ENERGY TRANSECT MODELING AND SUSTAINABLE URBAN CELLS APPROACH: HARMONIZING THE URBAN AND GREEN TISSUES

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SUMMARY

The global city of the 21st century faces major challenges & crises, including social and economic stratification, wasteful consumption of resources, transportation congestion, and environmental degradation with the omnipresence of global climate change. Our cities, communities and neighborhoods are undergoing also rapid transformation and retrofits in terms of energy efficiency and climatic adaptations almost to the point of drastic environmental determinism. The discussion in this paper explores ways for raising quality of life and the standard of living in a new modern era by creating better and more viable places to live through sustainable urbanism approaches. The assertion is that the Green (Sustainable) Urbanism approaches offer an environmentally sound way to plan and design more ecologically stable communities. Sustainable Urban Cells within the idea of the Urban Energy Transect is presented here as a new quantitative and qualitative modeling approach and analytical methodology in working with planning of sustainable urban communities, compatible with other analytical tools such as Space Syntax and other GIS tools. The empirical Swedish case introduced shows how a better understanding of an integrated system of zoning in a complex community urban setting can contribute to clearer planning and energy efficiency of buildings. The questions we raise are: How can we combat and reconcile urban growth with sustainable use of resources for future generations to thrive? Where and how urbanism comes into the picture? and what role "sustainable" urban forms can play and have in light of these events? These and some other issues are tackled in this paper whose conclusions point to the predilection that beyond being a system of classification, the cell and the transect model we present in this paper has also the potential to become a complementary instrument for planning and design for better places to live.

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1. ENERGY ISSUES AND NOWADAYS CHALLENGES IN URBAN AREAS

Our cities, villages, communities and neighborhoods stand at an important turning point - critical nexus of the most pressing issues of our time: rapid population growth and massive urbanization, energy inefficiency and scarcity, unbalanced resource consumption, growing air and water pollution, global and micro climate change, social exclusion and economic decline, unsustainable development of built environment at all scales and the relentless destruction of natural habitats which all degrades the quality of life (Calthorpe and Fulton, 2001 and Haas 2008). Sustainable urbanism, green urbanism, and smart growth are some of the theoretical and practical concepts developed to counteract these processes and steer the development to sustainable forms. As Peter Calthorpe (2011) points out, cities are not fixed elements and constantly remake themselves by demolish and rebuild all the time, which is a very important part of urbanism. This process is at the basis of the resilience of the urban fabric, an element that potentially can be continuously renewed and redone. However, a greater sensitivity to history and historic-cultural resources has to be part of urbanism to couple it with new designs that can offer alternative energy supplies, conservation and sustainability of the urban fabric on the long run.

Conservation, both in terms of the environment and in terms of culture and history; human scale, which translates into creating pedestrian environments that work; and diversity, which means you have to create mixed use communities for a full range of people are the three principles expressed by Peter Calthorpe when discussing the resilient city of the future.

The principles closely relates with the two key concepts in contemporary discussion of raising quality of life: those of livability and sustainability. Even though livability and sustainability may operate on different levels, scales, and contexts both can achieve similar outcomes. Both livability and sustainability support economic development and environmentally sustainable travel options, and address social equity issues and human health (Rue and Rooney et al., 2011).

Sustainable urbanism and community livability seem to present themselves as a viable platform of seeing and realizing integrated urban design projects. As

the Victoria Transport Policy Institute recognizes “Community Livability refers to the environmental and social quality of an area as perceived by residents, employees, customers and visitors”. This includes safety and health (traffic safety, personal security, and public health), local environmental conditions (cleanliness, noise, dust, air quality, and water quality), the quality of social interactions (neighborliness, fairness, respect, community identity and pride), opportunities for recreation and entertainment, aesthetics, and existence of unique cultural and environmental resources (e.g., historic structures, mature trees, traditional architectural styles) (VTPI, 2013).
Sustainable Urbanism has three basic aspects: environmental, social, and economic. An urban form which is environmentally sustainable enables its inhabitants to adopt a more ecologically aware, lower carbon lifestyle; in social terms, sustainable urbanism involves an appropriate mix of dwellings of different tenures, sizes and types, and a variety of spaces and buildings for recreational and community activities, as well as for service providers and commercial enterprises; and in economic terms, sustainable developments contain business activities and opportunities capable of providing jobs for many of their inhabitants across the social and economic spectra (Prince’s Foundation for the Built Environment, 2007; Haas, 2008; Steuteville and Langdon, 2009).

