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SELECTING SUSTAINABLE BUILDING MATERIALS USING SYSTEM DYNAMICS AND ANT COLONY OPTIMIZATION

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Abstract. Selecting environmentally preferable building materials is one way to reduce the negative environmental impacts associated with the built environment. This paper proposes a framework that incorporates environmental and economic constraints while maximizing the number of credits reached under the Leadership in Energy and Environmental Design (LEED) rating system. The framework helps decision makers with the appropriate selection of conventional and green building materials. It consists of two modules: System Dynamics module and Ant Colony Optimization module. The paper describes the developments made in these two modules, where the selection of building materials is carried out based on LEED credits and costs. The proposed framework provides more credits when using environmentally friendly materials. A case study of residential building is presented to demonstrate the main features of proposed framework.

Keywords: materials selection, environmental sustainability, green building materials, LEED, system dynamics, ant colony optimization.

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Introduction

Buildings have a significant impact on the environment due to emissions utilization of resources and energy. Most project stakeholders in the construction industry realize the significant impact of selecting the proper material for constructing residential buildings. Large or small projects gain more benefits from taking appropriate decision with respect to material selection throughout the construction phase. On a global scale, buildings account for 16% of the world's freshwater usage, 25% of its wood harvest, and 40% of its material and energy flows; nearly 25% of all ozone-depleting chlorofluorocarbons are emitted by building air conditioners and processes to manufacture building materials (Bilec 2007). Green or sustainable buildings use key resources like energy, water, materials, and land much more efficiently than buildings that are simply built according to recognized codes. They also create healthier work, learning, and living environments, which contribute to the improvement of employee and student health, comfort, and productivity. Sustainable buildings are cost-effective over their life cycle, because of their minimized operation, maintenance, and utility costs (Kats 2003).

Green buildings are high-quality buildings; they last longer, cost less to operate and maintain, and provide greater occupant satisfaction than standard developments. Sophisticated buyers prefer them and are often willing to pay a premium for their advantages. What surprises many people unfamiliar with this design movement is that good green buildings often cost little or no more to build than conventional designs. Commitment to better performance and close teamwork throughout the design process are very important aspects. Some existing researches on the construction phase have assumed the environmental impacts are negligible, while others have indicated that these impacts associated with construction are underestimated. Since a limited amount of research has focused on the environmental effects of the construction phase, this research tries to fill the gap in the existing knowledge of construction life cycle of the residential buildings, and it focuses on economic and environmental impacts for construction processes.

Buildings can be green without a single standard being applied to it. Actually, to reduce costs, green

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buildings are often constructed using a rating system exactly as a guide without ever formally registering the building. Green rating systems do offer a way to measure how green a building is and can supply recognition and validation of that level of commitment. Over the last few years, the green building movement has gained tremendous momentum. The United States Green Building Council (USGBC), a national nonprofit organization, has grown dramatically in membership. The USGBC's Leadership in Energy and Environmental Design (LEED) rating system has been widely embraced both nationally and internationally as the green building design standard (Kats 2003). The primary purpose of USGBC LEED certification is to make buildings "greener" by promoting a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality (Rajendran *et al.* 2009). A lot of research efforts have been made on sustainability and LEED rating system (Castro-Lacouture *et al.* 2009; Sobotka, Rolak 2009; Medineckiene *et al.* 2010; Denzer, Hedges 2011; Azhar *et al.* 2012).

Selecting building material is deemed important in sustainable design because of the efforts of extraction, processing, and transportation steps that are required to process them. Buildings construction activities cause air and water pollution, destroy natural habitats, and deplete natural resources. As stated before, there are a wide variety of material choices that can be selected during design phase, which influence the construction and operation of buildings. In order to address these impacts, many sectors of the building industry have developed products, services, and new practices. It is worth to note that environmentally friendly material strategies are becoming more widespread. The material selection problem has been treated extensively through many approaches, such as multi-objective optimization, ranking methods, index-based methods, and other quantitative methods like cost benefit analysis (Marzouk *et al.* 2010).

This research deals with material selection credits in the existing LEED rating system for new construction and major renovation projects. The proposed rating system makes an evaluation for the performance of the case study building in terms of the characteristics of materials, such as the proportion of recycled content, renewable materials, emissions from materials, and thermal comfort. For each criterion, the rating system awards points if requirements are achieved. In this research, LEED credits are considered as a factor that is required for getting building score due to using some materials along its construction life cycle. By computing the achieved score from utilizing various construction materials, the optimal combinations of these materials can be identified considering the resulting costs. Hence, this research is designed to develop a new framework that allows improving building construction decision making through the optimal selection of construction material for residential buildings and its relevance to sustainable design and construction.

