at present tends to increase to 8.9% in all product categories. Specifically, steel, cement, and concrete products [29], are the primary building materials. The causes are a recovery in construction demand, government support measures requiring the use of domestically produced construction materials, an increase in the cost of imported raw materials such as scrap and billets in line with the direction of world market prices, and rising electricity and fuel costs [16]. The approach to controlling the cost of this part is to modify the traditional house construction method to construct a modular house with a prefabricated house structure [10]. In terms of quality, it saves costs, shortens construction time, and reduces environmental pollution. Next, the use stage costs 24.6%, with the main cost of the implementation being 20.42% electricity, 1.68% water, 2.29% maintenance, and 0.20% cooking gas. Therefore, the main reason for the high cost is the long service time of the electrical appliances. The Ft adjustment is about 5% higher by the Metropolitan Electricity Authority [23]. By the way, the solution should be to improve the switch to using solar energy or solar cells to replace the primary electricity source. Installing a solar power generation system with an area of 20-40 square meters, with the total cost of panels and accessories around 350,000 - 470,000 baht. The investment can be returned within 7-9 years. The important thing that should take into account is the position and orientation of the house along with local conditions and environments, such as the context of the house's location [32]. Electrical equipment with a service life of more than 10 years should be replaced because of its low efficiency [14], and consumers should conserve energy, fuel, and water [26]. Lastly, the demolition stage accounted for 2.31%, which was the lowest cost ratio. Therefore, the cost of this demolition is the responsibility of the person who owns the detached house. The demolition contractors are the managers of the waste and scrap that occurs [30] in the following ways: scrap sorting, demolition, reuse, recycling, as well as transportation for scrap sale and disposal. Hence, this detached house cost analysis has parameters for cost calculations depending on the economic situation. This study can be applied to calculate the life cycle cost of other residential buildings for the benefit of those interested in making decisions in building construction project planning.

6. Limitations and Future study

Based on the literature review for calculating total cost in most case studies. It was found that there were some limitations to some variables, namely construction cost, operating costs, maintenance cost, and demolition cost, which were included in the total cost analysis. But this does not include the cost of decorating the house. In addition, most of the LCC calculations are made for residential homes and office buildings. There are only details of construction materials, electricity, water, energy, and transportation costs for each life cycle stage [6][7][22]. Therefore, the LCC analysis of case studies considers the detached houses in Bangkok, which can be studied further in the next work in the section on cost comparison of more than one building construction project to investment, calculating the Saving-to-Investment Ratio (SIR), and the payback period analysis.

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