Computing Towards Responsive Architecture

Energy based simulation software for responsive structures

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Abstract. *The paper has two targets: a theoretical and a practical one which are totally dependant on each other: Its first purpose is to prove based on detailed comparative study by use of competent software apparatus that rotation in a building abiding by strict rules of adaptation to environmental changes (climate, season, time of day, sun duration etc.) should be viewed by modern architecture as a sine-qua-non in terms of energy consumption economy, environmental resources protection, achievement of high standards of living in the city. The aforementioned benefits will be evidenced by means of comparison of responsive structures to traditional ones. The second and most important purpose is to elaborate and provide the fundamental data and information for the creation of a supporting software for the above described model. The two in interaction will result in "revolution" in modern architecture.*
Keywords. *Simulation software; responsive architecture; kinetic; energy consumption.*

Introduction

During the last decades, the exponential growth of environmental pollution, the rapid rate of conventional energy sources' depletion and the dramatic alteration of weather conditions, could not but challenge architecture to adapt. Architecture (buildings, cities or generally the built environment), as the transitional stage between the outer environment and the inner personal space of every human, literally a "shell", being cause and means of energy consumption and pollution, trying to respond to the challenge of the upcoming change introduced new vision-models of architecture. Studies prove that 40% of the stored energy resources in Europe are consumed in buildings and their maintenance, whereas 50% of emission of gases is due to power generation for use in buildings (electricity and heating); at the same time residues contaminate the environment. Environmental architecture confronts the problems, comes up with solutions, promises and fulfills, through a series of definitions and restrictions such as correct orientation, use of environmental friendly materials and renewable energy sources, etc., a new concept of construction triumphing over the conventional, with important efficiency gains.

Architecture's fast pace during the last years led to introduction of the responsive model, accepted by some with enthusiasm, by others with skepticism. Movement is the key word, usually a revolving one, which under certain conditions and with evolution in applications of technology enables even higher energy performance and rational buildings to combine with comfort for the inhabitants. Responsive architecture, term given by Nicholas Negroponte, is the natural product of the integration of computing power into built spaces and structures. Therefore it still expands mainly along with computing technology. It aims at the continuous adaptation, "response" and transformation of the construction to the changing weather conditions to adapt to the needs of the inhabitants, within the scope of economic and physical survival. In an attempt to simplify, responsive architecture is the crossroads where environmental architecture meets certain traits of kinetic architecture. It uses the same disciplines, principles, means, materials, renewable energy sources and construction methods as environmental architecture but with the additional ability, and in the cases that are being examined by this paper, of revolving along a central axis, to track or avoid the sun and have correspondingly greater energy absorb or sun protection when is needed, matters that impact energy consumption of a building. Most of the ambitious applications, such as the Rotating Tower of Dubai, are still in developing stage, due to the increasing need of more advanced technologies and computing aid. There are critical parameters that need to be developed, investigated, calculated, organized and systemized to guide to projects' realization. This paper aims at contributing to this vision to the least Nevertheless, realized projects, such as Heliotrop House by Rolf Disch in Germany, though scarce, succeeded through their analytical study to prove that responsive architecture may become reality and open horizon to the future of discipline.

Current situation

The building performance software that exist today can study thoroughly and precisely the performance of a building in terms of energy consumption but they are limited to fixed construction excluding circumstances of environmental alteration. At the same time nowadays visualization or simulation programs can represent the movement of the buildings but they cannot associate it with the terms of the energy consumption and the best building performance that movement of the shell is targeting to. Therefore the combination of the two would be a useful tool for the study of responsive constructions. The numerous possibilities and the challenge to encounter the limitations in the advances of Responsive architecture are the pillars of this research. Realizing the lack of means of study and the absence of representation of these constructions throughout the design process as well as the promising reward of the pioneering, yet experimental, revolving model, motivated my belief to attempt the creation of a software to systemize the responsive parameters.

It should be mentioned that, generally whenever subjects such as responsive or kinetic architecture appear, cost issues arise. Novelty of subject and insufficiency in quantity of evidence do not currently provide concrete answers. There is a trend for higher costs for projects, products, services when just released to the market, which drop at high rates, when they become vastly available to the public and everyday practice; these are the basic laws of market. Furthermore, the overall gain in energy consumption, in addition to prevention of depletion of supplies and environmental contamination by far offsets even the cost at this very point of experimental stage. Currently with the proof of some scarce examples and through some segmented fulfilled or ongoing studies, a general idea and an up to a point proof of the profit of these constructions can be given. As mentioned before responsive architecture is in its core environmental architecture. Nowadays it is a fact that environmental architecture is profitable in long term comparison with conventional architecture. In this sequence also responsive constructions are profitable.