All the discourse on resilient cities contributes to put the focus on the key element of the community – the neighborhood and housing as being a main node for the carrying capacity of sustainable transformations and consolidation, one founded around the human aspects of form and traditional, timeless practices of good city building. By looking at the physical environment that sustain the communities, block, and neighborhood city network design has a large influence in balancing the urban energy demand and production through adaptation to local climatic conditions and identification of the most suitable morpho-typological structures (Ratti et al., 2004). A coherent organization of the city and its functional mix can largely contribute in reducing energy needs (Jenks and Burton, 2000) for the production of goods and services, mobility, indoor climate control, and decrease of local energy peaks.
Our cities need to achieve a higher integration between urban and energy design (Droege, 2006), adopting cycle approaches to energy and materials within the larger framework of resilience concepts to optimize local resources and social-urban environments (Walker and Salt, 2006).

2. RAISING URBAN ENERGY QUALITY THROUGH DESIGN

The areas of urban design, urban and regional planning and the control of urban and regional development present still a great deficiency, especially in relation to neighborhood development and the housing sector. As for the energetic reorganization of city regions, the approaches oriented to the creation of compact, de-centralized housing spaces, the complex economical handling of resources or the minimization of auto-dependency – are practical requirements in future urban developments to create a truly unique model of integrated cities (Calthorpe and Fulton, 2001; Beatley, Newman and Boyer, 2009). Sustainable Urbanism, a phrase that is used widely and in combination with ecological and green connotations, is a rather new and complete framework for interdisciplinary planning and design of contemporary cities, neighborhoods and settlements. It explores in a more holistic manner sustainability and urban design in a rapidly urbanizing world, by focusing on the processes that shape the form and function of our built environment: infrastructures, land developments, built landscapes, social networks, systems of governance and economics, and facilities that collectively make up metropolitan regions (Farr, 2007; Haas, 2008; Newman, Beatley and Boyer, 2009).

The applied sustainable urbanism – to whom this paper refers to – focuses on identifying small-scale catalytic interventions that can be applied to urbanized locations, which in aggregate leads to an overall shift towards sustainable neighborhoods, districts, and regions (Newman and Jennings, 2008). In its fullest meaning, Sustainable Urbanism is made up of the following key concepts: building and growing more densely and compactly; creating walkable mixed use urban environments that permit and encourage walking and bicycling; investments in public transit and transportation; creating closed-loop urban eco-metabolism and a self-sustaining agricultural system - local production of foods, goods and materials (food, building, materials); and investment in and commitment to sustainable, renewable, and passive technologies integrated into the built form (e.g. solar, wind, biomass, etc.) as well as solar design to reduce the need of artificial light and heat (Congress for the New Urbanism, 1999 and 2013; Farr, 2007; Newman and Beatley, 2008, Talen, 2013).
Doug Farr, in his Sustainable Urbanism: Urban Design with Nature (2008) sums this up in five value points of urban design, resilience & sustainability:

- Increasing sustainability through density and compactness;
- Integrating transportation means, patterns, and land use;

- Creating sustainable neighborhoods, including housing, car-free areas, locally-owned stores, walkable neighborhoods, and universal accessibility;
- The health and environmental benefits of linking humans to nature, including walk-to open spaces, neighborhood storm water systems, waste treatment, and food production (permaculture);
- High performance buildings and district energy systems;

Furthermore, many kinds of 'values' can be considered – economic, environmental, social or even cultural, as the fourth pillar of sustainability. Viable urban design, or good urban design as some authors refer to (Haas, 2012), can offer significant benefits to the community by providing high quality public realm based on the principles mixed use-density, now integrated with the energy efficiency principle. The achievement of more resilient urban structure can be obtained via integrated decision-making, but it is also based on the capacity of buildings, neighborhoods, spaces, and communities to adapt to changing needs.

