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Parametric Design of a High-Rise Habitation Unit System through Lighting and Solar Energy Performances

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This paper refers to the design and analysis of a high-rise habitation unit system that is developed based on lighting and solar energy performances. Our aim is to integrate geometrical and environmental criteria in a general design methodology providing possibilities of morphological and functional design exploration of the system and its units in the initial design stage. In order to achieve this, digital parametric design and bioclimatic analysis software are used. The processes of planning and analyzing are included within a broader feedback loop mechanism that cyclically iterates between design creation and verification of results according to given criteria. The bioclimatic analysis software is used to introduce local climatic data and to find the levels of solar energy within each unit. The parametric control of the entire system and each unit separately allows a number of results to emerge offering possibilities for exploration as well as for selection of solutions that satisfy those criteria in the best possible way. In parallel, decisions in regard to the desirable design configurations are derived and investigated further aiming to satisfy functional, aesthetical, and other needs through design capabilities and performances of the proposed system.

Keywords: *analysis, habitation unit system, lighting, parametric design, solar energy.*

1. Introduction

Since the early developments in architecture, the application of bioclimatic criteria in the design of buildings and structures was a significant aspect influencing design decisions in various levels. Nowadays, this is becoming an indispensable and important direction in any design investigation process that aims towards the production of sustainable design solutions influenced by those criteria. The awareness in regard to environmental issues along with research into performance-driven design of buildings opens new possibilities for the use of advanced computational tools in design investigation. Within this frame a series of works have been developed stressing the importance of such design methodology used as the generator of architectural design solutions (Hensel *et al* 2010, Tang 2012).

Towards this direction, various processes have been developed focusing on the relation between design development and evaluation of results according to bioclimatic factors, aiming to achieve the connection of design and analysis tools and processes (Alfaris 2008). The application of processes in relation to bioclimatic principles leads towards the development of advanced software able to carry interrelated properties and parameters influencing geometrical entities. In this direction, the development and application of parametric design principles in different works has been demonstrated and discussed (Woodbury 2010, Aksamija *et al*. 2011).

The use of parametric design logic has become an influential direction in the area of computational design research leading towards alternative solutions of design that aims to improve various performances of buildings including bioclimatic ones. The relation between parametric design and bioclimatic principles aiming on spatial, functional, or morphological organization and typology of buildings is also examined (Bukhari *et al* 2010, Hachem *et al*. 2011), opening possibilities for developing bioclimatic solutions in different stages of design process including the early conceptual (Chronis and Liapi 2010).

This research examines such parametric design principles and their application in the design of high-rise buildings. Specifically, these types of building, depending on the form of their volume and their surface, are divided into categories, according to the direction of parametric design application as well as according to environmental elements influencing their design including wind, sun, water, etc. The appropriate orientation and morphology of the volume as well as the configuration of surface provides better conditions of comfort in the interior space taking advantage of natural ventilation and lighting, efficient use of renewable energy systems and collection of water to save water resources. Within this frame, a number of categories can be found: a) buildings whose entire volume and morphology has been affected by the above parameters, b) buildings whose volume has been split into smaller ones, c) buildings with atriums, d) buildings where attention was given on their surfaces, and finally e) buildings whose structure consists of individual units. Through examples of built, under construction and future projects, observations in regard to the tendency towards the design of high-rise buildings might be derived considering the role of environmental conditions as fundamental (Σαρβάνη 2013).

The current research is concentrated into the design development of a high-rise habitation unit system by integrating geometrical and bioclimatic criteria within a conceptual design process represented as a feedback loop mechanism cyclically iterated from design to evaluation, an idea included within the broader area of design process that is discussed in theoretical level (Rowe 1987) and is described as a sequence of actions including analysis, synthesis and evaluation. The evaluation and discussion in regard to performance-driven results and the use of parametric design tools aim to allow the exploration of solutions that meet those criteria in the best possible way. Specifically, by combining all possible aspects of design, the final aim focuses on the adequate natural lighting and solar energy benefits and on the design of units in such a way that their solar energy and lighting results are in the same level, taking into consideration the orientation, size and location of units within the system.

2. Methods

The importance of building form in regard to energy performance introduces a new dimension in architectural design. Therefore, the solar energy is found to be significant bioclimatic factor with important benefits and impact on buildings. In Greece and Cyprus one of the largest average of sunshine in Europe is observed, i.e. 1.800KWh per square meter in Greece (Κόκουβας *και συν*. 2012). Given that the building sector consumes more than 40% of the energy produced in Europe, energy saving becomes an important research area, since the techniques used for implementation can reduce energy consumption of a building up to 25% (Γιαννακούρας *και συν*. 2006).

The bioclimatic design based on sun factors aims on shaping buildings in order to accommodate the appropriate sunlight in each time period, firstly, by providing the right lighting in all spaces, and secondly, by using or avoiding solar energy as heating. Within this frame, the correct orientation of openings and their effective design can help towards the access of solar energy in any house or even in dense urban fabrics.

The current design process suggests the development of a high-rise habitation unit system through the application of parametric design principles. This is incorporated into a design process and analysis of bioclimatic building performances in order to investigate improved design solutions in the early conceptual design stage. In this context, a feedback loop process is developed, which cyclically iterates between design development and evaluation of results based on bioclimatic criteria. This can be explained as a heuristic method used in design decision making process, emphasizing the role of architect-user that is responsible to take design decisions according to hierarchically specified variables and criteria. This distinguishes current approach from other design methodologies that focus their attention on design optimization or problem solving procedures.

Taking into consideration the advantages of units' structures, research applies parametric design principles attempting to find the suitable morphology for the building and the units, the position of openings, the design of other architectural elements and their geometrical relations in a single system. Aim is to find a desired bioclimatic design proposal that can be applied in high-rise buildings.

The parametric design software is used for algorithmic development (visual programming) offering flexibility in regard to the modification of each unit as well as the structure and morphology of the system. The geometry of individual units and of the system is controlled through variables related to their dimensions, for instance the height and width of the unit, the length and height of the system, and so on.

