International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

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The Role of the City's Shape in Urban Sustainability

Giovanni Marco Chiri[a], **Ilaria Giovagnorio**[a*]

[a] *DICAAR (Dipartimento di Ingegneria Civile, Ingegneria Ambientale e Architettura) Faculty of Architecture, Cagliari University, ITALY*

ARTICLEINFO

Article history:
Received 14 April 2012
Received in revised form
25 May 2012
Accepted 30 May 2012
Available online 12 June 2012

Keywords:
Urban Design;
Urban Form;
City;
Energy;
Sustainability.

ABSTRACT

Cities are the main leak of Country. The process of urbanization denounces the need to transform settlement from a weak point to the strength of the future sustainability. Urban shape is deeply related to the availability of the energy sources in the territory, comparing city's behaviour to a living organism dependents on the energy flow into and out. This one-to-one relationship between form and energy sources emphasizes mutations engender each other on their develop and decline. According to scientific studies, relevant "physical" factors affect directly settlement's energy behavior and its microclimate. The ability of each city to work simultaneously on local and global objectives has driven Europe to indicate them as a crux and urban design as the appropriate tool for defining the shape compatible with sustainability goals. The use of this tool becomes prerogative to bear on urban form and reach the condition of self-sustainable energy's island.

1. The World's «Metropolitanization» Process

Since 2007, over 50% of the world population lives an urban life; this continuous process

*(I.Giovagnorio). Tel: +39-070-6755635. E-mail address: ilaria.giovagnorio@gmail.com.
©2012. International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies. Volume 3 No.3 ISSN 2228-9860 eISSN 1906-9642. Online Available at http://TuEngr.com/V03/245-258.pdf.

of world's urbanization has been intensified since the early '70s expressing the need of the city (Indovina, 2009) of mankind. According to UN data (2006), the agglomerations with more than ten million people, within the space of thirty years (1975 – 2005), have been quintupled from 3 to 21 today, 15 of which are located in developing countries (fig 1). A clear symptom of a wild urbanization (Veron, 2006) that is pushing hundreds of people poured daily in cities contributing to that Veron (2006) defined the "metropolitanization" process. The speed and extent of the phenomenon in developing countries grows and expands the vast urban centers, making the demarcation of the margins of the agglomeration increasingly blurred.

Figure 1: Cities with more than 10,000,000 inhabitants in 2015 (United Nation).

In the opposite way, the crisis in the western city is dominated by anxiety for its dissolution. The urbanization that has affected the developed countries as a result of the Industrial Revolution has slowly dried up as early as the second half of the last century, even go into reverse, giving life to what is now known as the *Lost City* (Secchi, 2008). Both crises, whether they follow the overcrowding or the dilution phenomenon, are united by the energy-intensive conditions and environmental effects. The close relationship between urbanization and fossil sources deliver to the city the leadership in global consumption (over 75%) and pollutant emissions with production of over 85% of CO_2. A record compounded by the knowledge that over 85% of that 75% comes from the use of non-renewable fossil fuels in depletion concentrated in limited geographic areas, whose intensive use has shown the fragility of the supply energy system ('70s crisis) and the vulnerability of cities due to the extreme meteorological conditions resulting from environmental effects. As reported by M.

Santamouris (2001) “an average European city of one million inhabitants consumes every day 11.500 tonnes of fossil fuels, 320.000 tonnes of water and 2.000 tonnes of food. It produces also 300.000 tonnes of wastewater, 25.000 tonnes of CO and 1.600 tonnes of waste”. This condition of “energy hole” (Butera, 2008) has led several scholars since the 70s to analyze the energy behavior of the city testing new renewable sources. These studies highlighted the close relationship between morphology and energy sources both on technology used and city’s final consumptions. In add, the emergence of global environmental issues and the concept of sustainable development (WCED, 1987) since the 80s, encourage us to investigate today this relationship to reflect on alternative urban model that can found in the city itself the necessary elements to transform it from a weak link of the fossil energy system to a “*self-sustainable island*” (Droege, 2008). “The prime imperative of the 21st century is the need to reduce energy use for reasons of its associated costs and emissions impacts” (Roaf, 2010).

