Emerging an Adaptive Kinetic Mashrabia for Reviving the Environmental Responsive in the Traditional Courtyard House of Aleppo

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Abstract:Due to the widespread of computational processes techniques, many manuals and modern automatic shading systemshave been developed. Although, of their high environmental performance, most of these systems failed to adapt neitherto the morphological configuration nor to the special character of the historical contexts. Thus, empowerment the roleof the bio-climatic design process in reconstructing the courtyard house in Aleppo post-war requires translating theform and structure of the vernacular architectural elements into adaptive and dynamic ones, for emerging newinnovative solutions with high environmental responsive. The research adopts this hypothesis for developing a newshading screen system with a kinetic structure technique. An evolutionary multi-criteria optimization for geneticalgorithm technique is used and integrated with bio-climatic tools such as Ladybug and Honeybee plug-ins forGrasshopper and Rhino software, for obtaining the optimum adaptive kinetic Mashrabia that enables reviving theenvironmental responsive in the traditional courtyard house of Aleppo post-war.

Keywords: *Keywords: Parametric Design, Environmental Responsive, Adaptive Kinetic Structure.*

1. INTRODUCTION :

Traditional courtyard house was based on a series of adaptive and sustainable-oriented principles which confirmed a high capacity to adapt with a different climate, social and cultural transformations. Moreover, in this unique typology, some vernacular architectural elements like Mashrabia was used for achieving social and environmental needs, which provides an effective protection against intense sunlight, thus it was utilized widely in the Middle East countries for several decades. Currently, this traditional Islamic window element fails to meet the contemporary needs for visual comfort due to insufficient day lighting. The design of a solar protection system that can minimize solar gains while maximizing daylight and view to the outside is particularly challenging in Aleppo city which has approximately 3000 hours of full sunshine, therefore an urgent need for effective shading devices is exist to avoid the solar heat gain, and consequently enhancing thermal comfort inside the building (Karamata, Giovannini, & Verso, 2014). In this regard, envelope components play a crucial role in controlling the energy performance of the building. Where, reducing the artificial energy demand in the residential buildings is based on minimizing heating, cooling and lighting loads (Demery, 2010). Determination of the quantities of energy loads is related to the amount of exchanged heat within the building during its working hours and the external environment (Looman, 2007).

For managing these problems and challenges, the research developed at the first phase, a multi-scale approach (at architectural and urban levels) for rehabilitating the traditional residential buildings within the old city of Aleppo (Salkin, Swaid, Greco, & Lucente, 2016). This approach has been implemented for optimizing the urban design of the case study Bab Al-Faraj area, which aims to fulfil the requirements of the neighborhood energy design and sustainable building design. An infinite number of solutions has been obtained, and the optimum solution that achieves minimum radiation loads at both building and urban scales have been selected as a pilot case project (Swaid, Salkini, Greco, & Lucente, 2016). For the second phase a new bio-climatic design has been embodied for efficient residential building in the historical context of Aleppo post-war, through evolving two different contradict scenarios for the pilot case project, based on specific design concepts of courtyard house, takes into account the spatial characters of the earlier building and then adapt them to the new environmental and social needs on one hand, and applying the passive house techniques on the other hand. Although that second phase clearly shows how much the new bio-climatic conceptual design could influence the environmental building behavior and performance, but there are still some of the traditional architectural elements that need to be reinforced to adapt to climatic and functional changes (Salkini, Greco, & Lucente, 2016). This paper illustrates the third phase of the research by emerging an adaptive kinetic Mashrabia for raising the efficiency of the evolved scenarios through reviving the environmental responsive in the traditional courtyard house of Aleppo.

The conceptual design of the new shading screen systems originally is inspired from Mashrabia and from the natural and biological systems, like Chameleon that adapts to its surrounding environment through changing the color of its skin in order to maintain its continuity. The adaptation of the living organisms with their surrounding environment is the basic essence of their continuity, therefore nature considers as an inexhaustible source of environmental, structural, functional solutions that possess many inspiring properties, which motivate the researchers to find some useful clues to generate new biological solutions characterized by powerful capacity for maximizing the thermal comfort of human beings.