Each unit's element and the whole structure are geometrically related by defining their parametric algorithm in Grasshopper software (plug-in for Rhino). By changing any variable the entire system is influenced, modifying the digital model accordingly. The Grasshopper software is associated with environmental analysis software Ecotect via Geco (plug-in in Grasshopper), which defines the variables for bioclimatic analysis and connects the results with Ecotect. The following diagram shows the proposed feedback loop process for the design, analysis, and evaluation of the system, Fig. 1.

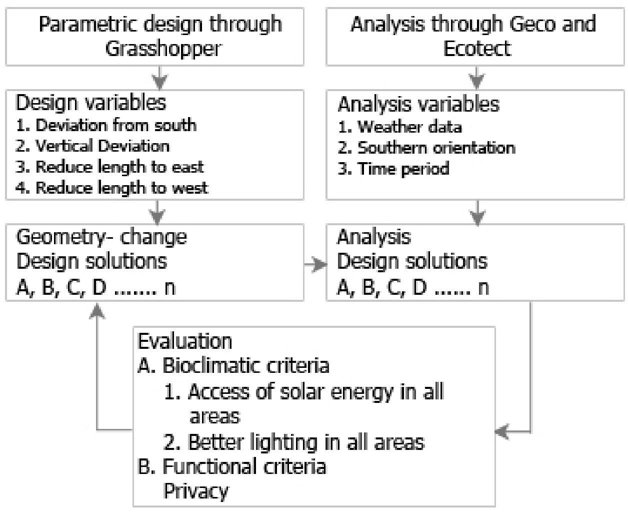

Fig. 1. *Proposed process of system's design and analysis*

Through parametric design, a number of design solutions (A, B, C, D, n) in regard to the system's geometry are created. These are tested in accordance with variables of analysis. Then, results are evaluated based on bioclimatic and functional criteria showing advantages and disadvantages of each solution. Finally, in order to improve the system, variables are redefined or supplemented. In regard to the units design, parametric logic allows changes of units' dimensions depending on their location and sunlight influences and according to specific variables. The Fig. 2 shows the diagram of the proposed process for the design and analysis of units.

The solutions obtained (a, b, c, d, n) through individual determination of units' design parameters are environmentally analyzed based on the variables introduced in analysis software. Then, conclusions in regard to the function of each unit's morphological elements are derived based on bioclimatic criteria. In order to improve the whole system, the design variables are redefined, one at each time, and then re-evaluated. Obviously, the number of design variables and evaluation criteria is tremendous involving objective or subjective ones. In any given design investigation their selection and application can vary according to the design decisions taken by the architect-user.

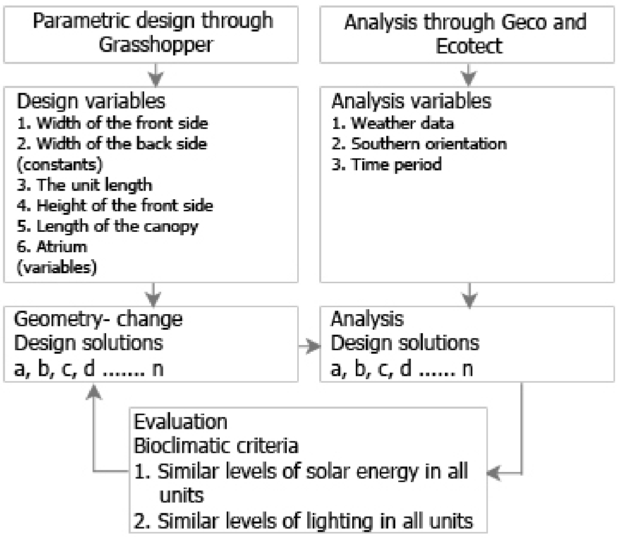

Fig. 2. *Proposed process of units' design and analysis*

2.1. Geometry and changes of the system

Through the appropriate morphology of the system, the relationship and composition of units are studied. Specifically, larger or smaller gaps between units are generated permitting or preventing the entrance of solar rays for lighting and solar energy purposes. These gaps help providing direct lighting (and, if it is not possible) diffuse lighting of premises with east and west facing. In addition, greater solar energy access is provided during winter by converting this into thermal energy, while during the summer this is avoided by suitable means (Bauer et al, 2009).

2.2. Geometry and changes of the units

The design of units allows or prevents the access of solar rays for lighting and solar energy by controlling the morphology and dimensions of units' structural elements including openings, recesses, atriums and canopies. Each habitation unit has certain dimensions and characteristics that vary depending on its location within the system. The geometry of each unit depends on six parameters where four of them function as variables and two remain constant. Specifically, changes occur in the length of the unit (affected by system's changes), the height of the front side, the length of the canopy, and the opening of the atrium while the width in front and in back side remain constant.

2.3. Energy analysis variables

As it has been mentioned, in order to analyze the solar energy levels in the indoor space, an algorithm is created in Geco and associated with Ecotect to analyze each digital model incorporating local climatic data into the topographical position and geometry of the building. The inclusion of these data in the design process is of particular importance especially during the early conceptual phase of design where desirable morphology is investigated.

The shortest (December 21), the longest (June 21) and the spring equinox (March 21) dates of the year at 9:00, 12:00 and 15:00 are used for analysis. The results of analysis are illustrated showing the levels of solar energy for each unit (Hirning *et al* 2010) represented on grid cells and expressed in Wh.

2.4. Lighting analysis variables

Regarding lighting analysis the same dates and times are used. Apart from transforming information through Geco, Radians software is used, a built-in lighting analysis program in Ecotect, which shows the levels of lighting on a scale range from 0 to 2000 lux (Ibarra and Reinhart 2009). The analysis is done in a specified single grid, 50 cm above the floor of the main zone.