3. URBAN DESIGN IN AN ENERGY PERSPECTIVE

Urban development – size of cities and spatial distribution – has on an historical perspective been strongly influenced by the availability of resources, where complex social and economic systems emerged and found their strength in the control and storage of resource flows, with energy – solar, biomass, animal, and human – playing a key role (Basalla, 1980 and Smil, 1994). The historical relation between urban growth, economic development, and impact on nature (biomass exploitation) has been recognized long-since as "[Ancient writers observed that] forests always recede as civilizations develop and grow […] conversely, when a society declines, forests tend to regenerate" (Perlin, 2005). With the advent of the fossil fuels society previous growth limits have been removed and the structures of cities changed to the so-called "oil city model" (De Pascali, 2008), where low cost largely available energy sources radically modified urban relations and morphology towards dispersed and highly specialized organizations (Burchell and Listokin, 1982). The design of cities and settlements without resource restrain, originally seen as sight of progress, is now undergoing strong critiques due to its long-run unsustainable and undesirable model. As human settlements have moved from a concentrated use of scattered energy resources (biomass, wind, water, animal/human) to a scattered use of concentrated resources (fossil), our next step is to again adapt our urban environments to the local conditions,

combining urban form with available renewable energies, thus creating global cities based on local resources (Troglio, Martschenko, Haas, 2012). As cities update their urban structures by inner growth there is the occasion to adapt morphologies to the new low-carbon and resilient needs. Despite a large amount of former industrial areas have been released during the last 15-20 years after the structural economic changes, many European cities have not fully explored the opportunity to update their structures towards sustainability urban forms. Nevertheless, infill and inner-growth redevelopment processes are still on-going and constitute fundamental occasions to rethink the urban environment – based on the local social-economic and geo-morphologic characteristics - and the connections with the regional environment.
Energy saving from counteracting or increasing the heat island effect, when cooling or warming need is prevailing respectively, can have substantial effects on the energy demand at the urban scale and significantly improve the indoor and outdoor well-being. Combination of green and blue elements, choice of construction materials (albedo characteristics, permeability, etc.), and urban morphology have proven effective in several project. As example, in the SolarCity district in Linz (Austria) or in the Western Harbor development in Malmö (Sweden) the heat island effect has been maximize to reduce energy losses (heat) during the winter months.

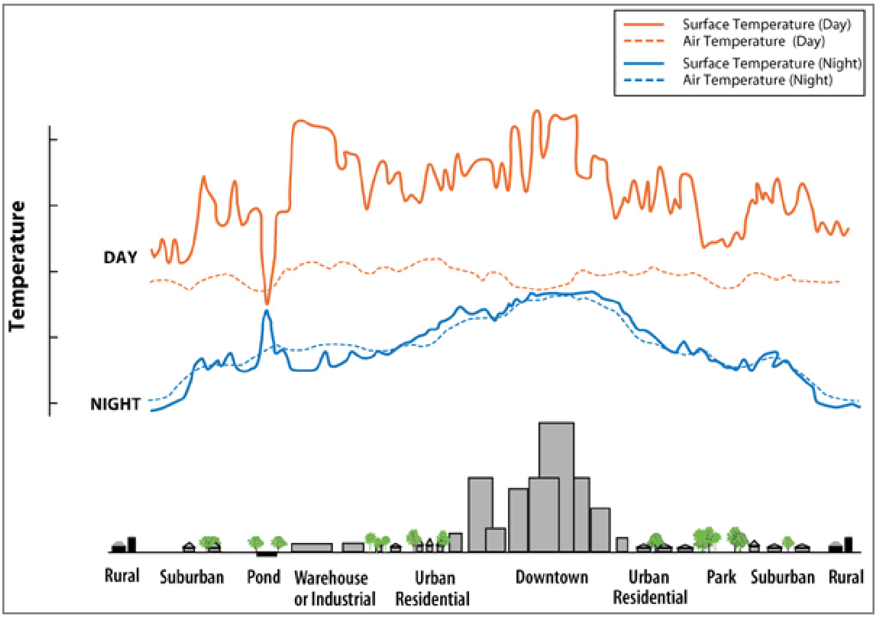

Figure 1: Scheme of the Heat Island Effect profile according with urban morphology; the temperatures shown refers to a late summer afternoon (EPA modified from Voogt, 2002)

