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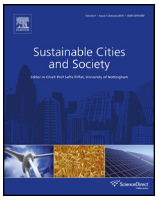

Applying urban parametric design optimisation processes to a hot climate: Case study of the UAE

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ABSTRACT

Parametric and algorithmic design is considered a current trend in architectural design processes. In recent times architects and designers have gained control over the design process by using parametric design to produce an original sustainable design that interacts with the project's environment, climatic and sustainable constraints. Research into parametric urban design shows it to be a good tool for achieving sustainable and healthy communities. It does this through minimum form and high performance spaces, particularly in hot climatic zones where outdoor life is absent, there is an abundance of solar radiation, and local materials and resources are rare or limited. Consequently, the aim of this research paper is to investigate the potential for applying parametric design optimisation processes over conventional urban design processes in order to achieve a more sustainable style of urban design. The methodology adopted for this study is the use of current state-of-the-art computer tools like Grasshopper and ANSYS CFX to achieve optimised parametric design. An urban area in Dubai was selected to act as the case study location for this project. An in-depth analysis was carried out between the base case and the optimised case. Future recommendations were drawn based on the findings and results. The study covered many environmental factors such as solar irradiation, urban ventilation, building form and orientation to achieve the optimum sustainable urban morphology.

1. Introduction

According to previous studies (Monedero, 2000) the parametric design method can be defined clearly as a way of generating diverse forms and design configurations by changing the input parameters of that design model. Although this simple definition looks easy and straightforward, parametric design can also be complex and complicated depending on the parameters under study or the interactions of these parameters with the respect to the final form generated within the constraints. These constraints may be imposed on the design by the designer themself to study a specific range of cases, or can be constraints related to environmental forces, factors and physics. The complexity of parametric design does not stop here, as input parameters may extend to these constraints. The interaction of these parameters and the way they are translated to create the form could be performed by simply altering the main dimensions of the main or sub elements in the design. Alternatively they could form an input to algorithms which are then translated into the final form of the design. The benefits that may come to architects and urban designers from adopting methodologies like parametric design is an enhancement of the process of design to cope with the demanding global energy and resources crisis that we are facing nowadays.

2. Urban environmental factors

2.1. Wind speed

One of the main effects of urbanisation and dense cities is the increase in the roughness of the urban surface within the urban canopy which applies a drag on both pedestrian and building level winds. Therefore in the long term with increased urbanisation, wind speed at the building level is decreasing (Edward, 2010). Creating design projects with better urban ventilation – especially for hot summers and dense cities – is a very critical matter for today's urban designers. City morphology and design are very important in achieving urban ventilation, since it is impossible for an architect to generate wind on the site of a building itself. Another study (Littlefair et al., 2000) highlighted five important parameters relating to building and urban morphologies and characteristics that affect urban ventilation and wind speed at both pedestrian and building level. These parameters are: air paths, deep street canyons,

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street orientation, ground cover ratio and differences in building heights. Street canyon width and height can affect the depth that the air circulation and vortex can reach in areas of dense cities. From a combination of the street canyons and air path it is obvious that the orientation of streets in accordance with the prevailing winds in summer is a crucial factor in promoting urban ventilation. When considering the actual physical phenomena of air flow and its dynamics, street orientation also has to take into consideration topography and solar access. The difference in building heights in a city has a very important effect on the ventilation of the general urban configuration. This means that a city with the same overall volume but containing a variety of building heights performs better than a city with a lower level of building height contrast.

2.2. Solar radiation

Radiation from the sun is the main energy source for all thermal and physical phenomena that happen in an urban context. Solar radiation reaching the earth heats the urban boundary layer, the urban canopy and all buildings within the urban context. This radiation is absorbed by the ground, buildings and other parts of the city. Some fractals of the rays are reflected back to the sky, to other buildings or absorbed by the air as latent heat. This phenomenon is somewhat complex and creates many other physical phenomena. In a hot climate the amount of solar radiation on the façade of a building may have direct and significant implications on both heat gain in buildings and energy consumption for indoor cooling. Many recent studies on the benefits of dense cities and their morphology have considered this situation in terms of solar insolation and mutual interaction. In dense, hot cities mutual shading is very important for the thermal behaviour of the street canyons and the spaces adjacent to them. Mutual shading can be achieved by proper street canyon orientation and urban morphologies, with buildings showing a proper harmony of heights and size. With good urban design morphology shaded areas in the streets and mutual shading between buildings can be achieved most of the time especially in hot summers (Hii et al., 2011). Previous researchers (Maizia et al., 2009) have also studied urban morphologies and high density residential urban forms in a tropical context and their performance in terms of total solar insolation on urban surfaces. The study also proposed a quantifying indicator for insolation performance relating to different urban forms and morphologies.

