INTEGRATION OF SOLAR-CLIMATIC VISION AND STRUCTURAL DESIGN IN ARCHITECTURE OF TALL BUILDINGS

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ABSTRACT

This article introduces the methodology and the results of an integrated design approach to optimize both structural system and building energy performance through architectural design process. The book titled *Intelligent Design using Solar-Climatic Vision* [1], introduced a number of practical and effective design approaches towards the creation of energy-efficient building façades as well as comfortable urban environments. Applying solar-climatic vision, especially during the procedure of optimizing tall structural systems, can develop sustainable frameworks that maximize thermal comfort while minimizing waste of resources (e.g. embodied energy of building materials).

The integrated design approach consists of three main areas: architectural, solar-climatic, structural and the interconnections between each two of the three. The final solution, thus, will be the multipurpose one meeting all the needs from all three areas. Both top-down and bottom-up approaches are used in the process and the final solution is mapped in two poles of integration; first, in overall concepts and large scale and second, in parts and details. Therefore, architects and the leading team members of such design projects require inter-/multi-disciplinary knowledge, the ability of whole-system thinking and developing versatile tools.

In two case studies, *SOLARCHVISION* (building simulation tool) in combination with *Karamba* (structural interactive, parametric finite element program) are applied to optimize solutions for specific climates in the Middle East and the United States. With minor alterations in techniques, similar method with similar principles can be used in other climates as well. Diverse suggestible solutions include: Shading/reflecting devices that perform the role of the main structure framework too; the entire building structure deviates from the direction of gravity (verticality) to optimally shade itself as well as the surrounding. Analysing the results of the current research in practice shows impressive reduction of heating and cooling energy demand and primary energy by designing optimized passive structures of high-rise buildings.

Keywords: integrated design, solar-climatic, structural design, tall buildings, sustainability

INTRODUCTION

Why to focus on high-rise buildings?

High-rise buildings are typically wasteful in energy when they are built, maintained and eventually destroyed. They also carry exponentially heavier structural elements as a result of wind and earthquake loads as well as the weight of upper floors on the lower ones. However, high-rise buildings can potentially be more energy-sustainable than others; for instance, their higher density and smaller footprints cause reduction in commute, urban sprawl, traffic and air pollution [2, 3]. Having vast skin surface enables them to take advantage of environment and natural light too. Most importantly and less noticed, tall buildings are gifted by their height; a layer of main massive structural elements is close to the façade. There is an unexploited potential for finding functionally consolidated elements responding to both structural loads and climate control factors.

Solar-climatic vision and ecological design

"There is much misperception about what is ecological design. We must not be misled and seduced by technology. There is a popular perception that if we assemble in one single building enough eco-gadgetry such as solar collectors, photo-voltaics, biological recycling systems, building automation systems and double-skin façades, we will instantaneously have an ecological architecture [4]." Robust design methodology combining network of parameters and approaches is close to passive design. Many old buildings used passive approaches that employs systems doing more than one thing (e.g. structural walls that also accumulate heat through thermal mass), since they were built in eras that oil was expensive or simply not available and transportation was hard. Modernism is essentially unsustainable as it evolved in the era of cheap fossil fuels. To achieve a new resilient architecture we need a big reconsideration about basic approaches, manufacturing, primary structural types [5, 6].

The book called *Intelligent Design using Solar-Climatic Vision* examines the critical role and influences of the sun on climate and built environment in varied scales and from different perspectives. 'To look from the sun' at objects and combination of solar beam radiation analysis with temperature patterns and other meteorological data (e.g. winds and clouds), enables the *SOLARCHVISION* building simulation tools to produce diagrams evaluating desirable/undesirable conditions in architecture as well as in urban scales. The research covers positive and negative effects of the sun in globally various climate zones including main cities from Australia to Europe and from Asia and Middle East to Canada and the US [1].

METHOD

The integrated architecture system evolves from three design areas: architectural, solar-climatic, and structural. Each two of the three sub-systems should collaborate to generate the final integrated solution. The system defines two poles of integration; one in large scale, overall conceptual stage of design and the other in small scale, in detailed design stage (Figure 1).

