A Model for Sustainable Site Layout Design with Pareto Genetic Algorithm: SSPM

Yazgı Aksoy[1], Gülen Cağdaş[2]
[1,2]Istanbul Technical University
[1]yazbadem@hotmail.com [2]cagdas@itu.edu.tr

In architectural design, computer aided design tools have an important impact on design process, but still early design stage and sustainable design are problematic issues. During sustainable architectural design process, the designer needs to comply with some regulations, which requires calculations and comparisons. Green building certification systems are developed to assist designers during this complicated process, but for an efficient sustainable design for different regions, environmental information and local building codes must be considered with green building certification system criteria. In this paper, LEED and BREEAM certification systems are going to be considered as being the most representative building environment assessment schemes that are in use. As there are conflicting criteria's according to LEED and BREAM sustainable site parameters, local building codes and environmental conditions; an efficient decision support system can be developed by using multi-objective genetic algorithm. This paper presents an effective site-use multi-objective optimization model that use pareto genetic algorithm to determine the most efficient sustainable site layout design for social housing, which could assist designers in the early stage of design process.

Keywords: *Sustainable Site Layout Design, Multi Objective Genetic Algorithm, LEED-BREEAM*

INTRODUCTION

In design industry, as a result of multidisciplinary researches, evolutionary computation is being used at least for 10-15 years (Bentley, 1999). In architectural design, advanced computer aided design tools have an important impact on design process, but still early design stage and sustainable design are problematic issues. Sustainable building design refers to a process that begins with selecting the site and optimizing economical and environmental performance throughout a building's life cycle. This situation leads to the fact that, architectural design process can be regarded as an open process, even though sustainable design process needs to comply with some regulations which requires calculations and comparisons. As Rivard (2006) declared that in order to achieve a successful sustainable building, particular attention needs to be paid to the conceptual design stage when the most important decisions are taken, nevertheless it is the stage with least computer support. As a result of this, the need for a decision support system in early stage of sustainable design is clear so that for designers some simulation tools and green building certification systems are developed to evaluate their designs according to sustainable building criteria.

There are huge numbers of simulation tools used for sustainable design; building energy simulation programs, shell analysis, cost calculation programs, indoor air quality analysis programs and finally developed computational fluid dynamics programs to calculate the energy and gas emissions, life cycle analysis (LCA) can be given as examples. Simulation tools assist the designers during sustainable design process. The decision taken in the early stages of design have the greatest impact on final form, but most of these simulation tools do not support conceptual designs appropriately. In addition, these simulation tools typically cannot communicate among themselves and have time-consuming data inputs and complex interfaces (Rivard,2006).

In addition, green building rating systems and certification programs play an efficient role in usage of green buildings. These systems are working according to the criteria defined on the basis of scoring. In this paper, LEED and BREEAM certification systems are going to be considered, as being the most representative building environment assessment schemes that are in use. Although these certification systems are used all over the world, the parameters are prepared according to America's and Britain's geographical, economical and cultural conditions. Other countries are experiencing difficulties during design process so that for an efficient sustainable design for different regions, environmental information and local building codes must be considered with green building certification system requirements.

As it consists of several possible conflicting objectives that need to be considered together, sustainable building design process becomes more complicated than traditional building design. At that point, the reason of preferring multi- objective pareto genetic algorithm in the model, which we will focus on this paper, will be better understood. The multi-objective optimization problems consist of the simultaneous optimization of several possibly conflicting objectives and result in a set of non-dominated solutions. In sustainable design, maximum energy conservation and utilization of natural light can be given as an example of two conflicting objectives, so during sustainable design process pareto genetic algorithm will be successful to generate design alternatives according to conflicting criteria.

To summarize, today some tools developed to assist designers during sustainable building design process, address more detailed design stages when important design decisions already have been taken in conceptual stage. A successful green building design can be performed by the creation of alternative designs generated according to all the sustainability parameters in conceptual design stage. As there are conflicting criteria's according to LEED and BREAM sustainable site parameters, local building codes and local environmental conditions, an efficient decision support system can be developed by the help of pareto genetic algorithm.

