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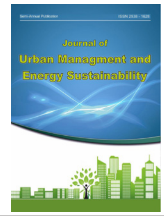

ORIGINAL RESEARCH PAPER

Explanation of sustainable energy evaluation methods in urban morphology

Wo Liu[1], Yuan Wo[1*], Nafiseh Hassanzadeh[2], Kosar Farhadi[3]

1 *Department of Urban and Regional Planning, The College of Urban and Environmental Sciences, Peking University, Bejing, China*

2 *Department of Architecture, Faculty of Art and Architecture, Tabriz Branch, Islamic Azad University, Tabriz, Iran*

3 *Department of Architecture, Faculty of Fine Arts, Design and Architecture, Istineye University, Istanbul, Turkey*

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ABSTRACT

In urban settlements a strong relationship exists between “urban morphology” and “sustainable energy performances” of settlements. More than half of the global population now live in cities and the United Nations. The study focuses on the dynamics of energy utilization in mega-cities, and ultimately aims at providing method categorizing for evaluating sustainable energy in large urban systems. The research into metabolic aims to understand the physical flows into, within, and out of the cities. Direct and indirect energy demand can be a proxy to emphasize how cities rely upon the outside in terms of energy demand. This research uses both theoretical exploration and field observation. It explores theories on the perspectives of sustainable planning and design. The problem-oriented methodology applied by this research has a system of basic problematic groups as the major perspectives of the sustainable approach. The main question is how can we assess the spatial interactions between urban morphologies and energy system? At last, three main approaches lead the subjects to urban morphology to being in evaluation stages. Finally, remote sensed dataset evaluation system is found the best method for urban-energy planning and design, and in this system, LIDAR technology has a maximum capability to evaluate urban settlements in transformation matters in geographical view. Lidar technology has allowed 3D information on the environment to be remotely obtained over large areas and in larger cities as case studies can be useful.

Running Title: Sustainable energies evaluation methods in urban morphology

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*Corresponding Author:
Email: woliuunipek@gmail.com
Phone: +01062751172
ORCID: https://orcid.org/0000-0003-2974-5869

1. INTRODUCTION

The starting hypothesis, supported by this research, is that in urban settlements a strong relationship exists between "urban morphology" and "sustainable energy performances" of settlements. The used re- search method is the inductive reasoning based on empirical observations. Humans can now officially be called an urban species (Oliver, 2007) More than half of the global population now live in cities and the United Nations (UN, 2017) estimates that by 2030, 60 percent of us will live in them. Despite only representing 2 percent of the world's surface area, urban settlements are responsible for 75 percent of the world's energy consumption (IEA, 2018) Almost 100 percent of this energy is imported in cities from outside. According to U.N. Habitat (UN-Habitat, 2019), the world's cities emit 80 percent of global carbon dioxide as well as "significant amounts of other greenhouse gases". The conclusion is easy: if you want to tackle the energy issue, tackle the cities. According to IEA (IEA, 2018) city planning influence, directly and indirectly, significant energy using areas. Improving the energy performances of cities can reduce energy consumption. In the past, to improve energy efficiency in cities, the solutions have been focused on the micro scale and segmented interventions, mainly on the improvements of buildings' and vehicles' energy performances. Very rarely, the researches were focused on the urban morphology at urban and territorial scales. The "pioneer" Owens, in 1986, wrote "Energy, planning and urban form" (Owens, 1986) This book, that could be defined a "milestone" in the research of sustainable urban morphologies from the energy point of view, suggested that cities spatial structure and built form affect the efficiency in the use of energy and the potential production of energy from renewable sources in cities. Unfortunately, her great work was delivered in the form of guidelines completely lacking of:

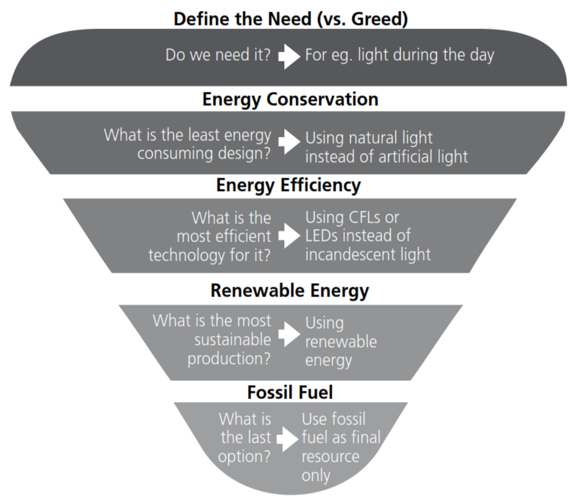
- Tools to assess the state of energy performances of existing settlements;
- Tools to produce the urban-energy datasets;
- Conceptual models to be used in the definition of assessment methodologies. On the wave of peak oil and climate change, many other contributions have been published by scholars on these themes in the last 5 years, but very few tried to face these issues.

Failures of macro plans, war, and social conflicts damaged the rural agricultural livelihoods of people and they rushed to the bigger cities. At the same time, the cities do not have the adequate infrastructure and urban spaces to welcome the people arriving (Zegras, 2005). Chauncy and Ullman believed that a city is the place of mutual relationships between humans and the city "Cities are the focal points in the occupation and use of the earth by man" (Burtch, 2020). As a general idea Fistola believes that a city should be a suitable place for intellectual and material functions and relationships of its habitants (Hollander, 2015), but the present urban areas are not as Chauncey, Ullman and Fistula pictured. The urban areas suffer from many problems that damaged natural resources. The high density of people, lack of water resources, degraded soil, the absence of vegetated surfaces, and the need of urban infrastructure made unsustainable cities with acute problems. It is why the need for new methods of planning and design have emerged and the urban planners recognize the need. For five decades, the decision makers planned to place the surplus inhabitants in new towns. While development projects in populated big cities were costly and problematic, new towns were an optimal solution to settle people in new urban communities. Cities are engines of economic growth. On an average they are responsible for more than 75 per cent of a country's Gross Domestic Product (GDP). The world's total population is close to 7 billion today, with half living in urban centers, and expected to increase to 68 per cent by 2050 (Doman, 2009). Asian cities will double in size over the next 20 years, adding more than 40 million each year. Hence, the 21st century will undoubtedly be the century of urban development in Asia. The challenge for Asia will be to provide the basic amenities such as food, water and shelter, transportation, education and sanitation for its urban and rural population, without disturbing the ecological balance. Cities are voracious resource consumers, and as cities grow, their consumption also follows suit, absorbing more resources and increasing the ecological footprint. Cities need an uninterrupted supply of energy to fuel their activities, and this is currently being met predominantly by fossil fuels. However, fossil fuels are finite; their availability is under question, with harmful effects on the environment. The way forward is likely to be an alternative development model that is not carbon intensive, one that is economically and socially inclusive, and focuses on the well-being of the population. (Smith, 2017) A systematic understanding of today's energy consumption and production systems will provide us with some insights on how to achieve this. Various initiatives in Asia and around the world can be replicated, adapted and scaled up by municipal authorities. In order to exert less pressure on energy production, cities need to cut down on consumption and make behavioral changes. An intervention that reduces energy use even by a small amount at the individual level, can translate into large reductions in the amount of energy that needs to be produced. (Fig.1)