1. Methods

1.1. Proposed framework

Designing frame work for selecting the proper material for constructing residential buildings is a great challenge in building construction. The decision regarding the selection of building materials has become more difficult in recent years as several green and conventional alternatives are becoming available. Selecting inappropriate materials can be expensive, and more importantly, may preclude the achievement of the desired environmental goals. Selecting the proper building materials depends on several factors, which include financial and environmental factors. The financial factor includes vendor prices and other labor and equipment expenses that are needed to perform the corresponding construction activity. The Environmental factor is quantified using the credits of the LEED rating system for new construction and major renovations that are related to material selection. The selected building materials should achieve the required aim that highlights the importance of using green materials, which leads to less cost and higher LEED credits.

This research presents a framework, which helps in providing the potential to assist decision makers and practitioners to make appropriate selection from various building materials throughout the construction phase. The developed framework helps decision makers to calculate the cost and the associated LEED credits for different materials alternatives. Also, it selects the proper materials that are performed in case of achieving the high score of LEED credits at reasonable and acceptable cost. The proposed framework consists of two modules to improve building construction decision making through the selection of materials. The System Dynamics (SD) module is one of the modules that considers both LEED and budget constraints to address realistic scenarios experienced by decision makers. In other words, the SD module attempts to know the materials while also satisfying more LEED credits and less money. The second module, named modified ant colony multi-objective optimization, is applied to search for the optimal solution of building material selection from the available database of green and conventional material alternatives. To illustrate the mechanism of SD module and modified ant colony multi-objective optimization, a case study of a villa construction is presented.

1.2. SD module

SD is a policy modeling methodology based on the foundations of decision making, feedback mechanism analysis, and computer simulation. Decision making focuses on how actions are to be taken by decision makers. Feedback deals with the generated information to provide insights into the subsequent decision-making process in similar future cases. Computer simulation provides decision makers with a tool to work in a virtual environment where they can view and analyze the effects of their decisions in the future, unlike in a real social system (Monga 2001). Plenty of efforts have been spent to model construction operations using SD (Peña-Mora, Li 2001; Tangirala *et al.* 2003; Lee *et al.* 2006; Taylor, Ford 2008; Prasertrungruang, Hadikusumo 2009; Thompson, Bank 2010). Although these efforts model construction projects using system dynamics, there are no efforts that exist to model building materials selection via the SD approach. The developed SD module in the proposed framework estimates the cost and the associated LEED credits for different materials alternatives to select the proper materials. This module is implemented using one of SD software called "STELLA". The module consists of three components: material input data, STELLA simulation model, and decision-making process.

The first component of the SD module is material input data. Building material should be defined first to classify each type of material in a given system. The procedure followed by the first component of the SD module can be summarized as follows:

(1) Building material systems should be defined in order to use them in mapping the simulation model;
(2) Defining building material alternatives for each system;
(3) Subsequently, defining and assigning the required data that are utilized by the simulation module to perform its tasks. These data include the total cost and LEED credits awarded, as well as the time of applying each material to take its impact on the building time schedule;
(4) Finally, the data can be changed and modified by the user or decision maker in any time and according to the market status.

STELLA simulation model is part of the SD module, developed for estimating the total LEED credits and total cost of materials in a residential building. The simulation model is developed using STELLA software, which is an icon-based modeling 'language' that provides easy-to-use generic building blocks through which specific components of building material selection systems can be modeled. The generic characteristics of STELLA objects can be used for modeling a variety of dynamic systems. For example, a stock can be used to model storage of any tangible or intangible quantities; flow can be adopted to model any time series of flow of quantities. Similarly, a connector can carry information about variables while a converter can be used to model functional relationships. STELLA can also provide some built-in functions (mathematical, logical, if-then-else, random, delay) and graphical interface (Graphs, Tables, Sliders, Sectors). To simulate a SD model using STELLA and build this model, it is required to define the objects that are used in the model. In this model, each system of building material systems includes many alternative materials, and each material has two types of information: cost and LEED credit. Table 1 provides a list of building materials selection components and equivalent modeling objects in STELLA environment that are used for modeling. After defining the objects that are used in the model, the process of building model network is performed, as depicted in Figure 1.

The mapping process can be described as follows:

(1) Draw one stock block for building that has two inflows (cost impact and LEED credit impact);
(2) Draw two inflow blocks (flow blocks) that gather information from converters to model any time series of quantities' flows;
(3) Draw two converter blocks to hold the two criteria (cost and LEED credit);
(4) Draw the building material systems in converter blocks, each system have many converters related to the alternatives that are used in these systems;
(5) Connect all converters with suitable blocks by connectors.