LITERATURE REVIEW

Simulation Models Used For Sustainable Architectural Design

Many simulation models have been developed to assist designers in green building design. GBTool [5] is a simulation model that evaluates buildings according to resource consumption and energy performance by using a rating system. ATHENA [6] model provides a convenient platform for simulating processes used in semiconductor industry, but it is limited with construction materials and installation. All simulation models try to explore effective ways to assist designer in complicated design process, but especially during the earlier stages of sustainable design, there are several limitations in practice. As indicated by Harputlugil (2010) previous studies about sustainable building design have some problems during design process. The program inputs are very detailed, scientifically there are wide ranges of inputs and the data are not yet available in the early stages of design. The outputs of the models sometimes become difficult to understand and interpret. In addition, most of the detailed energy simulation models are research-based and so it requires a long time to learn how to use them. Sustainable building design criteria needs to be evaluated from the sketch phase, because the most important decisions of sustainability are taken from the settlement of land. For these reasons, it is clear that there is a need for better decision support system to support the earlier stages of sustainable design.

Evolutionary Models Used For Sustainable Architectural Design

Evolution is a method of searching enormous number of possibilities to find the solution and in 1950s and the 1960s it became an optimization tool for engineering problems. The aim is to evolve a population of solutions using natural genetic variation and natural selection operators and genetic algorithms are the most prominent example (Mitchell,1996).

Genetic algorithm is a population-based search technique inspired from the biological principles of natural selection and genetic recombination. It operates on a population of solutions that are randomly generated for the first generation (Goldberg, 1989). Multi-objective problems have multiple objectives, which leads to the need to obtain a set of optimal solutions, known as effective solutions. Genetic algorithms is a suitable tool for multi-objective optimization problems because it can locate multiple Pareto optimal solutions in a single simulation run. Pareto optimality describes a situation in which the profit of one condition cannot be increased without reducing the profit of another. In attribute space, the set of non-dominated solutions lie on a surface known as the Pareto optimal frontier. The goal of a Pareto GA is to find a representative sampling of solutions all along the Pareto front (Horn, Nafpliotis and Goldberg, 1994). A reasonable solution to a multi-objective problem is to investigate a set of solutions, each of which satisfies the objectives at an acceptable level without being dominated by any other solution (Deb, 2001).

In green building design many efforts have been made, especially integrated simulation environment provided by tools to evaluate design alternatives according to different performance criteria. Since designers rarely consider only one criterion in the decision-making process, multi objective optimization models have been proposed.

Wang, Zmeureanu and Rivard (2005) optimized the building envelope using multi-objective genetic algorithm. Variables in the model include the parameters that are usually determined at the conceptual design stage and have critical impact on building performance. Life cycle analysis methodology is employed to evaluate design alternatives for both economical and environmental criteria. A multi-objective genetic algorithm is employed to find optimal solutions. They concentrate on building envelope because of its importance in environmental and economical performance of buildings. The multi-objective optimization model they developed can be used to locate the optimum or near optimum green building designs for given conditions (Wang, Zmeureanu and Rivard,2005).

In sustainable design, land use is another subject designers take care of. Zelinska, Church and Jankowski (2008) present a new multi objective spatial optimization model-SMOLA which minimizes the conflicting objectives of open space development, infill and redevelopment, land use neighbourhood compatibility and cost distance to already urbanized areas. They examine the applicability of spatial optimization as a generative modelling technique for sustainable land-use allocation. The model uses 400 raster cells, and they generate multiple solutions with importance of objectives, at the end they evaluate the patterns produced by the model with multi agent geo-simulation. (Zelinska, Church, Jankowski, 2008).

These developed models are chosen for using evolutionary algorithms for solving different scaled design problems. The plan optimization model for green building design developed by Wang, Rivard and Zimeureanu(2006) is functional for considering material and cost information with building form, but it is insufficient for early stages of design. Also it is mostly concentrated on energy conservation, site planning for building complexes is disregarded. SMOLA model developed by Zielinska, Church and Jankowski generates land use patterns according to the building functions. For city scale the model is useful and has visual readability, but it is not convenient for small-scale problems. The SSPM model presented in this paper is an integrated model that concentrates on not only energy efficiency but also wide sustainable design criteria; such as green building certification systems and local building codes for.