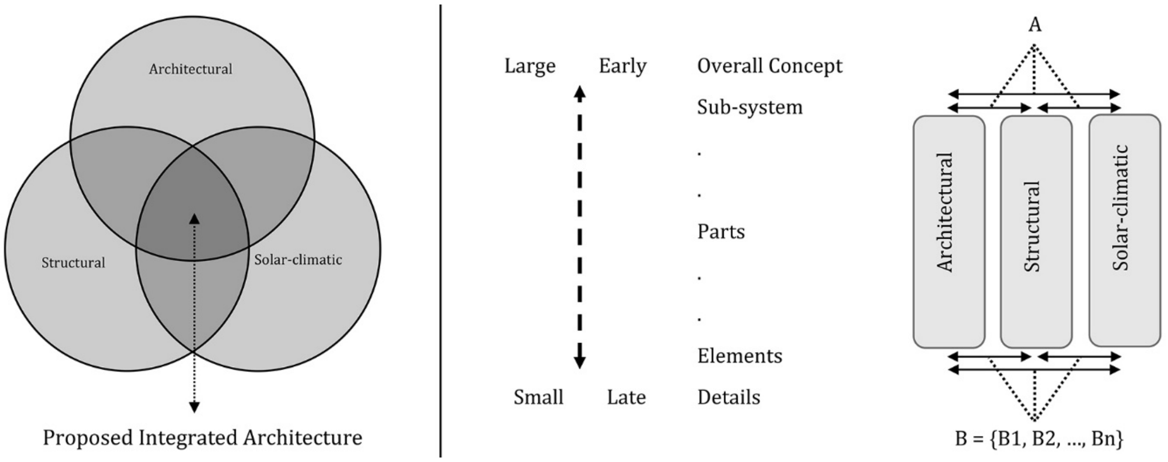

Figure 1: Integration takes place between two poles. Pole A represents conceptual early design stage and pole B consists of multiple combined solutions for various elements and details.

The criteria to evaluate the design products are: levels of visual integration (i.e. how things look unified), spatial integration (i.e. how things fit together), and functional integration (i.e. how things share roles) as well as sustainable interaction with the environment [7]. The method in action is a cycle which includes prototyping, evaluation of prototypes and reflections to produce design principles and techniques.

Case study 1. Cylindrical high-rise structure in Las Vegas

The reinforced concrete structure includes 40 floors slabs, a cylindrical central core, radial beams connecting the core to the outer ring beams and an exterior tube (Figure 2). The latter has the potential to adjust the sunlight. Therefore all the other parts have been optimized so that the only main question would be the design of the exterior tube.

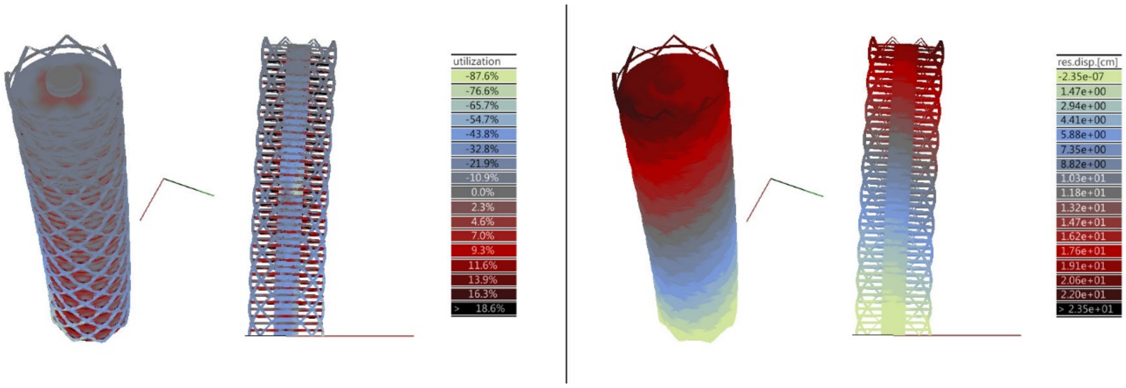

Figure 2: Karamba model view of the optimized structure (Alt.3) with gravity and wind loads.

