Modeling Sustainable Building Materials in Saudi Arabia

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ABSTRACT

Green building materials are composed of renewable, rather than non-renewable, resources. Green materials are environmentally responsible because the impacts of the product are considered over its life cycle. Depending upon project-specific goals, an assessment of green materials may involve an evaluation of one or more of the following criteria: resource efficiency, indoor air quality, energy efficiency, water conservation, and affordability. Product selection can begin after the establishment of project-specific environmental goals. The main objective of this research is to develop a framework that uses BIM to select optimum sustainable building materials in Saudi Arabia. To this end, a cost model will be developed to take into account initial costs, such as construction costs, and all life cycle costs including the operating costs and energy consumption of a building. The framework integrates the expanded features of BIM technology with an especially designed green building rating system for Saudi Arabia.

INTRODUCTION

Resources limitations and serious environmental impacts lead to increase the importance of adoption of more sustainable life style (Lennart and Ljungberg 2007). In Saudi Arabia, the extreme environmental conditions increase the need for water and energy. Saudi Arabia is one of the most water-consuming countries in the world in spite of limited natural water resource. About $53 billion has earmarked by Saudi government for various water projects to be completed by 2022. Moreover, over the next decade, about $79.9 billion was earmarked for energy projects (The Economic Times 2013). Accordingly, there is critical need to adopt the sustainability in many fields in Saudi Arabia including the construction field. Construction is a major consumer of nonrenewable resources. In addition, it is responsible for a huge portion of waste production and CO2 emissions (Bakhoum and Brown 2012). More specifically, the building sector in the developed countries consumes about 30% of total produced energy and it is responsible for 40% of carbon emissions (IPCC 2007). For example, in USA, buildings are responsible for 40% of the national energy consumption, 72% of electricity consumption, 39% of carbon emissions, and 13% of water consumption (U.S. Green Building Council 2012). These effects are increasing the need to develop sustainability measures that ensure obtaining sustainable and green buildings in order to minimize the negative environmental impacts (Abdallah et al. 2013). More than 600 rating systems for sustainability assessment of buildings are available worldwide (Saunders 2008). These rating systems are used to evaluate the sustainability of buildings by awarding points for satisfying green building criteria. The differences in environmental conditions from one country to another lead to different sustainability measures/criteria and different importance weights for these measures. Accordingly, each country needs to develop a sustainability rating system that fits with its environmental conditions.

BIM is the development and use of a computer software model to simulate the construction and operation of a facility (AGC 2006). The resulting model, a building information model, is a data-rich, intelligent, and parametric digital representation of the facility, from which data appropriate to various users' needs can be extracted and analyzed to generate information in order to make decisions and improve the process of facility delivery. BIM is a building industry development that represents a shift from electronic drafting to a model-based process. BIM is used to create a model that is not only a geometrical representation but also a representation with information and properties that can be used by project participants anytime and anywhere. The BIM model can be 4D model by connecting model elements to time schedules, and it can be 5D model by integrating cost estimation with model components. Several researches have been conducted in the areas of construction optimization and decision-making, leading to the development of a number of optimization models using a variety of approaches. In this paper, initial rating system for green building is proposed to fit extreme environmental conditions in Saudi Arabia. This rating system is called Saudi Arabia Green Building Rating System (SAGRS). The SAGRS would be integrated in a framework that is dedicated for selecting optimum sustainable building materials that was developed, expanding the features of BIM technology. The framework utilizes Genetic Algorithms (GA) optimization technique and Life Cycle Cost (LCC) analysis in order to perform its designated functions.

DEVELOPING SAGRS SYSTEM

In order to develop called Saudi Arabia Green Building Rating System (SAGRS) system, four steps are followed which are; 1) Review green building rating systems, 2) Initial Rating Criteria for Green Building, 3) Key Rating Criteria for Green Building, and 4) Develop SAGRS. Detailed description of each step is presented in below sections.

Review Current Green Building Rating Systems. This step highlights the technical information pertaining to other green building rating systems. After reviewing several green building rating systems, five recognized systems are considered to identify the initial sustainability criteria. These include three international rating systems (LEED-U.S., BREEAM-UK, and Green Globes-Canada) and two regional rating systems (GPRS-Egypt, and Pearl-UAE) in order to reflect widely range of environmental conditions. A wide range of criteria are classified in a number of groups along with its importance weight and measurement methods. A number of publications of selected rating systems were reviewed such as LEED-NC 2009; BREEAM Offices 2008; Green Globes 2004; GPRS 2011; and Pearl 2010. Table 1 shows the main groups for the selected rating systems.

