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# IMPROVING BUILDING SUSTAINABILITY BY OPTIMIZING FACADE SOLAR INSOLATION USE

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## Abstract

In R. of Macedonia, ongoing public procurement projects for facade renovation of existing buildings intend to improve their energy performance and sustainability. The current efforts for this realization focus primarily on applying thermal insulation while not considering the benefits of utilizing passive solar design. The facades of the aforementioned buildings are not designed according to these principles. We argue that redesigning and optimizing the facade shape and glazing percentage can substantially contribute to the energy performance of an existing building.

This paper presents the results of the study carried out on one of the ongoing procurement projects. A relevant facade of an existing building is analyzed in order to maximize its insolation by optimizing the shape and glazing. The optimization methodology applies evolutionary solving tool named Galapagos which retrieves solar insolation data from Ecotect via the Geco plug-in. A grid is plotted on the facade where each knot can shift its relative position in an iterative process until the most optimal facade shape is achieved. The optimized and existing insulated facades are compared in terms of energy performance, cost and return of investment. It is concluded that the total sum of construction and operational costs of the facade with optimal shape are higher compared to the insulated facade with existing shape; moreover, beside the larger energy savings the return of investment period is prolonged due to higher construction cost.

## Key words

Facade; insolation; optimization; renovation; sustainability

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# 1 INTRODUCTION

The construction industry is one of the most intensive industries participating with 50% of the resource consumption, 40% of the energy consumption and 50% in the creation of waste, [1]. Most of the existing buildings are planned and constructed in an unsustainable manner and are held responsible for nearly 40% of the global energy consumption and approximately 36% of the total carbon dioxide emissions, [2]. Therefore, the construction of sustainable buildings is of great importance for future sustainable development of humanity. The concept of sustainability inquires meeting the basic needs of all people and extending the opportunities for environmental, economic and social advancement.

In R. of Macedonia the housing buildings are the largest consumers of energy and they account for 36% of the total electrical energy consumption from which 71% of the total amount is used for heating and cooling, [3]. To improve the buildings environmental, economic and social impact the government puts its efforts for reduction of energy demand by 20% until 2020, [4].

The buildings' envelope and especially the facade is one of the main contributors to the buildings' energy consumption and environmental and economic impact. It is also a building element with its own distinct culturological and social influence. As discussed in the Strategy for energy efficiency, in environmental terms, the main focus should be given to the refurbishment of the building's facade through applying thermal isolation, window replacement and changing mechanical heating equipment with a more efficient one, [3].

Reduction of energy demand has greater potential in the design of new buildings where the process is controllable throughout the whole life cycle of the building. During refurbishment the opportunities for energy reduction are limited and usually focused on applying thermal insulation thus possibilities for redesigning the building are neglected.

Today there is awareness that architectural design is generally the more cost effective option, meaning that optimizing the design can reduce the energy consumption of buildings by as much as 80%, [5]. Despite the availability of design tools and technology currently used in science and the existence of powerful computational technologies and optimization techniques, the construction industry is far from implementing them in daily practice,[6].

The most widely adopted design process of buildings is where a certain design is drafted, then evaluated and new design is being made afterwards drawn from the past experiences to make the problem more tractable, [7]. As the design process is iterative it needs a tool to produce many design proposals which could be effectively evaluated. As stated in [8] early design decisions influence 70% of later decisions and in [9] it has been concluded that implementing optimal design for a given building can reduce energy consumption and environmental impact by 30-40% with no extra costs. Ellis, Torcellini, et al. in [10] have shown that massing changes made during late design stages were to have considerable environmental and economic cost ramifications. Despite the potential and the interest shown by some of the leading architectural practices, evolutionary optimization has not been used in real world design projects due to the lack of tools and expertise in the architectural community or as stated by other researchers in [11] not all of the optimization techniques are applicable to building performance simulation.

This paper introduces a method that optimizes the environmental aspects and a comparison is made on the economic aspects of different design proposals. The optimization methodology is tested on an ongoing public procurement project where the south facade is optimized. We argue that redesigning and optimizing the facade shape and glazing percentage can substantially contribute to the positive environmental influence as well as economic and social benefits. The evaluation of the social aspect is not included in the scope of the research.