2.5. Evaluation

The form of building is evaluated according to morphological and functional characteristics of high-rise structures, as well as to bioclimatic criteria such as solar energy and lighting performances. Based on these, good orientation of bioclimatic buildings is achieved by placing main interior spaces towards the sun, i.e. in the south side. A good location for the bedrooms is toward the east as the morning sun is desirable. In the west the sun disturbs so openings need to be small similar to the north where intense heating loss occurs, although, openings in both orientations are desirable for cross ventilation. In addition, the shading elements play an important role in the design of a building. In the south, canopies are placed in ratio ½ relative to the height of building. In the east (sunrise) and the west (sunset) vertical blinds and in the south horizontal blinds are added to avoid intense direct solar radiation. A greenhouse is usually oriented to the south and can store the desired solar energy.

The process of parametric design aims at finding the desired morphology, which allows satisfactory provision of natural light in the interior of all spaces and optimum use of solar energy. With the parametric interrelation of geometry, a large number of possible solutions emerge. The Fig. 3 shows a range of possible design solutions for the system from A to n.

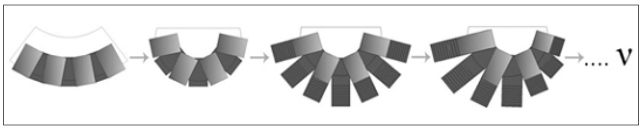

Fig. 3. Possible system's solutions A-n based on proposed design process

In order to improve the design of system, as it has been mentioned, changes on the dimensions of each unit are examined. Fig. 4 shows a simple square model of the unit with variable changes.

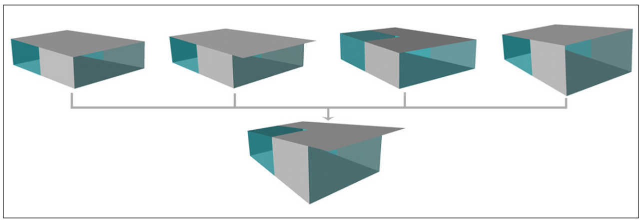

Fig. 4. Individual design variables and composition of unit – solutions a-n

3. Results

The development of proposed model is based on the process introduced in previous chapter. In the diagram below (Fig. 5) a comprehensive explanation of the current methodology is described. This shows the flow from design to analysis variables and then to evaluation based on bioclimatic criteria. These parts are cyclically iterated within a feedback loop process.

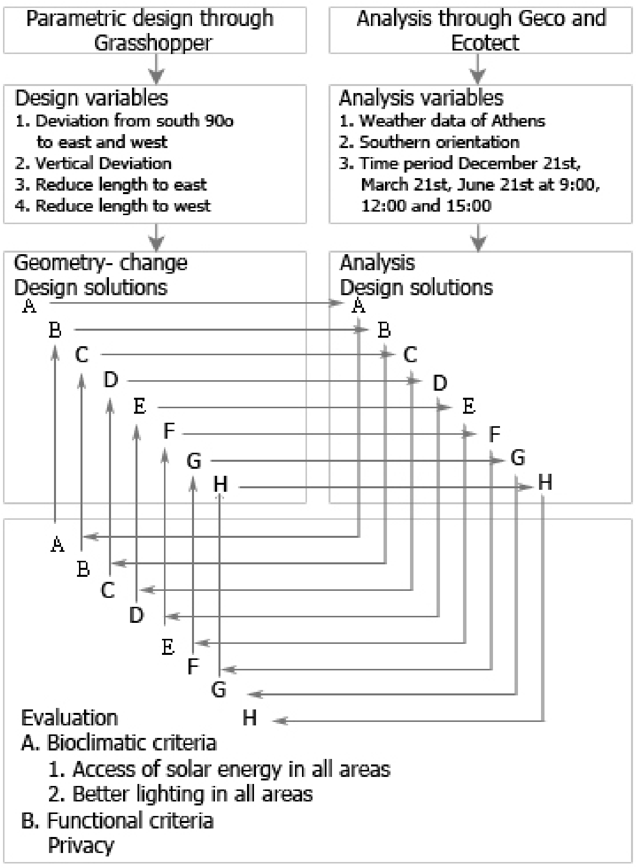

Fig. 5. Comprehensive diagram of the process used for system's design

Thereafter, the methodology describes the development of units as shown in Fig. 6, determining the design variables and evaluating the results based on specific bioclimatic criteria.

Based on the above methodology, conclusions are drawn in regard to the appropriate use of structural elements for each unit. In the process of unit design, the design variables change simultaneously and not individually as in the system's design.

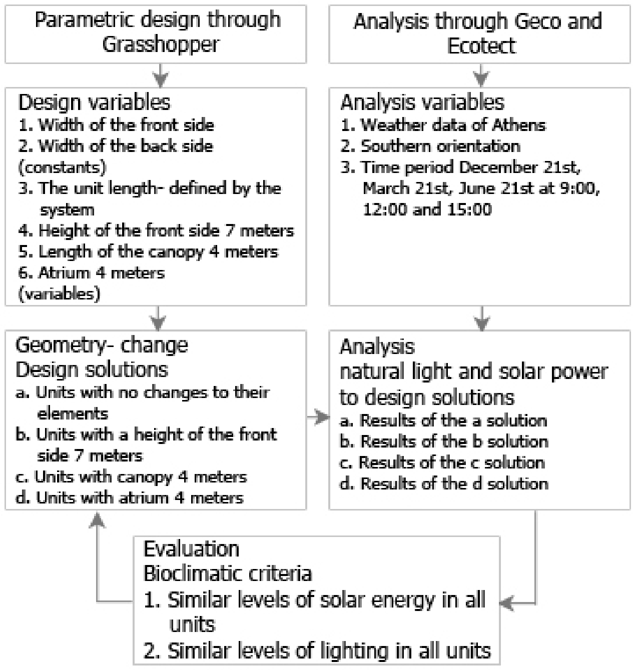

Fig. 6. Comprehensive diagram of the process used for units' design

As it has been mentioned, the methodology of design process is implemented using parametric design tools, which allow algorithms to be created, determining design parameters and producing a series of design solutions.

The suggested algorithm consists of four sections defined by their own parameters. In the first section the generic geometry of building (system's design) is defined (Fig. 7), in the second section the geometry of the units and their elements is parametrically controlled, in the third section the supporting structure is specified, and finally in the last section of the algorithm the overall geometry is linked with the analysis software.