2.3. Energy consumption in an urban context

Another study (Rasheed, 2009) considered energy consumption when heating four types of urban morphologies: dissentious housing, continuous housing, dense individual housing and dispersed individual housing. The study looked at the best urban morphology and the potential for solar gain in order to reduce energy consumption. The results concluded that dispersed individual housing received the most solar gain compared to the other types. The physical thermal phenomena of an isolated building are different to that same building within an urban context. As the studies in the previous section and related studies have shown, the energy consumption of a building in an urban context is affected by the mutual interaction between buildings and other structures within the surrounding urban context. Another factor that affects energy consumption within the urban context is that the effect of the urban heat island on the whole urban fabric is different to the effect on local scales of buildings. Researchers have highlighted that the energy consumption of a building in an urban context is affected by: high air temperatures because of the urban heat island effect, increased urban roughness in terms of slowing wind speeds, a reduction in heat radiation losses during the night, mutual shadings and mutual reflections which affect solar heat gain and a difference in radiation and heat transfer balance between buildings (second law of thermodynamics).

3. Methodology

3.1. Case study

The ‘Dubai Silicon Oasis’ development spans some 7.2 million square metres of the city of Dubai in the United Arab Emirates. The master plan is divided into five main zones; industrial, commercial, educational, residential and public facilities with a population of 162,400 (Fig. 1).

Dubai Silicon Oasis is designed as a hi-tech ecosystem which offers businesses a plethora of advantages including a state-of-the-art infrastructure, in-house business services and strong business support such as technology investment incentives for large enterprises, entrepreneurial support, an incubation centre and venture capital funding. The multi-zone design of Dubai Silicon Oasis divided the master plan into zones of symmetry. These zones are reflected on the urban morphology of the whole master plan and furthermore created a big step difference in terms of building heights, usage and size. The character of the Silicon Oasis urban morphology was taken into consideration in this study and the aspect of symmetry was taken to be the subject for the experiment in parametric optimisation (Fig. 2).

3.2. Climate and weather data

Dubai is a unique climatic zone, which affects both the design and the strategies that can be employed to achieve a healthy and sustainable ecological design. The severe weather outdoors impose a need to use the best cutting-edge design strategies and technologies to interact with it. Looking at the key issues with regard to the weather in Dubai and its climatic zone, the hot humid atmosphere and desert characteristics are the most prominent. The scarcity of water for domestic use and agriculture in the UAE is also a major obstacle when planning new sustainable buildings and master plans. So, the challenge is a very hot, humid, tropical desert and dusty climate which makes it very difficult to design social outdoor spaces and creates a sustainable environment. Winds at the project site are predominantly from the west northwest direction with the second most frequent direction being west southwest. ‘Shamal’ winds (strong winds coming from the northwest) are often associated with storms because they can last several days during the winter season. Recorded wind speeds at Dubai Airport are shown in Fig. 3. Using the Dubai Airport data, design wind speeds at the project site – sheltering or funnelling effects induced by future structures on neighbouring plots should also be considered – were assessed for the project. Winds – even the slightest breeze – at the project site play a very important job in changing the severity of the weather, they need to be induced and directed with the right urban morphology and architecture features. The continuity of wind movement over landscape (transpiration) or the bond with water can greatly improve ambient temperatures outside (or even inside) noticeably.

The location of Dubai close to the equator gives the sun an almost direct path to the centre (Fig. 4). This implies that mutual shadowing is minimal and difficult to design for it. Sun access is available most of the year, with days of partial cloud and rainfall being minimal.

The scarcity of annual rainfall in the UAE makes it very challenging to design urban and architectural features that can use or store storm water for domestic and agricultural usage. This has made water one of the most valuable resources in the UAE. Other conservation measures and technologies should be considered when