According to the World Bank (1992) we can identify three levels of environmental problems in urban areas, each of which corresponds to different levels of economic development:

- Poverty related issues such as slums, inadequate infrastructure etc.;
- Industrial pollution related issues such as air, water and soil pollution;
- Mass production and consumption related issues such as large-

Scale pollution, solid waste, etc. Bay and Imura (2001) developed a hypothesis that cities develop through these three stages (viz. Poverty stage, industrial pollution stage, and consumption and mass production stage) before approaching the sustainable city stage. However, this model explains how industrialized cities have evolved. For developing countries, the picture presented is quite different. In fact, we are witnessing a synchronicity of all phases - while poverty is rampant and the per capita energy consumption is low, there is a massive growth in production, which mostly caters the industrialized world. The urban rich are adopting lifestyles that are comparable to those of the developed countries. Even though Asia's ecological foot-print is still relatively low, there is a need for serious retrospection on whether it is wise to continue with development and lifestyles that are unsustainable.



(IUCT, 2023)

Figure 1: Energy Pyramid This diagram illustrates how energy usage can be lowered using a three-step process

MATERIALS AND METHODS

The research questions and conceptual model

Cities throughout Asia have experienced an unprecedented economic development over the past decades. In many cases, this has contributed to their rapid and uncontrolled growth, and has resulted in multiple problems, which include a rapid population increase, enhanced environmental pollution, collapsing traffic systems, dysfunctional waste management, as well as a rapid increase in the consumption of energy, water, and other resources. Considering sustainable development in relation to sustainable cities, as mentioned earlier, different interpretations and various aspects have been defined. However, they do not give a clear definition that can be easily implemented in practice. This paper focuses on energy use in mega-cities, and sustainability is interpreted as a future where the energy system is based upon renewable resources and energy efficiency. The energy system is characterized by both sides, those of supply and demand. The study focuses on the dynamics of energy utilization in mega-cities, and ultimately aims at providing strategies for maximizing the use of renewable energy in large urban systems. The study aims at providing an in-depth understanding of the complex dynamics of energy utilization in urban mega-centers. An initial general analysis will be complemented by a detailed study of the current situation and a future outlook for the city of Bangkok, Thailand. At present there is a lot of research and development regarding energy systems and sustainable cities.

Figure 2 shows the research concept model. The study begins with understanding energy flow in Asian mega-cities, and reviews studies from international research teams to quantify the energy demand. At this stage, the major drivers affecting the energy demand in the process of dynamic structural changes are also identified. A city's metabolism has been studied to distinguish the direct and indirect energy consumption by using Input-Output (IO) analysis The research into metabolic aims to understand the physical flows into, within, and out of the cities. Direct and indirect energy demand can be a proxy to emphasize how cities rely upon the outside in terms of energy demand.

This research uses both theoretical exploration and field observation. It explores theories on the perspectives of sustainable planning and design. Its literature review looks at the relevant theories and hypotheses on the subject of sustainable urban planning and design. The purpose of the literature review is to provide a conjectural agenda for the regional urban planning and design. Since the question of planning and design of a new town is multi-disciplinary, the methodological approaches shall include major perspectives in the planning and design. Van Dijk (2016) consider the sustainable development as a complex problem for which a specific solution usually is the result of a planning process in which people from various backgrounds are involved. The problem-oriented methodology applied by this research has a system of 12 basic problem groups as the major perspectives of the sustainable urban planning and design. This system, based on the literature review, the field observation, practical experiences and the regional opinions has thus 12 groups of problems that represent the overall obstacles on the way of the developers. The system of the problem-oriented methodology can facilitate the process leading to a workable consensus on sustainable urban planning and design. Michael Passione checked the helpfulness of the problem-oriented method to achieve the sustainable development results, see as a sample (Beattie, 2020). The problem-oriented methodology of this thesis as a systematic research way has the following 12 dimensions:

1- Cities are non-sustainable 2- Dimension of knowledge and new technologies 3- Natural resources particularly lack of water resources 4- Environmental degradation 5- Planning perspectives 6 - Skeletal design views7- Resistance and durability8- Infrastructures9- Functionality10- Architecture and Aesthetics11- Culture and traditions 12- Fairless and rationality The questions that remain opened and that this work contributes to partially answer are:

How can we assess the spatial interactions between urban morphologies and energy system? For these reasons the aim of this work is to propose, test and discuss a method to: Analyze the energy state of urban settlements from an urban morphological point of view; Assess the urban morphology from a "sustainable energy" point of view.

The research work faces the following issues:

- The actual controversial and debated definition of "sustainable energy";
- The complexity of the urban system;
- The poor knowledge, in literature, about the "interactions" between urban morphology and energy;
- The lack of urban-energy spatial dataset;
- The lack of methods and procedures, in literature, to collect, produce and analyze spatial energy databases;
- The high fragmentation, heterogeneity and segmentation of the available case studies.

Urban morphologies with sustainable energy performances: an operational definition

A very important step of the research was the definition of the "research domain" and the elaboration of an operational definition of "sustainable energy urban morphologies". A vast literature agrees that urban systems and urban planning interact with the energy system (Figure 3):

- Determining the location of the settlements in the geo-morphological context
- Determining the infrastructures according to the available and affordable technology
- And managing the human behaviors according with the local culture These considerations lead to define the "domain" of urban morphologies design that regards structures, textures and forms partially excluding the aspects related to culture and human behaviors. The relationships between sustainable energy development, energy system, urban systems and urban planning and, finally, the sustainable energy urban morphologies do- main, are presented in Figure 3 and 4.