Similarly, the siting, spacing and building shape can greatly affect the amount of potential solar gain and wind effect. Depending on the local environment, buildings and urban form can be designed for optimizing sunlight – passive solar gain – or increase the production of energy by improving roof quality for photovoltaic panels. Largely debated, the exploitation of wind power in urban areas finds still scarce integration in building or neighborhood design. Nevertheless, with increasing dependence on alternative power sources, interest and installation costs should drop significantly to make urban-based wind power generation a viable option (Grant et al., 2008). Beside the energy production factor, wind power can be passively exploited to improve indoor-outdoor micro-climate and air quality.

The adaptation of the urban morphology to respond to local climatic and geo-morphological conditions and the identification of energy conserving strategies, as this paper argues, should thus be explored before recommending high-tech solutions. Understanding the connections between different urban morphologies and their energetic outcomes can be difficult due to the multiple and complex interrelations of human and natural elements. To facilitate this process and support the actors involved in policy and design development towards more sustainable and resilient cities, we have further developed the transect concept to integrate energy issues. Also an important issue remains of how does energy performance enhancement inform urban design decision making to achieve outcomes of system resiliency? (Yang, 2015).

4. THE ENERGY TRANSECT

To reach sustainability goals urban planning and design choices need to be interrelated. Issues of reduced car use, energy efficiency, increased density, and mixed-use development become pertinent and cross connected (Farr, 2007 and Haas, 2012). When focusing on the complexity of our environment, more flexible methods and classifications should be used, providing a better understanding of the interlinks to citizens, planners and developers and helping create more livable places. As evaluation and assessment system for design, the Transect categorization is an empowering tool for communities to create and maintain sustainable places (Emerson, 2007, Low, 2010, and Thadani 2011). The transect model uses both a descriptive approach and a categorization system to identify and divide different land use into a sequence of human habitats from rural to urban zones (Coyle, 2011). Each habitat has a specific character and unique attributes, yet is also part of a network of other habitats that form a sustainable, cohesive system spatially, environmentally,

traffic and energy wise. In general, the Transect recognizes six zones, each of which can be adapted to local goals and character: 1) Rural Preserve, 2) Rural Reserve, 3) Sub-Urban, 4) General Urban, 5) Urban Center, and 6) Urban Core (Duany, 2002 and Thadani, 2011). Each zone addresses critical planning elements such as land use, roads, infrastructure, development, open space, energy, wastewater, and vegetation (Duany and Talen, 2002, Duany, 2002, Bohl and Plater-Zyberk, 2006).
Whether working on a new development or existing urban patterns, interconnected design aspects need to be included. The transect diagram can then be a useful device for explaining the intertwined components of coherent urban patterns in the adaptation towards sustainable principles (Troglio, Martschenko, Haas, 2012).

The role of energy in urban morphology is here analysed by starting from the minimum size component of the city; the typologies. In a simplified – thus reliable – analysis, the heat energy performances of buildings are related to form/dimension, age, and siting. The first parameter – which includes concepts of compactness and complexity of the building form (Olgyay, 1973) – describes the heat exchange relations between a structure and the surrounding environment. The second parameter shows the role of materials, technology and energy regulations as historical prospective, while the third one refers to the spatial configuration of buildings and their mutual relations.

In Table 1 are reported the estimated heat energy demand data from sample buildings in Uppsala (Sweden), a medium sized north European city. A representative city transect has been chosen to include the most representative morpho-typological configurations. As the data shows, both form (typology) and materials (technology) have a clear influence on heat energy reduction, and even clearer is the role of compact morphologies. Although technologies play an important part, the form effect is noticeably readable, with low mass / complex shaped buildings (i.e. detached houses) consuming twice the resources compared to more compact ones (i.e. towers or courtyard buildings).