Research methodology presentation

Like in a bizarre equation, 1) the creation of a functional responsive software and 2) the benefit of a responsive building are the variables and at the same time the result:

- Should we have known these two factors it would be of great assistance to the evolution of our model.
- The possibility of use of adequate software and the several benefits in energy consumption, ecology, quality of life would equal precedence of responsive architecture over traditional architecture.

In an attempt to cover both above functions the present research on one part attempts the creation of simulation-visualization software for responsive constructions, on the other part it evaluates the results for the existence or not of the benefits of responsive architecture. It is subcategorized into three stages, the case studies, the set of criteria and restrictions for the comparison of the results from the case studies and finally the identification and implementation of automation towards the creation of the visualization-simulation software. In this paper, elaborates more the third stage but also the first and the second will be described.

Stage 1: Case Studies

First, a number of case studies have being conducted in order to prove the principle that responsive architecture is more beneficial than environmental architecture, both in energy consumption maters as well as economically. For this, a number of buildings have been chosen and scrutinized as models; they are separated in three categories (Figure 1):

- Environmental buildings with an exquisite performance (production of energy through renewable sources of energy beyond their demands or very low energy consumption, zero CO2 emissions etc.) which have no mechanical movement
- Buildings which rotate along their central axis despite the beneficial traits of the movement.
- Buildings which belong in both of the two previous categories and are existing examples of the environmental responsive architecture.

The buildings have been thoroughly simulated and analyzed inside a CAAD interfaced Building Performance simulation software (DesignBuilder Software). All necessary information - i.e. materials, location, occupancy schedule and operational systems for heating and cooling have been taken into consideration and have been applied as parameters to the simulation. The simulations have been carried out throughout the period of one year on a daily basis, with results for every half hour and for every orientation of the 360 degrees with 15 degrees interval between every orientation. This has been performed taking after the rotation schedule of Heliotrop house, which every hour completes a rotation of 15 degrees, sufficient for trucking the sun and preserving the comfort of unnoticing the rotation for the inhabitants.

Stage 2: Comparison; Defining Criteria and Restrictions

The question of the beneficial in energy and economy character of responsive architecture has been answered with the help and application of the building performance simulation software, by comparative study between the results of performance in buildings in a fixed position and in buildings rotating. We had been aiming at providing evidence that performance of buildings of the first category increases by applying the rotation option, whereas at the same time that second and third category buildings improve performance with rotation option on. To simplify analyzing process the same parameter of rotation along the central axis, on the same rotating plane and with the same rotating mechanism was also used in buildings of the first category.

Even though this brief does not aim at presenting the test data or pointing out the underlying reasons behind the inherent performance advantages of rotation, but to introduce the apparatus, thus the supporting software, we will attempt to describe the

