AN ANALYSIS OF GREEN BUILDING COSTS USING A MINIMUM COST CONCEPT

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ABSTRACT

Green buildings are known for yielding a better indoor habitat, saving energy and protecting the environment. However, they require greater investment than conventional buildings. Green buildings can be classified at different levels ranging through certified, silver, gold and platinum. The classification chosen is likely to affect project costs. Adopting a platinum level of green building specifications tends to incur the highest project costs. While with gold, silver and certified levels expenditure will be reduced accordingly. The actual degree of project cost differences also depends on additional factors, such as site location, design specifications, construction condition, material and equipment selection and LEED consultant expertise. Construction budgeting represents a crucial factor for project owners developing green buildings. This research presents a method for determining the minimum project costs of green building developments. The processes and steps to be completed in determining such minimum project costs are presented based on a case study of a learning centre building which received LEED platinum certification. It was found that choosing certified and silver levels has an indifferent effect on project costs, whereas expenditure increases exponentially with gold and platinum levels of certification.

KEYWORDS

cost analysis, earning credits, green building, LEED-NC rating system

INTRODUCTION

In Thailand, LEED building construction practices are well-known among certain corporate developers. Most undertake projects with issues concerned with corporate social responsibility as the major consideration. Ensuring environmental friendliness and promoting the health of their employees occupy relatively secondary positions. There is only a limited amount of qualified LEED consultants in Thailand; thus the prerequisite experience in successfully developing green building projects is restricted to a certain small group of designers. The objective of this paper is to show an alternative means of developing green building projects based on a minimum project cost concept. The minimum project cost concept is used widely in solving time cost trade-off

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problems within construction planning (Liu et al 1995), (Feng et al. 2000), (Moussourakis and Haksever 2004), (El-Rayes and Kandil 2005), (Filion and Jung 2010), (El-Kholy 2015). A minimum direct cost curve as a function of time is developed to trade off with cost savings from indirect costs (Harris 1978). This concept can be used in developing green building projects as well since certain credits are expensive to pursue, while others are less prohibitive. It would be more efficient to sort cost per credit from minimum to maximum levels. This concept allows project owners, architects, and engineers to choose which credits to adopt and develop design drawings accordingly. As a result, this paper proposes a model for developing green building projects based on the minimum cost concept using a LEED platinum building as a case study. The techniques presented can be applied to formulating any green building project budget.

LITERATURE REVIEW

The Leadership in Energy and Environmental Design (LEED) rating system has become the most widely recognized and used certification system concerning green building design and construction (Golbazi and Aktas 2016.LEED has become a voluntary consensus standard developed by the U.S. Green Building Council, with particular input from the LEED-NC, to be used in conjunction with new construction and major renovation projects (USGBC 2017). Sustainable buildings incorporate the concepts and principles of sustainable site development, water conservation, energy efficiency, recycled-content materials, waste reduction, building longevity, healthy structures, and the integration of environmental concerns and green construction practices (Vijayan and Kumar 2005). The green building rating system aims to promote healthy, durable, affordable and environmentally-sound practices in building design and construction. It is awarded according to the following scale: certified, silver, gold, and platinum (USGBC 2017). From conducting a survey comprising 33 green buildings, Kats et al. (2003) found the average premium for green buildings to be less than 2%. The average green premium for certified, silver, gold, and platinum levels of certification were 0.66%, 2.11%, 1.82% and 6.50%, respectively. Kats (2006) studied 30 green school projects built in ten U.S. states during 2001 to 2006. He found that green schools require a 1–2% increase in additional costs when compared with conventional designs that had an average premium cost of 1.7%. Mapp et al. (2011) revealed that the building costs of LEED banks are within the same range as non-LEED banks, and the direct costs associated with seeking LEED certification fall below 2% of total project costs. By investing in green projects, an internal rate of return was possible to achieve from the energy savings gained by such buildings at a rate of approximately 12% (Ross et al. 2007). Morris and Matthiessen (2007) studied a total of 221 buildings of which 83 complied with LEED standards, with the remaining 138 being classified as non-LEED projects. The costs incurred in green building projects are not necessarily cumulative. In many cases, a project can meet many sustainable design criteria in terms of one design feature. Matthiessen and Morris (2004) compared the construction costs of 138 buildings, of which 45 were LEED and 93 non-LEED. Most of the building costs of projects which complied with green construction standards had a premium cost of 0%–3% of that incurred by conventional building projects. Non-LEED projects were able to achieve between 15 and 25 points with their conventional designs. Matthiessen and Morris (2004) suggest that most successful projects achieve a sustainable design within their initial budget by having clear goals and integrated sustainable elements at early stages of each project, and they drew two crucial conclusions. First, there is a very large variation in the cost of buildings, even if they are in the same building category. This is due to the fact that there are both low and high cost green building projects, which is similar to the case with non-green building initiatives. Second, comparing average cost premiums among buildings could be misleading. Instead, cost capacity methods should be used, such as assessing the cost per student of school buildings, as considering average cost premiums does not indicate the operating capacity of a particular building. Construction costs and the construction duration of green school buildings were significantly higher than with non-green school buildings (Shrestha and Pushpala 2012). Fuerst (2009) suggested that organizations seeking certification endeavor to minimize the effort and expense necessary to achieve the certification level they aspire to. In China, Zhang et al. (2011) found wall insulation, low-E windows, and solar heating appliances to be inexpensive to incorporate in green buildings, compared to solar PV or heat pump technologies. Thus, indicating that there may be both low cost and high cost components within the same certified levels of LEED building categorization. Fuerst (2009) suggested that scores around the lower boundary of each certification level reflect the principle of least effort being applied within eco-certifications. Wu et al.(2016)offered useful references for project developers in understanding the LEED v2.2 rating system, such as the significant improvements in variables connected to energy and atmosphere required for achieving certified and silver project status. In this research, one LEED platinum case study was selected and explored in order to detail how to use the minimum cost concept within green building budgeting.