(Sustainable Energy in Urban morphology, 2016)

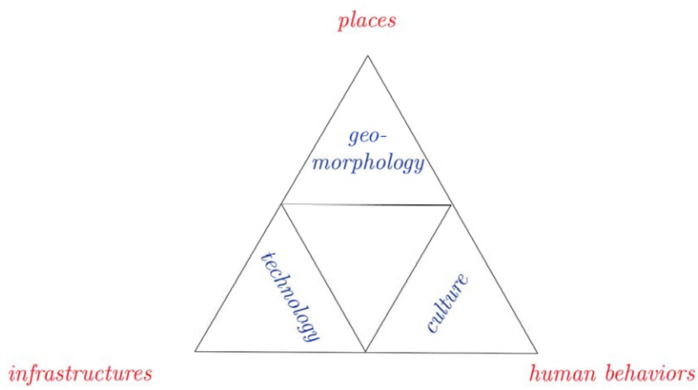


Figure 3: Urban system and urban planning aspects relevant for energy interaction.

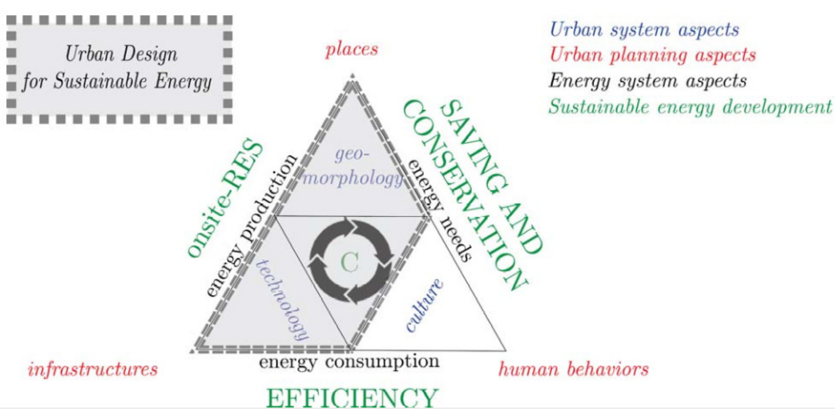


Figure 4: The domain of the research: Urban Design for Sustainable Energy. Relationship between Urban System, Urban Planning, Energy System and Sustainable Energy.

According to Alberti "The hypothesis that the spatial configuration of elements in an urban region influences ecosystem dynamics is based on the idea that the spatial pat- terns of the urban setting alter the biophysical structure and habitat and influence the flows of resources. Only recently the relationship between urban patterns and energy efficiency, energy saving or renewable energy local exploitation is becoming increasingly important (IEA, 2008) Summarizing the state of the art of the debate it is possible to say that from an urban morphology prospective, urban development affects settlements' configurations (i.e. Compact VS. sprawl) influencing their dimension, shape, localization, interconnection and composition, determining, then, different morphologies of settlements (structures, textures, forms). Various configurations of the urban structure textures and forms imply alternative energy uses, and affect efficiency, conservation and energy production capabilities. Some important implications of this relationship, as reported also by Alberti (Sanders, 2019) are:

- That spatial structure and land use patterns directly influence urban energy flows for example by redistributing solar radiation;
- That the energy requirements of human activities are indirectly influenced by spatial configurations of settlements;
- That spatial structure is an important determinant of future energy supply, distribution systems, and exploitation of ambient energy sources.

Then, since different settlement configurations modify the urban energy flows through: physical changes, induced consumptions and feasibility of using alternative systems to supply resources and services, alternative urban morphologies (structure, patterns, forms) are expected to generate different "energy performances of settlements". According to the previous assumptions, it is possible to define the "energy performances of an urban settlement" as:

- The stock of services that it needs to operate (functions that require energy);
- The stock of energy that it needs to provide the required stock of the functions;
- The amount of energy that it needs to import from outside systems.

Assuming that urban settlements could be modeled as desired, as Lynch stated, "We must learn what is desirable so as to study what is possible" it is possible to define the urban morphologies with sustainable energy performances" those morphologies that are optimized to:

- Maximize the energy conservation: use less energy to achieve a lesser energy function (reduce needs);
- Maximize the energy efficiency: use less energy to provide the same level of function (quantitative and qualitative);
- Maximize the exploitation of on-site and renewable energy sources to match local energy demand.

Figure 5 presents the relationship between urban morphology and energy performances of urban settlements.

DISSCOUSION AND FINDINGS

Methodology

City as a system: A complex system approach to human-nature interactions

The development of a model to estimate the energy performances of urban morphologies is required by emerging environmental and economic problems (i.e. Climate change, oil peak, etc.). (Alberti, 2018) Although present in the environmental debate since the early times, the interest in natural resources in the broad sense came to the forefront of the global scene in the Rio Conference of 1992 and the adoption of Agenda 21. This has boosted the development of economic-environmental accounting. In OECD countries the prevalent framework for reporting on the state of the environment are the linear Pressure-State-Responses (Rapport & Friends, 2005) and the more detailed variant Driver -Pressure-State-Impacts-Responses introduced by OECD in 1993. As reported also by

