THE EFFECT OF URBAN OBSTRUCTIONS IN MEDITERRANEAN CLIMATES: BUILT FORM TYPOLOGY, DENSITY AND ENERGY

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THE EFFECT OF URBAN OBSTRUCTIONS IN MEDITERRANEAN CLIMATES: BUILT FORM TYPOLOGY, DENSITY AND ENERGY

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Abstract

In spite of the ever increasing unsustainable nature of the “conventional” city and its concurrent assertion as a human habitat par excellence, it is important to define intervention strategies that can improve the “metabolic” operation of built environments. If related to urban morphology, these take on more effective potentiality and are a guiding tool for more appropriate, more beneficial interventions. In the specific context of the Mediterranean compact city, the interaction between density, morphology and energy discussed here is one of the components required if not for the complex solution of the problem, then at least for reducing the environmental impact of urban models. The results here proposed of a comparative study carried out on various fabrics in the city of Barcelona, in search of parametric relations between density and energy-environmental behaviour. The said relations, we analyse the effects of urban obstructions: the basis of knowledge required for conscious built environment transformation, towards more efficient conditions.

1. Introduction

In the past fifty years the planet has experienced a shift to a cultural model which has produced a violent reconfiguration of settlement systems, under the effect of a process of expansion, which is claimed as a *technological era* dogma. A period of rapid and radical changes, yet so very young that “corresponding thought does not yet exist” (Sertorio, 2002: 22). Technology, *spun* outside of the domain of activities controlled by man, becomes “the dynamic partner that helps to modify the motivations of man himself” (Sertorio, 2002: 24), causing the definitive separation from the natural limits of the *physiocratic era*.

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Figure 1. The rapid growth of metropolitan areas

Source: LONDON SCHOOL OF ECONOMICS (ed.), 2008.

The offspring of this cultural picture would seem to be today's urbanisation growth, which is described by many as *The Global Urban Age* and is distinguished by two quantitatively significant phenomena: constant, exponential population growth in existing cities and the simultaneous unstoppable emergence of new ones. The combined effect of these two events will mean that three quarters of the global population will be living in cities by 2050 (Figure 1) (Kanai and Soya, 2007). As the principal habitat of today human being, these are then widely considered to be the main cause of ecosystem destruction and the most significant threat to humanity survival (Rogers and Gumuchdjan, 1997). The very nature of contemporary cities has, however, illustrated the inadequacy of traditional disciplinary categories in architecture and urban planning, developed by modern culture, in analytically describing the structural complexity of the phenomena related to the Global Urban Age (Koolhaas, 2000).

However, in spite of their ever increasing unsustainable nature, cities mysteriously continue to exist, to operate, to attract an ever increasing number of people, constantly increasing their ecological footprint, eating up energy as well as environmental and economic resources. Although it is not always possible to fully understand the interactions between the environment and the metropolitan setting, it is clear that it is here where a wide margin exists which we can work on for greater *efficiency*.

If new settlement models (developed on the basis of technological innovations produced in recent years and directly influenced by growing awareness of energy and the environment) are still a small proportion compared to the great mass of the ordinary city, it nevertheless seems

clear that in the contemporary metropolis the fate of the *sustainable project* is in play (Figure 2). Research carried out so far in this field has been able to show that strategies and technologies which redefine more appropriate conditions for the metropolitan habitat are possible, yet on the other hand this research has lacked strength. It is now inevitable that this is to be integrated in a vision that enables us to grasp the complexity of the phenomena, also considering, of course, multiple perspectives and scales of reference (Mostafavi and Doherty, 2010).

Figure 2. Eco-cities and conventional cities

Source: Maas et al., 2010.

Nevertheless, how it cannot be ignored, that the *sustainable* approach to urban phenomena appears by its very nature to be many-sided and – in certain ways – even undetermined, which creates the suspicion in many that it lacks scientific nature. Research in the field is often contradictory, unclear in its disciplinary scope and the results often seem ambiguous. The very concept of sustainability is weak and lacks incisiveness, especially in contemporary design practice (Maas et al., 2010).

