

Mathematical Generative Approach on Performance Based Urban Form Design

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Abstract

The research proposes a mathematical generative methodology to identify performance linking urban forms and density indicators. Selected performance criteria for this preliminary study are shadow factor (on the public ground) and Urban Heat Island effect. The results are interpreted based on the mathematical correlation between building form factors and environmental qualities, depending on the building density, to identify the most performing cases by means of parametric design. The study shows that, in the case of buildings with square foot print, UHI is highly dependent on height of urban canyon and optimum shade factor is achievable with intermediate canyon width.

1 Introduction

Cities could be considered as live structures with complex metabolism including different scales changing over time. Solving this equation, designing and programming a liveable city could be achievable by rising quality of urban spaces. Talking about qualities in general could be a never ending discussion since qualities are always objective phenomena. However transforming quality into performance indicators could be a substitute translation to give more understandable sense and scale to measure assets of urbanity.

Thinking about environmental qualities will raise couple of keywords like: building shape factor, indoor solar access, outdoor comfort, urban heat island effect, sky view factor and etc. (Oke, 1982). Additional layer beside these qualities is the density, which has extremely direct exchange on the performance of the urban entities. Combining density factors with performance qualities will allow the designers and planners to understand and justify extreme bounds and consequences of rapid urbanization to look for optimized solution (Ng, 2010). To understand the correlation between urban form and performance through generic methods there are several directions to follow. Ratti, Raydan, and Steemers (2003) analyzed and compared the archetypes in terms of built potential and day lighting criteria as well as Surface to volume ratio, Shadow density and daylight distribution and Sky view factor with question of which building forms make the best land use? The suggestions indicate; larger surface area and high thermal mass, daylight via the courtyard and shallow plan form, narrow spaces for shade and improved thermal and comfort despite increased heat island. Balling, Taber, Brown, and Day (1999) used genetic algorithm was used to search for optimal future land-use and transportation plans for a high-growth city with the objective of minimization of traffic congestion and costs to control air pollution. Austern, Yu, Moral, and Jirathiyut (2014) suggested a framework for generating environmentally adapted urban tissue by using genetic algorithms as form-finding processes of environmental optimization considering solar exposure on the streets and facades, rate of wind flow on the pedestrian level and emergent pathways.

Looking back to the history and starting point of generative design, Mehaffy (2008) assesses the progress of generative methods in urban design and finds the roots in the ideas of Christopher Alexander about pattern language (Alexander, 1979). Alexander developed “laws of wholeness” with

detailed structural logic, to propose a method by which this quality can be attained again in a contemporary context – not through a conventional kind of master plan, but through a process involving the sequential collaboration of a series of participants, and such a method could be described as generative. However seems the fact is happening recently dependent on computer science achievements offering variety of tools and efficient computation power. Within such an approach the collaborating participants will together generate an evolving form that grows out of a complex transformation of the existing context, together with all its environmental, social, and cultural factors. Such a generative process is continuous, and cannot be frozen in a standardized master plan (Mehaffy, 2008).

Accordingly, the present study explores generative approach based on environmental and performance indicators measuring weight and value of each parameter on the final equation of the urban form. The aim of this approach is to focus on the form dependent performances criteria in urban context. The proposed and implemented parametric model could be used to generate desired set of urban forms to have holistic understanding performance and design proposal in the early stages of urban planning. In this study two main outdoor factors selected to simulate and measure performance. First, Urban Heat Island as temperature difference between urban and rural areas, and second shade factor with the definition of shade benefit on the pedestrian area on the public ground.

2 Methodology

2.1 Generative Approach & Rules

The concept of generative design is based on the incorporation of system dynamics into the production of experience and it offer a methodology to look to the facts in terms of dynamic processes and their outcomes. The generative methodology is an unconventional way of conceptualizing and working in design (McCormack, Dorin, & Innocent, 2004), However, generative systems are relevant to contemporary design practice in a variety of ways and intentions. The integration of generative concepts into the design process allows the development of novel design proposals through iterative workflows, which are not easy to achieve via other methods.