RESEARCH METHODOLOGY

In this research project, a case study of the learning centre of a corporate bank in Thailand, named Kasikornbank Public Company Limited (KBANK), was undertaken. It involved a newly constructed building, characterized as a lodging building. The building has the capacity to contain 192 people per day within an area of 49,428 sq.ft., or 4,457 sq.m. Figure 1 shows an exterior perspective of the KBANK learning centre. The overall points attributable to the building project are shown in Table 1. It earned 81 points and received a LEED-NC Platinum (2009 V3) certification in 2013.

Figure 2 shows a summary of the steps employed in this research project, examining the KBANK learning centre as a case study. Data was collected from in-depth interviews of project stakeholders, such as the LEED AP and his team, a project owner representative, A/E designers, and the construction manager, together with studying LEED project documents and cost data records. Details of the credit implementation and relevant additional costs of credits earned are

FIGURE 1. Exterior perspectives of the KBANK learning centre.

TABLE 1. LEED dashboard of the KBANK learning centre.

Subject	Possible Points
Sustainable Site	24/26
Water Efficiency	10/10
Energy and Atmosphere	18/35
Materials and Resources	9/14
Indoor Environmental Quality	12/15
Innovation in Design	4/6
Regional Priority	4/4

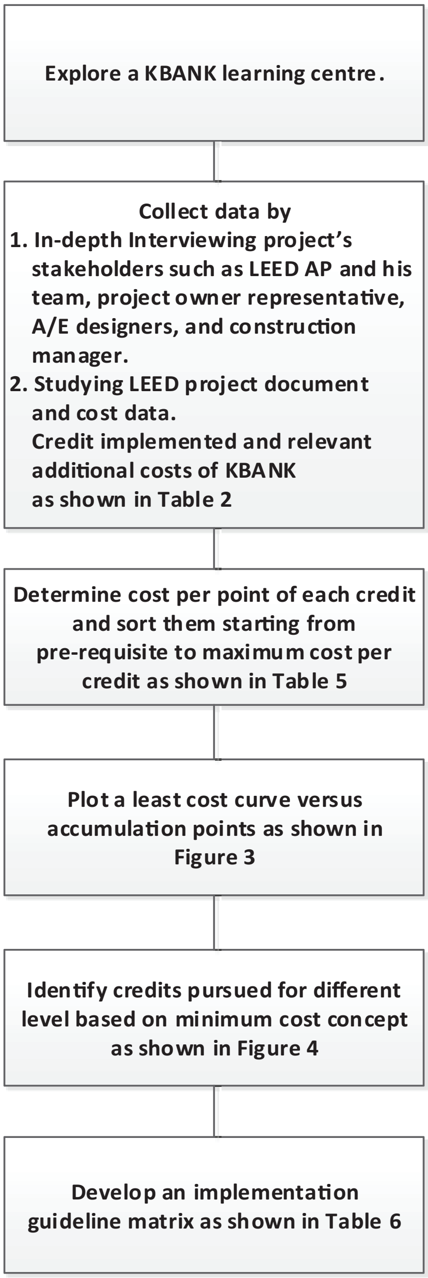
shown in Table 2. After determining the cost per point values of each credit, credits are sorted starting from pre-requisite to maximum cost per credit as shown in Table 5. Then, a least cost versus accumulation points curve is plotted as shown in Figure 3. Based on this example project, the credits pursued for different levels based on a minimum cost concept can be identified, as shown in Figure 4. Finally, an implementation guideline matrix and details of hidden cost credits can be shown in Tables 6 and 7, respectively.

'Additional costs' in the context of this research project refers to the extra costs incurred from traditional building requirements. The data for the additional costs in Table 2 was obtained through conducting in-depth interviews and studying LEED project documents and cost data breakdowns, which were both cost and non-cost related. For example, in SSp1 an earth dike, sedimentation tank, wheel wash tank, chemical storage, wash basin for paint brushes, silt fence and environmental report are not required in the context of a typical building project in Thailand. Therefore, the additional cost of $12,051 represents an extra amount required when constructing this green building. Some credits involve no additional costs, such as SSc4.3 or providing parking space for low-emitting vehicles. In this research, such credits are considered as zero additional cost credits since their details can be arranged during the design stage. However, this represents a subjective issue with varying opinions possible. Our research objective is to focus on presenting a method for determining the minimum cost curve of particular green building projects.

The credits in Table 2 comprise a range of variables and additional costs. The details of each credit are summarized in the description column. The only credit denied by the Green Building Council Institute (GBCI) was the sustainable site credit 5.1. Certain credits which were not included in this project are shown in Table 3.

Time cost tradeoff refers to a concept in construction planning used to accelerate construction scheduling, while minimizing increasing costs. In construction planning, the shortest project durations normally yield the highest project costs, and vice versa. This concept is similar to the project cost behavior of green buildings. Projects conforming to the platinum level of green buildings incur higher project costs than those at other levels. Therefore, the minimum project cost is able to be determined for projects at different certification levels. The cost slope or additional cost per point can be determined from Equation 1. All of the prerequisite items and credits are sorted according to the criteria shown in Table 4. Prerequisite items are the first

FIGURE 2. Model process for selecting credits pursued to obtain minimum project costs.



priority when sorting. They are categorized according to the applicable LEED system, which comprise SS, WE, EA, MR, and IEQ. The second priority concerns sorting credits from the lowest to the highest cost slope per point. A third priority is sorting credits from the highest to the lowest incremental point earned.

$$\text{Cost Slope} = \frac{\text{Additional Costs}}{\text{Points Earned}} \quad \text{Eq. 1}$$

TABLE 2. Description and cost details of each credit.