SUSTAINABLE SITE PLANNING MODEL (SSPM) WITH PARETO GENETIC ALGORITHM

SSPM model is at the intersection of two different disciplines which are evolutionary algorithms and sustainable architectural design. The SSPM (Sustainable Site Planning Model) will generate site-planning alternatives for social housing on selected site, according to LEED and BREEAM certification systems sustainable site usage criteria, local building codes and local climate conditions which are accepted as sustainable design objectives. Multi-objective genetic algorithm which is also known as pareto optimization will use sustainable design objectives as fitness functions to generate site planning alternatives.

Site Definition Method

The first step of the model is definition of the site to the computer. Matrix definition technique in Excel is used to define the site with numbers. The defined digital site is used as a base to generate site planning alternatives on by SSPM. Excel program is chosen for providing quick and easy data input for matrix definition

The rows and columns of the matrix represent 1 unit =1 m2 of the site. The x, y values of the site corner points and the centre or corner points of existing elements are used to define the matrix. Each of the Excel cell is considered as a point in a coordinate system. R1C1 reference style in Excel is used to represent x and y axes to make data input apparent. The rectangular area which uses the values of maximum x and y coordinates of site corner points as its dimensions, is the boundary of the matrix. The cells inside the defined boundary are collared according to their functions so that visual presentation is provided. Each cell has functions shown below:

0. Empty cells outside the site boundary: They have no functions only used to define the boundaries of the site to the model. They are represented with white colour.
1. Empty cells inside the site boundary: They can transform to different functions(housing, green, pedestrian road, vehicle road, car park, etc.) They are represented with beige colour.
2. Existing reserved tree cells: Their positions are fixed, cannot be changed. Two neighbour rows placed around these cells are accepted as green cells and their positions are fixed too. They are represented with dark green colour.
3. Housing unit cells: They don't appear in the excel matrix, they are generated by the model according to fitness functions. Housing blocks consist of 1m3 cubes, which are generated according to floor space ratio (FSR), floor area ratio (FAR) and maximum building height value, overlap housing cells. They are represented with red colour.
4. Vehicle road cells: They are generated by the model according to fitness functions. They are represented with grey colour.
5. Car park cells: They are generated by the model according to fitness functions. They are represented with dark grey colour.
6. Pedestrian road cells: They are generated by the model according to fitness functions. They are represented with brown colour.
7. Existing main vehicle road cells: They are outside the site boundary. They are represented with black colour.

8. Reserved water cells: Their positions are fixed cannot be changed. Two neighbour rows placed around these cells are accepted as green cells and their positions are fixed too. They are represented with blue colour.

9. Reserved green cells: Their positions are fixed cannot be changed. They are represented with light green colour.

10. Used polluted area cells: They are priority areas for generating housing cells on. They are represented with yellow colour.

11. Existing public transportation station cell: They are represented with the letter of "T".

12. Existing noise origin cells: They are represented with the letter of "N".

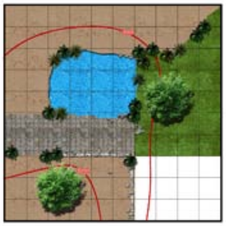
13. Underground cells because of the elevation difference: They are represented with slightly transparent grey.

In Figure 1, an example of a piece of land matrix defined in Excel is illustrated.

Figure 1
Piece of land matrix defined in Excel

1	1	1	1	1	1	1	1	1	9
1	1	1	1	1	1	1	1	9	9
1	1	8	8	8	8	9	9	9	9
1	1	8	8	8	8	9	9	9	9
1	1	8	8	8	8	9	2	9	9
6	6	6	6	6	6	9	9	9	9
6	6	6	6	6	6	9	9	9	9
1	1	1	1	1	1	0	0	0	0
1	1	2	1	1	1	0	0	0	0
1	1	1	1	1	1	0	0	0	0

Figure 2
Piece of terraced land matrix defined in Excel



1	1	1	1	1	1	1	1	1	9
1	1	1	1	1	1	1	1	9	9
1-3	1-3	8-3	8-3	8-3	8-3	9-3	9	9	9
1-3	1-3	8-3	8-3	8-3	8-3	9-3	9	9	9
1-3	1-3	8-3	8-3	8-3	8-3	9-3	2	9	9
6-3	6-3	6-3	6-3	6-3	6-3	9-3	9	9	9
6-3	6-3	6-3	6-3	6-3	6-3	9-3	9	9	9
1-3	1-3	1-3	1-3	1-3	1-3	0	0	0	0
1-6	1-6	2-6	1-6	1-3	1-3	0	0	0	0
1-6	1-6	1-6	1-6	1-3	1-3	0	0	0	0