2. Energy and Urban Structure

The closed link between urban form and energy form allows us to read the whole urban history as a sequence of mutations produced by the development and decline of energy sources. Starting from the first discrete settlements, moved by human and animal muscle power and narrowed to independent compact forms, it has subsequently broken the link between place of production and consumption. Depletion of wood resources has necessarily led man to seek a possible replacement in coal and the extraordinary power of this resource, albeit of lower quality, has led the development of transport systems and distribution infrastructure by establishing a new settlement pattern concentrated “indifferent to the place of origin of primary sources” (De Pascali, 2008). This urban revolution has made it possible to separate the place of extraction of the source definitively from that of energy production and bring it to the place of consumption; one last link that will be finally passed only at the end of the nineteenth century, with the birth of electricity. The development of an apparatus of distribution network, which allowed the energy’s transfer to large distances from the production site, along with the strong connotation of the urban system devoted to improving the conditions of daily life, has facilitated the process of vertical expansion of the city. In the same way in which electricity has contributed to the emergence of the vertical city, the oil’s discovery in the early twentieth century and the industrial-technological innovations related to the internal combustion engine and car ownership, have enabled the deployment of a

*(I.Giovagnorio). Tel: +39-070-6755635. E-mail address: ilaria.giovagnorio@gmail.com.

dispersed settlement pattern, also known as a *Horizontal City*, still present in the territory.

As confirmed by the history, the configuration of urban spatial structure, together with the different land use patterns, is dependents on the availability of renewable and energy resources in the area. These, through networking and technology supply, have profoundly influenced the city's shape and functions, as well as the anthropic use of the territory, have resulted in their development, integration or replacement.

This close two-way relationship means that energy technologies and distribution systems are the main factors in shaping the city contributing, at the same time, to determine their needs (the energy demand required to the spatial structure to carry out its activities) and the resilience inherent in every settlement (Owen, 1986).

Understand the functioning of urban structure led us to interpret the city in terms of urban organism, which is no longer considered as the sum of its parts but a complex ecosystem based on the comprehension of relationships between its components (Magnaghi, 1998; Solera, Alberti, Tsetsi, 1994; De Pascali, 2008; Butera, 2001; Scandurra, 1995). Because of their metabolism, modern cities have been defined by Wright (1958) like "immense mouths". We could assimilate their behavior to an energy-intensive and inefficient engine, where is converted a large amounts of energy and material at the cost of a huge waste of energy. Their ability to self-organize and react to external disturbances by modifying and reorganizing their own structure (up to a certain threshold) is common with large thermodynamic dissipative systems: "open systems that exchange energy with their environment: they retain their structure thanks to continuous flows of energy available through their system" (Magnaghi, 1998). In any re-organization, induced by external disturbance, increases the complexity of the structure and consequently its energy needs and vulnerability. These systems are fed by neg-entropy (high-quality energy and matter) which, once they meet their own needs, releasing a large amount of entropy (low-quality energy-disorder). To the initial input energy, in part used to organize their internal structure (goods, information, services, etc.) and partly to increase its size, follows the release of wastes and pollutants in the environment with the overall decrease of available energy and the deterioration of its quality (the second law of thermodynamics). This condition of "islands of decreasing entropy" (Schroedinger in Scandurra, 1995) means that today the city will survive and prosper off the environment in which they appear, without taking into adequate consideration its carrying capacity (in 2010, we consumed 150% of the annual available resources of the planet).

Aware of the problems related to the current energy-intensive settlement model and the need to switch to renewable sources with new technological systems, awareness of their direct impact on the formal structure and spatial organization of the city leads us to wonder how they could change the future shape of cities. Can the urban form participate actively in the creation of a new sustainable city? A question still unanswered, whose only certainty is the centrality of the city "called to make a difference by implementing incisive quickly measures" (Droege, 2008).