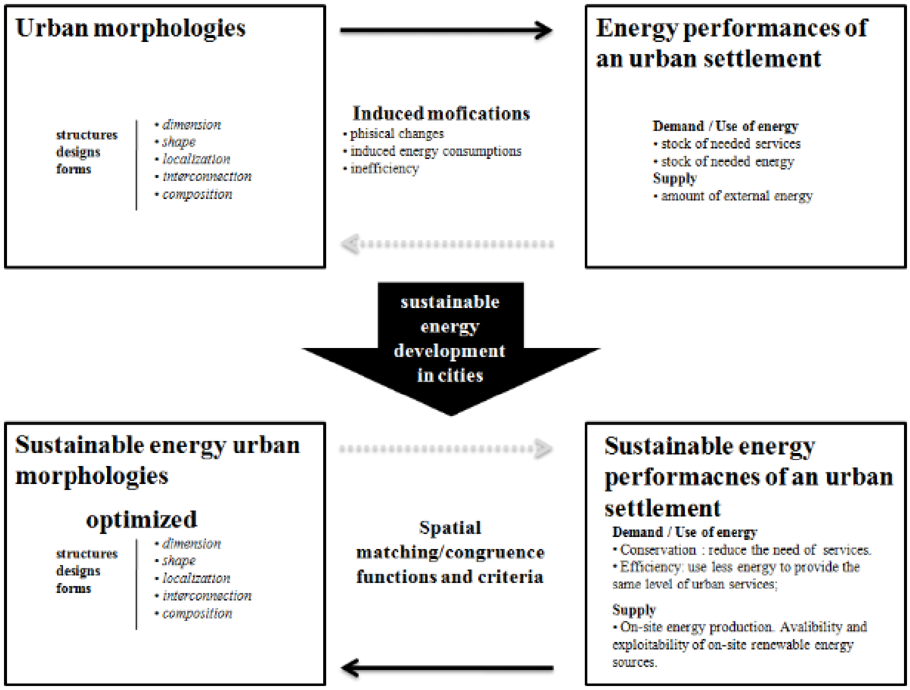


Figure 5: The relationship between urban morphology and energy performances of Urban settlements.

(Weber, 2010) our understanding of the world has changed since that time, partly because the achievements of the period (recognition of environmental statistics, production of indicators and regular publication of state of environment re- ports) have highlighted what has still to be done and the limits of the used environ- mental accounting approach to solve, for example, the energy and climate change issues. Rapport and Singh reported that the in PSR approach:

- The focus on isolating "pressures", "states", and "responses" tends to provide a static representation of the environment, ignoring the significant dynamic processes that comprise the interactions between these components;
- Lacks a 'bottom line' that would provide the policy community and the public with an overall assessment of environmental trends.

They concluded that these limitations can be overcome by adopting an ecosystem health approach, which allows for a determination of the overall viability of environments and for the identification of the collective pressures from human activity that threaten that viability. An ecosystem health approach also allows for a more explicit connection between the state of the environment and human well-being. Starting from these considerations Weber recently proposed to revise the DPSIR framework focusing on the STATE taken in the broader sense of "socio-ecological system" or "socio-ecological production landscape". Addressing pressure one by one, in fact, is not possible due to the complexity of the environmental system and, moreover, is not enough because positive and negative synergies have to be considered. From an urban energy point of view, for example, the indicators set proposed by the traditional DPSIR, based on the "pressure", is not suitable to measure the energy performances of an urban configuration. To assess all possible pressures it is costly; it is very difficult to add them up to a composite index or a general aggregate. On the other hand it is necessary to approach the energy performances of urban settlements by the direct observation of the urban system resulting as a consequence of these pressures. Concluding, according to the previous assumptions, the "pressure" approach is not viable to address the energy issues in socio-ecological systems. An approach focused on the State should be used instead. From an Urban Ecology point of view (Alberti, 2008), urban settlements can be defined as the places of human-nature interactions: the "socioecological system". "As humans transform natural landscapes into highly human-dominated environments, they create a new set of ecological conditions by changing ecosystem processes and dynamics." To effectively plan urban settlements that will be ecologically resilient recent advances in Urban Ecology theories propose to start from the idea that humans are an integral part of ecosystems and that cities cannot be fully understood outside of their ecological context. As reported by Alberti "the evolution of cities as part of nature is hardly new. It dates back at least to Geddes if not much earlier. Anne Spirn noted that an understanding of the interdependence between cities and nature had been already present in the writings of Hippocrates (ca. 5th century BCE), Vitruvius (ca. 1st century BCE) and Leon Battista Alberti (1485)". Despite this ancient knowledge about human-nature interactions only recently we understood that in studying the ways the humans and ecological processes interact, we must consider that many factors work simultaneously at various levels. Ecologists have primarily studied the dynamics of species populations, communities, and ecosystems in non-urban environments. They have intentionally avoided or vastly simplified human processes and institutions. Social scientists have only primitive ways to represent eco- logical processes. Neoclassical economics completely disregard the dynamic interactions between land development and environmental change for example using the theory of land rent to explain the behaviors of households, businesses, and governments that lead to patterns of urban development.

If we simply link traditional disciplinary models of human and ecological systems, we may misrepresent system dynamics because system interactions may occur at levels that our models fail to consider. This is particularly true in urban ecosystems, since urban development controls ecosystem structure and function in complex ways. Furthermore, these interactions are spatially determined. The dynamics of land development and resource uses and their ecological impacts depend on the spatial patterns of human activities and their interactions with biophysical processes at various scales. Humans generate spatial heterogeneity as they transform land, extract resources, intro- deuce exotic species, and modify natural agents of disturbance. In turn, spatial heterogeneity, both natural and human-induced, affects resource fluxes and ecological processes in urbanizing ecosystems Landscape ecology is, perhaps, the first consistent effort to study how human action (i.e., changing spatial patterns) influences ecological processes (e.g., fluxes of organisms and materials) in urbanizing environments. In this framework it is possible to consider the energy system in cities as an ecological process or an ecosystem service, an ecological function that has value to individuals or society (Wheeler and Beatlry, 2014) that like other ecological processes is sensitive to spatial configurations. Spatial configurations affect the fluxes of energy resources that ultimately control the underlying urban energy patterns and performances. Vice versa, in this context it is possible to hypothesize that, in cities, changes in spatial configurations of urban morphology can modify the fluxes of energy resources and then control urban energy patterns and performances. But as Lynch (Mega, 2010) suggested in A Theory of Good City Form "we must learn what is desirable so as to study what is possible". A gap exists between the "optimum" urban morphology that provides the best energy patterns and performances and the existing urban morphologies. This gap is the measure of the distance between what is possible

Modeling: Urban metabolism VS. Pattern Oriented (POM)

Cities are complex, self-organizing systems that evolve through a multitude of mainly bottom-up decisions and actions. However, the spatial organization that emerges profoundly affects how efficiently the system as a whole uses energy and processes materials. Complex systems typically keep the modelers from building models that are too simple in structure and mechanism, or too complex and uncertain. Exciting progress has been made in modeling urban metabolism, including energy dynamics, and developing an integrated theory of how cities evolve. These approaches, that aims to model the urban dynamics thought a very detailed representation of the "real word", similar to a "virtual reality" approach (Neumayer, 2014) uses very complex mathematical models that need a lot of information as input and are very difficult to be managed. Their aims, for ex- ample, to model the city object by object, building by building, road by road, tree by tree, person by person.

