Parametric Approach to the Bioclimatic Design of a Student Housing Building in Patras, Greece

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Abstract. *A new housing complex on the Campus of the University of Patras, Greece, is expected to serve as a test-bed for experimentation with a parametric design process that integrates significant climatic data. To optimize the environmental performance of the proposed housing complex a parametric design algorithm has been developed. The algorithm links the weather data in the area with the site topography and the basic geometric features of the buildings on the site. To explore the interaction of the building features with the prevailing winds in the area and the solar exposure throughout the year various software applications, including computational fluid dynamics (CFD) simulations, have been utilized. The inclusion of wind data in the algorithm renders it particularly effective. The developed parametric process has been useful during the early design phase when studies on various patterns for arranging the buildings on the site were conducted. The parametric process has facilitated the configuration of the typical building block as well.*
Keywords. *bioclimatic design; parametric design; design algorithms, sun control; wind analysis; CFD in building design.*

Background: Site and Climatic Considerations

The need to include sustainability among the major design parameters in projects of all scales will certainly lead to new and in some cases identifiable building morphologies. Eventually rediscovering old methods, coupled with the existing and developing generative and parametric processes and the fast developing building technologies, will lead to a new urbanity. Suburban sites can easier absorb such changes and can serve as a test-bed for experimental approaches to building sustainability before being applied to urban sites. University campuses often offer opportunities for experimentation with innovative approaches to building design which can then give rise to trends that change the face of our cities.

The design of a new student housing complex on the Campus of the University of Patras, Greece, is expected to serve as a starting point for experimentation with a design methodology that places emphasis on bioclimatic considerations. The housing complex is to be built on a steep mountainous site that overlooks the impressive Rio,Antirio Bridge - one of the largest cable-stayed bridges in the world. The area is characterized by strong winter winds, summer breezes, and solar exposure almost all year long due to sparse plants in the area.

In addition to the programmatic requirements, the peculiarities of the site and the unique views, the climatic conditions in the area will play a leading role to the proposed student housing complex. This will consist of an arrangement of linear building blocks; each housing block will include studios, small family apartments and communal spaces organized in three levels.

To optimize the environmental performance of the housing complex, a parametric approach was followed. An important feature of the approach taken was that the parametric model and the design algorithm that had to be developed should incorporate wind data, which are in general difficult to manipulate and visualize. A discussion of the approach taken with regard to the climatic parameters that were given consideration and the developed parametric methodology and algorithms is presented in the following sections.

Integrating Wind Data in the Design Process

Wind data can be used during the architectural design process mostly through the application of appropriate Computational Fluid Dynamics (CFD) methods. Several research studies on the application of such methods in architecture have already been carried out. Conducted CFD simulations have addressed both indoor and outdoor environments. In most cases of indoor environment CFD simulation studies the objective was to study airflow for efficient cross ventilation and for reduced heat gains (Zhai and Chen 2003), (Tsou 1998), while several studies have tried to combine CFD with other physical parameters, including studies that focus on CFD and solar parameters (Capeluto et al. 2003). The combined effect of wind and sun was a desired feature of our approach to the student housing project, yet the developed processes in the research mentioned above apply to indoor environment only which we did not intend to address at the current stage of the study.

Other more recent studies related to the use of wind data in the design process have tackled outdoor environment and urban scale projects (Yoshie et al. 2007), (Mochida, 2008), (Chung and Malone-Lee 2010). In the outdoor environment, CFD, beyond its use for estimating heat gains from air-conditioning condensers and building geometry, has also been utilized for determining the prevailing wind direction and speed in a given site (Priyadarsini et al. 2008). Relevant studies suggesting city planning strategies that incorporate air paths with regard to the prevailing wind are also encountered in recent literature (Ng 2008). An important recent study in this direction, in which CFD results have been verified with wind tunnel experiments, has shown that such techniques are particularly effective for predicting wind environments in pedestrian areas (Tominaga et al. 2008).

The need to include CFD simulation at the earlier stages of the planning and design processes has already been expressed (Den Hartog et al. 2009). However studies that focus on the specifics of the available software for architectural applications, their capabilities and limitations including their user interface and their ability to provide 3D visualizations, make clear that the application of a CFD model is very time consuming (Den Hartog et al. 2009). In addition, in most instances reported in literature an analysis of wind data could not be performed before a virtual model of the architectural or urban project, at an early or an advanced stage, of the architectural project was built. The parametric approach taken in this current study renders several of the above applications impractical.

