# Framework for Sustainable Low-Income Housing Projects in Egypt

Mohammed Marzouk[1] and Mahmoud Metawie[1]

[1]Structural Engineering Department, Cairo University, Giza, Egypt

## ABSTRACT

Low income housing is one of most important housing projects that are directed to serve low-income people in Egypt. The greatest challenge that faces the Egyptian government is to decrease the cost of low income housing project taking into consideration the concepts of sustainability aspects. This paper presents a framework that integrates Building Information Modeling (BIM) with optimization in Low Income Housing Projects in an effort to assure sustainability. BIM is used to represent the geometrical information and the other properties of Low Income Housing building such as building elements properties, material properties and its quantities, design alternatives and project location. On the other hand, Leadership in Energy and Environmental Design (LEED) rating system is used to evaluate the sustainability of buildings by awarding points for satisfying green building criteria such as regional material, recycled content, rapidly renewable materials. Genetic Algorithms (GA) Optimization is utilized in order to select the optimum building alternative that minimizes construction cost and duration, while achieving maximum LEED credit points. A numerical example is presented to demonstrate the practical feature of the proposed framework.

## INTRODUCTION

Despite its own relatively low level of greenhouse gasses emissions, Egypt is considered to be one of the countries that are most at risk from the impacts of global climate change and as a result of the increase in the population and the decrease of the income, Egypt government is demanded to provide sustainable low income housing projects. LEED (Leadership in Energy and Environmental Design) provides building owners and operators with a framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions. LEED concentrates its efforts on improving performance across five key areas of environmental and human health: energy efficiency, indoor environmental quality, materials selection, sustainable site development and water savings (U.S. Green Building Council 2012).Building Information Modeling (BIM) is an intelligent model-based process that provides insight for creating and managing building and infrastructure projects faster, more economically, and with less environmental impact. BIM supports parametric modeling, which is an important feature that enables objects and components within a model to be parametrically related; BIM enables the collaboration of team members in the early phases of a project through the use of consistent and more complete information, thus, it is more effective than traditional approaches. BIM will help in meeting the world's need for sustainable construction and climate protection. it will allow a design team to better take a "reduce and optimize" approach to reaching a client's and building project's sustainability and climate protection goals by focusing on reducing energy first (ASHRAE 2010). Kriegel and Nies (2008) indicated that BIM can aid in the following aspects of sustainable design:

- Building orientation (selecting a good orientation can reduce energy costs)
- Building massing (to analyze building form and optimize the building envelope)
- Day-lighting analysis
- Water harvesting (reducing water needs in a building)
- Energy modeling (reducing energy needs and analyzing renewable energy options can contribute to low energy costs)
- Sustainable materials (reducing material needs and using recycled materials)
- Site and logistics management (to reduce waste and carbon footprints)

A recent study demonstrates the ways designers and planners may use BIM for various sustainability analyses in pursuit of LEED certification (Azhar et al. 2011).BIM model can be a 4D model by connecting model elements to time schedules. The fifth dimension (5D) uses the 3D model data to quantify materials and apply cost information (McCuen 2008). BIM can be used to assist in the generation of accurate quantity take-offs and cost estimates throughout the lifecycle of a project. This allows the project team to see the cost effects of their changes, during all phases of the project, which can help curb excessive budget overruns due to project modifications. Specifically, BIM can provide cost effects of additions and modifications, with potential to save time and money and is most beneficial in the early design stages of a project (CIC 2009). BIM had been applied in different applications such as: cost estimation (Shen and Issa2010); lean construction (Sacks et al. 2009); construction process documentation (Goedert and Meadati 2008); and energy simulations (Cho et al. 2011).This paper presents a framework that integrates Building Information Modeling (BIM) with optimization in Low Income Housing Projects in an effort to assure sustainability.