These models are very comprehensive but also very expensive in terms of data needs and computational resources. Recently a new theory to address the complex-systems analysis applied to ecosystemmodeling. This is called Pattern Oriented Modeling (POM) strategy, and it has been presented to the scientific community and published in the Science Magazine [3.10]. The POM is presented as a way to focus on the most essential information about a complex system's internal organization. POM follows the basic research program of science: the explanation of observed pat- terns (Grimm, 2005) Patterns, in the POM model, are intended as observations of any kind showing nonrandom structure and therefore containing information on the mechanisms from which they emerge. Complex systems contain patterns at different hierarchical levels and scales. In the words of Grimm et al." Ecosystems, for example, contain patterns in primary production, species diversity, spatial structure, dynamics of component species populations, behavior of individual organisms, resource dynamics, and response of all these to disturbance events and stress. Useful patterns need not be striking; qualitative or "weak" patterns can be powerful in combination. For example, we can easily identify a person in a crowd even without a strong pattern (e.g., a photograph) by using a set of weak patterns: sex, approximate age, hair color, size, etc. Each of these characteristic patterns excludes many individual". Patterns are defining characteristics of a system and often, therefore, indicators of essential underlying process and structures. Patterns contain information on the internal organization of a system, but in a "coded" form. The purpose of POM is to "decode" this information. The motivation for POM is that, for complex systems, a single pattern observed at a specific scale and hierarchical level is not sufficient to reduce uncertainty in model structure and parameters. Thus, in POM, multiple patterns observed in real systems at different hierarchical levels and scales are used systematically to optimize model complexity and to reduce the un- certainty. Finding the optimal level of resolution in a bottom-up model's structure is a fundamental problem.

Modeling has to start with specific questions. From these questions, it is possible to formulate a conceptual model that helps us decide which elements and processes of the real system to include or ignore. With complex systems, however, the question ad- dressed by the model is not sufficient to locate the Medawar zone because they include too many degrees of freedom. Moreover, the conceptual model may too much reflect our perspective as external observers, with our specific interests, beliefs, and scales of perception. A key idea of POM is to use multiple patterns observed in real systems to guide the design of model structure. Using observed patterns for model design directly ties the model's structure to the internal organization of the real system. To develop a Pattern Oriented model the question to be answered is: "What observed patterns seem to characterize the system and its dynamics, and what variables and processes must be in the model so that these patterns could, in principle, emerge?" This use of patterns might force us to include state variables and processes that are only indirectly linked to the ultimate purpose of the model and are not part of our initial conceptual model. Ideally, the patterns used to design a model occur at different spatial and temporal scales and different hierarchical levels, because the key to under- standing complex systems often lies in understanding how processes on different scales and hierarchical levels are bound to each other. Again, according to Grimm eat at all (Dowling and Accad, 2015) when designed to reproduce multiple patterns, models are more likely to be "structurally realistic". In particular, model components correspond directly to observe objects and variables, and processes correspond to the internal organization of the real system, so that the model "not only reproduces the observed real system behavior, but truly reflects the way in which the real system operates to produce this behavior". The method proposed in this research applies the POM to the complex system "urban morphology – energy performances" assuming the model components as the urban morphology spatial patterns and the processes as their sustainable energy performances.

Sustainable energy and urban morphologies: an integrated PSR-POM approach for urban - energy systems

In the following paragraphs I included different aspects of sustainable energy that, as- cording to the literature, become important in the design of urban morphologies with sustainable energy performances.

- Energy Saving and Conservation
- Micro climate design of urban morphologies
- Passive solar design of urban morphologies
- Proximity design of urban morphologies
- Density design of urban morphologies
- Energy efficiency
- Transport modalities and urban morphologies
- Renewable Energy source exploitation

Scales

According to the sustainable development debate, the three components of sustainability in the city are Economic, Social, Environmental and have to be considered together. The challenge of finding a sustainable urban morphology has induced to propose new frameworks for the redesigning and restructuring of urban places to achieve a higher level of sustainability [3.47]. These approaches have been addressed on different spatial scales:

- The regional and metropolitan scale;
- The city/urban scale;
- The neighborhood/community scale;
- The building scales.

A critical review of these approaches demonstrates a lack of agreement about the most effective analytical scale in the context of sustainability (Jabareen, 2006) From the sustainable energy point of view some critical analysis can lead to the same considerations. According to [3.48] different aspects of spatial structures of settlements become important, if related to energy, as we move across various scales. In geography anyway, the notion of scale can be a source of ambiguity. It is always used in the sense of spatial resolution, but it can just as well refer to cartographic representation or levels of observation and analysis. Today, we no longer have to demonstrate that the analysis of a spatial event are directly linked to the geographical level of observation representing granularity, i.e. The order of magnitude chosen for the analysis. This leads to the consideration of space in relation to different orders of magnitude, each defining distinct perception levels. Moreover, as the notion of scale is connected to the notion of measure of space or time going from one scale to another means changing units of measure.

The method proposes the following scales, or order of magnitudes, for the spatial analysis: Table 2. Analytical scales With the development of geographic information systems (GIS), the acquisition of knowledge of different scales and the transition from one level to another are becoming technically easier. However, this creates new conceptual and methodological problems. Processing and management of data at different geographical scales will now become multidisciplinary. In the case of energy performances of urban morphologies, the disciplines involved are at least: urban planning and design, spatial analysis, statistic, engineering, technical physics, ecology.

The Interaction matrix

Driving from the considerations presented in the preceding paragraphs about analytical scales and interactions between sustainable energy and urban morphologies, an inter- action matrix that systematize these relationships is presented. The aim of this tool is to prepare the analytical framework for the analysis of the spatial relationships between urban morphologies and sustainable energy performances. The matrix is based on the PRESSURE-STATE-RESPONSE conceptual model. In the X axes we find the STATE represented by different urban morphologies ordered by scale (regional, urban and neighborhood) and by urban function (urban comfort, mobility, energy production). In the Y axes we find the RESPONSES, represented by three aspects of sustainable energy (saving and conservation, efficiency and renewable energy). The output of the matrix is then used to define the set of spatial indicators to describe the spatial patterns of energy performances of urban morphology. The structure of the interaction matrix is presented in Figure 9, while the complete interaction matrix is presented in Table 1.