In the study presented in this paper we attempted to develop a multi parameter model of the design project in which wind data would be a major, but not the only parameter, to be considered. The main goal that we wanted to achieve with the integration in the process of a CFD analysis was to enhance our understanding of the patterns of airflow on the site and their interaction with building volumes and envelope features at a very early stage of the design process. The possible combination of wind and solar data within the parametric model was an additional feature. Besides, ease in the application of the CFD analysis so that results could be effortlessly obtained, was a desired feature of the parametric model. The effect of air flow to reduce heat gains was beyond the scope of this study; it may be addressed at a following stage. Therefore, for the analysis of wind data, priority was placed on the use of a software application that would serve the above requirements. Additional requirements and challenges related to the wind data integration into the parametric model are briefly discussed in the following paragraphs.

Parametric Design Methodology

For the study of the environmental performance of the proposed housing complex, as already mentioned, in addition to the solar position, to be used for estimating self-shading and/or complete exposure configurations, the prevailing wind direction during each season for estimating cooling and heat losses in each housing module were also considered. For this reason the geometric representation of a) a critical sun path and b) the prevailing summer and winter wind directions in the area were needed. Since the topography of the site and the built environment is critical in determining the movement of the wind in the area, to properly describe the prevailing wind directions, the development of a 3-dimensional wind grid has been considered of critical importance. The wing grid that was developed is associated to both the topography of the site, and the geometry of the building blocks and can be updated each time a building block is placed on the site.

Hence to optimize the environmental performance of the proposed housing complex, the main steps in the developed process were:

- The climatic analysis of the project and the development of a digital database of the local climatic features of the University of Patras area.
- The development of a parametric model that joins the climatic analysis databases to the building geometry.
- The development of an algorithm to explore the geometry of the building at hand. The algorithm utilizes the parametric model that joins the climatic analysis databases to the building geometry and to the site features.

A more detailed description of the developed methods follows:

Solar Analysis

For the climatic analysis of the area, statistical data of the last ten years have been utilized. The raw data were provided by the Laboratory of Atmospheric Physics of the University of Patras and have been