Yet just below the *skin* of the cities there is an intertwining of deep ties between urban form, density and sustainability. The morphology of cities, the significant amount of land that they occupy, the energy they consume, the type of transport they adopt and the living model that they shape – these are all phenomena that profoundly affect the environment and determine the conditions of its social and economic sustainability. Cities are not just a concentration of problems (as they present themselves), but they are certainly the place where we need to look for the solutions.

We will now focus on by reflecting on the interrelations which link density - in its many aspects and declinations - to sustainability. Since the very first emergence of the modern metropolis, the growth of density has seemed out-of-step compared to the increase in well-being and the

quality of living; almost as if, beyond a certain point, the minimum conditions for living standards in an urban environment start to disappear. Overcrowding, poor solar access and less ventilation reduce the level of the quality of living in areas which are densely populated, despite the fact that energy, ecology and environmental performances still seem to have consistent margins of improvement, even beyond the critical value of density, defined in relation to the overall quality of metropolitan living. While the emergence of the first unwanted effects of high density has led to the identification of standard parameters - which have become one of the key points of urban planning -, the change in energy, ecology and environmental performance still awaits analytical study and effective modelling.

2. Built form typologies, solar radiation and energy consumption in dense contexts

Faced with the extreme complexity of environmental and energy interactions in metropolitan contexts, numerous attempts have been made at *neutral* comprehension supported by analytical parameters. Firstly, an attempt was made to overcome the multi-sided nature of the concept of density, by giving it objectivity and capacity for morphological description (Rapaport, 1975; Alexander, 1993; Churchman, 1999; Berghauser and Haupt, 2010). Following this, attention was focussed on the different aspects that influence the metabolic efficiency of the built form typologies that make up urban systems and on the definition of the concept of sustainability in the presence of high density (Isalgue et al., 2007, Ratti et al., 2005, Cheng et al., 2006, Zhang et al., 2011, Strømman-Andersen and Sattrup, 2011).

What appears clearly from these studies is the strong influence of the reference climate on the direction, the interest and the individual results of the research. The positive effect of the variation of a particular parameter (e.g. the density, the size of the urban canyon or the sky view factor) can be negative for other climatic conditions. It is certainly true that "in the already built cities of northern Europe, urban density is of particular concern, because the high latitudes and the associated low solar inclinations mean that the urban geometry affects solar access much more here than in other urban centres around the world. Overshadowing is an obvious problem." (Strømman-Andersen and Sattrup, 2011: 2012). Yet if we refer to Mediterranean climates - where energy consumption depends on the ever increasing demand for summer cooling - dense urban contexts, reducing direct heat gain because of reciprocal obstructions, end up being more efficient.

This study seeks to understand the type and extend of the interferences between morphology, density, solar radiation and energy consumption in modern-day European cities with a Mediterranean climate. The aim is to provide a contribution on what impact a specific urban context has on solar access and on the energy pattern of a residential block; to understand which of the geometric-analytical parameters is the most suitable in expressing a relationship between urban density and energy behaviour; and build a basis of knowledge which is able to define a domain of critical values of density, beyond which benefit from solar radiation is compromised and an increase in consumption is caused.

Answering this, although in a limited manner, can lead to the definition of a methodology for urban intervention that is aware of the interactions between buildings and energy and their

effects. In order to make this type of tool suitable in the early stages of planning, we aimed to develop a process that reduces the necessary input data, the calculation stage, and focuses on defining qualitative and quantitative features of the built form typology based on solar access and consumption.

Figure 3. **Selected case studies**

Source: By authors.