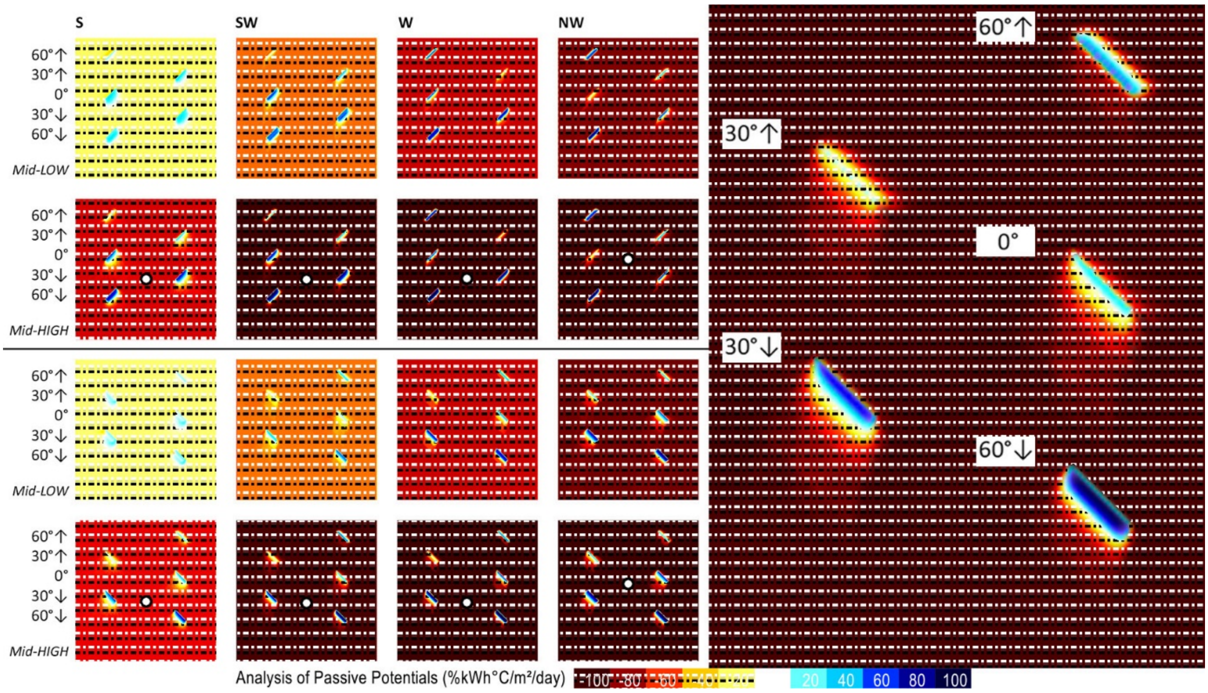

Figure 3: Diagrid orientations (up: ↗, dn:↖). S to NW. Right: SW Close-up view (30 °↓ picked)

Six different options are designed (Table 1) and in order to make them comparable, a maximum displacement value of 24 cm is set as fixed for all of the six structural systems. Gravity as well as the wind and possible storm loads in Las Vegas are applied in all models. The first one with radial framed tube positioned behind the glass façade. The second one is also 3 meters deep framed tube but with vertical elements exposed to the daylight. The rest alternatives are diagrid[1] structures with different cross-section properties; the third and the fourth have horizontal cross-sections with 1.5 and 3 meters depth.

An evaluation on various cross-section orientations of the diagrid elements is done to maximize annual solar-climatic performance (Figure 3). For this purpose, 5 different section angles from

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[1] Diagrid elements vertical angles are set to about 47° to optimize the structural performance [8].

upwards to downwards in 8 main planar directions (N, NE, E, SE, S, SW, W, NW) are tested on two main direction of diagrid elements (↗ and ↖).