Year built	Courtyard blocks	Low slab buildings		High slab buildings		Low tower buildings		Tower buildings		Row houses	Detached houses
	Close	Open	Close	Open	Close	Open	Close	Open	Close	Mid-Close	Open
1910-1930	167	235	179	166	143	295	243	195	156	N/A	288
1931-1975	143	215	189	142	127	208	174	147	120	221	307
1976-1995	72	113	107	72	67	94	78	71	63	98	123
1997-2007	59	68	65	66	62	107	100	50	48	90	126

kWh/Sq m/year	
	255-310
	220-254
	185-219
	150-184
	115-149
	80-114
	66-79
	<65

Table 1: Estimated average annual heat energy demand (kWh/Sq m/year) based on building form and urban morphology in Uppsala, Sweden (Source: Troglio, 2012)

Identifying the role played by age, technology and building form constitutes only the starting point of the analysis and design of a sustainable city. To describe the relations between different urban morphologies and their energy and environmental performances – and thus the interactions between buildings, open spaces and the urban grid, we have juxtaposed five major analysis issues to the transect model.

The “Energy Transect” is developed as supporting design tool for the analysis of urban areas and the definition of sustainable and holistic visions for settlements, applicable at different scale and contexts. The identified five categories of analysis – morphology, land use, mobility, urban natural areas and block energy characteristics – define a first toolkit for reading and understanding the connections between urban morphologies and their main impacts on energy. The different cells (morphologies) define our units of analysis, which allow a constant overview of the existing relationships and provide a guide to the design process. By using the cell categorization, the understanding and control of the existing local and global interactions is increased.

Starting from the transect zones described by the New Urbanism, we have identified and analyzed five recurrent urban patterns on the contemporary city: city core, dense city, modernist 1980’s-2000’s, special districts and suburban areas. Each urban pattern represents not only a different stage of the city’s evolution, but also different approaches to energy and environment, embodied in the morphologies and the concepts that generated them.

The first area of analysis, morphology, is conceived as a traditional Transect, highlighting the main conceptual characteristics of the urban patterns, section, and relations between buildings, open spaces, and greenery (Figure 2).

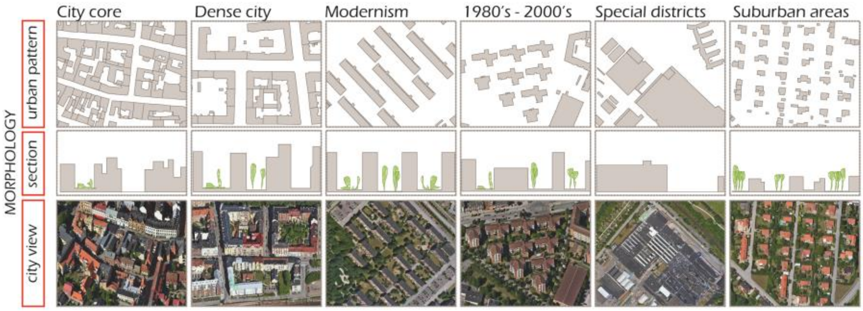

Figure 2: Different morphologies included in the transect, from the dense central areas to the scattered suburban developments (Troglio, Martschenko, Haas, 2012)

Land use (Figure 3) aims to describe the size, mix, and spatial distribution of functions in the different patterns and the related role for energy peaks control and feasibility for distributed energy resources (Holden and Norland, 2005), as well as support for sound social life and activities (ESCTC, 1994). These schemes highlight the complexity of the distribution patterns and ease the comparison between different systems. Thanks to the inclusion of the land cover factor, built density and footprint effects on heat island effect (Oke, 1982) and run off phenomena (Fiumi and Rossi, 2007) are highlighted.