Then, insert data into each converter, taking into consideration the execution time of the building construction. Finally, after inserting all data of materials according to the chosen scenario from the group of alternatives in building material systems, the simulation model is executed. The generated results include the total cost value and the total LEED credits. In addition, three charts for results are generated: cost vs. execution time, LEED credit vs. execution time; and LEED credit vs. cost. These charts depict all results in each scenario that is followed.

Table 1. Modeling building materials using STELLA

Building materials components	STELLA object
Building	Stocks
Cost and LEED credit impact	Flows
Data (Cost and LEED credits) of materials	Converters
Functional relationships and links	Connectors

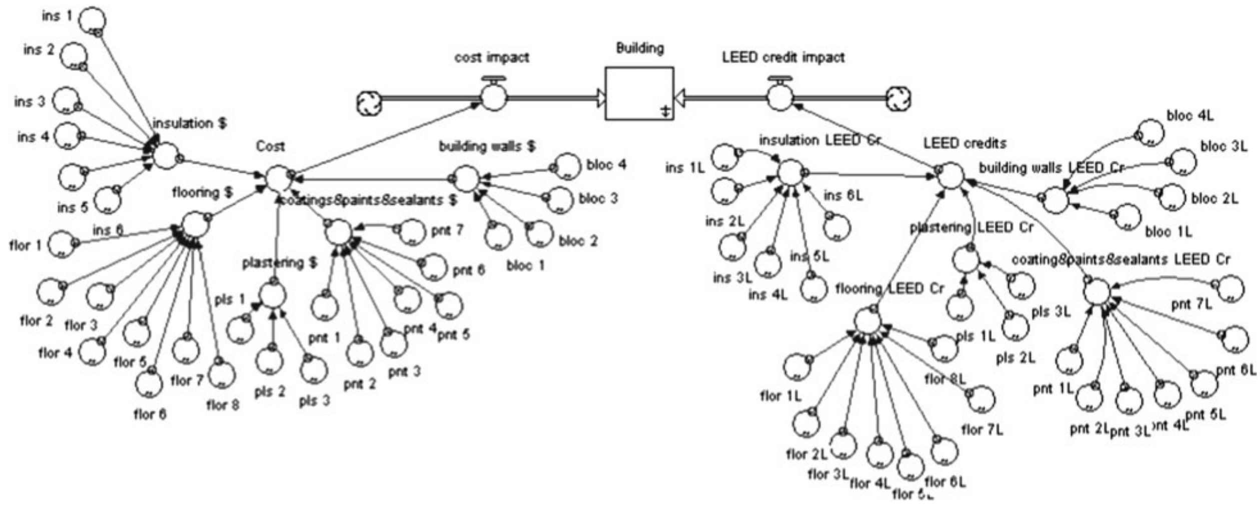

Fig. 1. Mapping model network

1.3. ACO module

A great challenge faces the decision makers to utilize building materials while considering minimizing cost and maximizing LEED credits that are achieved by using green alternative materials. Ant Colony Optimization (ACO) is a population-based, artificial multi-agent, general-search technique for the solution of difficult combinatorial problems that searches for optimal solutions in traversing multiple paths (Birattari *et al.* 2007; Huang, Liao 2008; Socha, Dorigo 2008). The characteristic of real ant colonies is exploited in ACO algorithms in order to solve, for example, discrete optimization problems (Blum 2005). Ant system is the original ACO algorithm. Researchers have been dealing with the ACO algorithm in solving the various problems of construction projects. Marzouk *et al.* (2009) used ant colony method to optimize launch girder bridges.

They performed a time-cost trade-off analysis to optimize the use of utilized resources of lunching girder method. Their optimization module utilized ACO to carry out the optimization analysis. They solved and calculated both deterministic and probabilistic CPM/PERT networks by ACO. The applicability of their proposed algorithm was demonstrated for a typical construction project and another project with uncertain data. A lot of research efforts have made that apply ACO algorithms in construction (Christodoulou 2010; Kalhor *et al.* 2011; Mokhtari *et al.* 2011).