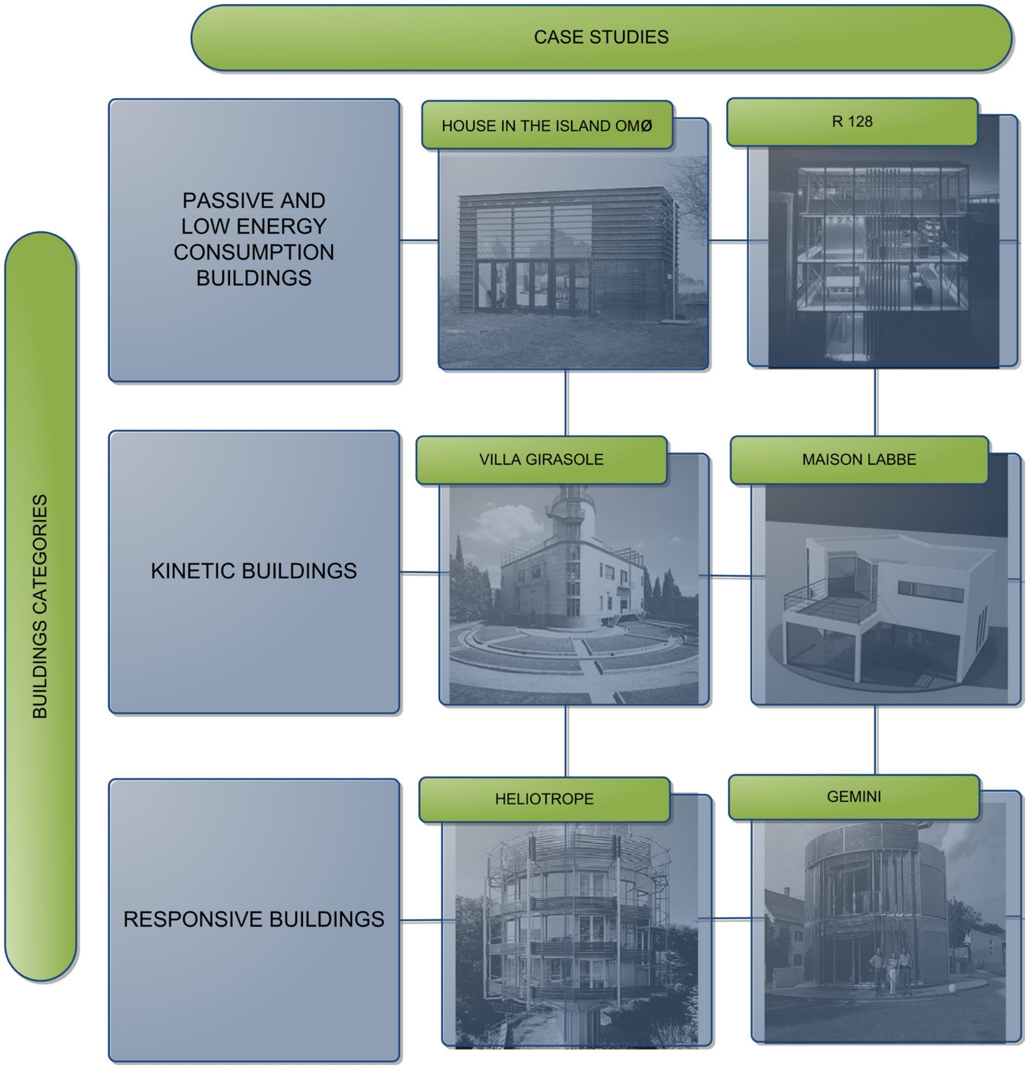


Figure 1
List of Case studies

comparison methods used and the environment: it was carried out for all the buildings in the area of energy performance (heating and cooling loads) and energy consumption as well as other areas of interest (CO_2 emissions, etc) both in fixed and rotating positions, as mentioned before. The numeric results either in a one-to-one diligent comparison or as an average outcome, in a more or less evident way by bigger or smaller value differences, advocate higher performance of the revolving building.

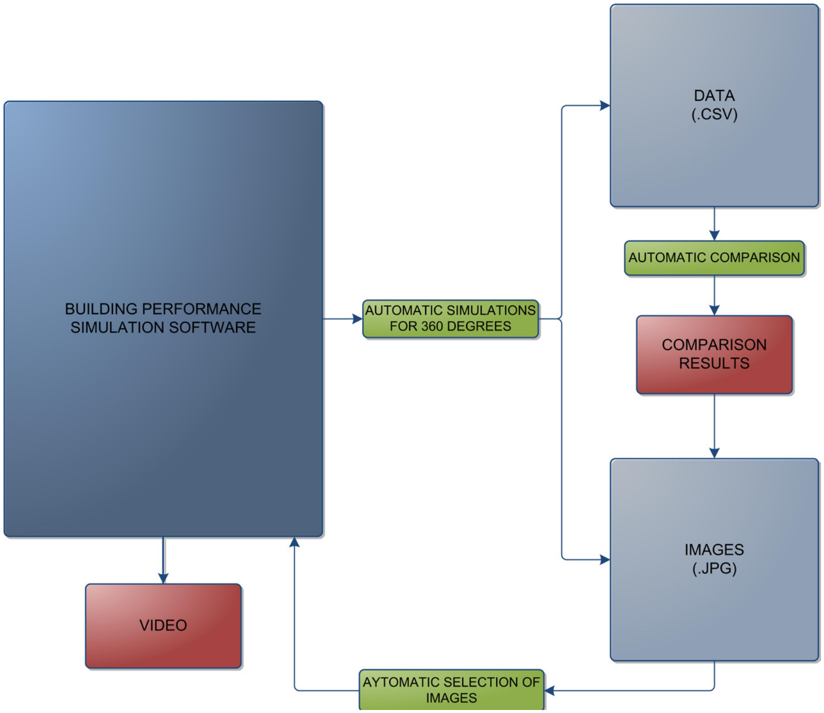
The analysis was carried out in terms of correlation under precise and very extensive criteria which involve the interaction and alteration of the inside average temperature of the construction with the energy consumption. The restrictions and the comparison criteria were set under the prism of procuring comfort to the inhabitants in combination to the least possible energy consumption of the building. The seasons and the corresponding differences in temperatures, the restriction of rotation to 15 degrees per hour and many other detailed parameters created a long list of limitations and rules for the systematic, without excluding any case and accurate comparison of the data.