This paper develops a computational procedure for evaluating and measuring the solar heat gain within the internal space, in order to select an appropriate shading threshold, and then transforms the vernacular wooden structure of the Mashrabia into a light adaptive structure facilitates the responsive to the sun path, due to the importance of the vertical and horizontal shadow angles for designing the shading device. In this regard, this paper outlines a parametric design and simulation-based process conceived and tested, for the automation of climatic building element (shading device) responsive to the sun position at different times through the year. Where an evolutionary multi-criteria optimization for genetic algorithm technique will be adopted (for managing contradictive objective simultaneously) and integrated with bio-climatic tools such as Ladybug and Honeybee plug-ins for Grasshopper and Rhino software, for obtaining the optimum adaptive kinetic Mashrabia that enable reviving the environmental responsive in the traditional courtyard house of Aleppo post-war.

1. **Responsive and Kinetic building facades:**

The increasing of carbon emissions from human activities have leading to many climatic changes, which have a profound impact on the buildings and neighborhoods design. In this regard, the main challenge is how architects could reduce the dependence on the imported sources of energy, and achieves sustainable buildings that interact with the natural climatic conditions adaptively?

During recent decades, two different trends had been emerged for developing high-performance dwellings. On one hand, the first trend has shown a large interest in the possibility to reconfigure the internal and external spaces for adapting with the environmental changes and user's needs. While the second trend has focused on the increase of materials efficiency and the optimization of building envelopes for reducing energy consumptions in constructions. Building envelope is the primary subsystem through which external conditions and environmental changes can be regulated, therefore it acquires great relevance in the development of new approaches to sustainable building solutions. It involved about 80% of an environmental solution, aid to create high efficient building interacts with its surrounding environment (Etman, Tolba, & Elddin, 2013). Therefore, special attention has been taken for developing of dynamic and adaptive shading systems, which have a high ability to reconfigure themselves to adapt to the climatic conditions changing for improving the indoor environmental quality (Attia, FavoinoFabio, Loonen, & Petrovski, 2014).

Virtually, vernacular courtyard houses have been extended over wide geographical areas with different climatic conditions through a long period, and they have been always able to respond to their natural environment effectively (Edward, Sibley, Hakmi, & Land, 2006). Moreover, vernacular Islamic architecture have various elements and characteristics neatly organized for enhancing indoor thermal comfort, where each vernacular element represents a solution or an answer to a different problem that appeared according to a specific condition, such as traditional shading device (Al Mashraia) which has been applied on the external openings as a climate regulator tool, to satisfy a variety of conditions or functions such as (1) controlling the passage of light, (2) controlling the air flow, (3) reducing the temperature of the air, (4) increasing the humidity of the air, and (5) ensuring privacy (Fathy, 1986).

Accordingly, many attempts have been done for developing this vernacular window element with its latticework characteristics. Several designers with the aid of craftsmen have transformed the vernacular wooden structure into high technical responsive systems through, such as the Institut du Monde Arabe building designed by Jean Nouvel in 1987, the architect has realized a dynamic redesign of the vernacular Arabic screen and maintained the local identity through utilizing of metallic solar blocker, which has fine and precise details similar to those of the traditional Mashrabia in order to optimize the thermal comfort inside the space dynamically, Fig1shows that the construction consists from 27000 light sensitive diaphragms regulate the amount of the daylight entering the building (Schilekhe, 2014)While other architects utilized the conceptual design of the vernacular Arabic screen combined with light structure and modern technologies to generate attractive mechanical complex systems, such as the dome of Montreal which designed by Richard Buckminster Fuller in 1967, as shown in Fig1the dome has constructed from a lattice steel structure with transparent acrylic sheets as façade material. In order to keep the comfort within reasonable levels, the faced sheets have fully controlled by a mechanical system (Modin, 2014).