The remainder of this paper is organized as follows. Related studies are reviewed in section 2. It is followed by a presentation of the proposed methodology for improving the building sustainability by reducing the environmental impact of the energy performance and ensuring economic benefits. The results are presented in the fourth section, followed by a discussion and conclusion.

## 2 LITERATURE REVIEW

A review on a previous research has been conducted on design optimization providing opportunities for sustainability improvement. The optimization utilizes mathematical quantitative measures to get the best course of action possible for a decision problem [12]. Researchers in order to investigate a large number of design alternatives for finding efficient design with a positive environmental impact and to explore multiple design scenarios have applied in general two approaches: parametric optimization and evolutionary optimization. Parametric optimization studies are rarely used in architecture because of their long computational time. Evolutionary optimization on the other hand reduces the number of simulations required for exploring large search space. It is a technique inspired by the Darwinian evolution theory and is used to automate the process of searching for an optimal solution[6]. The most widely used evolutionary optimization algorithms are the genetic algorithms (GAs) which are search methods for optimization based on analogies with natural genetics recombination and natural selection. These algorithms were firstly developed by Holland [13] and Goldberg [14]. The algorithms consist of a set of variables called genes which make a gene pool, then the evaluation is made and basic genetic operators are applied (reproduction, crossover and mutation) [15], [16]. Evolutionary computing works by giving each variable, called a gene, an assigned fitness value. The solver iterates and solutions are generated until the objective function converges to a specific optimum value set [17]. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory performance has been reached for the population.

Many researchers have used optimization methodologies for improving specific sustainability aspects of the buildings. Al-Homoud in [12] optimizes the heating and cooling energy, while Wetter in [18] optimizes the lighting energy consumption. Improving energy performance has been researched by Hauglustine et al. in [19]where they propose optimization for increasing energy as well as cost performances of the object by using a genetic algorithm. Researchers have also used genetic algorithms in optimization of time-costs relationship [20]. Other researchers have focused on technological optimization such as Flager et al. in [21]. They propose a method for optimization whose scope is limited to the building envelope and mechanical systems where the variables taken into account are limited to building orientation, glazing percentage and glazing type. This method provides systematic evaluation of a predefined range of design alternatives in terms of Life-Cycle Costing (LCC) and carbon footprint.

Wang et al. [22] discuss that if the operation energy is the only optimization criteria, the analyzed building would have over dimensioned insulation. To overcome this problem an inclusion of multiple aspects of the building in the genetic optimization algorithm has been made by many researchers. Marzouk et al.in [23] perform optimization of project objectives, taking into consideration the interaction amongst involved resources. They suggest that the total duration and costs can be estimated and optimized.

In general there is a great interest in the building research community and according to Nguyen et al. in [24] the future research on optimization should be oriented towards improving the efficiency of search techniques and approximation methods for large scale building operating performance and reducing time and effort.

In the review of the papers it could be concluded that an analysis of the return of investment (ROI) of an optimized model has not been taken into account. Therefore, this financial aspect of the sustainability is addressed by the proposed method.

## 3 METHODOLOGY

This paper introduces a new optimization methodology utilizing parametric optimization tools coupled with energy performance tools to evaluate several design proposals from environmental and economic aspects regarding the sustainability of the building. Optimization program is coupled with an energy simulation program which allows the design space to be explored in the search for an optimal or near optimal solution(s) for a predefined problem. Afterwards an economic analysis in terms of ROI is undertaken. The methodology workflow and software used are shown in Tab. 1.