3. The Role of Urban Form in Future Sustainability

If on one hand, the city is emblematic of the state of emergency (because of its exponential consumption), on the other hand, is referred to as a strategic element for the practical implementation of local and global objectives of sustainable policies directed towards the construction of new different urban models. Even from the early 70s, with the first international conferences and Community programs, cities attract world attention on the role they could play in energy and environment, thanks to the ability to combine, through the accurate action, important goals of local and global urban sustainability.

Nevertheless the complexity found in the changeover to new sustainable models cannot be attributed only to the moment of transition in which we live, rather than the confusion hidden behind the concept of "sustainability". In fact, the term used internationally as a result of the first definition expressed in the text Our Common Future (WCED, 1987), was from time to time extended and declined in many areas of interest from several international organizations. Among the many conjugations, sustainable development gains important meaning when it is applied to a complex object, as the city, helping in this case the construction of a holistic concept in which social equity, "ecological" economy and environmental protection are integrated within a new model of governance based on cooperation and active involvement of all decision-process makers. Obviously, this important goal of future urban sustainability cannot disregard to involve the shape of the settlement, considered to be responsible for the quality of human life (on the first point of the Rio Declaration, 1992), identifying in urban design the suitable tool to change and define the

*(I.Giovagnorio). Tel: +39-070-6755635. E-mail address: ilaria.giovagnorio@gmail.com.

structures and land uses compatible with sustainability's principles.

It is, in fact, the urban morphology which depend on the ability of sunlight to reach buildings facades and the use of natural ventilation in dwellings, acts directly on urban microclimate, affecting urban energy consumptions. According to Givoni (reported in Ratti, Steemers and Baker, 2004): “the outdoor temperature, wind speed and solar radiation to which an individual building is exposed is not the regional ‘synoptic’ climate, but the local microclimate as modified by the ‘structure’ of the city, mainly of the neighborhood the building is located”. Act on urban geometry, therefore, means to change its energy consumption. Do this with regard to European cities, the third in the world rankings for energy consumptions, in which have chosen to reside four out of five citizens, it becomes crucial.

3.1 The “Physical” Parameters of The City

Achieve urban sustainability by urban design take necessarily action on the spatial relationships that bind the city form to its energy efficiency. These relationships, in turn, are determined by the different relationships that the physical factors (density, H/W ratio, ventilation, etc.) established between them and the place (orientation, direction of prevailing winds, etc.).

The energy balance (1) in an urbanized area is governed by the flow of energy that the area receives, accumulates and loses daily:

$$[Qr + Qt = Qe + Ql + Qs + Qa] \quad (1)$$

The energy gains of the city, given by the sum [Qr+ Qt] (Qr - net radiative flux; Qt - anthropogenic heat) (Santamouris, 2001; De Pascali, 2008) stemming from direct and indirect solar radiation and anthropogenic heat associated with the use of fossil fuels. These are contrasted with the heat’s flow that the system stores and exchange inside (Qe - sensible heat; Ql - latent heat; Qs= stored energy; Qa= energy transferred to/from the system through advection), pointing out clearly the responsibilities of urban form on the energy performance of the settlement. The phenomenon of urbanization, in fact, alter the energy balance with detrimental impact on the local microclimate and comfort environment.

Among the main consequences of urbanization are:

rising temperature. The temperature difference between the urban area and the surrounding rural one recorded an increase of temperatures in the city due to the presence of Urban Heat Island's phenomenon (UHI). The increase in temperature changes the natural process of heating and cooling air, which also contribute to the multiple reflection of solar radiation between the facades of buildings (heat trap) and the use of materials with low values of albedo. This phenomenon, combined with the use of fossil fuels, engages in a circular process between the rate of air pollution and rising temperatures of the town centre with the consequence that the energy requirements increase exponentially and encourage the phenomenon of spatial dispersion on the surrounding areas of the city, characterized by significant climatic differences. Important research conducted in Athens (Santamouris, 2001) has found differences in temperatures ranging up to a value of 10 ° C.