Another example is Al-Bahr Tower in Abu Dhabi, the designers inspired their design concept from natural systems to invent one of a complex mechanical systems for external shading. The original design concept inspired from the traditional shading screen Al Mashrabia, and from natural systems (like flowers that adapt to sun movement), as shown in Fig1 the combination between these two concepts generated a contemporary attractive shading element, has a high capacity for maximizing the thermal comfort and minimizing the energy consumption (India

Figure 1
Figure.1. A) The Dome of Montreal. B) Al-Bahr Tower in Abu Dhabi. C) Institut du Monde Arabe.

& Spiegelhater, 2015). The main feature of the adaptive kinetic shading screen that comprises triangular units of translucent PTFE fabric that fold/unfold like umbrellas at various angles and connected with linear actuators, regulated by a pre-programmed sequence that sends different inputs during the day, activates the elements allowing five different operative configurations. According to the design estimates, this system has reduced the cooling loads by as much as 25%. During the historical development of Mashrabia, the role of the vernacular Islamic element has been changed from a layer to protect the privacy against outside views to a decorative element attracts the outside viewers. As a result, the modern shading systems cannot adopt to the courtyard houses, where privacy considered as an essential requirement as well as thermal comfort. Therefore, an urgent need has been emerged to reviving the environmental responsive element in the vernacular architecture with a kinetic structure that can cope with identity and environmental conditions.

3. PSYCHOMETRIC ANALYSIS AND DESIGN STRATEGIES:

Climate classification considered as an important tool for designing sustainable building. In this regard, understanding the bioclimatic chart of the site is essential to ensure positive environmental design outcomes (effective kinetic elevation) (bacha & Bourbia, 2011). Therefore, the psychrometric analysis was carried by using the Ecotect program to calculate the thermal comfort potential for Aleppo climate, this analysis allows the visualization of outdoor or indoor dry bulb temperature and relative humidity temperature. This chart helps architects to propose general decisions at the early design stage for developing more climate-responsive buildings (Singh, Devadutt, & Mantha, 2015). The range of comfort is considered as PMV between -1 and +1, and "Psychrometric Chart" follows these values for prediction of comfort band. The analysis started from 1 st January to 31st December during 24 hours of the day. The Ecotect program has an option to applicable passive strategies for increasing the comfort band. The default values for parameters like Mean Radiant Temperature (MRT), wind speed, and metabolic rate obtained through importing Damascus weather data file from EnergyPlus website, which arranged by World Meteorological Organization region and Country (Laboratory, 2017). Yellow area in Fig2 represents the comfort band throughout the year, and the percentage of comfort 11% annually, with a default set of values. Achieving a high level of thermal comfort based on selecting the appropriate passive design strategies for a certain climate (psychrometric chart). In this context, the percentage of comfort has increased to 20% annually, after applying passive solar heating techniques. Furthermore, the percentage of comfort has been raised to 60% annually, when applying passive design strategies which take advantages from renewable sources of energy (like the sun and wind) to cool, heat, ventilate, and light spaces for maximizing thermal comfort within a structure while minimizing energy consumption.

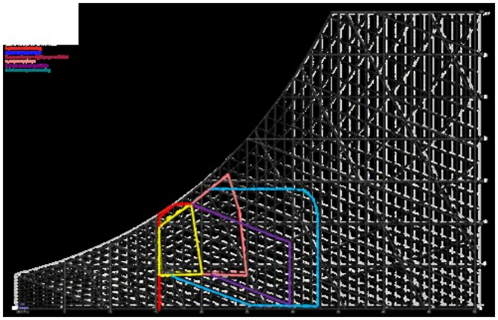


Figure 2
Figure.2.
Psychometric Chart Represent the Effective of Passive Strategies in Increasing the Comfort Band.