2.1 Scale of reference

In trying to define the spatial entities that make up the structural core of the urban space, Conzen (1960) and Muratori and Maretti (1960) identify three: the street system; the lot pattern; and the building configuration. As a scale of reference this study takes those in which the above-mentioned entities are central - the block and the fabric. On one hand they are the most suitable for describing morphological properties through parameters of density; on the other hand they enable us to control the interactions between resources, environment and the building, to a scale that has proved to be decisive for defining sustainability strategies. What is more, often the decisions to be made in the early project stages on an urban scale have a greater impact and *resilience* on the environmental and energetic behaviour of the building compared to the architectural and technological-constructive decisions, which are normally more costly (Strømman-Andersen and Sattrup, 2011). Therefore, this knowledge and the relative control in terms of environmental efficiency seem appropriate and necessary in order to achieve better results which can handle current challenges.

2.2 Methodology

In thinking about the search for critical values of density, it was deemed in keeping carrying out the comparison on various levels: the description of the physical consistency and the evaluation of energy and environmental behaviour. Starting with analysis (using a series of indicators) of the density of the real fabrics and then using digital modelling (which reflected the properties

observed) we were able to study the influence on solar radiation access and relative energy consumption.

Table 1. Data and reference parameters for analysis

	Barceloneta - [A]		Eixample - [B]		Mar Bella - [C]		Borrell i Soler - [D]		Raval - [E]		Gràcia - [F]	
Level of aggregation	Single block	Fabric	Single block	Fabric	Single block	Fabric	Single block	Fabric	Single block	Fabric	Single block	Fabric
Population (inhab.)	130	1,170	302	2,718	493	4,437	209	1,881	791	7,119	397	3,573
A - Base land area (m ²)	680	11,813	12,604	161,604	12,724	160,800	14,195	167,108	4,487	46,729	7,225	74,393
Land area density (inhab./km ²)	191,176	99,048	23,961	16,819	38,746	27,593	14,723	11,256	176,287	152,347	54,948	48,029
Built up volume (m ³)	11,220	100,980	177,785	1,600,066	114,673	1,032,058	57,040	513,360	81,077	729,693	61,758	555,822
Skin surface (m ²)	4,274	38,466	35,039	315,349	29,183	262,647	19,314	173,826	15,488	139,392	18,004	162,036
Urban density (m ³ /m ²)	16.50	8.55	14.11	9.90	9.01	6.42	4.02	3.07	18.07	15.62	8.55	7.47
B - Built up area (m ²)	680	6,120	11,148	100,332	5,874	52,866	3,803	34,223	4,158	37,420	5,324	47,916
F - Gross Floor Area (m ²)	3,400	30,600	58,225	524,029	46,487	418,383	22,815	205,335	24,947	224,521	17,924	161,316
FSI or F.A.R. (m ² /m ²)	5.00	2.59	4.62	3.24	3.65	2.60	1.61	1.23	5.56	4.80	2.48	2.17
GSI - Coverage (m ² /m ²)	1.00	0.52	0.88	0.62	0.46	0.33	0.27	0.20	0.93	0.80	0.74	0.64
OSR - Spaciousness	-	0.186	0.025	0.117	0.147	0.258	0.456	0.647	0.013	0.041	0.106	0.164
L - Building Height	5.00	5.00	5.22	5.22	7.91	7.91	6.00	6.00	6.00	6.00	3.37	3.37
Height/width ratio x	2.54	2.54	0.98	0.98	1.05	1.05	0.78	0.78	3.90	3.90	2.25	2.25
Height/width ratio y	2.20	2.20	0.98	0.98	1.19	1.19	1.10	1.10	3.90	3.90	2.25	2.25

Source: By authors.

The comparative studies were carried out on a sample of urban fabrics in the city of Barcelona (Figure 3), which represent the European compact city with a Mediterranean climate. Physical consistency and the relative density of the cases chosen (Table 1) were then examined with reference to the indicators used in *Spacematrix* (Figure 4) (Berghauser and Haupt, 2010).

Figure 4. FSI-GSI variations in the scale of the block and fabric

Source: By authors.