*Tab. 1: Optimization method workflow*

| **Procedure** | **Software used** |
|---|---|
| Building model | Rhinoceros 5 sp5 |
| South facade optimization | Rhinoceros 5 sp5, Grasshopper 0.9,Galapagos,Geco,Ecotectdefinition |
| Shape of surface + openings | Rhinoceros 5 sp5 |
| Energy analysis model 1,2,3 | Ecotect 2010 |
| Comparison of models energy performance, Bill of works and price estimation, ROI | Excel 2010 |

The methodology is tested on three models of an existing building which are described in Table 2. The building is part of an on-going public refurbishment program. It is situated in Skopje, positioned between three neighboring buildings where only the south-east facade is exposed to the sun. This facade has the largest potential for utilizing the solar insolation for heating the interior [25]. The building has two floors with dimensions of 13.9 m wide along the street and 8 m depth, with a total area of 222 m$^2$. The floors are made of reinforced concrete 12 cm thick. The height of the building is 8.5 m. The energy consumption due to lighting, heating and internal loads from inhabiting the space is calculated according to the schedule of operation for the building developed in Ecotect. Heating season starts from 17th of October and lasts until 15th of April. The indoor design temperatures are 18ºC and 26ºC in the heating and cooling season, respectively. Model 1 represents the building with its current energy performance. Model 2 represents the existing building refurbished with 8 cm EPS on the exposed facade. Model 3 represents the building redesigned with an optimized south-east facade. The existing south-east facade wall is demolished and is constructed as a structural facade. Installment of a 15 cm insulation is planned in the roof, floor and facade. The choice of isolation is from the programme of the manufacturer Knauf Insulation because of its sustainable characteristics. It is a product of the innovative ECOSE technology based on renewable materials and at the same time avoiding all the malign substances such as formaldehydes used as binder. This technology has a positive environmental influence due to reducing the embodied energy in the insulation material for up to 70% compared with standard materials using conventional binders. The embodied energy is a very important factor that needs to be taken into consideration, considering that the operational energy is decreasing (by efficient improvements), the embodied energy gains even more significance, [26]. Therefore, the production technology itself has big environmental impact. The rock wool produced with the ECOSE technology has a 0 global warming potential (GWP) and ozone depletion potential (ODP), [27].

*Tab. 2: Thermal transmittance values of building components*

| | **Model 1** | **Model 2** | **Model 3** |
|---|---|---|---|
| **Wall (U-value)** | Existing wall (mortar 1.5cm, 25 cm brick, 1.5 cm mortar) U = 1.607 W/m$^2$K | Existing wall + 8 cm EPS U = 0.276 W/m$^2$K | Structural facade wall (Knauf Gypsum board, Vapour barrier, Aluminum framing, 8 cm glass wool, Knauf Aqua panel 1.5 cm) U = 0.276 W/m$^2$K |
| **Floor (U-value)** | Existing floor structure (Parquet 2.5 cm, screed 4 cm, EPS 2 cm, RC slab 12 cm) U=0.438 W/m$^2$K | Existing floor structure (Parquet 2.5 cm, screed 4 cm, EPS 2 cm, RC slab 12 cm) U=0.438 W/m$^2$K | Existing floor structure (Parquet 2.5 cm, screed 4 cm, EPS 2 cm, RC slab 12 cm) U=0.438 W/m$^2$K |
| **Roof (U-value)** | Existing roof structure (Zinc sheeting, wooden boarding, glass wool 22 cm, Knauf GKF) U=0.155 W/m$^2$K | Existing roof structure (Zinc sheeting, wooden boarding, glass wool 22 cm, Knauf GKF) U=0.155 W/m$^2$K | Existing roof structure (Zinc sheeting, wooden boarding, glass wool 22 cm, Knauf GKF) U=0.155 W/m$^2$K |
| **Glazing (U-value)** | Double glazed Low-e glass U=1.4 W/m$^2$K | Double glazed Low-e glass U=1.4 W/m$^2$K | Double glazed Low-e glass U=1.4 W/m$^2$K |
| **South-east facade surface area m$^2$** | 118 | 112 | 126.5 |
| **South-east facade glazed surface area m$^2$** | 27 | 27 | 39.3 |
| **Glazing percentage (%)** | 23% | 23% | 31% |

The energy consumption of all models is analyzed in Ecotect where they are modelled as a single volume. The organization of the interior space is not included in the analysis due to the fact that in 90-95% of the cases, there is no heat flow in the interior, according to the First Law of Thermodynamics. The calculation of energy consumption is according to the following equation:

$$Q = (Q_c+Q_s)+Q_g+Q_i+Q_v \tag{1}$$

where,

$(Q_c+Q_s)$ - heat gains and losses through the building envelope due to conduction and indirect solar gains;
$Q_g$- direct solar gains through transparent surfaces;
$Q_i$ - internal heat gains from inhabitants, appliances etc.;
$Q_v$- natural ventilation heat gains and losses.