Finally, Psychometric chart confirmed that the implication of passive cooling design strategies such as (shading device, natural ventilation) within the reconstruction process of the Aleppo post -war succeeded in increasing the percentage of thermal comfort approximately 20% annually. Particularly, for Aleppo city climate shading is one of the most important design strategies due to exposure and intense of solar radiation. Therefore, implementation of an adaptive kinetic system that reacts to different levels of solar radiation is an essential issue for creating comfortable spaces.

4. PARAMETRIC DESIGN AND SIMULATIONS OF KINETIC ENVELOPE SYSTEMS

The development in computer technology has improved the capacity of handling complex simulation models which enabled more accurate calculations of the energy performance. These advanced technologies can be used as a design tool at an early stage, for designing an optimal envelope adopted to specific conditions and context, it enabled architects to explore new treatments for solving multi-architectural design problems (El-Sheikh & Gerber, 2011). In this paper, the research develops a new innovative shading screen system that has a kinetic structure technique to offer high potential for energy savings as well as improvement of indoor environmental quality.

4.1. Kinetic Optimization

The research proposes a solution relying on a simple strategy to deal with abundant solar radiation that is applicable in these specific climatic conditions, strong direct sunlight on a window must be blocked without compromise. In order to provide sufficient lighting during the day, this paper develops a kinetic system that allows tilting the external panel according to the sun angle to achieve more shading and better illumination of the interior space. The shading device is made of three identical frames that can slide together from one side to form two configurations, parallel or trapezoidal rectangles. Each frame consists of four corners sliding free and the last frame each covering by square panel.

The case study is a large rectangular space with an indoor area of 250 m2, the window located at the south elevation. Two main parameters have been considered shading screen geometry and kinetic structure as shown in Fig 3, these parameters have a large influence in the indoor environment, occupant well-being and the energy footprint of the building (Singh, Devadutt, & Mantha, 2015). The optimization process has been carried using the Evolutionary Algorithms embedded in Octopus tool included in Grasshopper. They apply the principles of mutation, selection and inheritance; populating virtually with a number of individuals that form generations. When new generations are created they keep the best individuals until their offspring gets closer to the peak values. An individual is a genome, and a genome is formed by genes. Each gene corresponds to a value that can be modified. Therefore, every time the gene changes the new genome is created. In this research, each genome consists of a gene that determines one of the three dimensions of the window. The gene X varies between 200 cm to 600 cm, while the gene Y varies between 0 cm to 150 cm,

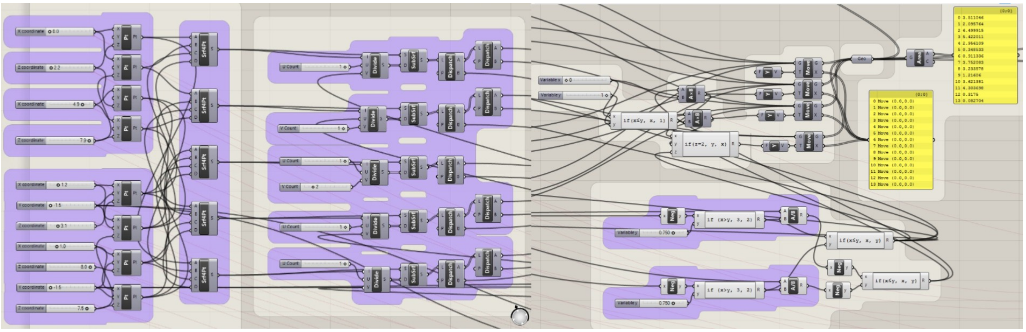


Figure 3
Figure.3. A) Al Mashrabia Parameters Consists of Five Dynamic Faces. B) Kinetic Structure Algorithm Consists of two Components: Multiple Frames Sliding; Automatic Regulator of Frames Number According to the Mashrabia Size.

and the gene Z varies between 200 cm to 800 cm. This method allows having a solar screen that can assume configurations at three axes. The implemented methodology involved two phases: environmental analysis and optimization algorithms.