Initial Rating Criteria for Green Building. A number of initial criteria were identified to be used for rating the green building as per Table 2. The identified criteria are classified in seven main groups including. They essentially represent the list of criteria that will be considered in a questionnaire which aims at identification of the appropriateness of these criteria for rating the green buildings in Saudi Arabia.

Table 1. Sustainability rating groups

No.	Group	LEED (USA)	BREEAM (UK)	GPRS (Egypt)	Pearl (UAE)	Green Globes (Canada)
1	Management	×	✓	✓	×	✓
2	Health and Wellbeing	×	✓	×	×	×
3	Transport	×	✓	×	×	×
4	Pollution/ Emissions	×	✓	×	×	✓
5	Waste	×	✓	×	×	×
6	Sustainable Sites/ Land Use and Ecology/ Site	✓	✓	✓	×	✓
7	Water Efficiency/ Water/ Precious Water	✓	✓	✓	✓	✓
8	Energy and Atmosphere/ Energy/ Resourceful Energy	✓	✓	✓	✓	✓
9	Materials and Resources/ Material/ Stewarding Materials	✓	✓	✓	✓	✓
10	Indoor Environmental Quality	✓	×	✓	×	✓
11	Innovation and Design Process/ Innovation/ Innovation and Added Value/ Innovating Practice	✓	✓	✓	✓	×
12	Regional Priority Credits	✓	×	×	×	×
13	IDP – Integrated Development Process/ Integrated Design Process	×	×	×	✓	×
14	NS – Natural Systems	×	×	×	✓	×
15	Livable Buildings Outdoors	×	×	×	✓	×
16	Livable Buildings Indoors	×	×	×	✓	×

Key Rating Criteria for Green Building. Based on initial criteria, a questionnaire has been designed for quick and easy completion. The questionnaire was divided into three main sections. The first section contains general information questions about both the company and respondent. The second section investigates the degree of appropriateness of the identified sustainability groups. The third section investigates the degree of appropriateness of each criterion in the list of initial criteria that identified in the second step. The respondents were asked to rate each criterion based on their professional judgment on a given five-point priority scaling (1: *Completely Inappropriate*, 2: *Usually Inappropriate*, 3: *Appropriate*, 4: *Usually Appropriate*, and 5: *Completely Appropriate*). At the end of each group of criteria, the respondents are given the chance to add and rate any additional criteria. An interviews and discussions are conducted with set of experts with experienced practitioners in construction in Saudi Arabia in order to fill out this questionnaire.

Table 2. Initial rating criteria

Code	Sustainability Criteria	Code	Sustainability Criteria
SS	***Sustainable Sites***	***MS***	***Material Selection and Recycle***
SS-1	Site Selection-Mitigating Ecological Impact	MS-1	Regional Materials
SS-2	Provision of Public Transport	MS-2	Use of Recycled Materials
SS-3	Parking Capacity	MS-3	Certified Wood
SS-4	Protection of habitat	MS-4	Low Impact Materials
SS-5	Maximize Open Space	MS-5	Insulation
SS-6	Travel Plan	MS-6	Elimination of exposure to hazardous and toxic materials
SS-7	Respect for sites of historic or cultural interest	MS-7	Materials fabricated on site
WE	***Water Efficiency and Conservation***	MS-8	Use of higher durability materials
WE-1	Water consumption monitoring	MS-9	Use of prefabricated elements
WE-2	Sanitary pipe used	MS-10	Recycled Aggregates
WE-3	Storm water Management	MS-11	Recyclable Waste Storage
WE-4	Waste water management	MS-12	Floor Finishes
WE-5	Innovative wastewater technologies	MS-13	Life Cycle Cost (LCC) analysis of materials in the project
EE	***Energy Efficiency and Conservation***	***DM***	***Design and Management***
EE-1	Ozone Impacts	DM-1	Construction Environmental Management
EE-2	Improved Energy Performance	DM-2	Security
EE-3	Green and Renewable Energy	DM-3	Life Cycle Costing
EE-4	Cool Building Strategies	DM-4	Environmental Purchasing
EE-5	Environmental Impact	DM-5	Emergency Response Plan
IE	***Indoor Environmental Quality***	DM-6	Guest Worker Accommodation
IE-1	Materials Emissions -Ceiling Systems	DM-7	Access for lorries, plant and equipment
IE-2	Materials Emissions-Flooring Systems	DM-8	Identified and separated storage areas
IE-3	Materials Emissions-Paints and Coatings	DM-9	Employing waste recycling workers on site
IE-4	Smoking Control	DM-10	Providing a Periodic Maintenance Schedule
IE-5	Ventilation System	DM-11	Protecting water sources from pollution
IE-8	Daylight	DM-12	Control of equipment emissions and pollutants
IE-9	Control of Indoor Pollutants		
IP	***Innovation and Regional Priority***		
IR-1	Innovation		
IR-2	Regional Priority		
IR-3	Exceeding Benchmark		