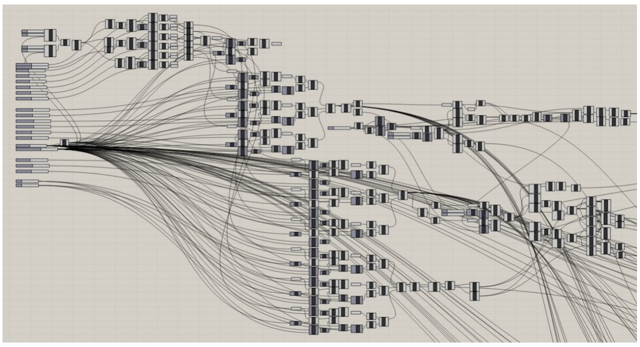

Fig. 7. Algorithm of building's generic geometry

3.1. Architectural design scenario

The proposed high-rise habitation unit building is located in Greece and for this reason climatic data of Athens are used in the process of analysis. According to proposed scenario, the building is positioned in an urban fabric at a sufficient distance from its neighboring buildings as its volume would be visually disturbing and aggravating in regard to human living conditions (poor circulation of air, turbulence at the back of building, lack of sunlight, noise, etc.).

Based on this scenario, the initial design decision that plays a key role in the formulation of the high-rise building system is its residential use, the choice to be composed by units and finally the use of the sun as the main bioclimatic factor. Each unit is a dwelling with covered area depending on its location in the system consisting of two zones in different levels, the southern zone that includes the main spaces, i.e. the living room and the kitchen, and the northern zone that consist of the bedrooms, the toilet and the greenhouse-atrium.

The openings of bedrooms are in the east side for greater exploitation of solar radiation during the morning. In the north side the bathroom is placed with very small openings. In the west, where the sun is particularly disturbing, a closed interior garden is created acting as a greenhouse. In the southern side of each unit a canopy is added in order to avoid intense solar radiation during summer. Also, with this structure it is possible to achieve wider openings of the unit towards the south, aiming on further annuity of solar radiation and reduction of the overall height. The design aims for each residence to operate independently from the neighboring units. This is achieved by the appropriate formation of openings and space arrangement in the interior. In front view, a diagonal system of units is created. Specifically, each unit is positioned between the overlying and underlying units. This aims to reduce the total height of building achieving in parallel the privacy of the residences.

3.2. Geometry and design solutions of the system

Initially, the system of units consists of twenty floors with four and three residential units alternately. These are located only in the south side, so all units can benefit from the advantages provided by solar radiation. The position angle of units ranges from 10° to 90° degrees from south to east and from south to west. On the north side, where the lighting is not sufficient and energy is lost, public and utility rooms are positioned. The initial model is symmetrical with an axis from the north to the south. The units are similar to each other and initially without atrium. Also, the front and back zones have a height difference of 50 cm, and in the south side a canopy of 2 m is defined. Parametrically, the overall geometry of the system is determined by two control points that define the length of the building. Through the points three curves are designed and copied at each level. The middle curve controls the position of units in the system; the southern curve specifies the length of units and the north curve the common area on each level.

According to the design variables, eight design solutions are derived. The design solution A has slight deviations of units from the south so all of them have almost south facing. In design solution B the units are placed symmetrically with deviation 90° angle from the south, creating a semicircle. As in solution A, the units are not altered and all floors appear on a vertical axis. The units in design solution C are oriented with a slight deviation to the south. What differentiate this model from the previous is that each floor is recessed relatively in regard to the underlying one, resulting declination of levels in vertical axis. Using the above information and in conjunction with solution B, the design solution D organizes units, which has not undergone any changes, in semicircle and appears with slight angle from the vertical axis in each floor. In solution E gradual reduction of units' length to the west is specified, as in the design solution F where units are positioned in a semicircle. In the design solution G the gradual reduction of units' length to the east is determined, and in solution H respectively, there is reduction of units' length to the east and semicircular distribution.

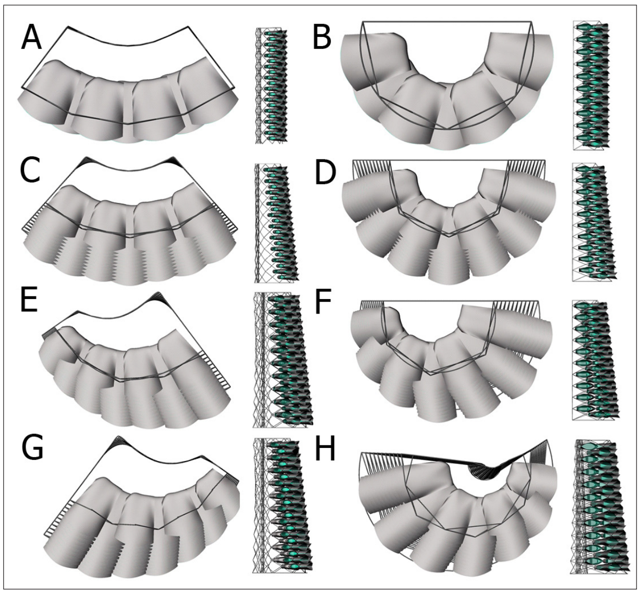

Fig. 8. *Design solutions of system's geometry*

For bioclimatic analysis purposes the four upper floors of the habitation system are used in order to include all possibilities of bioclimatic influences. The top floor is not obscured therefore it receives unobstructed sunlight. Similarly, on the 19th floor, the solar incidence is high due to the partial shading by units of 20th floor. In contrast, the other 18 floors are shaded in the same way from the overlying floors (Fig. 9).