In this research, ACO module is considered as the second part of the proposed framework that performs a cost-LEED credits analysis to optimize the selection of building materials. The developed ACO module provides decision makers with a set of optimal solutions. The developed optimization module uses a modified ant colony optimization algorithm (ACMO) to perform multi-objective optimization of the building material selection. It combines two objective functions (total cost and LEED credits) into one fitness function to be optimized by ACO. This is done by modifying ACO to account for multi-objective optimization. The function-transformation method is used and integrated with ACO. Function-transformation method depends on combining the considered objective functions into one nondimensional objective function to be evaluated using evolutionary algorithm. There are four approaches of function-transformation: lower-bound approach, alternative lower-bound approach, upper-bound approach, and upper lower-bound approach. In this module, upper lower-bound approach is the one that is applied. The function in Eq. (1) is considered to be the general form for optimization module objective function (Marzouk *et al.* 2009).

$$F\,trans(x) = \sum_{i=1}^{Q} \frac{F_i(x) - F_i^o}{F_i^{\max} - F_i^o}, \qquad (1)$$

where: $F_i(x)$ is the objective function i, $F\,trans(x)$ is the transformed function of i, F_i^o is the minimum value of objective function i, $F_i^{\max}$ is the max value of objective function, $i = 1,2,3,\ldots, Q$, and Q is the number of the objective functions. In this case, the fitness value has a value between 0 and 1.

Integrated ant colony multi-objective algorithm and the function-transformation method are carried out as follows:

(1) Estimating the fitness utilization function-transformation method in order to combine the cost and LEED credits into a single-objective function. Upper lower-bound approach has been adopted as following:

$$Fitness(k,t)$$
$$W_C * \left(\frac{Cost(k,t) - Cost_{\min}}{Cost_{\max} - Cost_{\min}} \right) + W_L * \left(\frac{LEED(k,t) - LEED_{\min}}{LEED_{\max} - LEED_{\min}} \right), \quad (2)$$

where: $Fitness(k,t)$ is a combined fitness for ant k at iteration t, $Cost(k,t)$ and $LEED(k,t)$ are the total cost and LEED credits of ant k at iteration t, $Cost_{\min}$ is the minimum value of total cost within iteration t, $LEED_{\min}$ is the minimum value of total LEED credits within iteration t, $Cost_{\max}$ is, $LEED_{\max}$ is the maximum values within iteration t, and W_C and W_L are relative consideration weights of the total cost and LEED credits, relatively, where $W_C + W_L = 1.0$.

(2) Estimating the change (from iteration t to iteration $t+1$) in pheromone concentration from i to j in ant k as follows:

$$\Delta\tau_{ij} = \sum_{k=1}^{m} \begin{cases} \frac{R}{Fitness(k,t)} & \text{if option } l \text{ is chosen by ant } k, \\ 0 & \text{otherwise,} \end{cases} \quad (3)$$

where: R is a constant called the pheromone reward factor.

(3) Estimating pheromone concentration (for iteration t) as follows:

$$\tau_{ij}(t) = \rho\tau_{ij}(t-1) + \Delta\tau_{ij}, \quad (4)$$

where: ρ is a constant called the pheromone evaporation rate factor. Estimating the probability that option l_{ij} is chosen by ant k at iteration t as follows:

$$P_{ij}(k,t) = \frac{\tau_{ij}(t)}{\sum \tau_{ij}(t)}. \quad (5)$$

(4) Storing Pareto vector for each generation in order to obtain Pareto front that contains optimal solutions.

Figure 2 illustrates the mechanism of ACO module. The module starts by identifying all optimization parameters and then the moving process of ants begins from first system (i.e. category of material type) to the last system. Finally, the ACO applies its functions to reach the solutions and terminates the process when the criteria are met. The module is developed in MATLAB Version 7.7.0471, which implements different user interfaces as shown in Figure 3. The interfaces contain the options of performing running and analyzing processes and inserting data of the building materials in a database to carry out optimization process.