Contribute to intensify the heat island phenomenon also other factors resulting from the urbanization process.

decrease in natural ventilation. The density of the settlement and its roughness affect the ability of the air flow to penetrate into the urban canopies. Without going into the individual studies to understand the flow process of the wind in the city in relation to the main height and orientation, we can say that the air flow speed decreases within the urban canopies, reducing the ability to use passive cooling and natural ventilation (Santamouris, 2001; Allard, Ghiaus, Szucs, 2010; Ng 2010). The low level of ventilation to the ground, also contributes to higher rates of air pollution.

decrease in solar radiation. Among the crucial parameters contributing to the effect, we find the distance between buildings and their height. In fact, especially in the case of high-dense settlements, the shading between the facades of buildings impedes the achievement of solar radiation to the ground. While, particularly in hot climates, this condition helps to keep low temperatures to canopy level, on the other hand, it hinders the proper lighting in the living spaces and reduces the heat input which can apply in a natural way the exterior walls of buildings, raising the energy requirement for heating/cooling buildings.

*(I.Giovagnorio). Tel: +39-070-6755635. E-mail address: ilaria.giovagnorio@gmail.com.

increase in turbidity of the sky. The use of fossil fuels is contributing hardly to raising the temperature and the rate of air pollution. The latter changes not only the radial spectrum of the atmosphere but reduces the duration of sunlight, reaching in the urban industrial cities amounting to 20-30% less (Oke, 1988) compared to other ones.

decrease evaporation. The lack of green areas within the city deprives the latter of the significant contributions made by the vegetation on the local microclimate (“oasis” effect). Among the advantages attributed to the presence of the green, we can include the shading of the routes and areas by solar radiation, decreasing in environmental-noise pollution, protection of residential areas exposed to wind, evapotranspiration and the natural cooling of air. Important research has shown that the effect of cooling due to a medium-sized tree, on a sunny summer day, is five times that of an air conditioning system (Ng, 2010). Thank to this it can be significantly reduced the requirement of air conditioners, especially in hot climates, with a total costs saving between 15% and 50% less. An american study showed by Parker (South Florida) proves that working only on urban green spaces can be also obtained a reduction in costs in the use of air conditioning market in the summer equal to -58-40%.

All these factors, expressed in the equation of heat urban balance, are strongly influenced by the urban geometry through one of its main parameter: the ratio between the height (H) and the distance of the built fronts (W). In addition to determine more or less detrimental configuration for the natural ventilation of buildings, the reverberation of noise between built fronts and the natural lighting of indoor and ground, the H/W ratio measures the strength of heat island in settlements (2) (Oke, 1988):

$$dT = 7{,}54 + 3{,}97 \ln(H/W) \qquad (2)$$

The main results show that increasing the value of the height (H), not only lessen the benefits of natural ventilation and direct lighting but increase considerably the temperature of the city center and cost of air-conditioning package. An interesting study by S. Roaf (2010) also shows that the costs related to construction of a building above a certain height, not make it more feasible and cost-effective in their implementation. A comparative analysis (Treloar et al. in Roaf, 2010) reveals that buildings of fifteen floors require +60% higher costs than three floors ones and +1/4 of seven floors ones. The cost of a tall building, as well as vary with the quality of construction, are strongly influenced by the sprinkler systems, lifts, the use of cranes during construction and pumping systems for water supply. These factors are summed with the use of energy-intensive materials in greater quantities.

Figure 2: Hong Kong (left) and The 'Ink-Stone'Island, Zhaoqing (Guangdong, R.P.C.).

4. What Density?

The weight that H/W ratio takes in the correct functioning of the urban system reopens an old debate on density, aimed at identifying the best values of this relationship through which to optimize the energy efficiency of the settlement. "At present there is a plethora of theories emerging about sustainable urban forms. [...] Should it be towards the compact city or not?" (Welbank, 1996). Although there seems to be a general consensus on the benefits associated with high density and its potential contribution to urban sustainability, the concept of high-density city is extremely complex and subjective, referring to different concepts and measures in different countries and cultures.