## PROPOSED FRAMEWORK

BIM is proposed to be used with optimization to select the optimum Low Income Housing (LIH) building alternatives that minimize construction cost and duration, while achieving maximum LEED materials credit points. The proposed frame work depends on integrating BIM with Genetic Algorithms (GA) Optimization in order to achieve these goals. To facilitates such objective, five features are augmented in the frameworks; 1) quantities of material that are extracted from the BIM model, 2) allowing different construction activities, 3) storing sustainable material data, 4) LEED materials and resources calculator, and 5) automating time schedule for LIH Building. The proposed framework is capable to estimates the project proposed duration, cost and the score of LEED materials and resources credits for the optimized chosen alternatives.

**Extracting Materials Quantities.** BIM model is developed using Autodesk Revit (Building information modeling software). The different material quantities such as concrete, plastering, painting, bricks, flooring materials are extracted from the generated model. The quantities of these materials are used in calculating project duration and cost. Also, the model allows LEED credit calculation by extracting them from the BIM model and exporting them in LEED calculator Module.

**Construction Activities Alternatives.** A typical Low Income Housing (LIH) building that consists of 44 construction activities is considered. Each construction activity has a number of possible alternatives or construction methods. Each alternative is associated with a certain productivity, total construction cost and sustainable material cost. Table 1 illustrates an example for construction alternatives of flooring activity.

**Table 1. Construction alternatives of flooring activity**

| Sustainable Material | | | Productivity (Unit/Day) | Construction Cost (LE) | | | |
|---|---|---|---|---|---|---|---|
| ID | Name | Cost/Unit (LE/unit) | | Material | Labor | Equipment | Total |
| M21 | Ceramic Tile with 75% RC | 40 | 25.6 | 40 | 10 | 2 | 52 |
| M22 | Wood Flooring | 140 | 20 | 140 | 14 | 2 | 156 |
| M23 | Cork Flooring | 50 | 30 | 50 | 10 | 4 | 64 |

**Storing Sustainable Material Data.** LEED materials and Resources calculator is utilized to determine the amount of LEED points achieved for specific chosen alternatives. This research focuses on five LEED materials and resources credits that are listed in Table 2. Each sustainable material has its own sustainable data which are; the percentage of Reused material, Post and pre-Consumer recycled content, regional material, rapidly renewable material and certified wood and the extraction and manufacture distance for the material. A spreadsheet is designed to facilitate this process.

**Automating Time Schedule.** The most widely used time scheduling technique is the critical path method (CPM). This technique calculates the minimum completion time for a project along with the possible start and finish times for the project activities. The duration of the critical path is the sum of the activities' durations along the path. Thus, the critical path can be defined as the longest possible path through the "network" of project activities. Construction operations in LIH Building are decomposed into activities using Work Breakdown Structure (WBS) method. The WBS of LIH building consists of substructure works and superstructure works. For the substructure works, there are four main work packages; Earth Works, PC Foundation casting, RC Foundation casting, and water insulation. For superstructure works, five floors are considered. In each floor, there are structural works and finishing work. Figure 1 depicts the Work Breakdown Structure (WBS) in the proposed LIH framework.

Based on work packages' activities and the relation between activities, a CPM schedule is created by inserting these activities and its predecessors and duration in CPM spreadsheet template. The spreadsheet was developed to calculate the project duration and total cost and the achieved LEED credit points by linking the schedule with the alternatives data module and the material LEED calculator. Each activity