In this way it is possible to link the quantitative parameters with the built form typology for the scale of the block and of the fabric. In the preliminary stage, six cases were identified to try out the methodological process and deduce trends and evaluations from the results. In order to prevent the formal singularities and spatial inconsistencies of the actual blocks from affecting the interpretation of the performance of the distinct morphologies, the cases underwent a process of *Normalisation and Replication* (Zhang et al., 2011). In this way, the urban contexts, modelled by tracing out the geometric structure of the actual fabrics, are made up of homogeneous blocks (Figure 5). Accepting, therefore, to work with “the arrogance of the media” (Berghauser and Haupt, 2010: 100) the effects of the specific features of the single element are excluded, which can compromise understanding of actual environmental behaviour and create difficulties in the interpretation of results.

Figure 5 Normalisation and Replication process for Mar Bella

Source: By authors.

The cases selected in Barcelona represent some of the typical urban blocks of the compact European city. The area of *Barceloneta*, near the port, was one of the first urban developments beyond the walls of the old town. Designed in 1753 with a unitary plan, it is made up of a fabric of long, narrow blocks, completely built-up, and a narrow road network. The basic module of the block is made up of square building units, 8.40 metres sideways. During the 19th and 20th centuries it underwent a process of densification which led to an increase in the average height of the buildings from the original two floors to the current four-six. The *Eixample* represents the typical fabric of the high-density, European city in the 19th century, made up of square blocks 113.3 metres sideways with the typical *chafalán* on the corners and wide road networks.

The blocks in their present condition are characterised by deep buildings of average height, with a considerable covered surface. *Mar Bella*, however, is one of the contemporary interpretations attributed to the urban planning of Ildefons Cerdà. The court is defined by a C-shaped building of similar height but lesser depth compared to the cells of the *Eixample*, and by a low building in line which contains a tower of thirteen floors in the corner. It represents, in fact, a typical case of contemporary intervention work within the European compact city. *Borrell i Soler* has a fabric of low-density detached buildings, often found in bourgeois residential developments of the second half of the 20th century. The *Raval* is one of the areas in the *Ciutat Vella* district which arose from expansion in the industrial age, outside of the medieval walls. It is a compact, very dense fabric made up of irregular blocks. Finally, *Gràcia*, the historic core with origins dating back to the 17th century, has compact edification grouped in courts of medium-low density.

Figure 6. Median solar flux received for three case studies (summer season)

Source: By authors.

Using the *Heliodon 2*² simulator, digital models were studied in terms of solar access. The calculation hypotheses underlying the software do not make it possible to determine the exact incident radiation, but on the other hand they closely relate it to the geometric properties of the objects, making it suitable for comparative studies on the relations between solar radiation, density and urban morphology. The performances are initially evaluated in reference to the summer season and in two conditions (the obstructed and unobstructed block).

² A computer tool that simulates the solar path in relation to geographical location and can deduce information and data on the quantity of solar radiation that the surfaces of a building receive, taking into consideration any obstructions in the urban neighbourhood. More information: <http://www.heliodon.net/>.

For the façades of each, the solar heat gains (kWh), the solar flux (kWh/m²) and the Sky View Factor [SVF] (%) are determined (Figure 6). The heat gains make it possible to examine the differences between the two urban situations, whereas the solar flux seems effective for comparing the different fabrics, e.g. by observing behaviour according to the floors and the orientation.

Table 2. Comparison of the effect of obstructions on solar radiation

Reference Scale - BLOCK	Barceloneta	Eixample	Mar Bella	Borrel i Soler	Raval	Gràcia
FSI or Building intensity	5.00	4.62	3.65	1.61	5.56	2.48
GSI or Coverage	1.00	0.88	0.46	0.27	0.93	0.74
Façade surface (m ²) [F]	2,914.00	12,770.00	16,338.00	11,709.50	7,171.10	7,354.80
Mean SVF	28.92	38.17	38.44	41.11	19.69	33.20
Facade energy gain (GWh) - Obstructed - Summer [A]	0.28	2.04	2.56	2.02	0.50	0.91
Max local flux - mean (MWh/m ²) - Obstructed - Summer [B]	0.152	0.176	0.176	0.177	0.114	0.165
Facade energy gain (GWh) - Unobstructed - Summer [C]	0.61	2.21	2.78	2.04	1.10	1.29
Max local flux - mean (MWh/m ²) - Unobstructed - Summer [D]	0.175	0.178	0.181	0.178	0.150	0.182
Façade energy gain factor [A/C]	45%	92%	92%	99%	45%	71%
Façade local flux factor [B/D]	86%	99%	97%	100%	76%	91%
Façade Energy gain Ratio (GWh/m ²) [A/F]	9.48E-05	1.60E-04	1.56E-04	1.73E-04	6.98E-05	1.24E-04

Source: By authors.