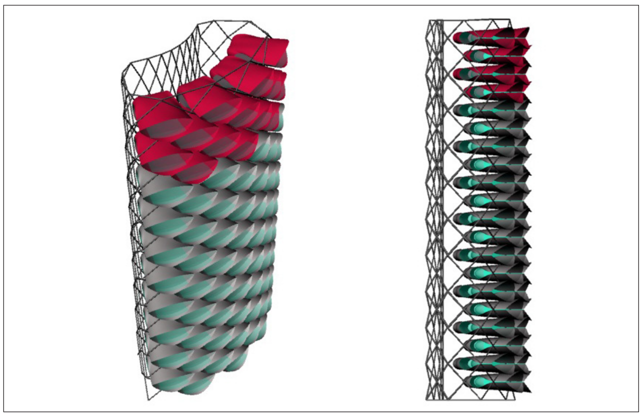

Fig. 9. *The four floors selected for solar energy and lighting analysis*

Energy analysis

The results below (Fig. 10) show the energy analysis for all design solutions on December 21 at 12:00. The selection for analyzing design outcomes at the same day and time is due to effective comparison between the eight solutions. In parallel, the selection of analyzing results during specific dates is due to the significant exploitation of solar energy for heating during winter period.

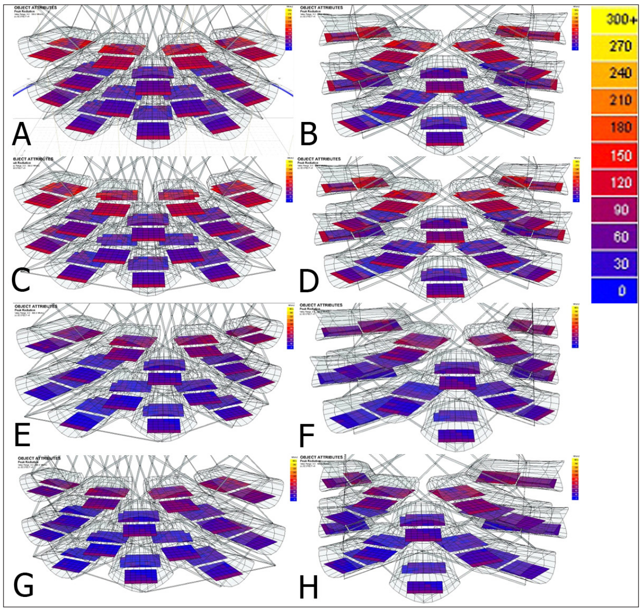

Fig. 10. *Energy analysis of eight design solutions of system on December 21 at 12:00 expressed in wh/m²*

Lighting analysis

The selected results (Fig. 11, Fig. 12) show the lighting levels in the interior space of units at the same floor. This is for easier comparison in regard to the adjacency of units allowing the choice of desirable geometry. The graphs in Fig. 11 show the lighting analysis of the first four design solutions on December 21 at 12:00. In this case, results are symmetric in respect to the north-south. The graphs in Fig. 12 show results of the rest four solutions on December 21 at 9:00. In this case, variations of units' length aim on better provision of natural light in the back zone during the morning hours.

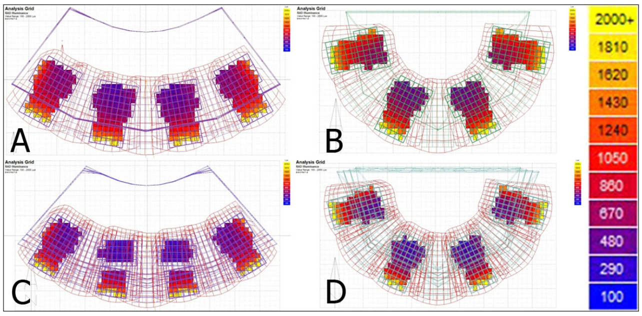

Fig. 11. *Lighting analysis on December 21 at 12:00 in Lux*

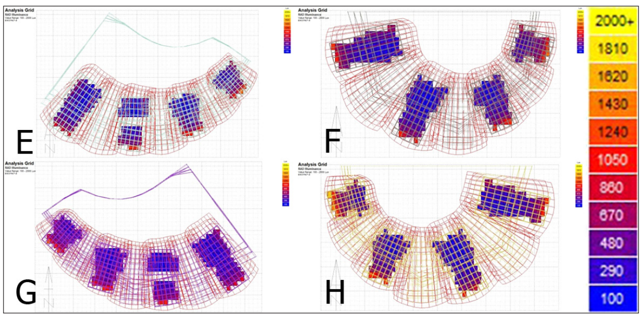

Fig. 12. *Lighting analysis on December 21 at 9:00 in Lux*

Evaluation

Comparing energy analysis results of design solutions A and B, it can be concluded that solution B has greater advantages. The structure of units in deviation 90° angle from east-west has little difference as regards the results of energy and lighting in relation to the results of units facing to the south. However, due to the large gap between the units, this leads towards greater solar radiation access in the back space.

By contrasting solutions C and D it is found that due to the great gap between adjacent units and the gradient in position of the overlying and underlying units better provision for lighting and energy in the secondary areas can be achieved. Disadvantage is that the units receive more solar radiation in the south side and for this reason canopy should be added. In order to improve the system, investigation on units' length in each floor to the east and west is decided. In solution E the units' length is reduced to the west, i.e. the main volume of building takes advantage of its position to the east. However, the disadvantage is that the remaining units are shaded during the morning hours reducing the incoming radiation in bedrooms. Also, in this way the western insolation of each unit grows, which is not particularly desirable. Similar results are obtained from the solution F where due to the greater variations and larger design of gaps between units the western insolation is maximized.

In the solution G the length of units is reduced to the east. The disadvantage of this solution is that the main volume of building is placed in the west side. The advantage is that the remaining units are shaded from the west where the sun is particularly disturbing. On the west side, an interior garden is placed in each unit. Effort has been made to place all the bedrooms to the east orientation, giving that the morning sun is more desirable in these spaces. With the gradual reduction of units' length, greater sun radiation is entering the bedrooms during the morning and afternoon hours. The same results are achieved in solution H where a greater gap between the units is determined. The units are distributed in 90° degrees angle to the east and west creating a semicircular model.

According to the results, all models show similar and adequate lighting levels range from lower value of 100 Lux during the winter to higher value of 2000 Lux during the summer. Thus, in the selection of desirable solution the energy factor plays the major role.