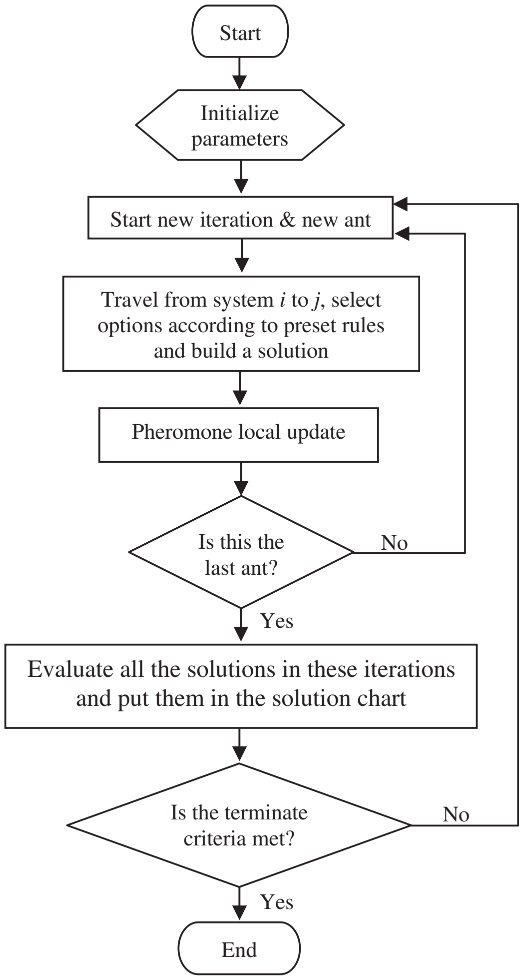

Fig. 2. Flowchart of ACMO module

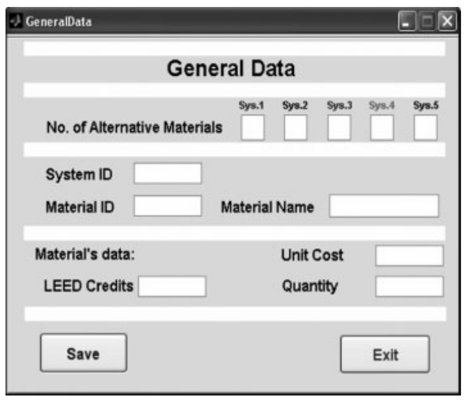

Fig. 3. Optimization module user interface

The optimization parameters interface contains the entities within the studied optimization functions. The developed program for this model connects a database developed by Microsoft Access that contains the case general data (i.e. building material systems and alternative materials) with other model components. Once all entities are fed, the execution process of the program begins. Finally, the program runs the optimization module function to provide different types of charts and the list of all solutions considering total cost and LEED credits for each iteration.

2. Results and discussion

A case study is presented to demonstrate the results of the proposed framework. This case study considers the construction of a residential building (Villa type A) that consists of two floors (ground and first) with a total area 400 m^2 in northern Egypt. The main types of work in the case study include civil and architectural works. A total of five building systems are considered in the case. These systems are insulation; flooring; plastering; coatings, paints, and sealants; and building walls. The building materials that are used for modeling this case study are obtained from Egyptian and international markets. The environmental properties required by LEED-based system are obtained from Building for Environmental and Economic Sustainability (BEES) software. It provides reliable information for a wide range of construction materials. However, some of the materials available in Egyptian and international markets, as well as some of its properties required by the LEED system, are not included in BEES. Thus, an effort was made to get their properties from local sources and experts to complete all required data. Finally, the cost per unit for each material is obtained from local materials' suppliers. The materials' costs that are used in this model include other expenses needed to perform the required type of work such as labor.

2.1. Case input data

In modeling this case study, two types of materials (traditional materials and green building materials) are considered along with their alternatives. The input data for the case study are listed in Appendix 1. Table 2 lists the LEED credits and associated cost for systems' alternatives. The data consist of building materials systems with their alternative materials and materials' total costs and LEED credits.

Table 2. General data of case study

Material		Type	LEED credit	Cost (LE)
System 1: Insulation				
ins 1	Bitumen	Traditional	–	4350
ins 2	Polystyrene sheets	Traditional	–	9570
ins 3	Tile foam	Green	1	7540
ins 4	Blue foam	Green	1	6760
ins 5	Lapinus rigid (Rockwool)	Green	1	18,720
ins 6	Vegatable-based foam	Green	1	16,510
System 2: Flooring				
flor 1	Ceramics	Traditional	–	18,330
flor 2	Mozaiko	Traditional	–	16,004
flor 3	Marble	Traditional	–	62,400
flor 4	Cement flooring	Traditional	–	6630
flor 5	Poly floor standard Xl with acoustic foam	Green	2	46,800
flor 6	Bambo	Green	2	68,900
flor 7	Cork	Green	2	65000
flor 8	Yugoslavia wood aro	Green	1	76,700
System 3: Plastering				
pls 1	Cement mortar	Traditional	–	20,848
pls 2	Kemaxit 210	Traditional	–	32,575
pls 3	American clay earth plaster	Green	7	27,363
System 4: Coatings, paints, and sealants				
pnt 1	Plastic (oil-based)	Traditional	–	14,608
pnt 2	Hashmi stone	Traditional	–	10,080
pnt 3	Linea (Listelli)	Traditional	–	18,000
pnt 4	Dry mix	Traditional	–	1200
pnt 5	Eco-green planet Premium paint	Green	1	54,780
pnt 6	Milk paint	Green	1	23,373
pnt 7	Clear coat	Green	1	36,520
System 5: Building walls				
blc 1	Clay brick	Traditional	–	10,763
blc 2	Sand brick	Traditional	–	13,282
blc 3	Cement brick	Traditional	–	16,442
blc 4	M2 system	Green	2	24,274