Figure 7. Analysis of trends between solar access and density parameters

Source: By authors.

The energy simulation carried out with *Archisun 3.0*³ software was set up in order to control as well as possible the variation of parameters, which play a main role in the study.

Default values were applied to all variables except for those related to urban morphology and its behaviour with regard to solar radiation. Geographical location, weather conditions and the alternation of typical days were the same for each of the six cases⁴. The thermal parameters of the skin and of the internal surfaces, just like the building services specifications, were kept by default.

A set value equal to 25% of the total was given to the vertical, transparent surfaces. *Archisun 3.0* makes it possible, with a graphic interface, to set up a model of the urban context, but in practice the tool does not enable you to model it with the precision required to be able to characterise them in the various fabrics. This is why in order to distinguish the obstructed case from the unobstructed; you need to examine the obstruction of the skin, determined with the calculation of the mean SVF for the separate façades with *Heliodon 2*.

2.3 Results and analysis of preliminary study

At this preliminary stage attention was concentrated on the comparison of solar radiation conditions in obstructed and unobstructed cases, in reference to the scale of the block and relative energy consumption. The results on radiation were compared by making reference to the summer period – in which it is presumed that the positive effect of reduction of incident radiation from the urban context is clearer – in the two different situations.

Figure 8. Effects of obstructions on solar access

Source: By authors.

³ A programme developed by the *AiEM* research group from the UPC Universitat Politècnica de Catalunya. Unlike other energy simulation tools, it is not based on models from the finite elements method. The description of the architectural organism is entrusted to functions designed to describe the external geometry-environment interaction using the properties of the volume and its skin. It cannot calculate exact values but it makes it possible to use coherent, general criteria of evaluation. The programme looks at the object of study according to the theoretical model of the *grey box* and associates climatic or geographical location to this as well as some basic parameters on the type of use and consumption. Available on line: <http://www.upc.edu/aiem/>.

⁴ In the alternation of the four seasons, the software considers average values for each month, taking into account the variation in the day-night cycle. It then defines, on a statistical basis and for each season, an alternation of three typical days, different for climatic conditions which may be different from the average condition. Here the small climatic differences that may exist between the distinct positions are entirely negligible.

First look at Table 1 and Figure 4. If we find interesting the descriptive ability of urban morphology with FSI and GSI (which follow the pattern of the other parameters of density), it is also equally interesting to relate them to the height-width relationship of the urban canyon which, however, diverges. Compare, for instance, the cases [A], [B] and [E], in which with comparable values of FSI and GSI do not correspond in the relationship mentioned. The data suggests that the geometric properties of the street system, even though influential in determining the effect of obstructions, are not enough to understand environmental behaviour, as they are unable to describe the morphology of the urban unit beyond the façade. If, however, we refer to *sky view factor* and *façade energy gain ratio* (FER) we get a description that can be related consistently to the *building intensity-coverage pair* (FSI-GSI). More specifically, the first refers just to the geometric properties of the built volume, whereas the second bears in mind the orientation, therefore providing information on the solar access. Figure 7 shows the behaviour of the study cases and trends deduced. Looking at the two pairs of graphs, we notice how [B] is the only one that optimises in each the environmental behaviour, favouring lighting and solar radiation. A completely opposite case can be seen in [E] however. It is equally interesting to notice the almost direct proportionality FER-SVF, which in a way confirms the validity and the inter-changeability of the parameters used.