3.3. Geometry and design solutions of the units

The parametric design process enables changes of units' elements variables according to their position and influences received from the sun. This results the redefinition of units' geometrical characteristics according to given criteria without losing the initial design principles. Aim is to make better use of solar radiation in all units of the high-rise building.

The geometry of unit is based on a single C-shaped curve in section, which creates a shell with enclosed spaces. The main façade is configured in such a way that the shell creates a funnel shape. The gaps serve as glazing. The dimensions and characteristics of each unit change depending on its position to the system. In order to illuminate all spaces from a single surface, one possible solution would be to arrange them in linear manner but in this case the space is not functional. A good solution would be to place the bedroom area close to the core of residential building, however this results problems in regard to lighting and ventilation. By using parametric design and by changing the morphology of units, aim is to find the best possible solution in order to improve lighting and ventilation in all spaces as well as to better use solar energy.

In order to improve bioclimatic characteristics of each unit in the system, an attempt to change variables of individual structural components depending on units' position and orientation is developed. The parametric design of units and their interdependency are described and shown in Fig. 13.

In the design solution a, units are without canopy and atrium, and their height in the south side is the smallest possible. In solution b, the only element that changes is the canopy that takes its maximum value. By adding full opened atrium in the solution a, the solution c emerges. Finally, in design solution d the height of southern opening is selected to be modified. By comparing the four different units in regard to the energy and lighting efficiency, conclusions are drawn in accordance with the structural elements. Purpose is all units, regardless of their location and orientation, to have approximately same levels of lighting and solar energy. This will be achieved in the next stage where changes of units' variables and bioclimatic analysis will lead towards desirable solutions.

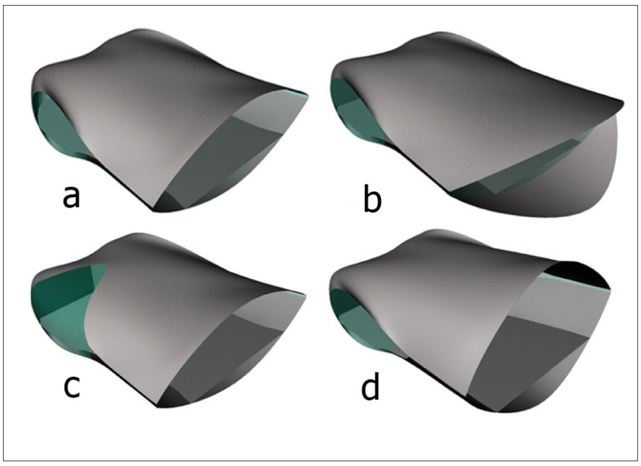

Fig. 13. *Design solutions of units' geometry*

Energy analysis

By comparing the energy and lighting levels, advantages and disadvantages can be found based on design variables specified initially.

Following illustrations (Fig. 14, Fig. 15) show selected units' results of energy analysis for each design solution on June 21 and December 21 at 15:00. In this case, the 8th unit is selected to be demonstrated due to its location in a typical floor. Another reason is that the design variables affect more the units at the edges of building. The 8th unit is the largest of the floor, so the effect of data is more apparent.

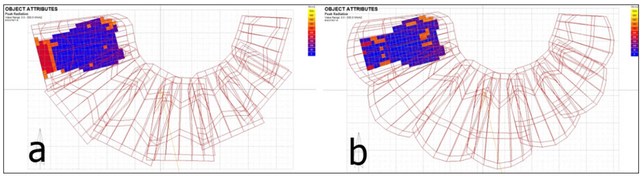

Fig. 14. *Energy analysis on June 21 at 15:00 with 71.11 wh/m² in design solution a, and 66.37 wh/m² in design solution b*

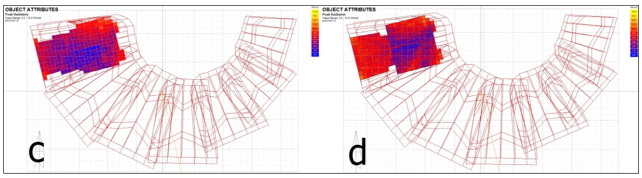

Fig. 15. *Energy analysis on 21 December at 15:00 with 2.77 wh/m² in design solution c, and 3.67 wh/m² in design solution d*

Lighting analysis

Similarly, Fig. 16 and Fig. 17 show the lighting analysis results of 8th unit on June 21 and December 21 at 15:00.

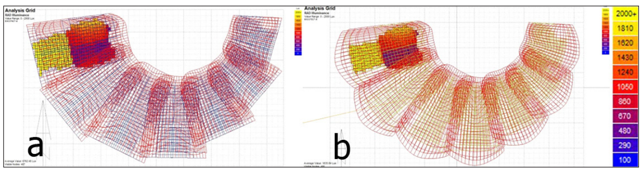

Fig. 16. *Lighting analysis on June 21 at 15:00 pm in Lux*

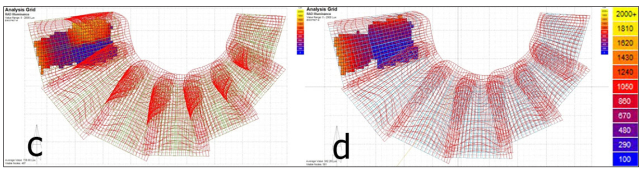

Fig. 17. *Lighting analysis on December 21 at 15:00 in Lux*

Evaluation

Based on the analysis results it is observed that units accept extremely high solar radiation, particularly the western and eastern units due to respective western and eastern exposure to the sun respectively.

The eastern and western units accept extremely large insolation levels, which need to be reduced using the canopy. Comparing the results obtained from solutions a and b, it is observed that solar radiation is reduced considerably in the openings, particularly in the western and eastern units.

The lack of atriums, especially in the western units that are facing to the north, does not help its bioclimatic purpose. Disadvantages of placing the atrium in the north side are, first, acceptance of minimum insolation and, second, performance of highest energy losses. The analysis results of solution c with the maximum opening of atrium, in comparison with the analysis results of solution a, shows that insolation increases in the back zone of western facing units, which is desirable, but becomes maximum in the back zone of eastern facing units, which results in overheating and high level of lighting.