Severity index (SI) was mainly used to analyze the data collected through questionnaire. SI can be calculated using Eq. 1. (Assaf and Al-Hejji 2006)

$$SI = \frac{\sum_{i=1}^{5} W_i \, X_i}{A \times N} \times 100$$

Where: W_i is the five-point priority scaling that ranges from 1 to 5, X_i is the frequency of the priority scale, A is the highest priority vale (i.e., 5), N is the number of respondents.

Severity index (SI) is used to identify the degree of appropriateness for each criterion according to the following scale (Al-Hammad and Assaf 1996):

- Extremely Effective Criterion (EEC); 80 < SI < 100
- Very Good Criterion (VGC); 60 < SI < 80
- Good Criterion (GC); 40 < SI < 60
- Poor Criterion (PC); 20 < SI < 40
- Not Applicable Criterion (NAC); 0 < SI < 20

The criteria that classified as NAC and PC indicate that these criteria are not appropriate to use in the developed rating system. Therefore, these criteria were ignored in the final list of criteria. Only the criteria classified as EEC, VGC, and GC were considered in the validated final list of criteria which represents the key criteria for the developed rating system. SI also gives an indication for the importance weights of criteria. The questionnaire results indicated the number of Extremely Effective Criterion (EEC), Very Good Criterion (VGC); Good Criterion (GC), Poor Criterion (PC); Not Applicable Criterion (NAC) are 25, 17, 7, 3, and 0, respectively. The next step in this research is to process the key criteria that have been identified in order to develop a green building rating system that reflects Saudi Arabia circumstances.

Selecting Sustainable Building Materials. Building Information Modeling (BIM) is proposed to be utilized as an effective tool in selecting sustainable materials, modeling, and rating buildings based on Saudi Arabia Green Buildings Rating System (SAGRS). The proposed methodology depends on integrating BIM with: SAGRS system, Life Cycle Cost (LCC) model, and Optimization model in order to select the optimum building materials that achieve SAGRS requirements. The required material properties are automatically extracted from BIM and integrated with the other components of the proposed system where optimum building materials are selected. The selected optimum materials are then integrated automatically with BIM in order to obtain an optimum BIM model based on SAGRS requirements. The connectivity amongst the proposed system components is presented in Figure 1.

Life Cycle Cost (LCC) Model. The proposed LCC model is capable to calculate initial cost using two methods; approximate cost estimation, and detailed cost estimation. The approximate estimation method depends on the materials' quantities and their corresponding unit prices; while the detailed estimation method requires extensive knowledge of productivity estimates of each element type, labor and equipment rates, and material costs, in addition to the quantities' calculations of elements. Default construction knowledge will be incorporated in the proposed LCC model to allow performing detailed estimation process in an efficient manner. This construction knowledge includes productivity rates and corresponding prices of each

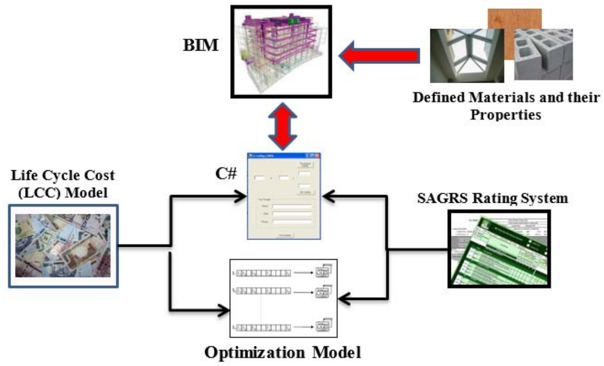

Figure 1. Proposed System Components

element type according to Saudi Arabia construction industry. The model user has the choice to use the default construction knowledge or to add his/her own knowledge. The construction knowledge includes the main information required to perform the cost analysis of other LCC components (operation, maintenance, etc.), such as: elements deterioration models, and maintenance techniques and their associated costs.