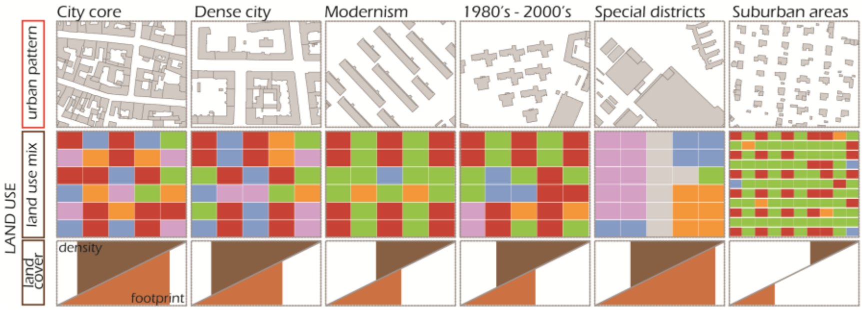

Figure 3: Visualization of the land use mix, parcel sizes, and land cover mostly recurrent in the different morphologies (Troglio, Martschenko, Haas, 2012)

The proportion of the different transportation modes is outlined in Figure 4. Common characteristic and trend in numerous European dense city cores is a high walkability and public transport service, while cars are often kept away to improve quality of life and public spaces, and to control pollution. On the contrary, suburban areas have shown difficulties in supporting walkability and collective transport due to the disperse pattern and predominant monofunctionality (Newman and Kenworthy, 1999). Though morphology influences transport choices, social-economic characteristics of the population strongly affect the modal split, and need thus to be considered in the policy system to produce effective car usage reduction (Dieleman et al., 2002).

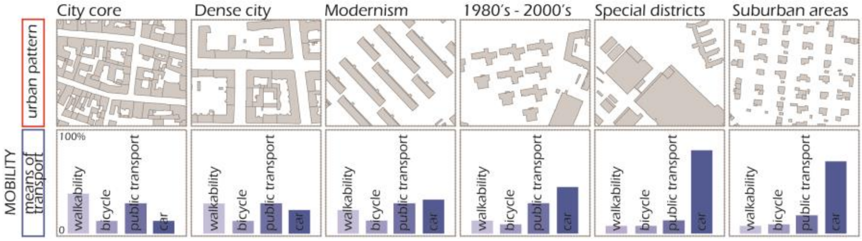

Figure 4: Modal split can be analyzed for each morphology, evaluating the sustainability potential of different configurations and posing the basis for cross-connection networks within the city (Troglio, Martschenko, Haas, 2012)

Energy performances and microclimate of urban settlements can be influenced by type and extension of green and blue elements as they affect transpiration, heat exchange, air flows, and pollution. Figure 5 describe the recurrent patterns that characterize each morphology, aiming to summarize the three main features – quality, size, and compactness/network – that mostly determine a decrease in the used energy and improve the microclimate.

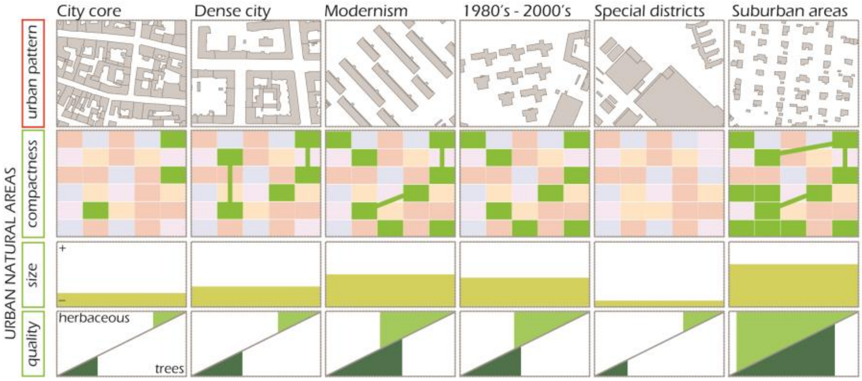

Figure 5: Visualization of green areas in urban settlements by connectivity, size and quality (Troglio, Martschenko, Haas, 2012)

By identifying compactness, extension and quality of urban natural areas in relation with morphology it is possible to set a clear framework for actions that maximize the benefits of an interconnected net of green areas. Trees and gardens, as well as green roofs, contribute to reduce the summer heat (thus reducing the need of cooling) by controlling the microclimate (Arnfield, 2003, Akbari et al., 1992), protect from winds (Givoni, 1998), reduce the air pollutants (Ratti et al., 2005), and prevent run-off effects and floods (Girling and Kellett, 2005). Nevertheless, it has to be noticed that lawns, despite their contribution in increasing permeable surfaces and reducing the risk of floods, have inferior value than trees, as energy and water consumption for their maintenance is high and the ecological and energy balance effect low.