The selected site must be digitized closed to the real terrain data without disregarding the topography and the natural formations, so that the site is presented in 3D grid with its slope data. User will divide the site into different zones according to its slope data. As a result of this, terracing sites which have elevation differences will be possible and environmentally sensitive solutions will be able to generated. The SSPM model will generated social housing cells according to this terraced site-zones.In Figure 2, an example of a piece of terraced land matrix defined in Excel is shown.

As it is shown in Figure 2, if an empty cell (presented with "1") are 5 meters higher than the accepted zero-level elevation, the cell is presented with the numbers of 1-5. If it is 10 meters higher than the zero-level elevation, it is presented with the numbers of 1-10. In addition, if a reserved tree cell (presented with "2") is 3 meters higher than the zero-level elevation, it is presented with 2-5. In this way, the visual readability of each cell's elevation is provided.

User Interface

After definition of the site with an Excel matrix by user, the model will use this data to visualize the selected site. At this stage SSPM model needs more information about the site. User interface is used to input essential data about the selected site by user. Processing 2.1 programming language is used to develop SSPM user interface and evaluating software, for having advanced visual environment and the ability of working with Windows.

User interface shown in Figure 3 has six values which will be determined by user:

- Climate type (temperate, warm, cold)
- Direction of prevailing wind
- Direction of view
- Floor space ratio (FSR)
- Floor area ratio (FAR)
- Maximum building height value

- Open space ratio

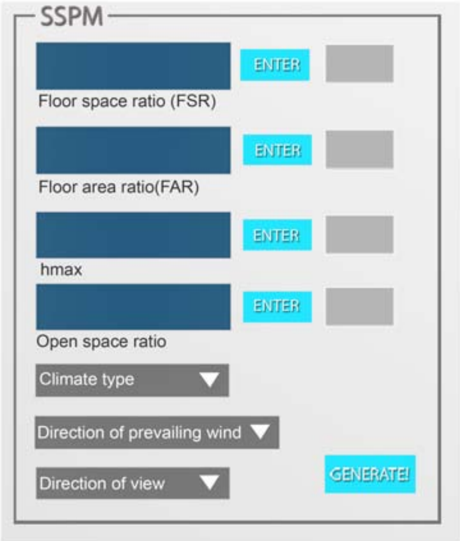


Figure 3
User interface

Each cell in Excel matrix is used as a gene of genetic algorithm. After defining the site with existing elements and the user chooses climate type, the direction of sun, wind and view the model will start producing site layout alternatives according to the sustainable design parameters. This step is where the genetic algorithm takes place. The fitness functions of genetic algorithm are the sustainable architectural design parameters mentioned below. Pareto genetic algorithm evaluates each alternative according to priorities and ranks the each alternative to find the best sustainable site alternative. SSPM generates site-planning alternatives on defined cells that include buildings, green areas, roads, car parks, pedestrian roads, bicycle roads according to fitness functions and crossover and mutation operators are applied to the population to find the pareto optimal site planning solution.

Evaluation System of the Model: Fitness Functions

The conflicting parameters will be evaluated according to their importance values by the model to find the optimal site planning with the help of pareto genetic algorithm. The sustainable design parameters that are going to be used in the model coming from LEED and BREAM sustainable site parameters, local regulations and local climate conditions can be classified in four objective functions:

- Site usage: The placement of the building and its surroundings are determined at this stage. It is a need to focus on the existing ecological values on the site. Maximizing open area and reducing heat islands have priority.
- Building Orientation: According to climate, wind and view direction housing units that are placed.
- Building Form: According to climate and local regulation formulas (FAR-floor area ratio, FSR-floor space ratio and maximum height) buildings get form.
- Accessibility: Model will use neighbourhood relations and formulas coming from rules to generate site layout alternatives.

The conflicting parameters will be evaluated according to their importance values by the model to find the optimal sustainable site planning with the help of pareto genetic algorithm.