Changes on the height of main south opening can reduce solar radiation exposure in units. The increase of height in solution d, can achieve better insolation in the southern units, while this is also increased in western and eastern units during the evening and morning hours (that is undesirable).

3.4. Geometry of final proposed model

By comparing the four different design solutions and by changing the design variables as well as after a series of test through analyses, the final model has been produced (Fig. 18). Purpose is regardless units' position and orientation within the system, similar levels of lighting and solar energy for all units to be obtained. Firstly, this can be achieved by adding a canopy that starts at 3 m in the eastern and western units and ends at 1.5 m in the southern units. Secondly, by changing the height of main south façade, range from 3 m in the east and west and 4 m in the center. Finally, by varying the opening of atrium from the west to the east, starting from 3.5 m and gradually decreasing this into zero value.

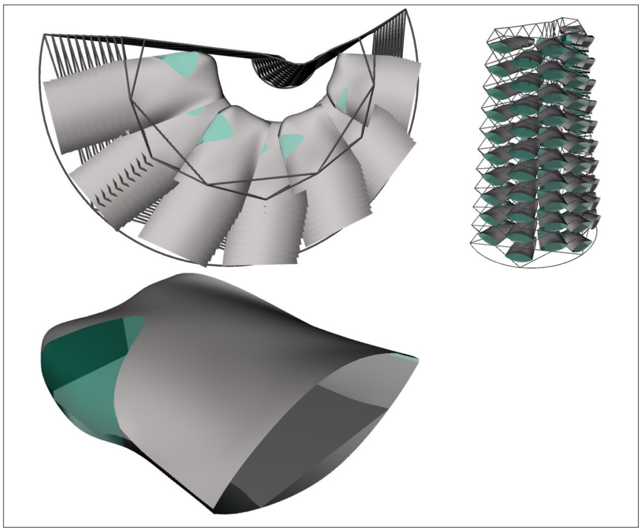

Fig. 18. *Final proposed model*

Obviously, an optimal solution for each individual unit is difficult to be achieved because in this process a large number of factors play important role such as orientation, morphology and size of units. In the current research the goal is not to optimize specific units, for instance units facing south that are clearly more favorable than other, but to adjust geometric characteristics in such a way that all units can benefit in the same way in regard to the climatic conditions.

Energy analysis of final proposed model

After a large number of tests in regard to design variables of units, the final desired model has been found in which all units appear with similar bioclimatic performance results of analysis. In this investigation, units on the same floor with different orientation and same date and time are compared.

Following Fig. 19 indicates energy analysis results for 8th and the 11th unit's final solutions on December 21 at 15:00, which appear to be similar. In the Fig. 20 energy analysis results for 12th and 14th unit final solution on June 21 at 12:00 is demonstrated showing similar energy levels.

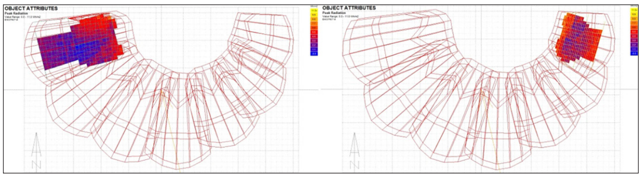

Fig. 19. *Energy analysis on December 21 at 15:00 for 8th unit is 2.91 wh/m^2 and for 11th unit is 3.96 wh/m^2*

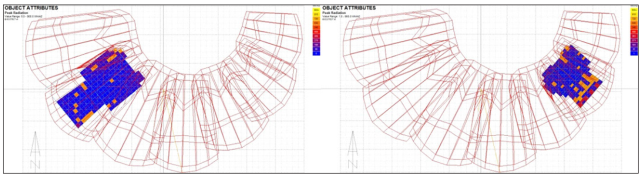

Fig. 20. *Energy analysis on June 21 at 12:00 for 12th unit is 92.92 wh/m^2 and for 14th unit is 155.89 wh/m^2*

Lighting analysis of final proposed model

Following illustrations indicate lighting analysis results in order to make comparisons of units' lighting levels in the same floor, the same date and time but with different orientation.

Fig. 21 shows the lighting levels for 8th and 11th unit on June 21 at 15:00, which appears similar. Also, in Fig. 22 lighting levels for 12th and 14th units on December 21 at 12:00 are demonstrated. Aim of these comparisons is to verify the proper use and dimensions of structural elements in each individual unit so the lighting levels will be similar.

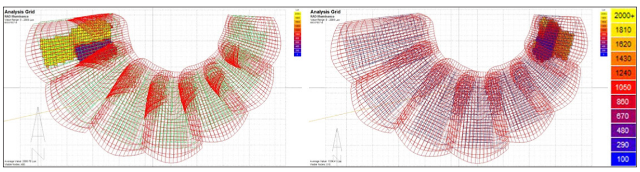

Fig. 21. *Lighting analysis on June 21 at 15:00 for 8th and 11th unit in Lux*

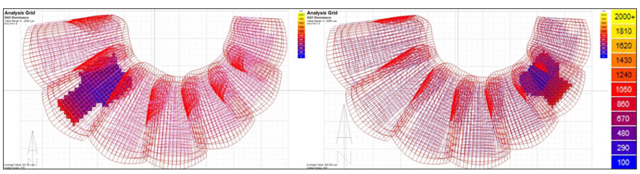

Fig. 22. *Lighting analysis on December 21 at 12:00 for 12th and 14th unit in Lux*

Evaluation

In order to achieve similar lighting and solar energy performances, selection of changes in regard to the dimensions of units are developed. After a large number of analyses, conclusions about the function and dimensions of any design variable are drawn. With the addition of extra canopy, the lighting and solar energy levels are reduced in the western and eastern units achieving desirable results.

The length of atrium rising eastwards provides with similar results in all units. To this end, the opening of atrium is necessary to be increased from the east (without atrium) to the west (maximum opening of atrium of 4 m). With this strategy, the incident solar radiation is increased from the roof when this is reduced from vertical glazing. In the eastern units, maximum irradiation from the vertical opening are obtained and for this reason the atrium is not necessary. Unlikely, in the western units, the incident radiation in the vertical opening is almost zero and therefore, the atrium's opening is essential to have maximum value.