Stage 3: Identification of needed modifications

All results of the building performance software used for the purposes of this research, as well as every software of the kind, arrive in the form of .csv file, which open with excel and include long lists of information in tables. Each one of these files describes extensively the performance of the building for a certain orientation throughout the simulation period whilst it includes the output intervals as defined by the user. At the same time the building performance software described provide the possibility of creating for the specifically chosen period of simulation a visualization video, by creating in a directory a list of images corresponding to the intervals set by the user for the simulation; simulation is concluded by combination of the separate images into a video file.

Throughout the procedure of comparison, the levels and the points of automation towards the realization of the software have been identified and can be described as shown in the graph (Figure 2):

Figure 2
Operational procedure of software. Positions of needed automation



- In order to create a study for a responsive construction, as a total, series of consecutive simulations which will cover all the possible orientations for the full range of 360 degrees in segments of 15 degrees are needed and therefore an automation of the simulation resulting in images-fragments is absolutely necessary. Variety of programming tools along with the use of scripting language to create a possible plug in or an optional function for the building performance software is the only way out in form of operational solution.
- All the data which are being produced by the simulation can be stored in a common directory. Comparison is crucial between these independent files; therefore data should be summarized in a general table where the evaluation is possible. This procedure for the case studies has been performed manually, through a time consuming procedure. At the same time the evaluation and comparison of the inside data from the general table, was extremely difficult to be performed as the possibility of mistakes as well as the time consuming evaluation was equally against it. In this stage the approach towards a solution of the problem of automation can be traced through Excel with the use of formulas and macros. Based on the list of criteria and limitations used for the comparison, a series of corresponding formulas and functions can be created to fully automate the excel software based evaluation procedure.
- The sequence of images necessary for the generation of the video is created by a selection on the basis of the comparison results mentioned above. This selection can be functional and operated as well through a course of programming because it depends on a previously automated function.

Preliminary Results

Seeing the possibilities and limitations, as well as the nature of problems that had to be faced, as a first approach, a creation of a simulation-visualization software for responsive constructions parallel to the building performance software has been chosen. By retaining the form of a plug in to the primary software it gives the possibility of eliminating the prior obstacles towards the automation of the procedure in a less complex way and at the same time provides the flexibility to the existing software to function in "cooperative" modus to software for the sole use of responsive architecture. The current state of the suggested procedure towards visualization is partly automated, but is continuously developing and is expected to be fully operational. The first results of testings exhibited a satisfactory performance according to the intended target; however a great load of work is required until full development. Therefore finalization of the plug in should be expected after additional research.

Conclusion and future work

The comparison of the energy performance between fixed and variable position under conditions has proven the gain of the second case both in matters of energy and cost. In responsive constructions excess energy is produced through the movement; this results not only in decrease of the energy consumed from the grid for function of the building, but in some cases the excess energy produced may be sold back to the grid, which means significant income instead of expenditure. Therefore the future of architecture lies in the movement of adaptability. Positive research results dictate the need of relevant technologies and therefore supporting software.

Once simulation of responsive constructions is achieved and becomes fully operational and automated, the possibility of introduction of responsive architecture in other areas of interest of environmental architecture will be tangible and extremely useful. Examples follow:

- The simulation of the responsive structures will be performed inside a design (CAD) software and not in a building performance software.

This will be an apparatus for the architect, who will have thus the possibility during the design process, by entering extra information and data regarding construction materials, the axis and angle of rotation and the moving elements, to have a first representation of the movement according to the best energy consumption of the construction. The program, depending on the input and the detailed information, will produce an energy performance simulation for the whole range of the given by the user movement. Then by evaluating through different functions and taking into consideration specific parameters such as the overall temperature of the space and the amount of energy consumption will be able to provide best construction position information, i.e. for specified moment in time (e.g throughout a whole certain day). The more analytical information about the model entered by the user, the more accurate the simulation and the visualization of the movement. The program at the end of the design process and with the most detailed description of the construction will be able to give a full report of the energy performance of the building but also a visualization of its movement throughout a whole, chosen by the user, day of the year.

- Application of the model and the software not only to revolving constructions, but to constructions with other types of mobility as well.
- Cooperation with software regarding responsive tensegrity structures when those are forming a closed space.
- The implementation and formation of a materials' and elements' database to assist in the easy creation of multiple mobility constructions.

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