**Table 2. LEED-based credits considered in the Proposed Framework**

| Credit Name | Description | Credit Calculation |
|---|---|---|
| *Materials Reuse* | To reuse building materials and products to reduce demand for virgin materials and reduce waste, thereby lessening impacts associated with the extraction and processing of virgin resources. | Total cost of salvaged, refurbished or reused materials to Total materials cost. If the ratio in the range of 0.05 to 0.1, *ONE* credit point is earned. If it is equal to or greater than 0.1, *TWO* credit points are earned. |
| *Recycled Content* | Increase demand for building products that incorporate recycled content materials, reducing impacts from extraction and processing of virgin materials. | Total cost of recycled material (postconsumer+0.5 pre-consumer) to Total materials cost. If the ratio in the range of 0.1 to 0.2, *ONE* credit point is earned. If it is equal to or greater than 0.2, *TWO* credit points are earned. |
| *Regional Materials* | Increase demand for building materials and products that are extracted and manufactured within the region, supporting local economies and reducing the environmental impacts resulting from transportation. | Total cost of rapidly renewable building materials and products to Total materials cost. If the ratio is greater than or equal 0.025, *ONE* credit point is earned. |
| *Rapidly Renewable Materials* | Reduce the use and depletion of finite raw materials and long-cycle renewable materials by replacing them with rapidly renewable materials. | Total cost of materials extracted, harvested or recovered, as well as manufactured at distance less than 500 miles to Total materials cost. If the ratio in the range of 0.1 to 0.2, *ONE* credit point is earned. If it is equal to or greater than 0.2, *TWO* credit points are earned. |
| *Certified Wood* | Encourage Environmentally responsible forest management. | Total cost of certified (FSC) wood-based materials and products to Total wood materials cost. If the ratio is greater than or equal 0.5, *ONE* credit point is earned. |

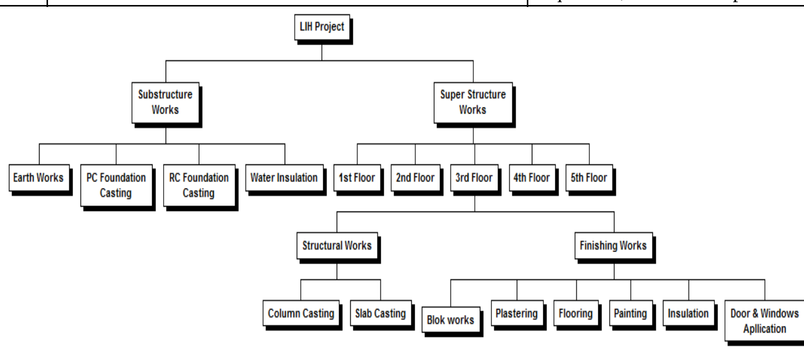



**Figure 1. Built-in WBS in the proposed LIH framework**

alternative has its own data that could be used in cost, time, and LEED credits calculations. For construction time calculations, the duration of each activity alternative is calculated based on alternatives' productivity for each activity and the extracted BIM quantities. The schedule model uses the calculated durations and the relations between activities to calculate total project duration for a specific scenario of alternatives. For Cost calculations, total cost of the project is calculated by summing all activities alternative scenario cost. For the same alternatives' scenario, the Material LEED Calculator determines the amount of LEED credit achieved.

**Optimization Algorithm.** In order to select the optimum building alternatives that minimize construction cost and duration, while achieving maximum LEED credit, an optimization model is developed using Microsoft Excel add-in which uses NSGA-II genetic algorithm to solve multiple-objective problem. NSGA-II is multi-objective optimization algorithm based on non-dominated sorting. The procedure of NSGA-II optimization module developed by deb et al. (2002) has six main steps:

*Step 1:*

The optimization model retrieve the parameters needed by the NSGA-II algorithm, which include: number of generations (g), population size (s), mutation rate (m), and crossover rate (c), and then the algorithm generate the first population with different (s) solutions.

*Step 2:*

For each solution in the population, the three main objective functions (time, cost and LEED Credits) are calculated based on the automated time schedule and the LEED Calculator.

*Step 3:*

In this step the algorithm finds all solutions that are not dominated by other solutions

*Step 4:*

All solutions defined as non-dominated solutions in the previous step constitute. The first front of non-domination, then the solutions of first front are excluded and step 3 are repeated to form the second non domination front which dominated by the individuals in the first front only and so on.