In the case of Model 3, a configurable south-east facade surface is drafted in Rhinoceros replacing the existing facade. It is then parameterized with a Rhinoceros plugin module and Grasshopper, using points to describe the surface. Each of them can have values from 0 m to 1 m with an increment of 0.1 m which describes their position perpendicular to the initial position. These points are set as the genes describing the gene pool. The objective is to find the most optimal position of each of the points in order to produce a surface that has a maximum exposure to the sun‘s insolation. Therefore the fitness value is defined as a maximum solar insolation. This insolation would then be used for passive solar heating of the building and reducing its energy demand. The solar insolation values are retrieved from the software Ecotect via the Geco plugin used in the genetic algorithm definition [28].

The optimized surface which has the strongest genes and maximal fittest value is subjected to window perforation by means of a modified Grasshopper definition [29]. The facades' surface is subdivided with an array of 6 smaller surfaces in each direction which are defined by four points. The average solar insolation value on each of the surfaces is calculated via Geco plug-in in Ecotect. Given that each subdivided surface receives different insolation value, the window sizing is proportional to this value. Surfaces receiving largest insolation would have largest windows and the opposite applies for the surfaces with least insolation. The total amount of glazing should not exceed 30% from the total area of the south-east facade which is slightly above the maximum glazing percentage for the latitude of the reference building [30].

After the surface and window optimization, an energy comparison is conducted between three models of the reference building followed by an ROI analysis. In the following sections the results are presented and discussed.

## 4 RESULTS

Due to the inherent randomness of GA, the program run three times for approximately 10h on a computer with a Windows 7 system (1.8 i3 core processor, 2 GB RAM). The most optimal scenario is presented in detail. The Galapagos optimization process is shown in Fig. 1 starting from the least optimal until the most optimal solutions.

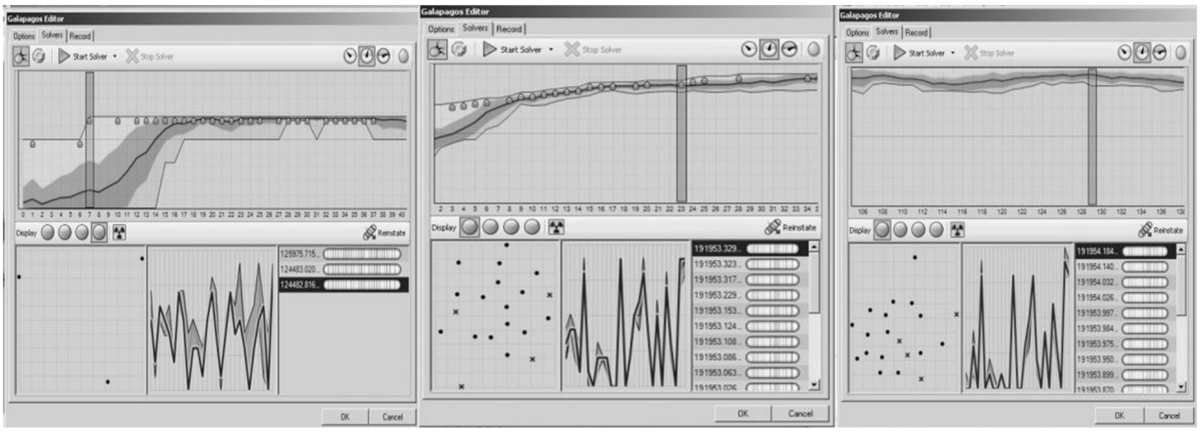


*Fig. 1: Galapagos optimization of the model*

The optimization process quickly enters in the area of optimal solutions by selection of the fittest genes. After retrieving the solar insolation data from Ecotect, the most optimal surface is selected as shown in Fig. 2. It consists of planar surfaces, each having different insolation. Further in the process on these planar surfaces a window is placed and sized according to the insolation value of the specific surface.