CONCLUSION AND RESULTS

The indicators set: energy performances of urban morphologies

From the interaction matrix a set of spatial indicators is derived. These indicators are given in the form of spatial pattern metrics. Every spatial pattern metric can find in literature several ways to be calculated. For ease of presentation the procedures to obtain the indicators are not described in this section. Table 3 contains the list of the spatial pattern metrics and the corresponding references in literature. In the case study section, instead, the procedure followed to obtain each single metric is described.

	RESPONSES				
			Energy saving and conservation	Energy Efficiency	Renewable energy production
	Regional scale				
		Comfort			
		Mobility			
		Production of energy			
STATE	Urban scale				
		Comfort			
		Mobility		INTERACTIONS	
		Production of energy			
	Neighborhood scale				
		Comfort			
		Mobility			
		Production of energy			

Table 1: Multi-scale structure of the interaction matrix

Pixel by pixel analysis

Spatial indexes are rendered in raster images of a standard resolution to permit the use of the pixel-by-pixel comparison approach. Each pixel refers to a land unit, according to the spatial resolution of the grid, and represent the value of the spatial index. The pixel composition renders the spatial patterns of the indexes. Traditional pixel-by-pixel comparisons involve overlaying mappings to evaluate the similarity between two or more maps.

Multivariate statistical analysis

Once the locations have been characterized, the intensity and the types of spatial differentiations have been determined, and the similarities and contrasts have been brought to light, the next task consists of finding the relationship between these features of spatial organization and to determine the exchanges these locations maintain among each other, as well as the mutual influences they have on each other: the inter- actions driven by spatial organization (Marks, 2020) Multivariate Statistical Analysis applied to raster images (MSARI) is selected to examine relationships among the spatial patterns metrics that are treated as variables. The MSARI technique allows exploration of relationships between many different data layers or types of attributes (Meadows et al., 2012) The Multivariate statistics is a form of statistics encompassing the simultaneous observation and analysis of more than one statistical variable. In particular the Principal Component Analysis (PCA) involves a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. It is mathematically de- fined as an orthogonal linear transformation that transforms the data to a new coordinate system such that the greatest variance by any projection of the data comes to lie on the first coordinate (called the first principal component), the second greatest variation on the second coordinate, and so on. In particular the correlation matrix is used to verify the relationships between the variables and to identify positive and negative correlations between them.

A ranking system

Finally, a ranking system is used to assign scores to each aspect of "sustainable energy performances". In particular, arbitrary thresholds derived from the literature are used to as- sign a score to each pixel for each spatial index. The scores are then summed for each pixel and for each spatial index belonging to a sustainable energy performance aspect (Saving and Conservation, Efficiency and Renewable energy production). The resulting maps are used to visually appreciate the differences in sustainable energy performances for the urban settlement's areas.

Remote sensed datasets: new frontiers for the construction of a dataset for urban-energy planning and design

Remote Sensing is a powerful tool to assess environmental phenomena. The process of collecting geographic data to describe environmental phenomena over the past thirty years has seen the mapping industry moves from brute force approaches (e.g., field surveying) to passive sensing approaches (e.g., photogrammetry and passive remote sensing) (Hu Yong, 2013) Today the integration of Aerial Photography, Multispectral Images and low resolution Digital Elevation Models (DEMs) represent the core of most environmental process modeling (Olsson and Metzger. , 2022) This technique proved to work very well at the regional scale, but local environmental phenomena exist that call for a deeper scale analysis. Urban Environments' phenomena are among them. In Urban Environments it is very difficult to automatically distinguish the objects by using traditional classification methods because of the high complexity of the urban pattern. A Three-dimensional urban model is necessary as a base for many urban energy analysis such as urban morphology energy efficiency, solar energy source potential estimation and urban heat island assessment. Recently, the panorama of mapping industry for geographic data collection moved to active sensing approaches: e.g., lidar and Radar (Rachel, 2017)

The opportunities given by the Airborne LiDAR sensor for 3D representation of urban morphology spatial patterns relevant for energy

The LiDAR Technology the LiDAR (Light Detection and Ranging technology) is an optical remote active sensor that measures properties of scattered light to find range and/or other information of a distant target. The method to determine distance to an object or surface is to use laser pulses. Using accurate timing, the distance to the feature can be measured. By knowing the speed of light and the time the signal takes to travel from the sensor to the object and to come back to the sensor, the distance can be computed using the basic relationship:

D = vet/2

Where D is the distance from the aircraft to the object (this is one-half the total distance that the laser signal actually traveled), v is the velocity or speed of light, and it is the time between emitting and receiving a particular signal (Rees, 2017) (Fig. 6)

The LiDAR technology has been in existence for 30 years but became commercially available only recently .Airborne LiDAR is a relatively new technology complementary to traditional field surveying, multispectral and photogrammetric approaches. This system collects data from the first surface hit by laser beams. The resulting DEMs are representative of the elevation of that surface composed of both the “bare earth” surface and above ground features. Used in combination with an aircraft (Fig.6) the LiDAR provides laser-based