Optimization Model. The proposed optimization model utilizes Genetic Algorithms (GA) to select the optimum building materials alternatives for different materials types/groups. The decision variables of this model are the status of selection of each material alternative which are represented by binary values, where “1” represents selected material alternative, while “0” represents non-selected material alternative (see Figure 3). The objective of this model could be adjusted according to user preference to one of the following three objectives: minimizing the total Life Cycle Cost, maximizing SAGRS score, minimizing total life cycle cost while maximizing SAGRS score (multi-objective optimization). The constraints include: maximum initial construction cost; minimum SAGRS score (in case of using the first objective); maximum total Life Cycle Cost (in case of using second objective); limitations for selecting two alternatives of different materials groups together (such as limitations of using specific type of wall finishes with a specific type of blocks); and constraints that assure using at least one material alternative from each material group. The proposed optimization model performs its functions considering SAGRS system, LCC model, and the properties of the materials alternatives (previously defined in BIM software) in addition to the material type quantity (see Figure 2).

Material Alternative	Selection Status
CIP-Mix 1	1
CIP-Mix 2	0
CIP-Mix 3	0
PRECAST-Mix 1	0
PRECAST-Mix 2	0
PAINT-Type 1	0
PAINT-Type 2	1
PAINT-Type 3	0
PAINT-Type 4	0
PAINT-Type 5	0

Model Results	
Selected Concrete Material	CIP-Mix 1
Selected Painting Material	PAINT-Type 2
Construction Total Cost	1,488,354
Life Cycle Cost	2,530,202
Pearl Score	3

Figure 2. Optimization Model Parameters and Output

Linking BIM with System Components. In order to achieve integration between BIM and other system components (SAGRS system, LCC model, and optimization Model), BIM API (Application Programming Interface) has to be utilized. BIM API enables the extension of BIM package uses by creating new features and applications related to the 3D BIM by using several programming languages such as C# and Visual Basic. The work presented in this paper utilizes C# language in order to develop a program that integrates BIM with the proposed system components. The proposed C# program integrates BIM with SAGRS by incorporating SAGRS calculation methods and equations with the intelligent BIM attributes that could have effective role in calculating SAGRS score, such as: recycled content; materials emissions, thermal conductivity; durability; and prefabrication status. It also integrates BIM with the LCC model by incorporating LCC model equations and construction knowledge with intelligent BIM attributes that could have effective role in cost calculations, such as: types of elements; types of materials; and quantities of materials. The role of C# program in integrating BIM and LCC model to calculate initial construction costs by approximate and detailed estimation methodologies. The proposed C# program also integrates BIM with the optimization model as depicted in Figure 3. This is performed by extracting BIM attributes (such as quantities and material properties) to the optimization model where optimization is performed and optimum building materials are selected. The selected optimum materials are then retrieved by the C# program and used to modify the BIM model automatically in order to obtain an optimum BIM model considering SAGRS and LCC requirements.

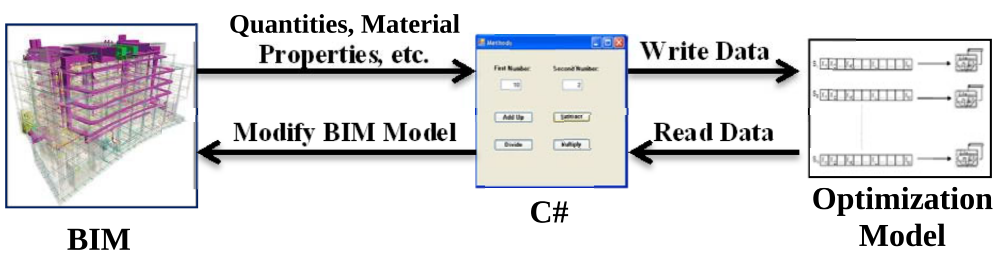

Figure 3. Integrating BIM with Optimization Model

SUMMARY

The paper presented a framework for developing Saudi Arabia Green Buildings Rating System (SAGRS). This required four main steps which are: reviewing current green building rating systems; obtaining initial rating criteria; obtaining key rating criteria; and final development of SAGRS system. The paper then presented the integration of Building Information Modeling (BIM) technology with SAGRS system, Life Cycle Cost (LCC) analysis, and Genetic Algorithms (GA) optimization technique in order to select sustainable building rating materials. This integration was achieved by utilizing C# programming language that automates data flow and calculations from one system component to another. A numerical example was presented to demonstrate the use of the proposed methodology.

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