4.2. Environmental Analysis:

The methodology for the environmental analysis of the proposed shading screen (Al Mashrabia) has two steps: building and street radiation analyses. Where solar radiation is an important factor to consider in occupant thermal comfort and energy use of the buildings, research utilized integrated and open source climate design tools such as Ladybug plug-ins for Grasshopper and Rhino. This tool helps to realize integrated building performance solutions at an early stage. Which makes the analysis highly interactive, and facilitates the process of environmental design analysis during different stages of the design by integrating weather data analysis and advanced simulation in a parametric environment (Roudsari & Pak, 2013). The standard Energy-Plus Weather files (EPW) were imported by "Ladybug" Technology combined with visual programming of Grasshopper as a plug-in to "Rhinoceros 5" software. Which provides a variety of interactive graphics to support the decision-making process during the initial stages of design. It also simplifies the process of analysis, automates and expedites the calculations, and provides easy to understand graphical visualizations in the 3D modelling interface of Rhino/Grasshopper (Roudsari & Pak, 2013). For building and window radiation analyses, various environmental parameters like generated geometry, generated cumulative sky matrix (uses Radiance's Gendaymtx function to calculate the amount of radiation for different sky patches of the Sky-dome and colours the sky patches based on the result), grid size (the average size of a grid cell for radiation analysis on the test surface) and distance from the base (represents the offset distance of the test point grid from the input test geometry) are evaluated.

4. 3. Optimization Algorithms:

The optimization process is essentially seen as system improvement in order to identify, arrange the effective variables and facilitates success in achieving objectives while satisfying constraints. Problems related to one or more than one objective, originate in several disciplines; their solution has been a challenge for a long time (EnginSoft, 2015). For addressing several objectives, the research has further investigated this problem using the algorithm of Hypervolume Estimation (HypE), which simply measures the volume of the space that is dominated by a solution set and bounded by a so-called reference point (Anon, 2016). Also, HypE enables the design of efficient search algorithms and, at the same time, opens up opportunities to express user preferences in the search by means of weight functions (Brownlee &

Wright, 2012). The research adopted a quality indicator called Hypervolume Indicator, in order to define the optimization goal for the multi-objective problem. This indicator assigns each Pareto set approximation a real value reflecting its quality and therefore can be used as an objective function for the underlying set problem (Brownlee & Wright, 2012). The optimization algorithm was generated by Octopus (is a plug-in for Grasshopper, which implements two multi-objective evolutionary algorithms: SPEA-2 in its original form and HypE from ETH Zürich (Vierlinger, 2016), combined with the visual programming of grasshopper, and is responsible for applying evolutionary principles to parametric design and problem-solving. Due to the octopus's capacity to benefit from multiple CPUs running the study, therefore the study executed in an acceptable amount of time.

Octopus introduces multiple fitness values to the optimization (In total 12 genes or design variables were manipulated by minimizing generated form's street and building radiation loads values at the south faced during cooling period from June till September, where the output is the total amount of radiation for each option, and a colored mesh of the result is produced so that the result can be referenced). The best trade-offs between those objectives are searched, producing a set of possible optimum solutions that ideally reach from one extreme trade-off to the other (Vierlinger, 2016). The research has chosen the strategy of HypE reduction' of how a Pareto non-dominated front should be truncated to fit the archive size when it is too big, also choose HypE mutation strategy.

RESULTS AND DISCUSSIONS:

The task was environmental analyses (represented by street and building radiation analyses, which allow to study the relationship between shading geometry and the amount of incident solar radiation or sunlight hours) by HypE for the evolved geometries, through manipulating the genetic code (where the parameterization comprises the geometry of the shading screen and the kinetic structure). In a finite number of results have been obtained table 2 present twelve solutions, from different generations. Where inefficient solutions were highlighted in red color, while efficient solutions were highlighted in green color. As shown when the overhang shading located on the top-left corner of the window high efficiency have been achieved in reducing the solar radiation on both building and street surfaces. While the horizontal narrow shading device, located over the window presented the worst solution in terms of solar radiation as well as reducing considerably energy consumption.