Application of generative approach for creating urban forms is not entirely new method however coupling it with performance indicators could be the added value. The current workflow is being developed in Grasshopper (visual programming interface) to generate parametric and iterative urban forms. Additional tool is scripted and implemented in Python to calculate urban heat island and shade factor from derived urban forms. Recording the output data was also important for each iteration, so the workflow after each generation and performance calculations, writes results to CSV files in real time. Afterward these outputs could be processed to generate visual map and also apply statistical methods to find correlations between inputs and outputs (Figure 1). In order to control amount of variants and to avoid specious outputs set of boundary circumstances are defined:

Simulation Area	Blocks	Block number	Floors	Window to wall Ration (WWR)	Height per floor
200 × 200 m	16 < x < 28 m	9-16-25	5 to 20	0.3 - 0.5 - 0.7	3.2 m

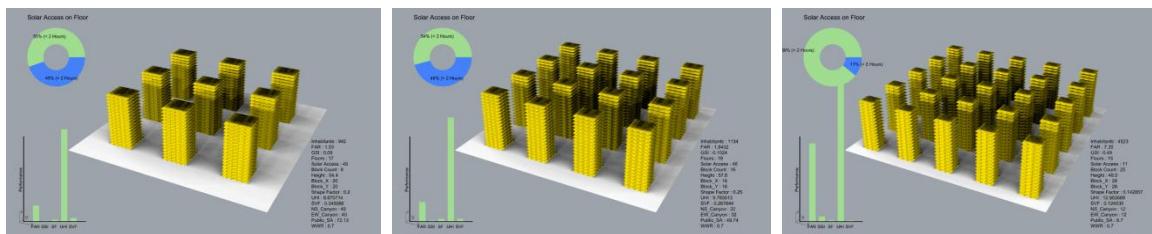


Figure 1: Visual interface of urban forms and simulation parameters

For building density factor, the floor area ration (FAR) is calculated which represents the relation between the total area and the floor area (Berghauer Pont & Haupt, 2010). For performance indicators

the shadow factor (SF) for public ground is calculated considering the pedestrian area shaded at least 50% of the day on the 21st of each month of the year in Munich, Germany. The urban heat island (UHI) is calculated using formula(1), where W is the canyon width, H is the canyon height (Oke, 1981).

$$UHI = \Delta T_{u-r} = 7.45 + 3.97 \times \ln(H \div W) \quad (1)$$

2.2 Data analysis and statistical approach

In order to identify the correlation between performances (UHI and shadow factor) with geometric outputs (FAR, canyon height, width, building size, WWR and etc.) the recorded data is elaborated by means of a statistical approach. Due to high number of different configurations (600 cases), a valid interpolation between the parameters investigated, i.e. between UHI-FAR and SF-FAR, is not always obtainable. Therefore, three different groups are identified according to canyon width (w) and building size (x) and the results are analyzed consequently: $x + w = 40$, $x + w = 48$ and $x + w = 60$ m. In this manuscript, the results related to the $x + w = 60$ configurations with square building footprint are specifically presented.

3 Results and discussion

The geometric parameters, i.e. width of the canyon, buildings dimensions, and the relation between these two parameters (sum and ratio) highly influence shadow factor and urban heat island values (Table 1). Figure 2 shows that the shadow factor (SF) mainly depends on the canyon width (w). SF is higher when the width of the canyon is increasing, with a linear dependency and high reliability. For the same canyon width (w), the variability of SF is low for deep canyons (40-45 meters) and narrow ones (up to 20). Differently, the variability is higher with intermediate width canyon. Figure 3 focuses on the results related to the $x + w = 60$ m configurations. Results highlight that SF depends on the ratio between w and x. Thanks to this graph it will be possible to identify the most performing configuration for different FAR values, according to w/x ratio and number of floors, in terms of shadow factor. As shown in Figure 4, in a similar way it is possible to identify the most performing $x+w=60$ m configuration (canyon width and number of floors) in terms of UHI for different FAR. Indeed, UHI depends highly on the height of the canyon. Eq. (2) defines the relation between UHI and FAR.

$$UHI = 7,45 + 3,97 \log e \left(3,2 FAR \frac{\left(1+\frac{w}{x}\right)^2}{w} \right) \approx 12,08 + 3,97 (\log e FAR + 2 \log e \left(1 + \frac{w}{x}\right) - \log e W) \quad (2)$$

Table 1. Geometric parameters and related SF (average and standard deviation) and UHI (range) values.

w Canyon (m)	x Block (m)	W + X (m)	W / X (m)	average SF (%)	STDEV-SF	UHI Range (°C)
12	28	40	0.43	8,83	0,23	8,59-14,10
16	24	40	0.67	14,02	1,76	7,45-12,95
20	20	40	1.00	21,57	6,17	6,56-12,07
24	16	40	1.50	33,19	12,25	5,84-11,84
20	28	48	0.71	24,16	4,66	6,56-12,07
24	24	48	1.00	32,23	8,13	5,84-11,84
28	20	48	1.40	44,00	11,27	5,23-10,73
32	16	48	2.00	63,37	11,50	4,70-10,20
32	28	60	1.14	53,06	8,49	4,70-10,20
36	24	60	1.50	64,80	0,04	4,23-9,73
40	20	60	2.00	77,72	5,42	3,81-9,32
44	16	60	2.75	89,14	1,57	3,43-8,94