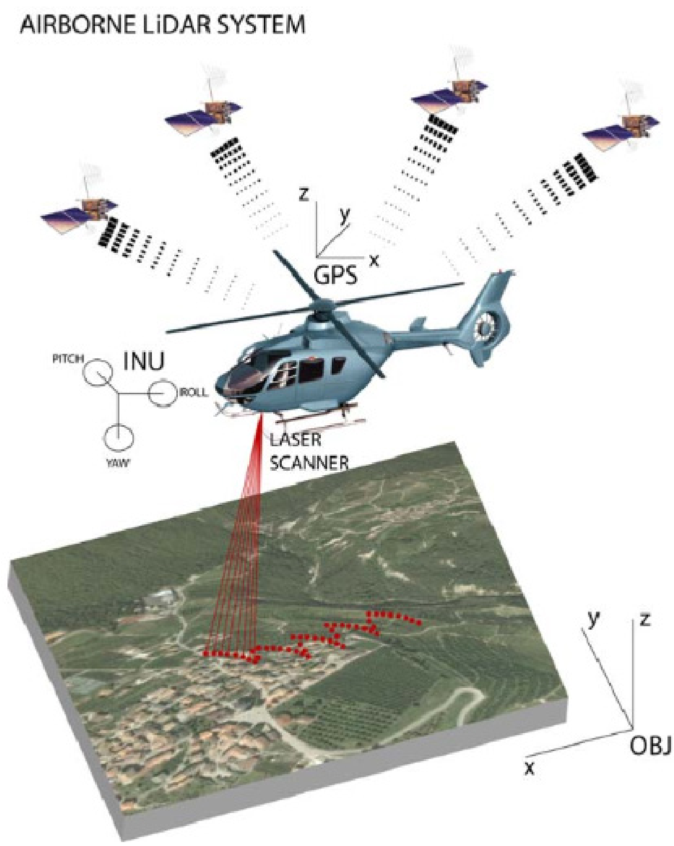


Figure 6: Airborne LiDAR system

measurements of the distance between an aircraft carrying the sensor and the ground. At a functional level, airborne LIDAR is typically defined as the integration of three technologies into a single system capable of acquiring data to produce accurate ad high resolution DEMs in physical applications. These technologies are: Lasers, Global Positioning System (GPS), and Inertial Navigation Systems (INS). Combined, they allow the positioning of the footprint of a laser beam as it hits an object, to a high degree of accuracy. The integration of LiDAR with airborne GPS facilitates the wider use of high resolution DEMs in physical applications .Advancement in LiDAR technology have allowed 3D information on the environment to be remotely obtained over large areas. Lidar produces fine scale 3D data from which environmental, structural attributes can be de- rived. It can operate during the day and the night, and it is not affected by shadows, dark soils, and different light conditions, unlike conventional aerial photography or multispectral images (Dowling, 2015) The resulting measurements can be post-processed to pro- video a DEM with a precision up to 15cm .The method of survey with an airborne LiDAR is rapid, relatively economic, allows survey over difficult terrain, and large areas providing information simultaneously of both surface and topography. It was estimated that LiDAR allows a quick collection of topographic data for large areas, up to 90 km2 per hours (Schumann, 2019), and while the first-pulse LiDAR measures the range of the first object encountered, such as the vegetated surface the last-pulse LiDAR measures the range to the last object represented, for example, by UN vegetated surface. By acquiring such, first and last pulse data simultaneously, both object heights and the topography of the ground beneath can be addressed in a single pass. The 3D point cloud could be then filtered and classified as ground, vegetation, structures etc., in order to obtain a Digital Terrain Model (DTM) (Fig. 7) Depicting only the ground and Digital Surface Model (Fig. 8), which also includes all other objects like for example buildings and trees. The difference between DSM and DTM produces the Normalized DSM, nDSM, (Fig. 9).

Accurate 3D digital models of urban environments are required for a variety of applications. Using the proper operational parameters, airborne LiDAR offers the ability to accurately map urban environments without shadowing. Detailed DSM can be extracted from the LiDAR data, and enhanced for applied analysis using specialized 3D rendering software. By adapting a set of appropriate geometric primitives and fitting strategies, the system can model a range of complex buildings with irregular shapes. The amount of information contained in such high-density 3D point clouds is enormous. A number of natural and manmade features, such as bare topsoil, trees, roads, buildings, waterways, power line, bridges and ramps are all easily discernable to the human eye in cross sections and range and intensity images. The panorama of application that LiDAR data can support in urban environment modeling is very wide. The first uses of airborne LiDAR in urban modeling include telecommunications, law enforcement and disaster planning, but there are still many applications to be explored. For example demonstrate the effectiveness of LiDAR data in the estimation of potential solar energy applied to building roofs to produce energy by thermal or photovoltaic solar panels.

However, there are also drawbacks and limitations related to the use of LiDAR senses. Some difficulties, for example, were reported when determining the level of precision of LiDAR measurements for some surveys. The post-processing of data seems to be, so far, the main problem of LiDAR. While the LiDAR technology continues to advance, the algorithms required and the amount of data that they have to process is significantly more. A better development of soft- ware to keep up with the demand for a new application is necessary. 3D urban modeling, automated classification and vegetation mapping are three sectors to be deeply developed yet. The LiDAR market is growing all around the world, but LiDAR handling software is not.

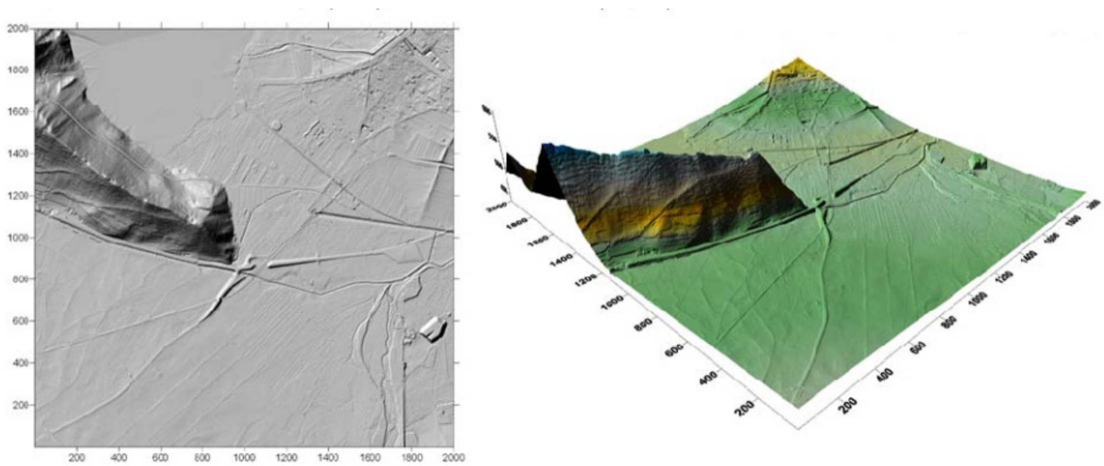


Figure 7: Digital Terrain Model (DEM derived from Last-pulse LiDAR) 1m resolution, depicting only the ground, the "bare earth". Levico lake area – Province of Trento, Italy: shaded relief map (left), surface render (right).