Some solutions achieved high efficiency in reducing the amount of radiation falling on the building surface such as the configuration has three vertical panels, each one could move independently at the (X) axis to block the solar radiation in the outside notwithstanding the sun angle, but this configuration has low performance in decreasing the radiation at the street surface, because the variable (Y) have low value. As expected the amount of shading has direct proportion with a value of the variable (Y). Nevertheless, all results have been achieved good performance notwithstanding the parameters for the optimization process considered a high number of individuals and initial boost.

Therefore, when taking into account a large amount of possible values for the three dimensions and size in the solar screens, it will lead to more varied results. It's worth to mention that, the designers allowed the optimization process to full control the decision-making for generating the optimal shading screen form and structure, without restricting the sliding movement in the kinetic structure on two axes. Therefore, as expected many extreme forms and structures that could not be applicable in the courtyard houses have been generated

For highlighting the role of the kinetic structure on the optimization process the research makes a comparison between the closed and open forms and their solar radiation loads for both inefficient and efficient solutions, as shown in Fig 6. Although, the ki-

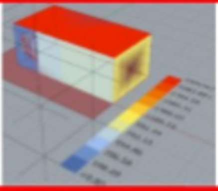
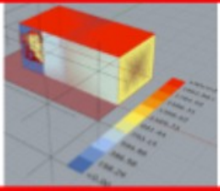
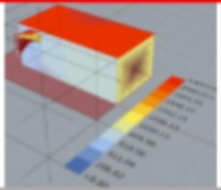
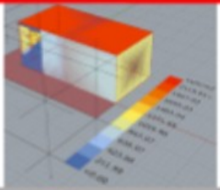
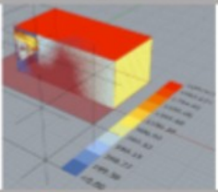
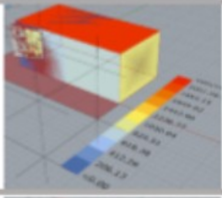
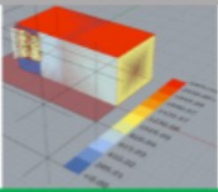
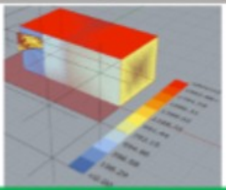
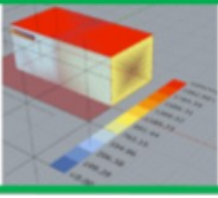
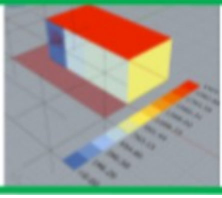
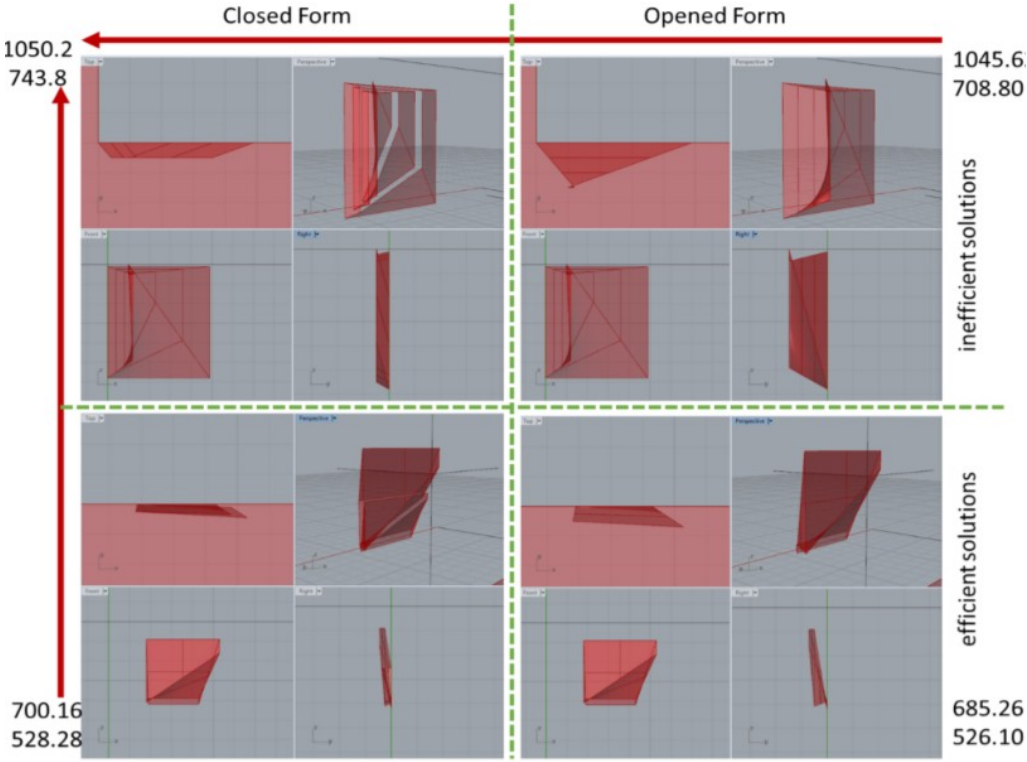
Shading Urban Geometry	Solar radiation Urban	Solar radiation Building	Shading Urban Geometry	Solar radiation Urban	Solar radiation Building
	1071.72	522		1045.62	708.80
	1040.42	790.23		1034.27	747.73
	1033.29	789.25		957.44	656.52
	939.61	681.11		948.61	640.08
	825.75	600.53		685.26	526.10