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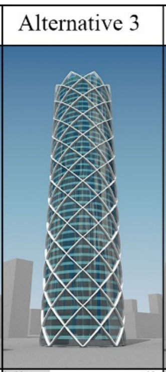
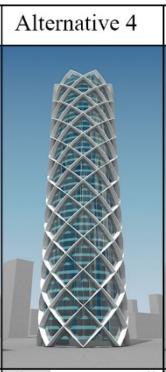
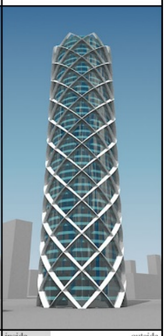
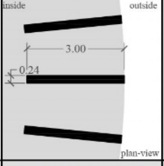
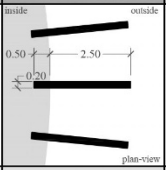
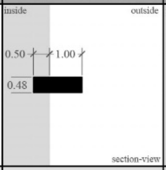
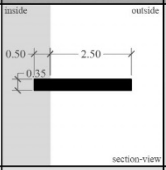
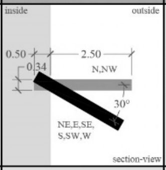
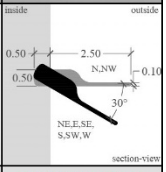
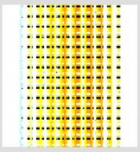
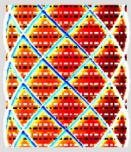
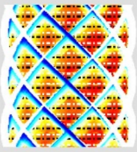
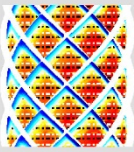
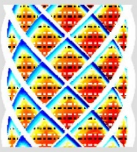
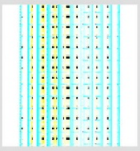
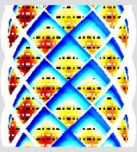
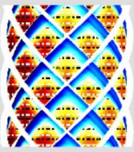
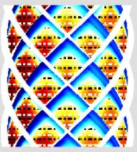
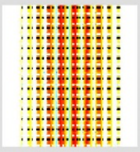
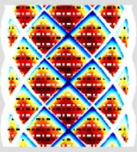
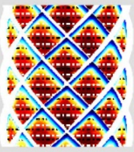
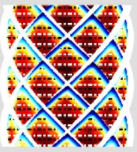
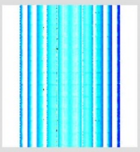
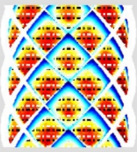
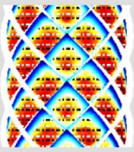
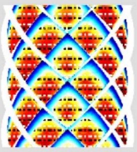
view from southeast							
tube elements cross-sections							
solar-climatic performance analysis visual outputs for Mid-High temperature weather scenario  Analysis of Passive Potentials (%kWh°C/m²/day)	east						
	south						
	west						
	north						
structure mass (kg)		4.0009 e+7	3.8519 e+7	3.7382 e+7	4.0322 e+7	3.9623 e+7	3.85630 e+7
energy efficiency index		-138.4	-79.1	-99.2	-71.6	-67.7	-67
relative structural efficiency		10.6%	61.3%	100%	0%	23.8%	59.8%
relative energy efficiency		0%	83%	54.9%	93.5%	99%	100%

Table 1: Solar-climatic and structural analysis of the six developed alternatives.

Results of case study 1

The 80 cross-section cases test results (Figure 3) show that in Las Vegas climate, the appropriate orientation for diagrid structural elements is about 30° downwards in all directions except the north and the northwest; whereas a horizontal device can perform better. These choices are selected due to the fact that the structural grid pattern is not dense and it is preferred that each element can affect a relatively vast area of the building skin. Thus for more dense patterns of louvers -to be added in next design stages- a slight change in orientation can be applied. The cross-section orientations of the fifth and the sixth alternatives are optimized due to solar-climatic test results. As for the latter, cross-sections are also optimized from rectangular to a new shape in structural analysis.

Comparing structural properties of the alternative options illustrates that diagrid tube is the lightest structure (Alt. 3) (see Table 1). Combining diagrid system with optimized solar-climatic cross-section orientations (Alt. 5), results in a relatively light structure with maximum energy efficiency (Alt. 6). At this stage of design, none of the structural systems can provide complete thermal comfort conditions, so parts of the façade should be enhanced by secondary shading elements in smaller scales. For the environmentally-optimized alternatives (e.g. in the last proposed model), a smaller area of the façade requires extra shading devices in the next design stages. Therefore, such optimized structural systems ultimately result in lighter and less expensive buildings while providing comfort conditions.

Case study 2. Sustainable high-rise building skin in Tehran

The aim of the case study (Figure 4) is to design a sustainable cladding for a high-rise building in Tehran (Latitude 36N). The structure of the building is already designed and half built, so there is no chance to change its overall structural design. A layer of louvers can be attached to the main structure. The building façades mostly face west and east which by default overheat the structure in Tehran climate. The orientation of shadings should be optimized to provide desirable thermal comfort without adding too much weight to the main structure. Optimum orientation angles and proportions of shading devices in Tehran climate are indexed in the book ‘Intelligent Design using Solar-Climatic Vision’: in the western and eastern parts of the façade, the louvers cross-section should be slightly downwards and in the southern parts should be upwards while in the northern part there is no need to have horizontal louvers on the façade. The final solution is based on a network of louvers around the structure that their cross-section orientations gradually change on the round corners of the building.