Concept 1: Site Usage. The placement of the building and its surroundings are determined at this stage. It is a need to focus on the existing ecological values on the site. The fitness functions for sustainable site usage are listed below:

- Rule 1.1: Conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity so all existing elements which are needed to be protected on the site such as trees, lakes must be defined to the model. [1]

- Rule 1.2. Design the project to conserve 100% of all water bodies, wetlands, land within 30.00 meters of water bodies, and land within 15.00 meters of wetlands on the site.[1]

- Rule 1.3. For the reserved trees provide minimum 25 m^2 green area around, which means 2 rows of neighbour cells must be green cells.

- Rule 1.4. The percentage of the open space must be more than 25% of the value of open space given in the land use regulation. [1]

- Rule 1.5. If there is zoning but no open space requirement, provide open space equal to 20% of the site. [1]

- Rule 1.6. If there is no regulation, the open space area must be equal to building footprint. [1]

- Rule 1.7. If it is impossible to provide the value of open space ratio , roofs must be green roofs and they can be added to the value of open space area.

- Rule 1.8. Reduce heat islands to minimize impact on microclimate and human and wildlife habitat. [1]

- Rule 1.9. Polluted areas on the site are preferential to be used as a building placement area. [2]

- Rule 1.10. If there is an on old building on the site, 50% of outside area or 20% of the site area must be used as open space. [1]

- Rule 1.11. Parking areas and car transport interchanges should be far away from the areas to be protected. [1]

- Rule 1.12. If there is a noise source around, buildings must be placed 800 meters away from the source. [2]

Concept 2. Building Orientation. In this context detached building type is preferred so that detached building regulations are considered and floor height is accepted as 3.00 meters. For the model maximum building height is limited up to 60.00 meters.

- Rule 2.1. For detached building minimum distance of the front and side garden which coincided with the edge of the road must be minimum 5.00 meters. Buildings up to 5 storey, side garden distance is minimum 4mt and over 5 storey for each floor 0.5 meters is added to side garden distance.(Istanbul Zoning Regulations, 2007) [4]

$$\text{Side garden dist} = 4 + [((h/3) - 5)x0.5] \tag{1}$$

- Rule 2.2. For detached buildings up to 5 storey, backyard distance is minimum 5.00 meters. Over 5 storey, for each floor 1.00 meter is added to backyard distance (Istanbul Zoning Regulations, 2007). [4]

$$\text{Backyard dist} = 5 + [((h/3) - 5)x1] \tag{2}$$

- Rule 2.3. Orientation according to the view has the priority.

- Rule 2.4. For cold climate, wind direction must be direct to short edge of the building and for hot climate wind direction must be direct to the long edge of the building (TS825, 1999, Rules of Thermal Insulation in Buildings, Turkish Standards Institute). [3]

- Rule 2.5. For hot and dry climate, valley bottoms that are influenced by flows of cold air must be chosen to place. For warm climate valley ridges and for humid climates valley slopes are suitable (TS825, 1999, Rules of Thermal Insulation in Buildings, Turkish Standards Institute). [3]

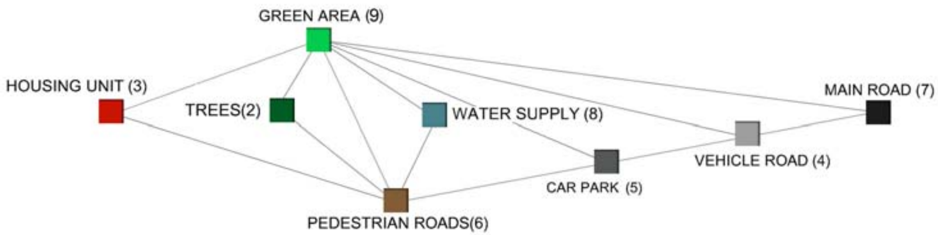


Figure 4
Neighbourhood relations of the model

Concept 3: Building Form.