*Step 5:*

After completing the non-dominated sorting, each solution in each front is assigned rank values. First front solutions are given a fitness value of 1 and second front solutions are assigned fitness value of 2 and so on. In addition to fitness value another parameter (crowding distance) is calculated for each individual. The crowding distance parameter measures how close an individual is to its neighbors. Large average crowding distance will result in better diversity in the population.

*Step 6:*

A new child population is created using genetic algorithm operators of selection, crossover and mutation. The selection operator chooses the solutions that will go through the reproduction process. Solutions with better (lower) rank will be selected. If there are two solutions have the same rank then the solution with larger crowding distance will be selected. In case that both solutions have the same rank and also crowding distance then selected solution is chosen randomly. The crossover operator is designed to share information between individuals to create entirely new solutions which have some of the attributes of their parents. Normally, two solutions are crossed at randomly determined point and swapped the variables at this point. The mutation operator is designed to provide new genetic material during an optimization. Without the mutation operator, the algorithm could find locally optimal solutions without searching for better globally optimal solutions. The mutation operator works by selecting a gene at random in a chromosome and changing it to a random value.

Then, a new combined population with 2s size is formed by combining the initialized population with the new child population. Then, the previous steps are carried out for the new population to assign the fitness and calculate the crowding distance for each solution in the new population to be sorted again based on non-domination and only the best (s) individuals are selected. The previous steps are continued till the number of generations is completed.

The decision variables (genes) for this algorithm are the main 12 activities. For each activity, there are five possible alternatives. The algorithm tries to find the optimum alternative scenario that achieves the objective functions.

## NUMERICAL EXAMPLE

This section describes the implementation of the proposed frame work on a LIH Project. Based on 2D CAD drawings, BIM model is developed using Autodesk Revit software. The different material quantities such as concrete, plastering, painting, bricks, flooring materials are specified based on the developed model. Sustainable material data are utilized within the Revit model such as Material Recycled content, Rapidly Renewable Material content, and Regional Materials content (see Figure 2).

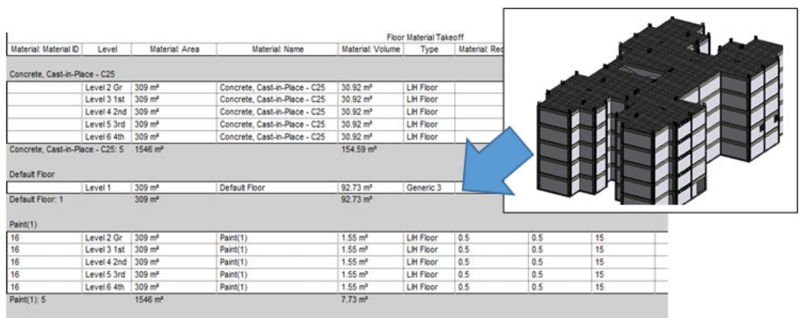
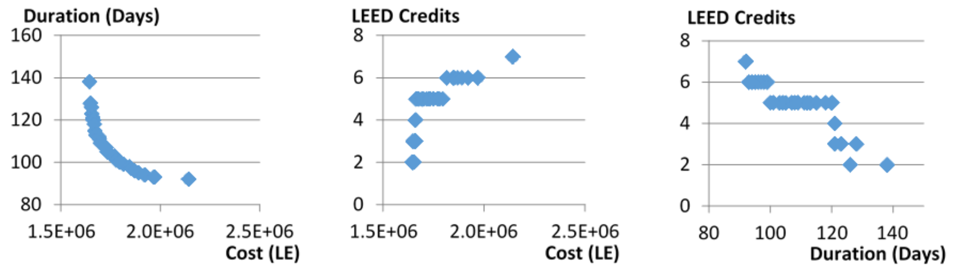