Fears emerged in the '70s have certainly suggested as useful actions the immediate re-localization and higher functional density (Owen, 1986). European Community is one of the major supporters of the effectiveness and sustainability of the compact city. The Commission, at the first time with the Green Paper on the Urban Environment (1990) and subsequently with the European Charter II (2008), indicated the dense and compact city as the solution to the gains on urban efficiency and quality. “52.We must rethink our cities around compact and densities urban forms, which require minimal resources for their operation and allow residents to have access, nearness their homes, to the various facilities they need, to services and spaces for leisure, to protect areas and natural parks. We want a city that knows how to save at the level of its resources, its soil, of movement within it, the energy. Only the consistency and firmness of our cities will make the urban space easier, more accessible, more alive to all residents, regardless of their social conditions, their age or health conditions” (EC, Strasburg 2008).

Although the density has a deep relationship with the urban morphology, it alone is not sufficient to ensure high levels of quality and efficiency. In fact, research conducted in support of a higher density or, conversely, greater spatial dispersion, still show partial results probably still insufficient to say with certainty the greater sustainability of either. Likely, “the question is not 'are high-density settlements sustainable'; rather, for any place and people on this Earth, 'what is the optimal density for this city' ” (Roaf, 2010).

While the compact city seems highly efficient with regard to land use and public transport, on the other side it is inefficient with regard to the ability to store energy for domestic use and transportation. The post-oil scenarios seem so give birth again to two large urban models that, in the history of architecture, have divided the international scene between “centralist” and “decentralist” (Breheny, 1996):

- the American sprawl, consists of self-sufficient cells scattered on the surrounding area, located at distance to enable each of them to have enough space to ensure its independence;
- the compact city, symbolized by the great urban utopia of The Villas Radieuse (Le Corbusier).

Perhaps the solution lies in the middle of the extremes, in a Howard's vision able to apply strategies for urban regeneration and densification, and at the same time to create a network of medium-small settlements, environmental and energy managers, equipped with needed services and connected by an efficient public transport system. It is particularly damaging for the city continues to be linked to an energy-intensive lifestyle in an uncertain future, both as regards the provisions that the costs of resources. It is advisable, instead, the transition to renewable energy sources used on a local scale and in a decentralized system, as opposed to the existing centralized governamental system.

Table 1: Comparison of the pros and cons of the compact city model.

Pros	Cons
Saving land-use; conservation of the countryside surrounding the cities and agricultural areas	Risk of overcrowding in the urban area
Optimizing and saving both costs and size of the infrastructure of urbanization	Risk of overloading the urban infrastructure systems
Cost saving and propulsion to the use and the efficiency of public transport	Risk of traffic congestion and overcrowded of public transport in the absence of adequate planning strategy
Getting closer activities and attractions and proximity of services from residential areas (functional mix)	Lack of agricultural areas within the city, requiring a transport system that brings the products from the countryside to the city. (food footprint = 1.5 ha/person)
Increase in alternative modes of transport (bicycles, pedestrian streets, electric trams, etc.).	Reduction of natural ventilation in urban areas;
Decrease in per capita consumption of oil (related to car ownership)	Decrease of green areas and, consequently, evaporation, natural shading and cooling due to the presence of trees and shrubs.
Decrease in the rate of air pollution and CO_2 emissions;	Reduction of natural lighting in buildings and the sky view factor because of the proximity and height of buildings
Ability to raise the temperature of the city center than the surrounding areas, reducing the need for use of heating in winter.	Rising temperatures in the urban areas (Urban Heat Island) because of the heat trapped between the buildings and multiple reflections. The rising temperatures, encouraged by material's albedo, decreases the comfort of the inhabitants and contribute to higher rates of air pollution and turbidity of the sky. In hot climates, the phenomenon has serious consequences on energy consumption of cooling systems.
Optimization of alternative centralized energy systems (CHP, trigeneration)	Reduce the opportunity for integration and use of renewable energy in buildings (because of shading)
Greater richness and spatial/ functional complexity with raising level of psychological satisfaction of population	Reduction of privacy among people with psychological consequences that lead to manifestations of anxiety and loss of control
---------	Increased vulnerability to terrorist attacks and to the spread of infectious diseases.