- Rule 3.1. The maximum building height value defined by the user must be considered (Istanbul Zoning Regulations, 2007). [4]
- Rule 3.2.For detached buildings, building depth must be lower than 30.00 meters and for each building ground floor area cannot be higher than 900 m^2 (Istanbul Zoning Regulations, 2007). [4]
- Rule 3.3. Building envelope width should be minimum 6.00 meters from the front of the building and should not exceed 30.00 meters (Istanbul Zoning Regulations, 2007) [4], which means for housing cells minimum 6 units of cells should be side by side with a maximum of 30 cells unit.
- Rule 3.4. FAR (floor area ratio) and FSR (floor space ratio) values must be considered.

$$FAR = \frac{\text{Total number of housing cells}}{\text{Total number of site cells}} \tag{3}$$

$$FAR \leq 40 \tag{4}$$

$$FSR > \frac{\text{Total number of Housing Cells}\,x(h/3)}{\text{Total number of Site cells}} \tag{5}$$

- Rule 3.5. Building form has a huge impact on building energy performance. Compact forms must be chosen in cold climate to reduce the heat losses. (TS825, 1999, Rules of Thermal Insulation in Buildings, Turkish Standards Institute) [3]

Concept 4: Accessibility.

- Rule 4.1. Public transportation should be the minimum distance to the entrance of the buildings. [2]
- Rule 4.2. Maximum 1 car park place for 1 residential must be placed, for cars unit area for car park is 20.00 m^2.[1]
- Rule 3.3. Model will use neighborhood relations shown in Figure 4 to generate site layout alternatives.

According to the fitness functions of genetic algorithm mentioned above, evolutionary model will generate site layout alternatives on defined cells that also include green areas, roads, car parks and pedestrian roads.

Algorithm.

1. Defining site and selecting climate type, view and wind direction by user;
2. Create and visualize the site by using Excel matrix data prepared by user before, with regular grid of d dimensions (d = 1mt);

3. Initialization: Randomly generate an initial population;
4. Evaluation: Calculate the values of the n objectives for each solution in the current population. Then update the tentative set of non-dominated solutions;
5. Selection: Repeat the following procedures to select (Npop - Nelite) pairs of parent solutions; give points to population according to fitness functions and show the solutions that have maximum fitness value points. The user selects pairs of parent solutions.
6. Termination Test: If the user cannot select and wants to change, the input data return to Step 1, if selected go Step 5;
7. Crossover and Mutation: Apply a crossover operator to each of the selected (Npop - Nelite) pairs of parent solutions. A new solution is generated from each pair of parent solutions. Then apply a mutation operator to the generated new solutions;
8. Elitist Strategy: Randomly select Nelite solutions from the set of non-dominated solutions;
9. Show pareto optimal solution;
10. Termination Test: If the user is not contended and wants to change the input data return to Step 1; if stopping condition is satisfied, end the algorithm;

In Figure 5 flowchart of the SSPM model is illustrated.

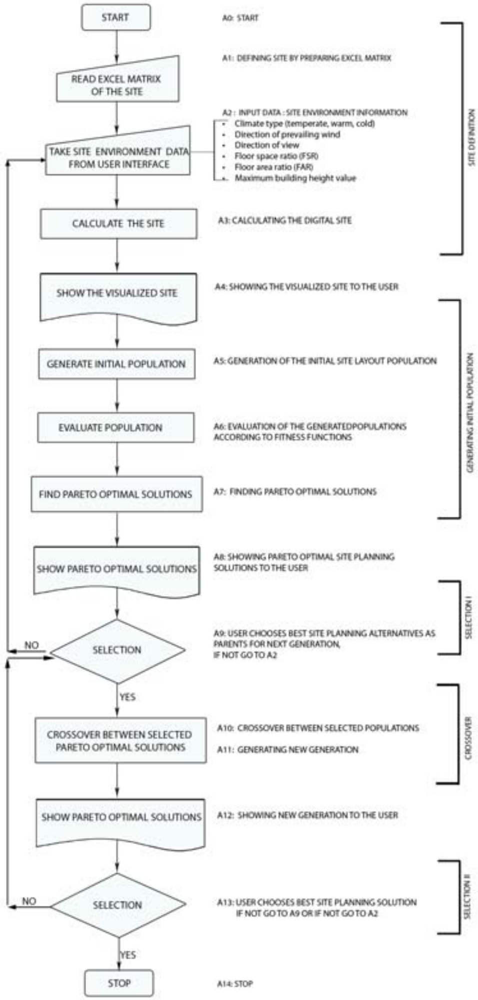


Figure 5
Flowchart of the model

Testing the SSPM Model
The SSPM model was tested on a site in Kağıthane in İstanbul. The reason for choosing Kağıthane was twofold. First, urban regeneration in the residential areas of Kağıthane has recently been a central issue of