Y	N	Credit	Credit Description	Point	Additional Cost (US$)	Description
SUSTAINABLE SITES (26)				24		
Y		Prerequisite 1	Construction activity pollution prevention	P	$12,051	1.1 Construction of earth dike at a length of 490 m. for $3,465. 1.2 Install sedimentation tank at a cost of $303. 1.3 Install a wheel wash tank at a cost of $1,477. 1.4 Install chemical storage for an area of 20 square meters at $4,646. 1.5 Prepare paint wash basin at a cost of $1,263. 1.6 Silt fence to control soil erosion at a cost of $392. 1.7 Documents and reports on preparation at a cost of $505.
Y		Credit 1	Site selection	1	0	The project site is located in an appropriate site that meets SSc1 criteria.
Y		Credit 2	Development density and community connectivity	5	0	Select Option 2. Community Connectivity by investigating a project boundary using Google Maps, and conducting a site survey at the area of project.
	N	Credit 3	Brownfield redevelopment	0	n/a	The project was not developed in any brownfield site.
Y		Credit 4.1	Alternative transportation—public transportation access	6	0	Provide shuttle bus program for building occupants.
Y		Credit 4.2	Alternative transportation—bicycle storage and changing rooms	1	$1,010	Providing secure bicycle racks, storage, colour lane painting, and user's facilities, including showers and changing rooms in the building.
Y		Credit 4.3	Alternative transportation—low-emitting and fuel-efficient vehicles	3	0	Provide preferred parking for low-emitting and fuel-efficient vehicles. Special painting for FEV parking

TABLE 2. Description and cost details of each credit. *(Cont.)*

Y	N	Credit	Credit Description	Point	Additional Cost (US$)	Description
Y		Credit 4.4	Alternative transportation—parking capacity	2	0	This project provides 32 car parking spaces which meets and does not exceed minimum local zoning requirements.
	N	Credit 5.1	Site development—protect or restore natural habitats	0	0	GBCI rejects this claim credit due to the project having a large lawn area.
Y		Credit 5.2	Site development—maximize open space	1	0	Applicable for Case 1. Sites with local zoning for open space requirements. Use efforts in developing a project master plan at the initial stage of planning.
Y		Credit 6.1	Storm water design—quantity control	1	$2,222	A large retention pond is provided with a volume of 450 m^3. The retention pond is constructed on an area of 250 m^2 and has an average depth of 1.8 m. The excavating cost is $1,414. Another absorption pond is also constructed with an area of 40 m^2 and an average depth of 3.05 m., thus yielding a volume of 122 m^3. The excavation cost of this pond is $808.
Y		Credit 6.2	Storm water design—quality control	1	0	Managing storm water runoff in terms of quality by using sand infiltration systems. This corresponds with SSc6.1 as a synergy credit.
Y		Credit 7.1	Heat island effect—non-roof	1	0	In Option 2, the project initially involves preparing a 50% car parking space beneath the building.
Y		Credit 7.2	Heat island effect—roof	1	0	In Option 1, qualified Solar Reflectance Index roofs are used. They cover more than 75% of the roof surfaces which have SRI values of greater than 78 and 29 in low-sloped roof and steep-sloped roof, respectively.

TABLE 2. Description and cost details of each credit. *(Cont.)*

Y	N	Credit	Credit Description	Point	Additional Cost (US$)	Description
Y		Credit 8	Light pollution reduction	1	0	It is a synergy credit with IEQc6.1. There is no additional cost incurred in the lighting simulation process by using Dialux software. The cost is included in IEQc6.1.
WATER EFFICIENCY (10)				10		
Y		Prerequisite 1	Water use reduction—20% reduction	P	0	Reduce water using by 20% of baseline calculations. This was implemented together with the WEc3 credit, which seeks to reduce water usage by more than 40%.
Y		Credit 1	Water efficient landscape (reduce by 100%) No potable water use or irrigation	4	$252	In Option 2, this building uses non-potable water in an all landscaping area by planting the little yellow star varietal, which does not require regular irrigation and is a native shrub.
Y		Credit 2	Innovative wastewater technology	2	$1,263	Implement a natural wastewater treatment initiative by planting Papyrus and Cattail in ponds. The budget cost of such planting is $1,263.
Y		Credit 3	Water use reduction Reduce by 30% Reduce by 35% Reduce by 40%	4	$18,945	Use high-efficiency fixtures including faucets, water closets, and urinal flushing to reduce water usage by more than 40% of baseline calculations. This is considered concurrently with WEp1.
ENERGY and ATMOSPHERE (35)				18		
Y		Prerequisite 1	Fundamental commissioning of building energy systems	P	$10,101	Engage a CxA as an early stage in the design phase, the hired cost is $10,101.
Y		Prerequisite 2	Minimum energy performance	P	0	This is a synergy credit with EAc1 by establishing building envelope and systems to meet baseline requirements, and analyzing energy performance to comply with ASHRAE 90.1 -2007.

TABLE 2. Description and cost details of each credit. *(Cont.)*

Y	N	Credit	Credit Description	Point	Additional Cost (US$)	Description
Y		Prerequisite 3	Fundamental refrigerant management	P	0	The project chose Non-CFC base refrigerants in HVAC systems, thus there is no additional cost.
Y		Credit 1	Optimize energy performance (building renovation// improved by 46% for new buildings or 42% for existing building renovations)	9	$82,713	Perform whole building energy simulation in Option 1. Calculate a percentage improvement by comparing with baseline building performance, according to Appendix G of ASHRAE 90.1 -2007. The additional cost incurred is as follows: The project team used single green glass panels and sun shading devices. Additional cost is $3,769. For the building envelope, use of light weight bricks as external walls. No additional cost incurred. The project team chose to install a high performance central air-conditioning system with two cooling towers. The cost is $41,795. Preventing corrosion in air condenser units by using a special substance for long-term maintenance of the cooling tower at a cost of $34,356. Two sets of variable speed drive fans were installed at an additional cost of $2,793. Using T5 fluorescent bulbs and light colour paint in rooms to reduce luminous intensity with no additional cost.
	N	Credit 2	On-site renewable energy	0	n/a	Not applying for this credit.
Y		Credit 3	Enhanced commissioning	2	$10,101	The total cost of EAp1 and EAc3 is $20,202 by hiring a commissioning agent to perform these tasks.