Table 1
Table: 2 Natural Selection of Twelve Solutions Based on Optimization Process: Inefficient Solutions in Red Color; Efficient Solutions in Green Color.

Figure 4
Figure.4.
Comparison between the Closed and Open Forms and Their Solar Radiation Loads for both Inefficient and Efficient Solutions



netic structure has proved a high capacity to influence the solar radiation loads at building and urban levels which enable the inhabitants the power to control in/outdoor temperature as well as thermal comfort the during winter and summer semesters.

6. CONCLUSION:

An effective ecological design is becoming an increasingly complex task, due to a growing demand to satisfy more ambitious environmental, social and economic performance requirements. Building needs to be in closer relation to the climatic context, as the building envelope is the border between the surrounding climate and the interior, the envelope component design is becoming a crucial parameter in sustainable and energy efficient building design. Several variables influence performance of external shading systems, there are some trade-offs that must be made to optimizing shading devices performance, that the main challenge lies in balancing conflicting criteria. For example, a desire to maximize transparency, daylight, and views, often be at odds with the need to minimize the solar heat gain and reduce air-conditioning loads. The combination of parametric design with evolutionary optimization is a valid strategy for addressing multi-objectives design problems and calculate multiple performance criteria, finding the optimum solutions in a short period of time. In this study, research has presented the design of a shading and daylighting system customized for hot arid climates. One limitation of this study that the authors allowed the optimization process to full control the decision-making for generating the optimal shading screen geometry, as result many genetic mutations with non-familiar style have generated during the optimization process. In this regard, to adapt with the historical character of the courtyard house, research will develop a hybrid approach to control the decision-making that enables the designer to orient and guide the optimization process towards emerging an adaptive kinetic Mashrabia compromises between environmental responsive and historical values. Evolving different shading devices more suitable for historical context is under investigation.Finally, applying the passive solar system approach for the reconstruction process of Aleppo post-war in combination with preserving the identity and the special character of the old city, successfully hybridize both the rehabilitation and energy conservation efforts.

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