consideration in Turkey. Second, the selected study area is a realistic example that has reserved water supplies, green areas and polluted areas to test sustainable social housing units. In Figure 6 selected area is shown with existing elements. Polluted area, shown with yellow in Figure 6, is preferential to be used as a building placement area. Reserved trees, green areas and water body will be protected and buildings will land with 30 meters of water body.

Figure 6
Selected Site in Kağıthane

The input data coming from user interface are:

- Climate type : Temperate
- Direction of prevailing wind: East
- Direction of view : West
- Floor space ratio (FSR) : 0.25
- Floor area ratio (FAR): 1.2
- Open space ratio: %20
- Maximum building height value: 45.50 meters

In Figure 7 two different generations which have different floor area ratio values are shown. High floor area ratio provides more building area. The polluted area shown in Figure 6 has the priority for the placement of the building blocks so that model starts to generate blocks from the polluted area first.

SSPM model generates housing unit alternatives according to fitness functions. First generations according to selected area information coming from the user interface are shown in Figure 8. Existing water body is protected and neighbour cells in 30 meters are accepted as green area, which means placement of buildings are not allowed. Number of generated buildings depends on FSR, FAR and maximum height value. Maximum building height value is not an obligation, it is used to limit the height of the building. Using floor space ratio limit has the priority which means low-rise buildings are preferred. At this run, model produces first population according to half of the fitness functions mentioned before (Rule 1.1, Rule 1.2, Rule 2.1, Rule 2.2., Rule 3.1, Rule 3.2, Rule 3.3., Rule 3.4). For future works, direction of view and direction of prevailing wind are going to be added to the fitness functions and also pedestrian roads, vehicle roads and car parks are going to be generated according to all the fitness functions mentioned before.User will choose each of the parents from generated alternatives and model will do crossover and mutation to find the pareto optimal solution for sustainable site planning.

CONCLUSION

This study is in the intersection of two different disciplines that are evolutionary algorithms and sustainable design. In this paper, it is proposed to combine cellular structures with a multi-objective genetic algorithm for using its search ability to find Pareto-optimal sustainable site planning solutions for social housing complexes.

The green building plan optimization model developed by Wang, Rivard and Zimeureanu (2006) is only focused on building envelope in early design

Figure 7
Comparison between different FAR values

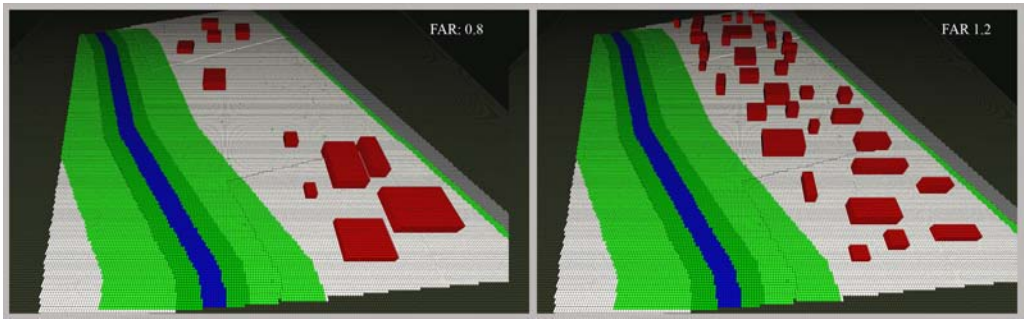
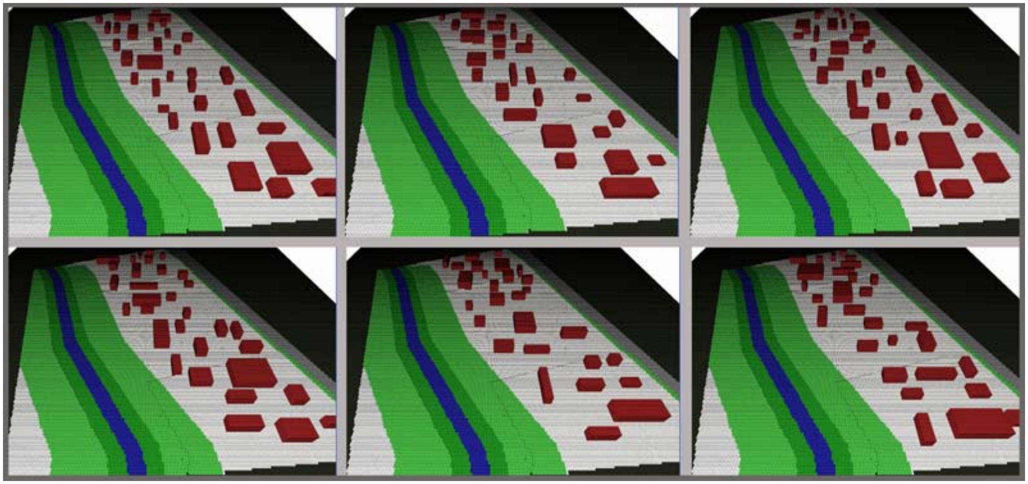