Table 3. Costs and LEED credits for all scenarios

Scen.	Combination	Cost (LE)	LEED credit
1	ins1, flor1, pls1, pnt1, pnt4, bloc1	70,099	0
2	ins1, flor2, pls1, pnt1, pnt2, bloc1	76,653.1	0
3	ins1, flor3, pls1, pnt1, pnt2, bloc1	123,049	0
4	ins2, flor1, pls2, pnt1, bloc1	85,846	0
5	ins2, flor3, flor4, pls2, pnt4, bloc2	100,437	0
6	ins2, ins3, flor1, flor4, pls3, pnt4, bloc1	68,006	8
7	ins1, ins4, flor3, flor4, pls2, pnt4, bloc3	103,837	1
8	ins1, ins5, flor2, flor5, pls2, pnt3, bloc4	148,753.7	5
9	ins2, ins6, flor4, flor5, pls3, pnt2, bloc4	133,947	12
10	ins1, ins4, flor4, flor7, pls2, pnt5, bloc2	177,657	4
11	ins2, ins6, flor2, flor8, pls3, pnt7, bloc1	179,900.7	10
12	ins1, ins3, flor4, flor6, pls1, pnt4, pnt6, bloc4	151,394.8	6
13	ins1, ins5, flor4, flor8, pls3, pnt2, bloc3	154,565	9
14	ins2, ins6, flor4, flor6, pls2, pnt2, pnt7, bloc4	197,779	9
15	ins1, ins4, flor4, flor7, pls3, bloc4	128,657	6
16	ins1, ins3, flor3, flor5, pls1, pnt4, pnt5, bloc1	165,781	12
17	ins2, ins6, flor3, pls3, bloc4	137,257	4
18	ins1, ins2, flor2, flor7, pls3, pnt6, bloc2	140,262.5	10
19	ins1, ins6, flor2, flor8, pls2, pnt3, pnt5, bloc4	231,223.7	5
20	ins1, ins5, flor4, flor5, pls3, bloc4	122,417	12

2.2. STELLA simulation model

The modeling of the selection process for the building materials in this project starts with defining the objects of STELLA model, and the mapping process can be started as shown in Figure 1. Once the mapping process is conducted, the data of total cost and LEED credits that refer to alternative materials can be assigned. After assigning data, the functional relationships and variables can be defined. Then, the number of proposed scenarios for building materials selection is followed using equal weight of cost and LEED credits. Twenty scenarios have been considered as listed in Table 3.

Table 4. Optimum solutions parameters

No.	Cost (LE)	LEED credits	(G,ρ,R)
1	135,500	13	(200,0.3,50)
2	128,000	12	(100,0.6,50) and (100,0.8,50)
3	105,000	11	(150,0.3,100) and (200,0.8,100)
4	92,000	10	(150,0.3,10)
5	88,500	9	(100,0.6,10) and (200,0.3,50)
6	78,000	8	(150,0.3,10)
7	74,500	7	(100,0.3,10)
8	72,000	1	(150,0.6,50) and (150,0.8,50)
9	68,500	0	(200,0.3,10) and (200,0.6,100)

2.3. Analysis of STELLA simulation results

After generating the results, the decision process starts to identify the best scenario using a comparative analysis. Thus, scenarios are examined to account for different material combinations as shown in Table 4. The scenario that achieves high LEED credits at reduced costs is the one that has the best alternative materials to be selected. The module is capable of demonstrating the cash flow of the project during the construction process for the selected building systems. Also, it demonstrates cost and LEED credits of all scenarios during construction time. This ability can be performed by moving STELLA chart's indicator on the graphical results and compare between materials cost at any specific point in time.