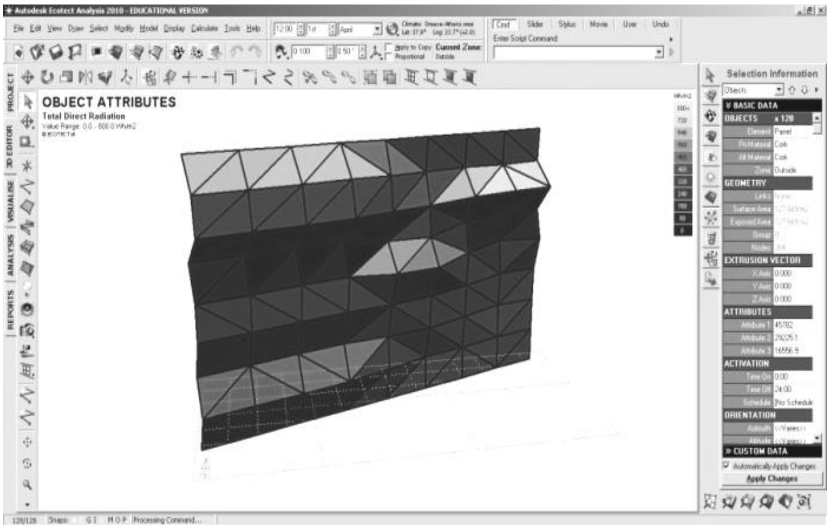
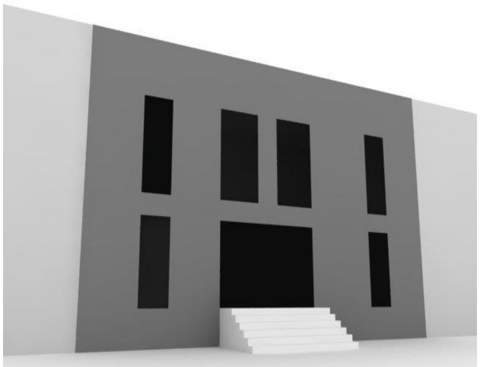



*Fig. 2: Most optimal surface shape*

Model 3 is glazed with windows with different sizes according to the insolation as described in the previous section. In Fig. 3 the visualization of the models 1 and 2 is shown.



*a. Model 1, 2*

*Fig. 3: Existing building form*

In Table 3 are presented the fabric gains and losses, direct solar gains, ventilation and internal gains, as well as their total sum calculated according to the Eq. 1. From the presented data it could be concluded that the largest energy savings are in the Model 3. The total energy costs are calculated according to the current energy price of 0.13 €/kWh (7.9 MKD/kWh), with an expected tendency for its increase.

*Tab. 3: Energy performance comparison*

| **Heat Gains and Losses** (kWh/m$^2$.a) | **Model 1** | **Model 2** | **Model 3** |
|---|---|---|---|
| Fabric gains and losses - $Q_f$ | -83.4106 | -27.3386 | -23.4864 |
| Direct solar gains - $Q_s$ | 9.763396 | 7.161221 | 11.89515 |
| Ventilation gains and losses - $Q_v$ | 41.48998 | 41.48998 | 41.48998 |
| Internal gains - $Q_i$ | -44.2822 | -44.2822 | -44.2822 |
| Yearly energy consumption - Q | -76.4394 | -22.9696 | -14.3835 |

The investment is calculated according to the bill of works and average construction prices in the country. The energy savings for the Model 2 and Model 3 are calculated as the difference between their energy consumption and the nominal consumption of Model 1. The total yearly energy costs are calculated by multiplying the yearly energy consumption with the total heated area and the energy price. The simple ROI is calculated as a quotient of the investment and the economic savings. From the values shown in Table 4 it can be concluded that the ROI period is shortest in Model 2, and almost the double time for the investment return in Model 3.