Figure 8
First generation of the site planning layout



stage and as sustainable design parameters , only energy conservation, maximum daylight and minimum cost are considered. Furthermore, the SMOLA model developed by Zelinska, Church and Jankowski(2007) only generates land use patterns and it addresses the problem with optimization of such sustainability objectives like new development, redevelopment, land use compatibility, and accessibility. This model is only focused on sustainable large-scale land-use in 2D space. The SSPM model presented in this paper is used for building scale and the layout of the site is detailed with roads, lakes, trees and buildings. The slope of the site and the buildings are presented in 3D space. SSPM is tested on an existing site which is in Kağıthane in Istanbul to find pareto optimal sustainable site planning alternative for a social housing complex. First population according to limited fitness functions are generated. In future studies,as fitness functions of the model are widened, generated alternatives will be more functional and effective for detailed sustainable site planning including pedestrian roads, car parks, vehicle roads, bicycle roads. This approach would introduce an effective computational design tool for early design stage of sustainable design, which does not currently achieved by current technologies.

REFERENCES

Bentley, PJ 1999, 'Aspects of Evolutionary Design by Computer', in Roy, R, Furuhashi, T and Chawdrhy, PK (eds) 1999, *Advances in Soft Computing*, Springer, London, pp. 99-118

Deb, K 2001, *Multi-objective Optimization Using Evolutionary Algorithms*, John Wiley & Sons

Goldberg, DE 1989, *Genetic Algorithms in Search, Optimization and Machine Learning*, Addison-Wesley

Harputlugil, GU 2010, 'Analysis and Simulation on Energy Performance Based Design', *Journal of Megaron*, 6(1), pp. 1-12

Horn, J, Nafpliotis, N and Goldberg, DE 1994 'A Niched Pareto Genetic Algorithm for Multiobjective Optimization', *Proceedings of the First IEEE*, pp. 82-87

Mitchell, M 1996, *An introduction to genetic algorithms*, The MIT Press

Rivard, H 2006, 'Computer Assistance for Sustainable Building Design', in Smith, IFC (eds) 2006, *Intelligent Computing in Engineering and Architecture*, Springer-Verlag, Berlin, pp. 559-575

Wang, W, Zmeureanu, R and Rivard, H 2005, 'Applying Multi-objective Genetic Algorithms in Green Building Design Optimization', *Building and Environment*, 40(11), p. 1512–1525

Zelinska, AL, Church, R and Jankowski, P 2008, 'Sustainable Urban Land Use Allocation with Spatial Optimization', *Geographical Information Science*, 22(6), pp. 601-622

[1] http://www.usgbc.org/

[2] http://www.breeam.org/

[3] http://www.vitrafix.com/assets/pdf/TS825.pdf

[4] http://www.ibb.gov.tr/tr-TR/kurumsal/Birimler/ImarMd/Documents/imar_yonetmelik.pdf

[5] http://www.iisbe.org/down/gbc2005/GBC2k2/GBC2k2_Manual_A4.pdf

[6] http://www.athenasmi.org/news-item/guide-to-lca-credits-in-green-building-programs/