2.4. Analysis of ACO results

In order to run the optimization session of the developed module, the optimization parameters inputs of optimization module have been fed to the framework. Then, the module initializes the parameters and starts a new iteration (generation) with a new ant until building a solution. Completing one solution means that the ant travels from i to j, the options visited by the ant would change its pheromone according to the updating rule. This process is repeated until meeting the terminate criteria. As for the stopping criteria, a maximum number of iteration is used in the proposed model due to its convenience and popularity. The ACMO algorithm loops back to the selection probability phase for iteration until the maximum number of iterations is reached. As such, the larger the project scale is, the more number of iterations would be needed to search for the optimal solutions. The implication of 50, 100, 150, and 200 iterations (generation) to the numerical example has been examined. Three different R values (10, 50, and 100) and three different ρ values (0.3, 0.6, and 0.8) are tested with equal weight of W_L and W_C to produce better results to demonstrate

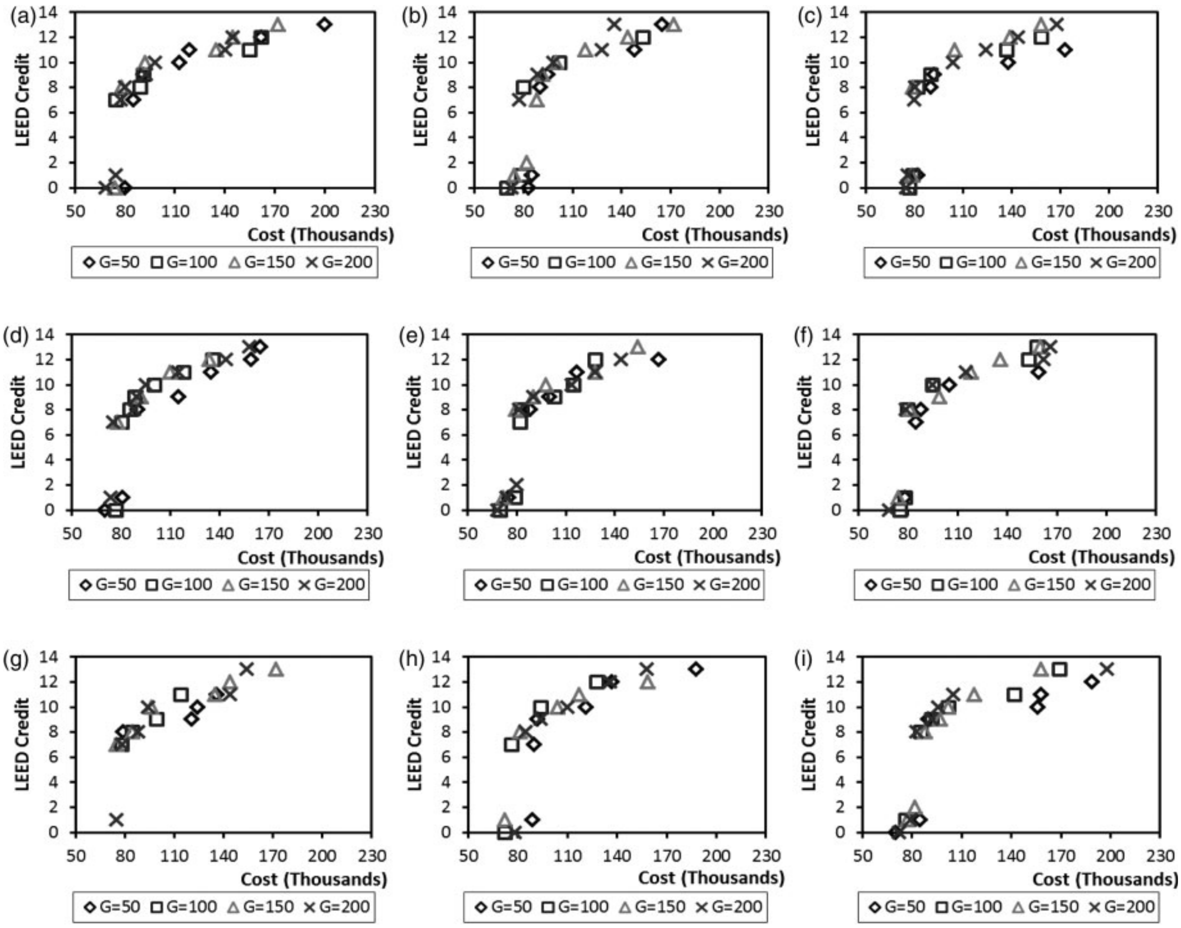

Fig. 4. Sensitivity analysis of ACMO parameters: (a) $\rho = 0.3$, $R = 100$; (b) $\rho = 0.3$, $R = 50$; (c) $\rho = 0.3$, $R = 10$; (d) $\rho = 0.6$, $R = 100$; (e) $\rho = 0.6$, $R = 50$; (f) $\rho = 0.6$, $R = 10$; (g) $\rho = 0.8$, $R = 100$; (h) $\rho = 0.8$, $R = 50$; (i) $\rho = 0.8$, $R = 10$