TABLE 2. Description and cost details of each credit. *(Cont.)*

Y	N	Credit	Credit Description	Point	Additional Cost (US$)	Description
Y		Credit 4	Enhanced refrigerant management	2	0	The project team decided to install a high performance central air-conditioning system. It is a synergy credit with EAp3.
Y		Credit 5	Measurement and verification	3	$1,260	Five digital meters are installed on each floor of the residential zone, ground floor, and air conditioning systems.
Y		Credit 6	Green power	2	$5,051	The project team purchased green power certification from a renewable energy supplier for $5,051.
MATERIAL and RESOURCES (14)				9		
Y		Prerequisite 1	Storage and collection of recyclables	P	$2,525	Five storage rooms designed to collect and store different recycled materials, namely glass, plastic, paper, cardboard paper, metal and to install exhaust fans in every room at a cost of $2,525.
	N	Credit 1.1	Building reuse—maintain existing walls, floors, and roof	0	n/a	This project is a new building construction.
	N	Credit 1.2	Building reuse—maintain 50% of interior non-structural elements	0	n/a	This project is a new building construction.
Y		Credit 2	Construction waste management 50% recycled or salvaged 75% recycled or salvaged	2	$10,480	Hire a specialist in recycling and salvaging construction waste materials for a lump sum amount of $4,167. While management fees and the preparation and reporting of documents for 18 months is $6,313.
Y		Credit 3	Material reuse Reuse 5% Reuse 10%	2	$30,200	The additional cost of reused hardwood eaves and ceilings is $30,200.

TABLE 2. Description and cost details of each credit. *(Cont.)*

Y	N	Credit	Credit Description	Point	Additional Cost (US$)	Description
Y		Credit 4	Recycled content 10% of content 20% of content	2	0	Recycled content materials are fly ash in concrete, roof insulation, re-bar metal, and roof iron cast beams. There is no additional cost.
Y		Credit 5	Regional materials 10% of materials 20% of materials	2	0	The percentage of regional materials was 53.77% of total materials costs. There is no additional cost since it is incorporated with MRc3. and MRc4 as synergy credits.
Y		Credit 6	Rapidly renewable materials	1	0	The rapidly renewable materials in the project were cotton curtains. Their value equalled 2.92% of the total value of all building materials.
	N	Credit 7	Certified wood		n/a	Not applying for this credit.
INDOOR ENVIRONMENTAL QUALITY(15)				12		
Y		Prerequisite 1	Minimum indoor air quality performance	P	$1,712	Additional costs are fresh air supply fans and MERV 13 cabinets
Y		Prerequisite 2	Environmental tobacco smoke (ETS) control	P	0	A non-smoking policy will be posted at the building main entrance and printed and placed as a permanent document in guest rooms. As a training centre and residential rooms, the guests will be asked to sign an agreement form accepting the terms of the non-smoking policy before checking in.
Y		Credit 1	Outdoor air delivery monitoring	1	$11,105	Air velocity sensors, CO_2 sensors, controller system, control panel, and alarm module are installed to monitor outdoor air quality.
Y		Credit 2	Increased ventilation	1	$182	It was designed to have 30% more ventilation capacity than typical buildings, as specified by ASHRAE Standard 62.1-2007.

TABLE 2. Description and cost details of each credit. *(Cont.)*

Y	N	Credit	Credit Description	Point	Additional Cost (US$)	Description
Y		Credit 3.1	Construction IAQ management plan—during construction	1	$11,466	Renting 10 units of ventilation fans (3000 CFM) for 6 months for $1,263. Install plastic sheeting for covering, wrapping, and protecting entire air-conditioning plenums, ductwork, and ventilation ductwork during construction. Materials and labor costs were $884 and $303, respectively. Costs related to sequencing of some material cutting activities to minimize IAQ issues in separated area are $884. Housekeeping practices to ensure a clean job site twice a day cost $1,061. Management fees and document reporting by contractors are costed at $7,071. Therefore, total cost of IEQc3.1 is $11,466.
Y		Credit 3.2	Construction IAQ management plan—before occupancy	1	$1,010	Rent four air flushing fans for 7 days at $252.50/unit.
Y		Credit 4.1	Low-emitting materials—adhesives and sealants	1	0	Specify adhesive and sealant properties in building specifications according to LEED requirements. No additional cost.
Y		Credit 4.2	Low-emitting materials—paints and coatings	1	$2,290	Additional cost incurred from low VOC anti-rust paints for $2,290.
Y		Credit 4.3	Low-emitting materials—flooring systems	1	0	Floor system details are specified in building specifications that: Carpet floor products must be under the green label of the CRI. Wooden floors must contain low VOC materials. There is no additional cost.

TABLE 2. Description and cost details of each credit. *(Cont.)*

Y	N	Credit	Credit Description	Point	Additional Cost (US$)	Description
	N	Credit 4.4	Low-emitting materials—composite wood and agrifiber products		n/a	Not applying for this credit.
Y		Credit 5	Indoor chemical and pollutant source control	1	$1,894	The following activities were implemented: Exhaust fans were installed in copying and printing rooms, and their capacity totalled 600 CFM at a cost of $505. MERV 13 filters were installed as the fresh air intake system of the residential zone at a cost of $758. Fresh air intake system for mixing air from AHU in class room at a cost of $631. The total cost of this credit was $1,894.
Y		Credit 6.1	Controllability of systems—lighting	1	$27,917	The following costs incurred from the implementation of individual controls in guest rooms, task lightings in office spaces, and dimmers in open planned workstations. CBUS controlling system in multi-occupant spaces for $25,897. Two-way control switches for $2,020. Total cost of this credit was $27,917.
Y		Credit 6.2	Controllability of systems—thermal comfort	1	0	Use of thermostats to control room temperature at no additional cost.
Y		Credit 7.1	Thermal comfort—design	1	0	The installed HVAC system can provide temperature and relative humidity in a comfort zone according to ASHRAE 55-2004 at no additional cost.