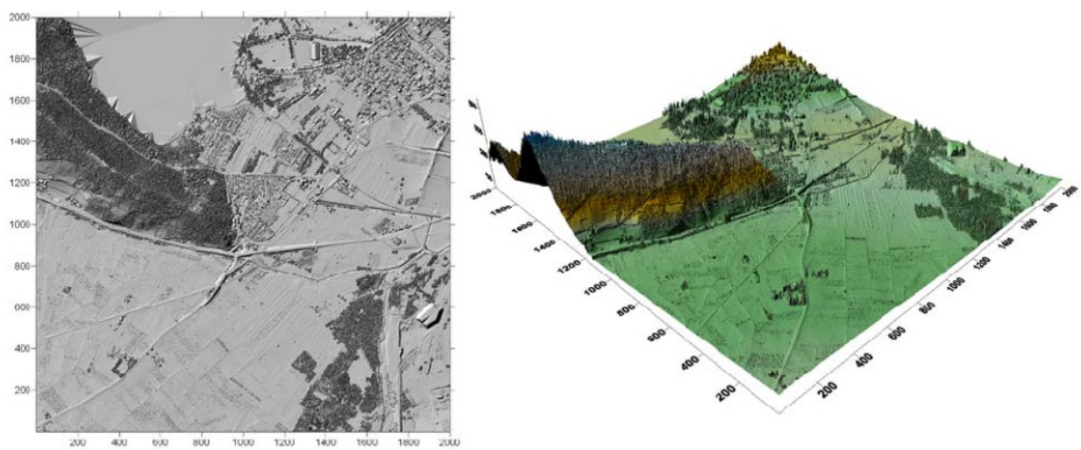


Figure 8: Digital Surface Model (DEM derived from first-pulse LiDAR), 1m resolution, includes buildings and trees. Levico lake area – Province of Trento, Italy: shaded relief map (left), surface render (right).

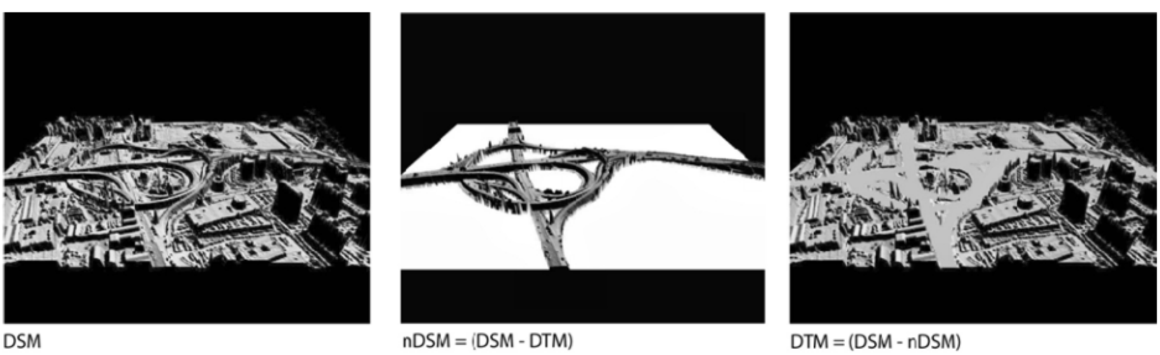


Figure 9: DSM, DTM and nDSM. Trento northern area.

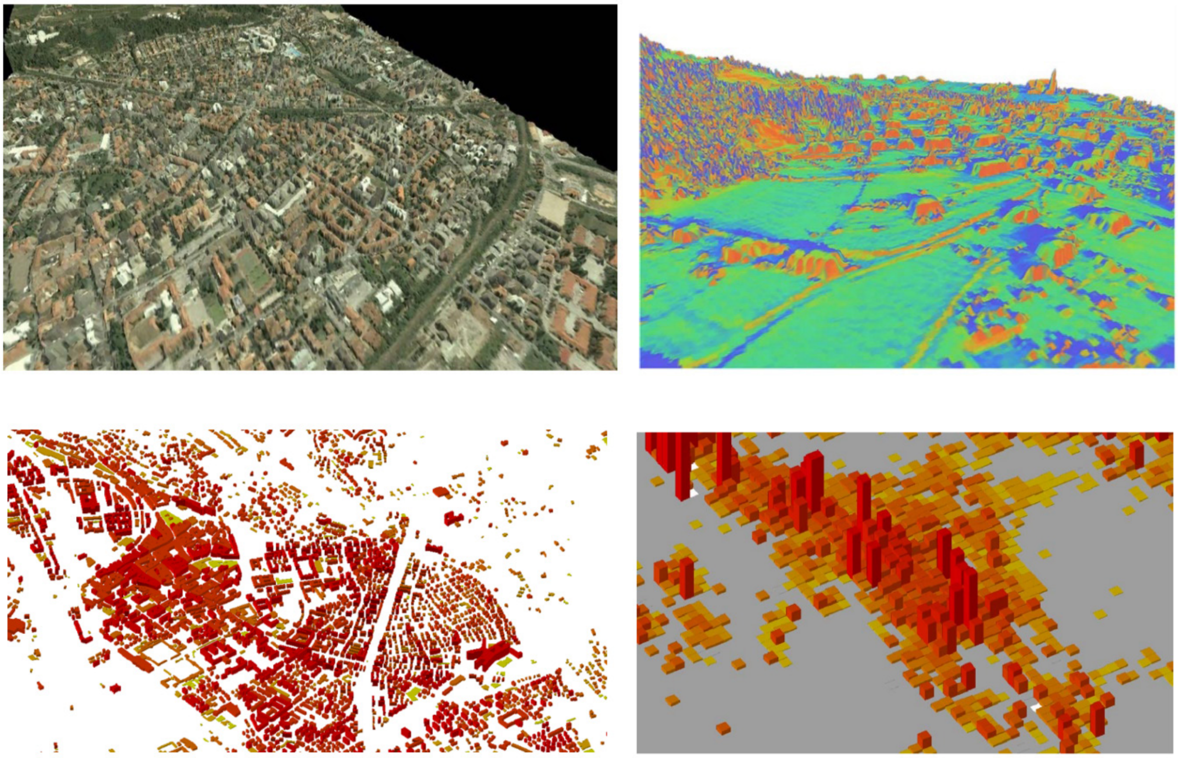


Figure 10 to 13: Solar Irradiation Model applied to LiDAR data in an urban context. Roncegno Terme – Trentino, Italy, Trento center area: 3D render of buildings (height), extracted from the LiDAR survey. Trento southern area: 3D renders of Floor to Area Ratio (FAR). Trento southern area: 3D renders of Floor to Area Ratio (FAR).

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