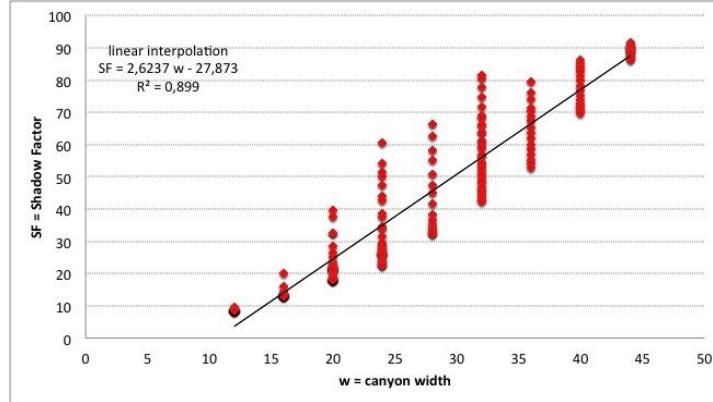


Figure 2: dependency of shadow factor on canyon width (all urban configurations analyzed)

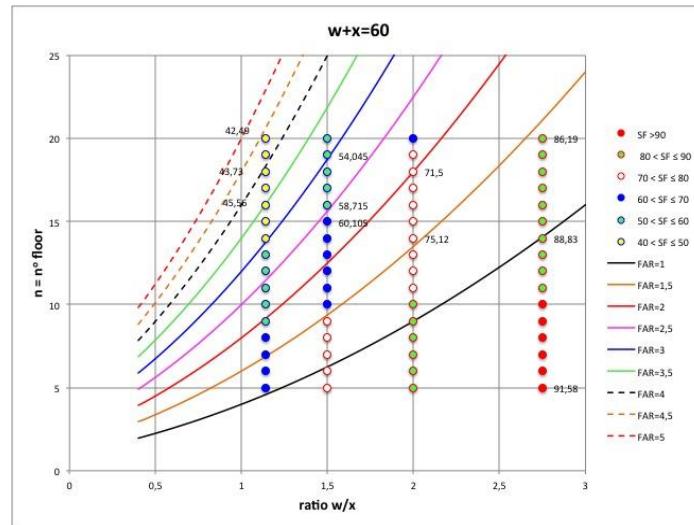
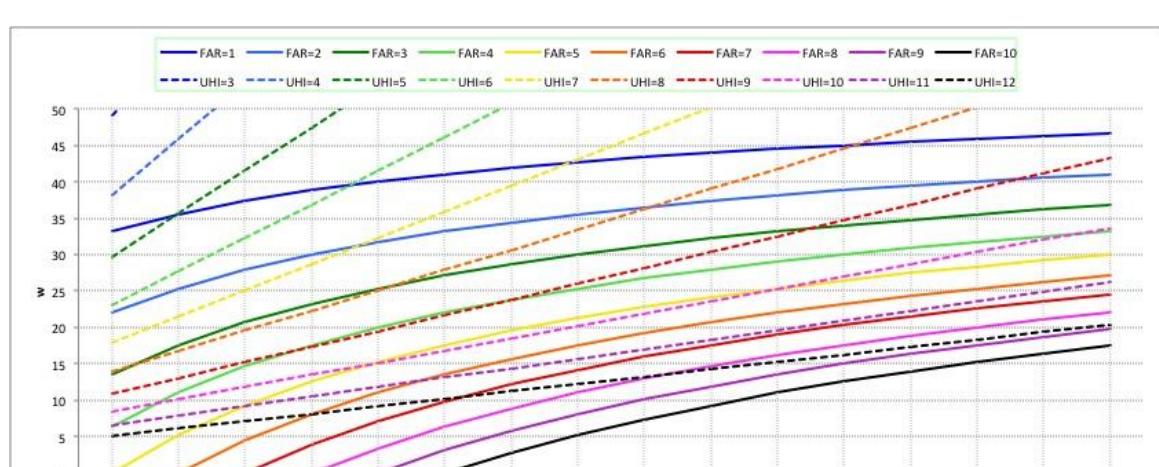


Figure 4: relation between canyon width (w) and number of floors (n) and FAR and UHI, for the cases where width of the canyon and size of the building is equal to 60 m.



4 Conclusions

Generative framework explained so far could clearly highlight dependencies of urban form on environmental performance criteria. This approach could be applied for any location to propose a guideline for optimum performing densities within each context. The mathematical dependency uncovers main role playing parameters in urban design and planning. As highlight, due to high correlation of UHI and density, the proposed equation can predict UHI potential based on floor area ratio of each neighborhood.

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