TABLE 2. Description and cost details of each credit. *(Cont.)*

Y	N	Credit	Credit Description	Point	Additional Cost (US$)	Description
	N	Credit 7.2	Thermal comfort—verification	0	n/a	Not applying for this credit. (For residential project, IEQc7.2 was not eligible).
	N	Credit 8.1	Daylight and views—daylight	0	n/a	Not applying for this credit.
Y		Credit 8.2	Daylight and views—views	1	0	Following the designs, a direct line of sight to the outdoor environment via vision glazing above the finished floor is 90.61% of all regularly occupied areas. There was no additional cost.
INNOVATION and DESIGN PROCESS (6)				4		
Y		Credit 1.1	Water use reduction	1	0	Water Use Reduction, the project can reduce water usage by 58% more than the baseline. This was above the WE criteria of 18%, therefore, an automatic point could be gained with no additional cost.
Y		Credit 1.2	Site development—maximize open spaces	1	0	The area of open space exceeds local zoning requirements in this credit by 187.83%. Therefore, an automatic point could be gained with no additional cost.
Y		Credit 1.3	Heat island effect—non-roof	1	0	This project includes 100% of parking space under roof covering. Therefore, an automatic point could be gained with no additional cost.
Y		Credit 2	LEED accredited professional	1	$10,101	Hire LEED Accredited professional in a project team as a LEED consultant.
Regional Priority (6)				4		
Y		RPc1: EAc3	Enhanced commissioning	1	0	Gain 1 automatic point from EAc3 and EAp1.
Y		RPc2: WEc1	Water efficient landscape (reduce by 100%) No potable water use or irrigation	1	0	Regional Priority credit, for option 2. Non-use of potable water in the landscaping area. Due to the selection of native shrubs, water usage can be reduced by 100%.

TABLE 2. Description and cost details of each credit. *(Cont.)*

Y	N	Credit	Credit Description	Point	Additional Cost (US$)	Description
Y		RPc3: WEc2	Innovative wastewater technology	1	0	The project uses natural wastewater treatment ponds in landscape areas.
Y		RPc4: WEc3	Water use reduction	1	0	Using high-efficiency fixtures, water usage can be reduced by more than 40%.

TABLE 3. Non-submitted credits of the KBANK learning centre project.

Subject/Credit	Description
SSc3	Brownfield Redevelopment
SSc5.1	Site Development—Protect or Restored Habitat
EAc2	On-Site Renewable Energy
MRc1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof
MRc1.2	Building Reuse—Maintains 50% of Interior Non-Structural Elements
MRc7	Certified Wood
IEQc4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products
IEQc7.2	Thermal Comfort—Verification
IEQc8.1	Daylight and Views—Daylight

TABLE 4. Credit sorting criteria.

Sorting Priority	Description	Criteria
1	Prerequisite items	LEED subjects
2	Cost slope	Lowest to highest cost slope per point
3	Incremental point	Highest to lowest point earned

In Table 5, all credit items which have $0 are sorted from the highest to the lowest incremental points earned from line number 9 to 25. From line number 26 to the end of Table 5, they are sorted according to the cost slope per point. The lowest cost slope calculation is chosen to be performed first. By setting priorities like this, a minimum cost curve can be developed, as shown in Figure 3. This concept can help building owners and design teams to pursue credits based on the lowest cost concept in order to achieve different levels of certification within green building construction.

TABLE 5. Sorting credits according to additional cost per point.

ID	Prerequisite/ Credit	Cost premium to earn credit (USD)	Point earned	Cost slope per point	Accumulation points	Accumulation cost premium (USD)	Level
1	SSp1	12,051	—	—	—	12,051	Prerequisite
2	WEp1	—	—	—	—	12,051	
3	EAp1	10,101	—	—	—	22,152	
4	EAp2	—	—	—	—	22,152	
5	EAp3	—	—	—	—	22,152	
6	MRp1	2,525	—	—	—	24,677	
7	IEQp1	1,712	—	—	—	26,389	
8	IEQp2	—	—	—	—	26,389	
9	SSc4.1	—	6	—	6	26,389	Pre-Certified
10	SSc2	—	5	—	11	26,389	
11	SSc4.3	—	3	—	14	26,389	
12	SSc4.4	—	2	—	16	26,389	
13	SSc5.2 & IDc1.2	—	2	—	18	26,389	
14	SSc7.1 & IDc1.3	—	2	—	20	26,389	
15	EAc4	—	2	—	22	26,389	
16	MRc4	—	2	—	24	26,389	
17	MRc5	—	2	—	26	26,389	
18	SSc1	—	1	—	27	26,389	
19	SSc7.2	—	1	—	28	26,389	
20	MRc6	—	1	—	29	26,389	
21	IEQc4.1	—	1	—	30	26,389	
22	IEQc4.3	—	1	—	31	26,389	
23	IEQc6.2	—	1	—	32	26,389	
24	IEQc7.1	—	1	—	33	26,389	
25	IEQc8.2	—	1	—	34	26,389	
26	WEc1 &RPc2 (WEc1)	252	5	50	39	26,641	

TABLE 5. Sorting credits according to additional cost per point. *(Cont.)*

ID	Prerequisite/ Credit	Cost premium to earn credit (USD)	Point earned	Cost slope per point	Accumulation points	Accumulation cost premium (USD)	Level
27	IEQc2	182	1	182	40	26,823	Certified
28	EAc5	1,260	3	420	43	28,083	
29	WEc2 &RPc3 (WEc2)	1,263	3	421	46	29,346	
30	SSc4.2	1,010	1	1,010	47	30,356	
31	IEQc3.2	1,010	1	1,010	48	31,366	
32	SSc6.1 and SSc6.2	2,222	2	1,111	50	33,588	Silver
33	IEQc5	1,894	1	1,894	51	35,482	
34	IEQc4.2	2,290	1	2,290	52	37,772	
35	EAc6	5,051	2	2,526	54	42,823	
36	WEc3/ IDc1.1 & RPc4 (WEc3)	18,945	6	3,158	60	61,768	Gold
37	EAc3 & RPc1 (EAc3)	10,101	3	3,367	63	71,869	
38	MRc2	10,480	2	5,240	65	82,349	
39	EAc1	82,713	9	9,190	74	165,062	
40	IDc2	10,101	1	10,101	75	175,163	
41	IEQc1	11,105	1	11,105	76	186,268	
42	IEQc3.1	11,466	1	11,466	77	197,734	
43	IEQc6.1 and SSc8	27,917	2	13,959	79	225,651	
44	MRc3	30,200	2	15,100	81	255,851	Platinum

In Table 5, prerequisite items require cost premiums amounting to $26,389. On this project, the certification level can be reached by spending $26,823. By correct guidance being given to a design team by LEED-AP during the design stage and an elaboration report being submitted to the USGBC, certification was able to be earned. To attain a silver level, an expenditure of $6,765 is needed on IEQc2, EAc5, WEc2, RPc3, SSc4.2, IEQc3.2, SSc6.1, and SSc6.2 to acquire the sufficient accumulated points of 50. For a gold level on this project, implementation in credits of IEQc5, IEQc4.2, EAc6, WEc3, IDc1.1, and RPc4 are required with a cost of $28,180 in order to attain the required number of accumulation credits of 60.