Results of case study 2

Comparing the energy-efficiency calculation results of the proposed building skin with ordinary glass curtain-walls, shows a significant reduction in the demand for heating and cooling energy and primary energy use by applying solar-climatic principles in the design process. The calculations cover both direct and diffuse solar radiations in different hours and months.

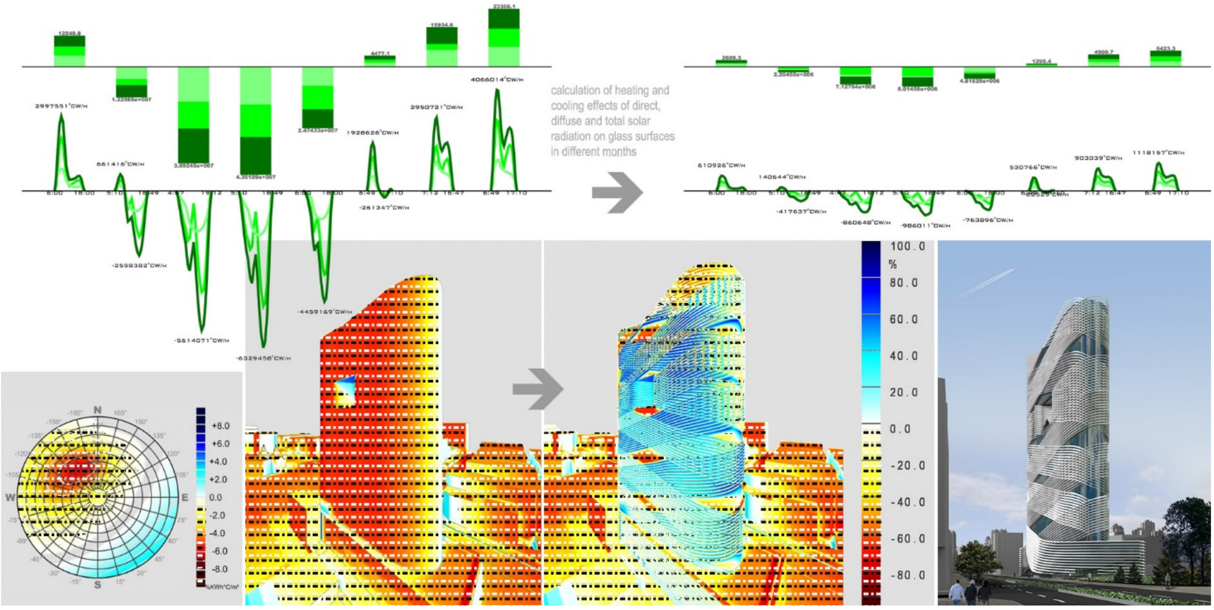


Figure 4: Reduction of heating and cooling energy demands by controlling solar radiation.

DISCUSSION & CONCLUSION

The design method and approach used in the case studies can be applied in an infinite spectrum of scales. For example, one can optimize orientations and proportions of building’s overall structural system, through the method described in this article. Regarding location climate conditions, vertical 90 degree extrusion can be optimized to new direction, and it can introduce new typology of self-overshadowing tall structures. The interaction between structures and urban pattern situations can also be optimized by implementing similar strategy and new computational tools.

A further step in the research, should aim to define a measurement index in common between structural-efficiency and energy-efficiency. This will help in precise decision makings (e.g. where there are two good options, each having an advantage over the other).

Based on sustainable interaction with the environment, this essay attempts to introduce a systematic method of integrated design. While aiming to upgrade comfort, conserving energy and minimizing waste of materials, the methodological approach can result in a new visual, aesthetical and semantical alternative in architecture discourse. Solar-climatic vision and structural design are capable of being integrated into sustainable high-rise buildings architecture. This integration needs whole-system-thinking, close teamwork of professionals of the correlated fields and multidisciplinary approaches. The result of this integration would not only be more sustainable tall structures with minimum waste of building materials and embodied energy, but also passive desirable environments which bring health and comfort to the inhabitants of buildings and cities. In the holistic view, solar-climatic vision can be effective in preventing the growth of urban heat islands and global warming.

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