*Tab. 4: Construction works and ROI*

| | **Investment** (eur) | **Energy savings** ($kWh/m^2.a$) | **Total yearly energy cost** (eur) | **Economic savings** (eur) | **ROI (years)** |
|---|---|---|---|---|---|
| **Model 1** | 0 | 0 | 72*0.13*222 $m^2$ = 2077 | | - |
| **Model 2** | 6.500 | 53.4 | 22*0.13*222 $m^2$=634 | 2077-634=1443 | 4.5 |
| **Model 3** | 16.600 | 0.155 | 62*0.13 *222 $m^2$=432 | 2077-432=1654 | 10.03 |

## 5 DISCUSSION

In this paper an optimization method for improving the sustainability of an existing building is proposed. In the evaluation are considered the environmental aspects and a comparison on the economic aspects of several models is conducted. From the iterative optimization of a buildings' south-east facade and by a ROI analysis several insights were gained. It could be concluded that the Model 3 is most optimal in terms of energy performance due to several factors. The most significant factor is the optimal shape of the facade and its irregularity outperforms the existing facade in terms of optimal solar insolation and possibilities for passive solar heating. The materials chosen for the improved Model 2 and Model 3 are different in favour of Model 3. The materials for Model 2 have higher admittance values and thermal capacity compared to the applied materials in Model 3, which are selected for their low GWP properties as well as embodied energy. Therefore, the environmental aspects of the comparison altogether are in favour of Model 3. By comparing the simple ROI it could be concluded that the Model 2 has shorter period for ROI. The longer period for ROI in case of Model 3 is due to the high construction costs. The steel construction works is not used frequently in the country and the prices of the steel work are high. The specific steel forming for constructing the irregular facade shape increases the construction costs as well. Other factors which influence the higher costs of Model 3 are the window irregularities given that each window has different size and also the demolition of the existing facade wall increases the total cost.

## 6 CONCLUSION

The goal of the proposed methodology is to enable designers to have a more sustainable driven design process. Also, the intention is to provide them with a more profound insight in the energy, economy and performance aspects of the design decisions. It is essential to have suitable tools available at the conceptual design stage that can assist designers in finding better design alternatives efficiently. The case studies demonstrated that the surface optimization has a large impact on the environmental performance and special attention should be given when designing the facade. In this paper the investments are not optimized but merely an outcome of the optimization process.

The current stage of this study, however, focuses on optimizing only the building envelope. Future work should focus on inclusion of multiple parameters that can be optimized. The scope should be expanded to cover day lighting aspects, mechanical systems, other passive solar design strategies and economic optimization. To fully complete the sustainability goals a social assessment should be undertaken as well.

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## REFERENCES

[1] David A., Chiel B., John M. (1996). *Handbook of Sustainable Building: An Environmental Preference Method for Selection of Materials for Use in Construction*. Earthscan Publications Ltd.; Revised edition.

[2] Mumovic D., Santamouris M. (2009). *A Handbook of Sustainable Building Design and Engineering: An Integrated Approach to Energy, Health and Operational Performance*. First edition. London ; Sterling, VA: Routledge, 2009.

[3] Nexant, Inc., ICEM-MANU, Timel proekten inzenering, and Organizacija na potrosuvachi na RM, "Strategy for energy efficiency in R. of Macedonia (in Macedonian)," Skopje, 2010.

[4] Strategy for energy efficiency improvement in R. of Macedonia until 2020 (in Macedonian). Ministry of Economics, Skopje, 2010.

[5] Lechner N. (1991). *Heating, cooling, lighting: design methods for architects*, 3rd ed. Hoboken, N.J.: Wiley.

[6] Naboni E., Korolija I., Zhang Y., Maccarini A. (2013). Comparison of conventional, parametric and evolutionary optimization approaches for the architectural design of nearly zero energy buildings. *Building Simulation for a sustainable world*, Chambery, pp. 2559–2566.

[7] Cross N. (2004). Expertise in design: an overview. *Design Studies*, **25**(5), pp. 427–441.

[8] Bogenstätter U. (2000). Prediction and optimization of life-cycle costs in early design. *Building Research & Information*, **28**(5–6), pp. 376–386.

[9] Association of Cost Engineers (1999). *A green vitruvius: sustainable architectural design*. London: James & James.