Ultimately, EAc3, RPc1, MRc2, EAc1, IDc2, IEQc1, IEQc3.1, IEQc6.1, SSc8, and MRc3 should be performed in the context of this project to reach a platinum level with an additional cost of $194,083. The accumulation credits and costs of this project then are 81 and $255,851, respectively. The accumulation costs and points obtained from Table 5 can be plotted as shown in Figure 3. This figure shows an incremental slope running from low to high starting from prerequisite to platinum. In Figure 3, each coordinate represents (points, $). The points can be substituted with credits on the x-axis. The results can be written in Figure 4. This figure enables us to identify high cost through to low cost credits. These research results are summarized in Table 6. Low cost credits are classified as $0 to $253 per credit. High cost credits are more expensive than $2525 per credit. Some credits are easy to implement, whereas others are more difficult. Easy to execute credits comprise those which are comparatively simple and not complicated to implement. Some credits can be independently justified, or may just comprise ordinary checklist items. While hard to execute credits are complicated to identify in order to isolate credits; they represent related-credits and can be considered with project stakeholders as constituents of a multilateral approach in long-run conditions. These findings were achieved through interviewing the project manager, LEED consultant, A/E designers and construction manager. The hard versus easy credit distinctions, with low/moderate/high cost per credit categorizations, identified within this project are summarized in Table 6. Wu et al. (2016) explained that innovation-related points are the easiest to obtain, while energy-related and material-related are the most difficult. This research found that most MR credits in Thailand are difficult to obtain, except MRp1 and MRc3. However, different countries may have different costs and difficulties in implementing operations. Meanwhile, most SS credits may be classified as easy, except SSc5.2, SSc6.1 and SSc6.2.

TABLE 6. An implementation guideline matrix for the KBANK learning center.

	No Cost to Low Cost	Moderate Cost	High Cost
Easy to Execute or Implement	SSc1/SSc2/SSc4.1/ SSc4.3/SSc4.4/ SSc7.1&IDc1.3/ SSc7.2/EAp3/ EAc4/IEQp2/ IEQc6.2/IEQc8.2	SSc4.2/MRp1/ IEQc4.2	WEp1/WEc3/ IDc1.1&RPc4/ EAp1EAc3&RPc1/ EAc6/ MRc3/IEQc1/ IDc2
Hard to Execute or Implement	SSc5.2 & IDc1.2/ WEc1 &Rpc2/EAp2/ MRc4/ MRc5/MRc6/ IEQc4.1/IEQc4.3/ IEQc7.1	SSc6.1/SSc6.2/ WEc2&Rpc3/ EAc5/IEQp1/ IEQc2/ IEQc3.2/ IEQc5	SSp1/EAc1/ MRc2/ IEQc3.1/ IEQc6.1&SSc8

FIGURE 3. Least cost curve versus accumulation points.