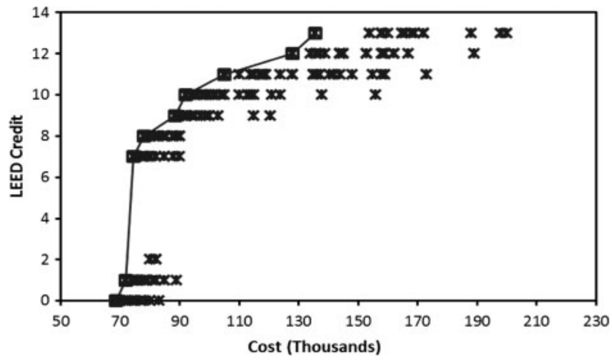

Fig. 5. Pareto front of ACMO model

the convergence of ACMO model in solving problems under different scenarios as shown in Figure 4. Subsequently, all results have been integrated in one figure to obtain the Pareto front, which contains optimal solutions in all scenarios as depicted in Figure 5.

Conclusions

This paper presented a framework for green selection of building materials that has the following characteristics:

(1) It consists of two modules, SD and ACO, to improve building materials selection process.
(2) The modules of the framework consider both LEED credits and cost as two objectives to address realistic scenarios experienced by decision makers.
(3) It helps to satisfy more LEED credits with less money. It defines the optimum solutions, considering these two objectives.
(4) The outputs are essentially the total cost and LEED credits of the materials.
(5) It can be expanded to encompass different types of construction, taking into consideration the different combination of materials.

A case study of a residential building (villa) that consists of two floors (ground and first) was presented to demonstrate the use of the proposed framework. Sensitivity analysis was conducted to determine the feasible solutions that have less cost and high LEED credits.

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Appendix 1.

System	Alternative materials: ID	Alternative materials: Material name	Element location	Quantity (m^2)	Cost (LE)	LEED reference
Insulation	ins 1	Bitumen	Foundations	275	2750	
			Bathrooms	30	300	
			Roof	130	1300	
	ins 2	Polystyrene sheets	Foundations	275	6050	
			Bathrooms	30	660	
			Roof	130	2860	
	ins 3	Tile foam	Roof	130	7540	IEQ.CR.4.2
	ins 4	Blue foam	Roof	130	6760	IEQ.CR.4.2
	ins 5	Lapinus rigid (Rockwool)	Roof	130	18,720	IEQ.CR.4.2
	ins 6	Vegetable-based foam	Roof	130	16,510	IEQ.CR.4.2
Flooring	flor 1	Ceramics	Indoor	260	12,220	
			Outdoor	130	6110	
	flor 2	Mozaiko	Indoor	260	10,669	
			Outdoor	130	5334	
	flor 3	Marble	Indoor	260	41,600	
			Outdoor	130	20,800	
	flor 4	Cement flooring	Indoor	260	4420	
			Outdoor	130	2210	
	flor 5	Poly floor w/t acoustic foam	Indoor	260	46,800	IEQ.CR.4.3, ID.CR.1
	flor 6	Bambo	Indoor	260	68,900	MR.CR.6, IEQ.CR.4.4
	flor 7	Cork	Indoor	260	65,000	MR.CR.6, IEQ.CR.4.4
	flor 8	Yugoslavia wood aro	Indoor	260	76,700	IEQ.CR.4.4
Plastering	pls 1	Cement morter	Indoor	913	14,608	
			Outdoor	390	6240	
	pls 2	Kemaxit 210	Indoor	913	22,825	
			Outdoor	390	9750	
	pls 3	American clay earth plaster	Indoor	913	19,173	MR.CR.6, IEQ.CR.4.2, ID.CR.1-1.4, MR.CR.5.1, MR.CR.5.2, MR.CR.2.1, MR.CR.2.2
			Outdoor	390	8190	
Coating, paints, and sealants	pnt 1	Plastic(oil-based)	Indoor	913	14,608	
	pnt 2	Hashmi stone	Outdoor	120	10,080	
	pnt 3	LINEA (Listelli)	Outdoor	120	18,000	
	pnt 4	Dry mix	Outdoor	120	1200	
	pnt 5	Eco-green planet premium paint	Indoor	913	54,780	IEQ.CR.4.2
	pnt 6	Milk paint	Indoor	913	23,372	IEQ.CR.4.2
	pnt 7	Clear coat	Indoor	913	36,520	IEQ.CR.4.2
Walls	blc 1	Clay brick	All walls	458	10,763	
	blc 2	Sand brick	All walls	458	13,282	
	blc 3	Cement brick	All walls	458	16,442	
	blc 4	M2 system	All walls	458	24,274	IEQ.CR.7.1, ID.CR.1

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