[10] Ellis P. G., Torcellini P. A., Crawley D. B. (2008). Energy design plugin: an EnergyPlus Plugin for SketchUp. *National Renewable Energy Laboratory*.

[11] Bandara R., Attalage R. A. (2012). Optimization Methodologies for Building Performance Modelling and Optimization. National Engineering Conference 2012, 18th ERU Symposium, Sri Lanka, pp. 32–37.

[12] Al-Homoud M. S. (1997). Optimum thermal design of office buildings," *International Journal of Energy Research*, **21**(10), pp. 941–957.

[13] Holland J. H. (1975). *Adaptation in natural and artificial systems: An introductory analysis with applications to biology, control, and artificial intelligence*. Vol. viii. Oxford, England: U Michigan Press.

[14] Goldberg D. E. (1989). *Genetic algorithms in search, optimization, and machine learning*. Reading, Mass.: Addison-Wesley Pub. Co.

[15] Fasoulaki E. (2007). Genetic Algorithms in Architecture: a Necessity or a Trend? 10th Generative Art International Conference, Milan, Italy.

[16] Palonen M., Hasan A., Siren K. (2009). A genetic algorithm for optimization of building envelope and HVAC system parameters. *Building simulation 2009*, Glasgow, Scotland.

[17] Jin J. T., Cho H. J., Jeong J. W. (2012). Optimization of Freeform Building Shape Using Genetic Algorithm. ASim2012 Proceedings.

[18] Wetter M. (2001). GenOpt®, Generic Optimization Program. Seventh international IBPSA conferencem, pp. 601–608.

[19] Hauglustaine J. M., Azar S. (2001). Interactive tool aiding to optimise the building envelope during the sketch design. Proceedings of the Seventh International IBPSA Conference. IBPSA, pp. 387–94.

[20] Praščević N., Praščević Ž. (2012). Time-cost Optimization of a Construction Project by Genetic Algorithm. *Proceedings of International Scientific Conference People, Buildings and Environment 2012*, **2**, pp. 359–365.

[21] Flager F., Basbagill J., Lepech M., Fischer M. (2012). Multi-objective building envelope optimization for life-cycle cost and global warming potential. *eWork and eBusiness in Architecture, Engineering and Construction-Gudnason & Scherer (Eds)*, Reykjavik, pp. 193.

[22] Wang W., Zmeureanu R., Rivard H. (2005). Applying multi-objective genetic algorithms in green building design optimization. *Building and Environment*, **40**(11), pp. 1512–1525.

[23] Marzouk M., Osama O., Hamid Abdel M., El-Said M. (2014). A simulation optimisation tool for planning of low-income housing projects. *Civi Engineering and Environmental Systems*, **31**(1).

[24] Nguyen A. T., Reiter S., Rigo P. (2014). A review on simulation-based optimization methods applied to building performance analysis. *Applied Energy*, **113**, pp. 1043–1058.

[25] Petrovski A., Samardzioska T., Trombeva Gavriloska A. (2014). Comparison of insolation applied on surfaces of model placed in the area of Skopje. *Proceedings of First International Academic Conference on Places and Technologies*, Belgrade, 2014, pp. 758–765.

[26] Hanák T., Dosedělová P. (2012). Environmental Evaluation of Energy-Saving Measures – a Case Study. *Proceedings of International Scientific Conference People, Buildings and Environment 2012*, **2**, pp. 147–153.

[27] Knauf Sustainablity Report 2013. Available at: http://www.knaufinsulation-ts.com/en/content/sustainability-report-2013 (Accessed 30April 2014).

[28] [Geco] - Solar access. Available at: http://www.a-ngine.com/2012/03/geco-solaraccess.html (Accessed 28 April 2014).

[29] Geco responsive surface openings. Available at: http://www.grasshopper3d.com/forum/topics/geco-responsive-surface-openings?page=1&commentId=2985220%3AComment%3A1019232&x=1#2985220Comment1019232 (Accessed 28 April 2014).

[30] Mazria E. (1979). *The Passive Solar Energy Book: A Complete Guide to Passive Solar Home, Greenhouse and Building Design*. Rodale Pr, 1st ed.