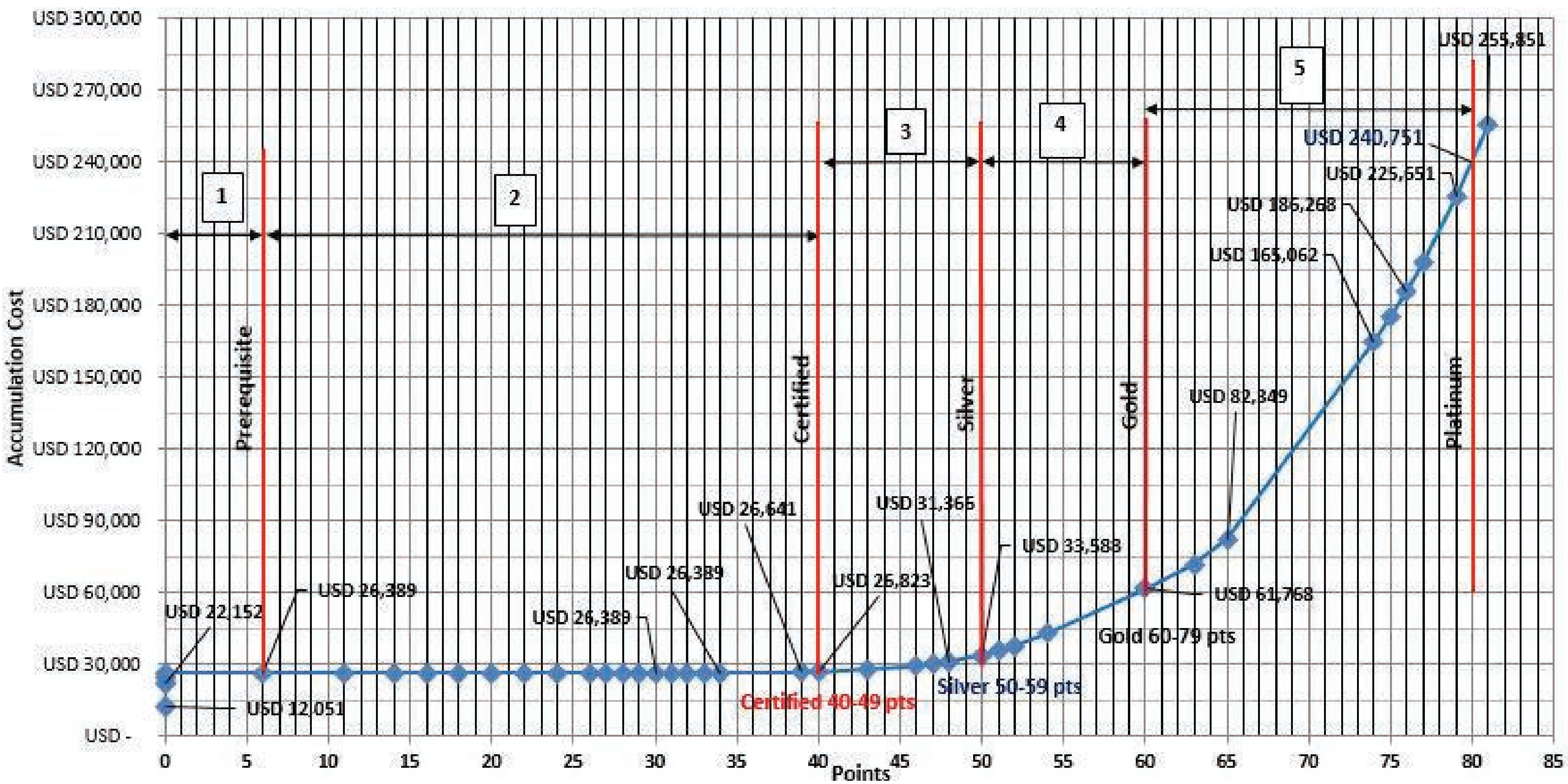
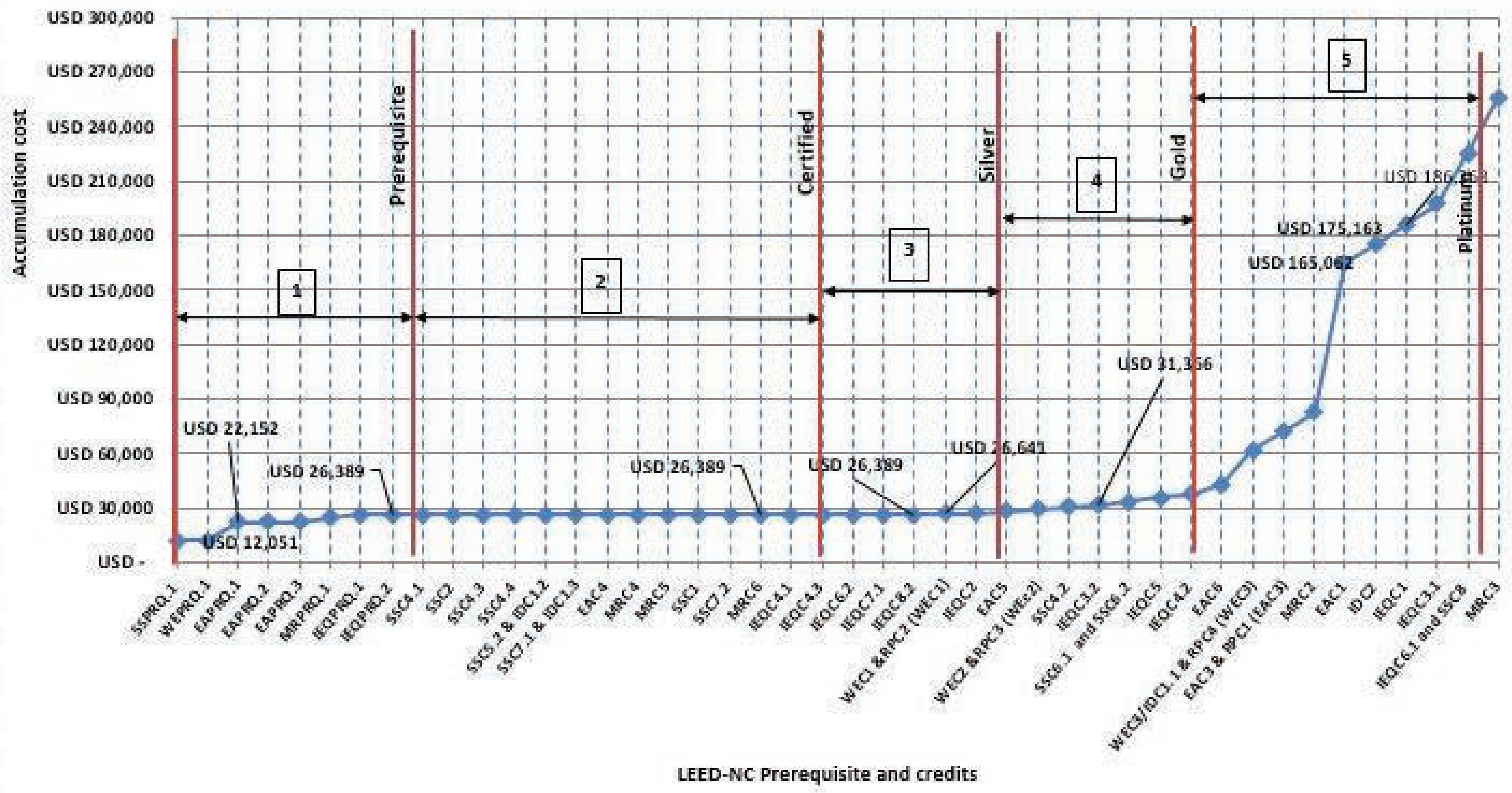


FIGURE 4. Credits pursued versus accumulation costs.



Indirect cost

From our study, some credits have zero additional costs attached, while at the same time are able to earn some credits, as shown in Table 2. This research paper identifies and summarizes 30 such credits, as shown in Table 7. These credits could be called hidden cost credits.

TABLE 7. Classification of the indirect cost credit which have zero additional costs.