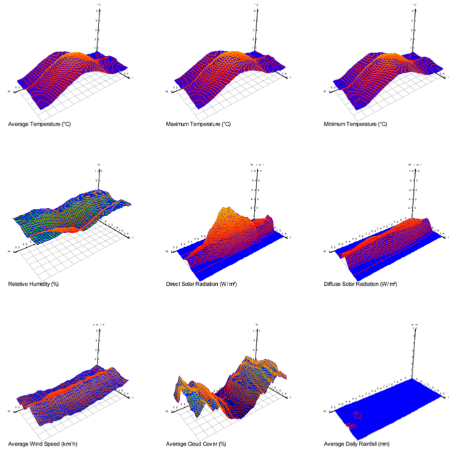


Figure 1
Prevailing climatic conditions at the University site

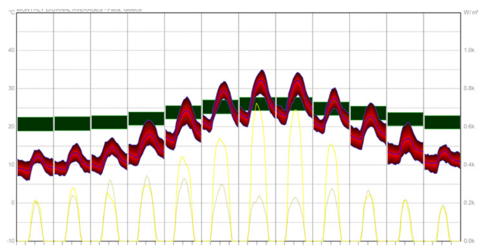


Figure 2
Thermal comfort conditions

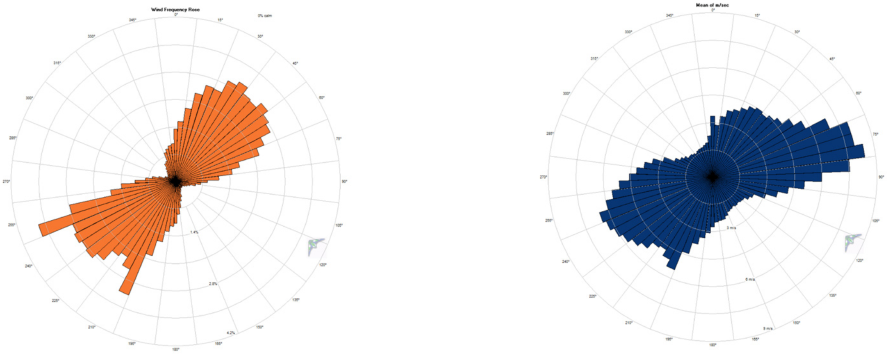


Figure 3
Wind diagrams for the University of Patras Campus

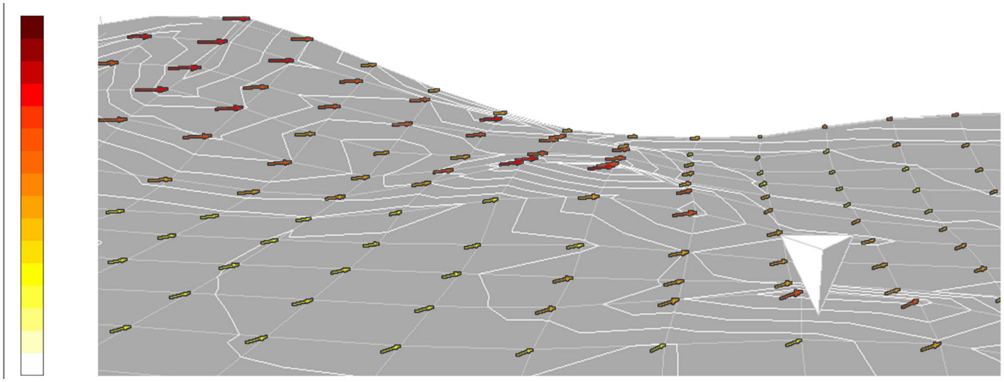


Figure 4
CFD model of the winter and summer prevailing wind directions

processed to produce a typical meteorological year (TMY). The Autodesk Ecotect software has been used for the conversion and the analysis of the data. The developed graphs with the assistance of the Ecotect Weather Tool display the prevailing climatic conditions at the University area (direct & indirect solar radiation, precipitations etc) in an hourly, weekly and yearly basis and their deviation from the thermal comfort conditions in each instance (Figures 1 and 2). These deviations lead to the definition of a critical sun path that determines the changes in thermal strategy throughout the year and which is incorporated in the parametric model. The purpose of the climatic analysis is to develop a better understanding of the combined sun and wind effect and to lead to informed design decisions.

Wind Analysis

The prevailing wind directions, described by the wind grid, combined with the building modules' arrangement on the site affect the wind's direction between and through the buildings. The wind analysis diagram indicates the winter wind directions that need to be avoided, and therefore driven away from the modules. On the contrary, summer winds, which can be beneficial, should be driven through the modules to provide for natural cooling. Trapping the air through decreasing openings between the modules can decrease the wind's temperature due to Bernoulli's principle. To take advantage of this principle the modules were placed in a rather parallel direction to the summer winds while the distance

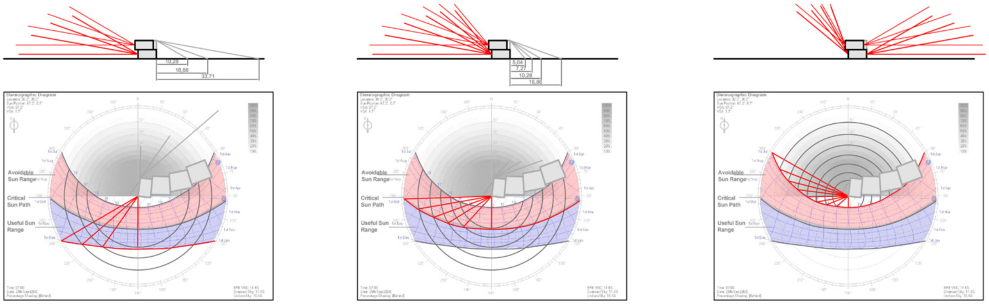
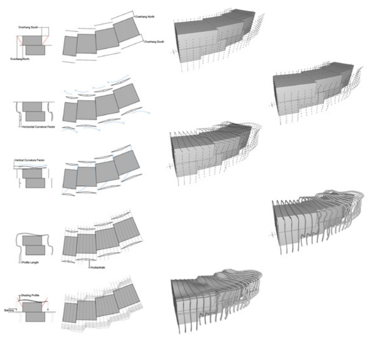


Figure 5
Shading Studies



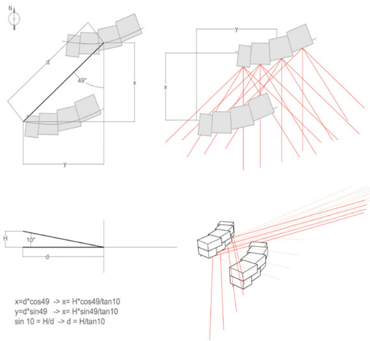


Figure 6
Building Envelope configurations

Figure 7
Building Orientation Studies

between adjacent modules was decreasing.

The wind data, since they are given in a vector form, have been processed with the assistance of specified algorithms. The time series of data were analyzed with the Windographer software [1], so that the most possible winter and summer wind directions could be visualized in the wind metric diagrams (Figure 3). The time series were also exported for use in a CFD model of the site.

Computational Fluid Dynamics

In order to determine the prevailing wind direction and intensity with respect to each building block, the changes in both direction and intensity due to the site geometry was needed. WindSim [2], a wind farm design tool, was used for the development of the computational fluid dynamics (CFD) model of the winter and summer wind directions.