**Figure 2: Material data and quantities extracted from BIM**

After extracting quantities, project schedule is determined, taking into the considerations the construction materials, labors, and equipment alternatives related to each activity. LEED Materials calculator uses the defined material data to calculate the LEED points achieved. The project schedule and cost is determined using the quantities extracted from Revit and the defined alternatives. The optimal solutions are obtained by using the genetic algorithms add-in. For Genetic algorithm operators in the optimization module, population size, number of generations, crossover rate, and mutation rates are set to 50, 100, 0.5, and 0.2, respectively. Figure 3 shows how the total project cost, durations and LEED points are changed throughout the generations. The selected solution has a total cost of 1815303 LE, duration of 99, and associated LEED credits 5. The selected alternatives are marked with '*' in Table 3.




**a) Cost vs. Duration** **b) Cost Vs. LEED Credits** **c) Duration vs. LEED Credits**

**Figure 3: Optimization Outputs**

**Table 3. Construction alternative data**

| Task Name | Sustainable Material | | Cost/Unit (LE/unit) | Productivity (Unit/Day) | Construction Cost (LE) | | | |
|---|---|---|---|---|---|---|---|---|
| | ID | Name | | | Mat. | Lab. | Equi. | Total |
| *PC Foundation casting* | *M1 | 21 mpa Concrete with Portland Cement | 300 | 30 | 400 | 50 | 50 | 500 |
| | M2 | 15% Fly Ash Cement | 320 | 33 | 320 | 50 | 50 | 420 |
| | M3 | 30 % Fly ash cement | 325 | 34 | 325 | 50 | 50 | 425 |
| | M4 | Concrete Products with slag | 330 | 35 | 330 | 50 | 50 | 430 |
| | M5 | Precast Conc. 21mpa | 800 | 40 | 800 | 50 | 50 | 900 |
| *RC Foundation Casting* | M6 | 21 mpa Concrete with Portland Cement | 400 | 8.8 | 800 | 250 | 50 | 1100 |
| | M7 | 15% Fly Ash Cement | 420 | 9 | 820 | 250 | 50 | 1120 |
| | M8 | 30 % Fly ash cement | 410 | 9.5 | 840 | 250 | 50 | 1140 |
| | *M9 | Concrete Products with slag | 450 | 11 | 860 | 250 | 50 | 1160 |
| | M10 | Precast Conc. 21mpa | 800 | 13 | 1000 | 300 | 200 | 1500 |
| *water Insulation* | *M31 | Insulation type 1 | 60 | 160 | 60 | 10 | 10 | 80 |
| | M32 | Insulation type 2 | 65 | 165 | 62 | 10 | 10 | 82 |
| | M33 | Insulation type 3 | 70 | 170 | 64 | 10 | 10 | 84 |
| | M34 | Insulation type 4 | 72 | 166 | 66 | 10 | 10 | 86 |
| | M35 | Insulation type 5 | 75 | 180 | 68 | 10 | 10 | 88 |
| *Columns Casting* | M6 | Concrete with Portland Cement | 400 | 3 | 1200 | 250 | 50 | 1500 |
| | M7 | 15% Fly Ash Cement concrete | 420 | 4 | 1200 | 250 | 50 | 1500 |
| | M8 | 30 % Fly ash cement | 410 | 5 | 1200 | 250 | 50 | 1500 |
| | *M9 | Concrete Products with slag | 450 | 4 | 1400 | 250 | 50 | 1700 |
| | M10 | Precast Conc. | 800 | 6 | 1400 | 50 | 300 | 1750 |
| *Slab Casting* | M1 | 21 mpa Concrete with Portland Cement | 350 | 10 | 1000 | 250 | 50 | 1300 |