As prior discussed, if considered as single elements, buildings' energy performances can be easily estimated and categorized by looking at form, surface complexity, and materials. Since constructions are not separated by the urban context in which they lay and interact, the energy performances of cities are strongly influenced by their specific evolution, depending thus not only on the characteristics of the single elements (the buildings), but also on the urban grid – the morphology – and the adopted retrofit / upgrades policies. Figure 6 exemplifies, starting from the results obtained for the city of Uppsala, the average block characteristics of European cities and the influence on energy performances. City centers are often characterized by older buildings, high density, and compactness of the built environment which correspond to low solar radiation, characteristics that progressively change towards the outskirts and suburban areas.

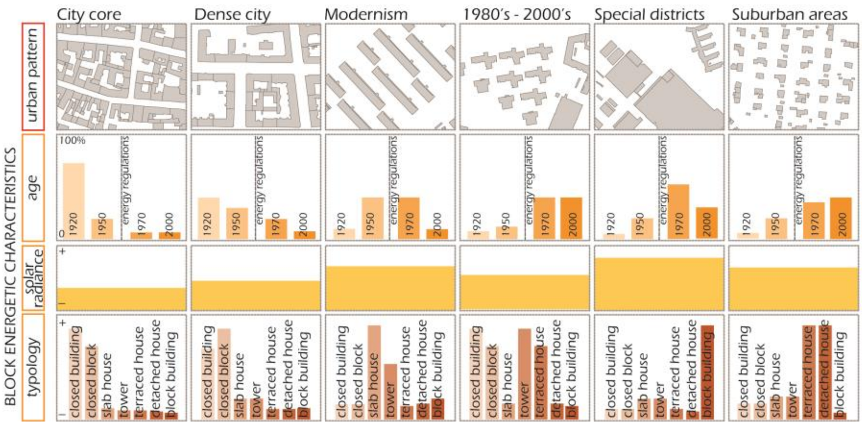

Figure 6: Age, solar radiance, and typology mix of the different urban morphologies can greatly influence the overall energetic performances (Troglio, Martschenko, Haas, 2012)

CONCLUSIONS

Cities are not static and they constantly change and evolve in new directions. Any new development is a challenge to the current situation, as it can transform the status quo in unprecedented ways (Madanipour, 2006). In neighborhoods, housing and real estate markets, we see this transformation evolving in all kinds of emergent ways, not least of sustainability. Achieving true sustainability and resilience as a way of raising the quality of life through urban design will not happen without the promotion of energy efficiency in each neighborhood and housing area. Furthermore the issues of maintenance, management and refurbishment the housing stock and housing affordability are paramount and go hand in hand with the renewed interest and need for social and low-cost housing. Overall in sustainable urban development, raising the quality of life through livability will be carried on the way we treat resilience vis-a-vis to climate change and the way we decide increase density and efficiency of urban areas – making them truly smart, lean, green and livable cities based on sustainable urbanism principles (Lehmann, 2016 and Lehmann and Bay, 2017)

Understanding and visualizing the energy characteristics of urban morphologies by adopting a transect approach contributes to focus the attention on the need of interdisciplinary planning to fully understand and exploit the potentials of urban areas to reach a more sustainable development (Farr, 2007). By adopting Sustainable Urbanism as theoretical background, the energy transect aims to contribute in the planning, design, and management of cities and districts by helping the processes that shape forms and functions of the built environment.

Internal organization of a city and relations with its region are important elements to be analyzed in their mutual connections to create the necessary environmental and socio-economic conditions (Nijkamp and Perrels, 1994) which support urban services and functions (Hardoy et al., 1992). The synergy of physical urban form, transportation patterns, natural resources, and land use, together with their socio-economic aspects became crucial for creating livable cities and communities, elements of a sustainable metropolitan-regional city network (Haas, 2012 and Haas, 2016). The value of using an energy transect become particularly important to explain the components of coherent urban patterns and improving their energy performances, to define density and human access to nature as well as design and energy saving schemes, new parameters to overlay with the city morphology (Farr, 2007).

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