A three dimensional terrain model of the greater university area was used along with the wind data to determine the effect of the site's geometry on the wind direction and intensity. The resulting vector field was imported into the parametric model and associated with the building design algorithm. The CFD model can be updated each time a building block is generated to reflect the changes in the wind flow of the site (Figure 4).

Shading studies

The study of the solar position during the critical days was used to determine self-shading and/or complete exposure configurations and for

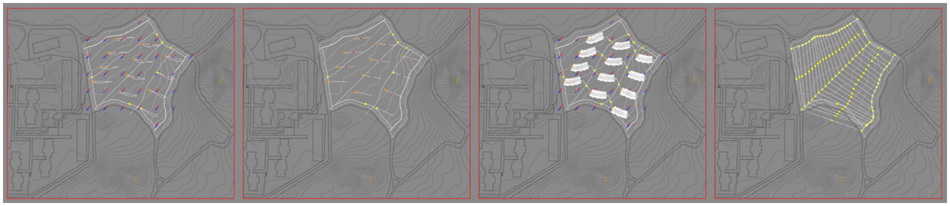


Figure 8
Site geometry generation

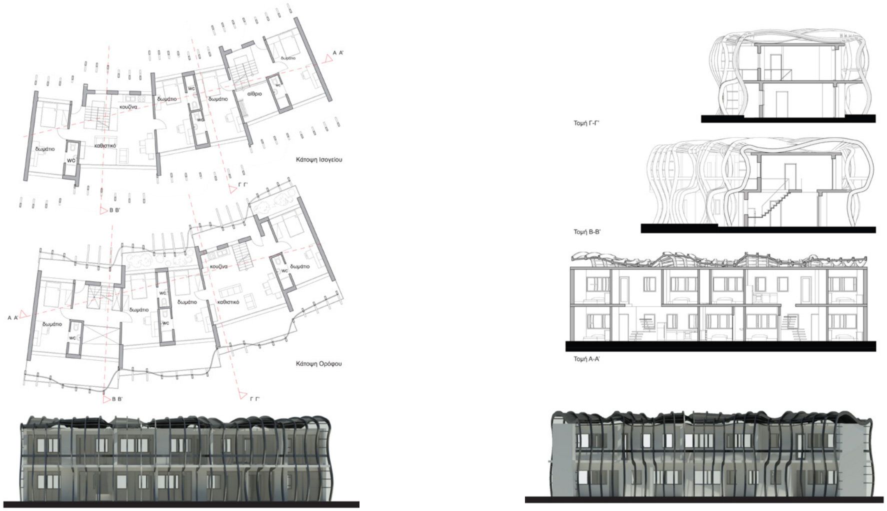


Figure 9
Early form exploration studies

calculating heating and cooling loads. The effect of changes in the building block geometry and the shape and position of the openings of the buildings were also studied (Figure 5). Shading from the adjacent hills that would lead to reduced passive heating during the winter where also taken into account. The resulting shading parameters derived from changes in the thermal strategies for the winter and summer seasons were also incorporated in the design algorithm.

Building Design Algorithms

The development of the algorithm that was used for this study involved a step by step process. The first step was to determine a basic curve which would become the basis for joining the parametric geometry of the building block to the climatic data and the site geometry. Then the parametric description of the core of the typical building block was developed in association with the shading parameters and the prevailing wind directions. At a following stage an envelope that directs the wind away or through the buildings during the winter and summer months, respectively, was developed. Additional algorithms had to be developed. These are:

Orientation and Proximity Algorithms

The orientation algorithm joins the site topography with the optimal orientation of the building blocks to maximize the south solar exposure. The optimal orientation is derived from both the solar study for the underheated and overheated periods, as well as the shading study of the site's adjacent hills.

The study of the solar position generates the minimum distances between the buildings so that the best insolation is achieved. These distances are then used as parameters in the development of the site geometry algorithm (Figures 6 and 7).

Site Geometry Algorithm

Based on the already mentioned relationships, the algorithm that generates the relative positions, the orientation, and the base curve for each point of the site was developed (Figure 8). The parametric solutions that are automatically generated from the algorithms allow for experimentation and study of many design options (Figure 9). The Generative Components software application has been used for this study.

Conclusions

For the bioclimatic design of the student housing at the Campus of the University of Patras, Greece, a methodology that makes use of a powerful parametric model has been used. Joining the environmental analysis to the geometry of the building blocks and the site topography are the basic features of a developed algorithm that has made possible the experimentation with various design parameters. The inclusion of wind data in the algorithm renders it particularly effective. The developed multi-parameter model has been useful during the early design phase when studies on various patterns for arranging the buildings on the site were conducted. The parametric process has facilitated the configuration of the typical building block as well.

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[1] www.mistaya.ca/windographer/

[2] http://www.windsim.com/