Table 3. **Energy consumption for summer cooling and heating**

	Energy consumption (kWh/m ³ year)	Obstructed	Unobstructed	%
Barceloneta	Heating	3.81	1.68	226.8%
	Cooling	8.16	11.42	71.5%
	Heating + Cooling	11.97	13.1	91.4%
Eixample	Heating	1.94	1.52	127.6%
	Cooling	7.05	8.49	83.0%
	Heating + Cooling	8.99	10.01	89.8%
Marbella	Heating	2.54	1.65	153.9%
	Cooling	5.88	7.82	75.2%
	Heating + Cooling	8.42	9.47	88.9%
Borrel Soler	Heating	4.27	2.98	143.3%
	Cooling	4.37	6.27	69.7%
	Heating + Cooling	8.64	9.25	93.4%
Raval	Heating	1.25	0.55	227.3%
	Cooling	8.97	10.78	83.2%
	Heating + Cooling	10.22	11.33	90.2%
Gràcia	Heating	2.62	1.77	148.0%
	Cooling	8.22	10.05	81.8%
	Heating + Cooling	10.84	11.82	91.7%

Source: By authors.

We will now analyse the effect of obstructions in the different urban contexts (Table 2, Figure 8). Comparing the gradients between the obstructed condition and the unobstructed one with the GSI values, we see a trend for an inverse proportionality, from which once again it is [B] that diverges the most. The fact that the urban area has less effect on solar radiation is to be attributed not so much to the orientation of the blocks (which is similar to the other cases) as to

the morphology of the fabric; its *largeness* means that in summer there is almost undisturbed solar access.

These differences seem to flatten out however if we refer to energy consumption for heating and cooling in the two conditions (Table 3 Figure 9). Despite the fact that the increase in winter consumption represents a greater percentage than the percentage of the reduction in summer, the final energy balance take an advantage in favour of actual urban systems (i.e. with obstructions) with gains ranging from 6.6% and 11.1%. In addition to the reduction of the gradient between different built form typologies, relations with density parameters appear less evident at first sight. If more detailed research seems necessary to understand these interactions rationally, it now seems evident that, in terms of consumption, the European compact city has a margin where we can work to reduce inefficiency. The positive effect of obstructions on the energy balance opens up the field to possible transformation work through densification (or thinning depending on the climates), which if controlled using a methodology of this type favours control and improvement of the environmental and energy performance of urban fabrics.

Figure 9. Percentage of consumption reduction due to obstructions

Source: By authors.

2.4 Limitations and future developments

The study is a preliminary stage in the development of an appropriate methodology and the investigation of possible results. The process has shown that, even though we need to broaden the reference case survey and develop the investigation method, potential in its application can be seen in the preliminary project stages, as a control tool for modifications on metropolitan systems and as an element that strategically directs the types of intervention according to the urban morphologies. It must be said however that an advancement of knowledge in this sector is one of the components that constitutes reaching the complex state of balance for urban contexts which falls under the name of *sustainability*. That same condition which we tend to today, which can be found in natural systems, for which the *minimum entropy* is produced (Sertorio, 2000: 7).

In order not to distort the results reached so far, certain considerations are necessary. It is important to remember that the simulation carried out with *Heliodon 2* provides radiation values that are not real (even though they are reliable as proportional to a large extent) and therefore suitable only for comparative studies. Another significant aspect concerns the evaluation of

consumption and heat characteristics of the skin. In *Archisun 3.0* the effects of the obstructions were considered by modifying the parameter only on the transparent parts. The software, based on the fact that the thermal effect of solar radiation on the opaque surfaces can be let it out on the global thermal balance, neglects the possible effects of the obstructions on these.

Faced with the unsustainable nature of the *conventional* city and the contemporary assertion that it is a habitat par excellence, it is important to define intervention strategies that improve the *metabolic* functioning of built-up environments. If connected to the urban morphology, these gain more effective potentiality and are a guiding tool for more appropriate, more beneficial interventions. The interaction between density, morphology and energy shown here, is one of the components required if not for the complex solution of the problem then at least for the reduction of the environmental impact of urban models, which today has become urgent and unavoidable.

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