*(I.Giovagnorio). Tel: +39-070-6755635. E-mail address: ilaria.giovagnorio@gmail.com.

In this way, the main features of the efficient city will be: compactness, functional mix, some degree of autonomy to the sub-urban scale together with flexibility and resilience (Owen, 1986). It will be possible to organize the city "into districts, each autonomous in terms of energy and environmental balance nonexistent. Each district will be part of a regional network made up of mesh and will relate itself in aggregated form disguised as relationships and interactions with the neighboring mesh. The islands within the same district will put a common factor of all available resources, diversified and full-finished on the basis of availability of the single area: solar, wind, biomass, cogeneration. The entire surplus of one island will be used from the island of the same district before being poured on the external network" (De Santoli, 2005).

5. Conclusion

The energy and environmental state of emergency ask for the integration and the replacement of the old fossil fuels with new sources of clean and renewable energy. As has historically demonstrated, the transition toward new sources and new technologies will transform the spatial form of cities prompting us to ask legitimately, what will be the future shape of sustainable cities and what the role of form in this step. Scenarios are still open; although there is a strong tendency to support the compact city as the future urban form, the real evidence on its capability to ensure superior quality of life damages the certainty of governments. This big moment of transformation that we are living needs probably time to experiment, even through great utopian visions, what will be the best roads to undertake. Probably the strength of sustainability lies for every community in the possibility to become self-sufficient by using the resources on its disposal in the environment, in a fair and respectful of the natural time, replacing the current centralized management system with a suitable local one. In this way the opposite urban visions that have historically divided centralist and decentralist, led by two prominent masters of Wright and Le Corbusier, could find a compromise in a Howard term vision, based on a network of self-sufficient agglomerates of small-medium size held together by an efficient public transport system.

6. Acknowledgements

This work is founded by Sardinia Region with founds from PO Sardinia FSE 2007-2013 (L.R.7/2007) "Promotion of scientific research and technological innovation in Sardinia".

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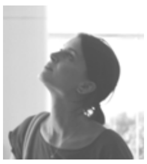
Gianmarco Chiri (Palermo, 1971) studied Architecture in Palermo. Since 2008 he has been an Assistant Professor of Architecture and Urban Design, and has served as the activities coordinator of the OffiCINA research group, studying Chinese urban development and landscape transformation. In 2009 he was appointed by the Zhaoqing Planning Bureau (P.R.C.) as a consultant for urban design. He is a member of several academic research groups and heads many project teams. Chiri is also is in charge of the La Maddalena Urban Plan, about which he has recently written the books Archipelago and Peacekeeping Design Strategies, both published in 2009.



Ilaria Giovagnorio (Rome, 1983) lives in Cagliari, where she graduated in 2008 from the School of Architecture with a thesis entitled “Extra Moenia” (La Maddalena, OT). She has participated in local and international architectural competitions and projects with the Archides office since 2006. Giovagnorio is currently conducting her PhD research on the relationship between energy and urban settlement, for which she has won the regional research grant for young researchers financed by the Sardinia Region. Since 2008, she has been a member of the OffiCina research group of Cagliari's School of Architecture, where she has worked as a teaching assistant for two years.

Peer Review: This article has been internationally peer-reviewed and accepted for publication according to the guidelines given at the journal's website. Note: This article was accepted and presented at the 2nd International Conference-Workshop on Sustainable Architecture and Urban Design (ICWSAUD) organized by School of Housing, Building & Planning, Universiti Sains Malaysia, Penang, Malaysia from March 3rd -5th, 2012.