Also, by increasing the height of the front of the central units and by decreasing the height on the west and south side similar results in all units might be derived. Specifically, the eastern and western units receive more radiation, so it is better to have smaller height (3 m) to the east and west, and largest height (4 m) in the center.

4. Discussion

The proposed forms are evaluated according to morphological and functional characteristics exhibiting in high-rise buildings, as well as according to bioclimatic variables of solar energy and lighting. In the present study, a final model is revealed based on the proposed methodology. Through changes of system's geometry and design variables results can be obtained. By comparing the results of analysis, the final geometry of proposed model is selected (Fig. 23, Fig. 24).

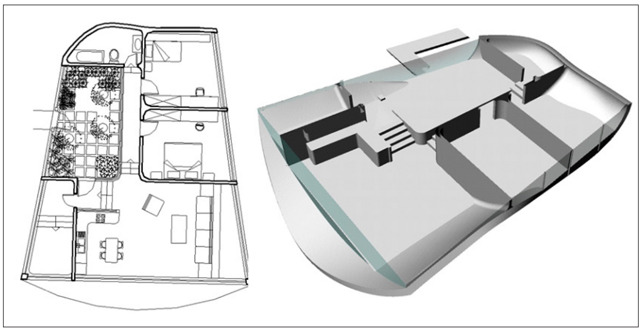

Fig. 23. *Floor plan and horizontal section perspective of the proposed unit*

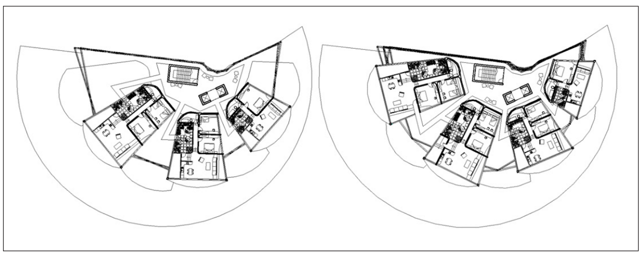

Fig. 24. *19th and 20th floor plans of building*

The investigation of unit's geometry is also important. Initially, variables are changed separately, i.e. the height in the front side, the length of canopy and of atrium. By comparing the results, it has been concluded that each structural element in regard to bioclimatic performances works differently in each unit. By combining appropriate variables for the structural elements it is possible to produce final results and achieve current research objectives, i.e. each unit of the system to receive similar lighting and solar energy.

The above application showed that a model might not behave optimally throughout the course of a day or a year. The position of sun varies continuously resulting different exposure of units to sunlight changes. Depending on the time of the day and the time period, advantages and disadvantages for each unit can be drawn.

In order to improve the performance of units, it is essential to add some bioclimatic elements in the final proposed model for bioclimatic design purposes in Greece and appears in design guidelines (e.g.: (BDIG 2013). These might include passive heating and cooling systems, Trombe-Michel wall mass, natural cooling as radiation barrier and ventilated shell, glazing with low emissivity Low-e, vertical blinds in the western and eastern side and horizontal blinds in the southern side for window shading, materials with low thermal conductivity to reduce heat transfer to and from the external environment, and so on (e.g.: (BDIG 2013).

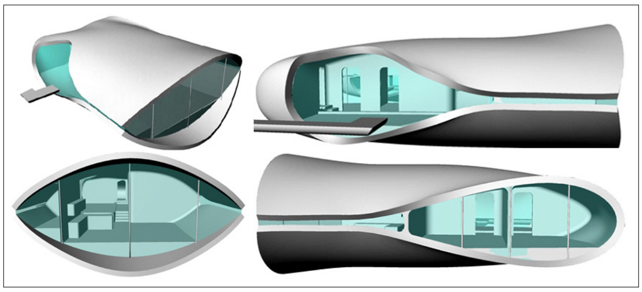

Fig. 25. *3D architectural model of individual unit*

5. Conclusions

This research presents a design process methodology for developing a high-rise habitation building with units, which combines parametric and bioclimatic design principles. In this case, the development of the model in regard to the sun factor is significant in order to improve building's morphology. This work aims on bioclimatic benefits and improvement of life quality in urban areas in Greece and Cyprus.

Individual residences that include large spaces and green areas are combined achieving their privacy. Through the bioclimatic direction of investigation each unit takes the sun advantage for the effective use of lighting and solar energy. According to the bioclimatic analysis results obtained, it is concluded that the proposed solution has significant levels of lighting and ventilation in contrast to buildings found in urban areas, where lack of lighting and obstruction of views as well as large energy losses occur.

The proposed methodology is based on the feedback loop process that iterates between design outcomes and bioclimatic analysis. After a number of stages in the research investigation, results of a desirable model that meets the initial objectives are obtained. Within this process, a number of possible morphologies are derived from this interdependence, suggesting possible solutions for the design of bioclimatic high-rise buildings consisting of units. This is considered as a heuristic approach applied in design decision making process moving beyond design optimization or problem solving procedures. Within this frame, the role of architect-user is found to be significant because he/she is able to control the decisions taken in different stages of design process as well to apply specific variables and criteria according to the problem under investigation.

In the first stage, investigation is concentrated on the ability of each unit, regardless of its position and orientation within the system, to achieve desirable lighting and solar energy levels. In the second stage, by changing the individual structural elements of the units, similar levels of lighting and solar energy for all units are achieved.

In conclusion, the current design methodology has shown that despite the complexity of such buildings, it is possible to design based on bioclimatic principles, incorporating criteria that improve quality of people's lives since every unit is functioning as a small bioclimatic house. This methodology and the model being developed could be used for further studies and improvements in regard to the geometry and structure of such buildings incorporating or introducing new parametric variables or evaluation criteria aiming towards sustainable design. The large spectrum of objective or subjective criteria that might be applied open discussions in regard to the way these can be integrated in the suggested computational design technique. Also, future direction could be the development of a methodology and its application in other bioclimatic design studies.

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