| | M2 | 15% Fly Ash Cement 3KSI | 360 | 11 | 1000 | 250 | 50 | 1300 |
| | M3 | 30 % Fly ash cement 3KSI | 365 | 12 | 1000 | 250 | 50 | 1300 |
| | *M4 | Concrete with fly ash 28mpa | 370 | 12 | 1300 | 250 | 50 | 1600 |
| | M5 | Precast Conc. 21mpa | 600 | 14 | 1400 | 50 | 300 | 1750 |
| *Block Works* | M11 | Block type 1 | 250 | 11 | 300 | 90 | 10 | 400 |
| | M12 | Block type 2 | 260 | 12 | 330 | 90 | 10 | 430 |
| | *M13 | Block type 3 | 270 | 13 | 350 | 90 | 10 | 450 |
| | M14 | Block type 4 | 280 | 13 | 360 | 90 | 10 | 460 |
| | M15 | Block type 5 | 320 | 14 | 400 | 90 | 10 | 500 |
| *Plastering* | M16 | Plaster type 1 | 5 | 230 | 5 | 5 | 2 | 12 |
| | *M17 | Plaster type 2 | 8 | 233 | 8 | 5 | 2 | 15 |
| | M18 | Plaster type 3 | 9 | 230 | 9 | 5 | 2 | 16 |
| | M19 | Plaster type 4 | 10 | 235 | 10 | 5 | 2 | 17 |
| | M20 | Plaster type 5 | 15 | 240 | 15 | 5 | 2 | 22 |
| *Flooring* | M21 | Ceramic Tile With Recycled Glass | 40 | 25.6 | 40 | 10 | 0 | 50 |
| | M22 | Linoleum Flooring | 70 | 26 | 70 | 20 | 2 | 92 |
| | M23 | Terrazzo | 90 | 28 | 90 | 15 | 0 | 105 |
| | M24 | Wood Flooring | 140 | 28 | 140 | 20 | | 160 |
| | *M25 | Natural Cork Flooring | 50 | 30 | 50 | 20 | 2 | 72 |
| *i n t i* | *M26 | painting type 1 | 50 | 275 | 50 | 5 | 5 | 60 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | M27 | painting type 2 | 60 | 277 | 60 | 5 | 5 | 70 |
| | M28 | painting type 3 | 65 | 278 | 65 | 5 | 5 | 75 |
| | M29 | painting type 1 | 67 | 280 | 67 | 5 | 5 | 77 |
| | M30 | painting type 5 | 75 | 300 | 75 | 5 | 5 | 85 |
| *Insulation* | *M31 | Insulation type 1 | 120 | 38 | 120 | 20 | 0 | 140 |
| | M32 | Insulation type 2 | 125 | 39 | 125 | 20 | 0 | 145 |
| | M33 | Insulation type 3 | 127 | 40 | 127 | 20 | 0 | 147 |
| | M34 | Insulation type 4 | 130 | 42 | 130 | 20 | 0 | 150 |
| | M35 | Insulation type 5 | 145 | 45 | 145 | 20 | 0 | 165 |
| *Doors & Windows Installation* | *M36 | Wood Doors and windows 1 | 400 | 17.3 | 400 | 100 | 0 | 500 |
| | M37 | Wood Doors and windows 2 | 420 | 17.4 | 420 | 100 | 0 | 520 |
| | M38 | Wood Doors and windows 3 | 450 | 18 | 450 | 100 | 0 | 550 |
| | M39 | Aluminum Doors and windows | 430 | 18 | 430 | 100 | 0 | 530 |
| | M40 | Aluminum Doors and windows 2 | 440 | 20 | 440 | 100 | 0 | 540 |

## SUMMARY

The paper presented a framework for integrating Building Information Modeling (BIM) with Genetic Algorithms (GA) optimization in Low Income Housing Projects in an effort to assure sustainability. The proposed framework utilizes BIM technology for developing 3D models. Materials quantities and properties are extracted from the BIM model. Then an optimization model was developed to use the extracted quantities to determine the optimum building activities' alternatives. The objective of the optimization model is minimizes construction cost and duration, while achieving maximum LEED credit points.

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