Credit	Credit Description	Point	Additional Cost (US$)	Description
1) SSc1	Site selection	1	0	This plot of land is a typical land plot within KBANK's land acquisition department.
2) SSc2	Development density and community connectivity	5	0	These are the jobs identified by the LEED consultant team to be dealt with by the A/E designers. The indirect cost is included in the consultant and designer's fee.
3) SSc4.1	Alternative transportation—public transportation access	6	0	This is an accommodation prepared by the KBANK learning centre. The expenditure is not shown in this item.
4) SSc4.3	Alternative transportation—low-emitting and fuel-efficient vehicles	3	0	Special painting for FEV parking. The preferred parking had been prepared since the initial design phase of the project.
5) SSc 4.4	Alternative transportation—parking capacity	2	0	All parking capacity was re-checked and had been prepared since initial design phase.
6) SSc5.2	Site development—maximize open space	1	0	The character of buildings and surroundings are lodging style involving a training centre. The executives of KBANK decided to keep the existing area for green purposes.
7) SSc6.2	Storm water design—quality control	1	0	The combination cost is within SSc6.1
8) SSc7.1	Heat island effect—non-roof	1	0	There is no additional cost in the initial stage of the design.
9) SSc7.2	Heat island effect—roof	1	0	The project budgeting of these components is covered in the design stage.

TABLE 7. Classification of the indirect cost credit which have zero additional costs. *(Cont.)*

Credit	Credit Description	Point	Additional Cost (US$)	Description
10) SSc8	Light pollution reduction	1	0	The cost is included in IEQc6.1.
11) WEp1	Water use reduction—20% reduction	P	0	Using ordinary fixtures, water usage can be reduced by more than 20%.
12) EAp2	Minimum energy performance	P	0	To achieve the minimum energy performance of the building within the design based on common practices,
13) EAp3	Fundamental refrigerant management	P	0	The project chose Non-CFC base refrigerants inherent in the new technology of all HVAC systems.
14) EAc4	Enhanced refrigerant management	2	0	The project team decided to install a high performance central air-conditioning system. It is a synergy credit with EAp3.
15) MRc4	Recycled content 10% of content 20% of content	2	0	Recycled content materials in the construction business are now available, A/E designers and LEED consultants must endeavour to construct projects using such eco-products.
16) MRc5	Regional materials 10% of materials 20% of materials	2	0	The percentage of regional materials comprised 53.77% of total materials costs. There is no additional cost since this is incorporated with MRc3. and MRc4 as synergy credits.
17) MRc6	Rapidly renewable materials	1	0	There is no additional cost since this is incorporated with MRc3. MRc4 and MRc5 as synergy credits. They were considered within the initial project spreadsheet.The products were available and within the budget.
18) IEQp2	Environmental tobacco smoke (ETS) control	P	0	A non-smoking policy will be posted at the building main entrance and printed and placed as a permanent document in guest rooms. Guests using the training centre and residential rooms, will be asked to sign agreement forms accepting the terms of the non-smoking policy before checking in.

TABLE 7. Classification of the indirect cost credit which have zero additional costs. *(Cont.)*

Credit	Credit Description	Point	Additional Cost (US$)	Description
19) IEQc4.1	Low-emitting materials—adhesives and sealants	1	0	Specified adhesive and sealant properties in building specifications sourced according to LEED requirements. No additional cost incurred. Plenty of eco-products meet the green requirements at no additional cost.
20) IEQc4.3	Low-emitting materials—flooring systems	1	0	Floor system details are specified in the building design stage.
21) IEQc6.2	Controllability of systems—thermal comfort	1	0	Thermostats to control room temperature are available for each room.
22) IEQc7.1	Thermal comfort—design	1	0	The installation of HVAC systems provides temperature and relative humidity in a comfortable zone according to ASHRAE 55-2004. This is a common practice for engineering designers.
23) IEQc8.2	Daylight and views—views	1	0	A/E designers with LEED consultants use their calculations in compiling the initial Excel spreadsheet.
24) IDc1.1	Water use reduction	1	0	This is a combination cost with WEc3
25) IDc1.2	Site development—maximize open spaces	1	0	The area of open space exceeds local zoning requirements in this credit by 187.83%. Thus, an automatic point could be gained with no additional cost.
26) IDc1.3	Heat island effect—non-roof	1	0	This project includes 100% of parking space under roof covering. Therefore, an automatic point could be gained with no additional cost.
27) RPc1: EAc3	Enhanced commissioning	1	0	Gains one automatic point from EAc3 and EAp1.
28) RPc2: WEc1	Water efficient landscape (reduced by 100%) No potable water use or irrigation	1	0	This gains one automatic point from WEc1.
29) RPc3: WEc2	Innovative wastewater technology	1	0	The project uses natural wastewater treatment ponds in landscape areas. Gains one automatic point from WEc2.
30) RPc4: WEc3	Water use reduction	1	0	This gains one automatic point from WEc3.

TABLE 8. Cost premiums for each green building level of the KBANK learning center.

Level	Project Cost	Cost Premium	Incremental Percentage	Kats et al. (2003)
Traditional Building	2,868,832	—	—	—
Certified	2,895,655	26,823	0.93%	0.66%
Silver	2,902,420	33,588	1.17%	2.11%
Gold	2,930,600	61,768	2.15%	1.82%
Platinum	3,124,683	255,851	8.92%	6.50%

CONCLUSIONS

The model presented in this research could be used as a guideline in determining the project costs of green buildings by adopting a minimum cost approach to attain different levels of LEED certification. The processes recommended are helpful in prioritizing credits by their cost. This potentially will help a project owner decide on selecting credits to promote efficient decision making during the design development stage of a project. In this case study, an extra investment from traditional building practices was employed to earn a certified level of 0.93%, as shown in Table 8. This is consistent within the range given by Matthiessen and Morris (2004). They found that most certified LEED construction projects involve a premium cost of between 0% and 3% when compared to a specific project's initial budget. The cost premiums of silver, gold, and platinum levels are slightly higher than costs involved in traditional building projects at 1.17%, 2.15%, and 8.92%, respectively. The incremental percentages are higher than Kats et al. (2003)'s results, except in the case of silver certification. However, different countries may have different cost slopes to implement. Different countries may have alternative guideline matrices, as suggested in Table 6. More research could be undertaken in the context of different countries to determine the particular costs and difficulty levels involved in the implementation of each credit. Finally, the methodology for determining the minimum project cost concept is developed as a guideline that can be applied to any green building project budgeting process.

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