Sustainable solar urban design: education linked with research

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ABSTRACT: One of the most important tasks of mankind is to take responsibility for a sustainable life for future generations. Education along with research plays a key role in the reduction of energy demands and spreading of utilisation of renewables. An energy revolution has to take place at the level of urban planning. This article deals with sustainable urban design, and it presents two solar strategies based on the energy efficient urban structures generating and on the principle of synergic energy cooperation among urban structures within a city district. New energy-related urban indicators have been defined and verified on a typological variety of urban structures. The article presents doctoral research of volumetric optimisation of urban blocks using IT script written in Grasshopper software. The authors' examination is based on information technologies and software simulations. CAD-technologies are gaining importance in the holistic architectural and urban design process. All these aspects have to be implemented in education, what will positively affect the future urban development in a sustainable way.

INTRODUCTION

The city as a global phenomenon originated from one universal idea. The concentration of human activities - be they trade, production, safety, education, etc - has followed the increase in their efficiency. As a unifying principle (using Mumford's term *urban implosion*) the city has diversified over time. The efficiency of a city has gradually surpassed its own boundaries while repeatedly seeking new approaches. Like a *liger* (a hybrid cross between a lioness and a tiger, a *product* capable of living only in captivity because of its size) that makes an about-face of its effectiveness, the contemporary city collides with the barriers of its own sustainability. In his biological research Geoffrey West observed certain regularities, e.g. that the lifespan of an organism is determined by its size - larger life forms live longer matching exact mathematical relations.

> *In this crucial sense cities are completely different from biological organisms, which slow down with size; their relative metabolism, growth rates, heart rates, and even rates of innovation - their evolutionary rates - systematically - and predictably - decrease with size. (…) People actually do walk on average faster in larger cities whereas heart rates decrease as animal size increase,* said West [1].

According to the *urban scaling laws* defined by West, just by knowing the number of inhabitants, numerous parameters can be predicted, including the number of patients, crime rate, citizens' average walking pace and many other *properties* of the city, such as cases of AIDS, infrastructure efficiency or income of inhabitants. Understanding these correlations humanity bears more and more responsibility for the survival of its own creation - the *city*. Traps, challenges and responsibilities in relation to the city can be seen, for example, in Lewis Mumford's definition:

> *From its origins onward, indeed, the city may be described as a structure specially equipped to store and transmit the goods of civilization, sufficiently condensed to afford the maximum amount of facilities in a minimum space, but also capable of structural enlargement to enable it to find a place for the changing needs and the more complex forms of a growing society and its cumulative social heritage* [2].

CITY - CULTURE VERSUS SUSTAINABILITY

Today's polemics consist of two apparent platforms. Authors discuss the sustainability of a city with respect to its *physical/material functioning* and the dichotomy *cultural identity - global generic.* These two platforms need to be integrated or at least, the series of vertical interconnections need to be explored. The discussion cannot be based on the necessity of choice between *energetic* and *economic* and *sociocultural sustainability*, because the surrender of either of these aspects results in an atrophying city. Final solutions must come from a *win-win* principle. On the one hand,

literary statements might sound melodramatic; on the other hand, serious scientific research. Which truth is the right one? The one people understand or the one people feel? This conflict can be underlined by Kurt Vonnegut's words:

> *We are killing this planet as a life-support system with the poison from all the thermodynamic whoopee we're making with atomic energy and fossil fuels, and everybody knows it, and practically nobody cares. This is how crazy we are. I think the planet's immune system is trying to get rid of us with AIDS and new strains of flu and tuberculosis, and so on. I think the planet should get rid of us. We're really awful animals. (…) Yes, the planet is trying to get rid of us, but I think it's too late. And I said good-bye to my friend, hung up the phone, sat down and wrote this epitaph: The good Earth - we could have saved it, but we were too damn cheap and lazy* [3].

What would an appropriate answer and a responsible solution be? This contribution is based on the premise of cultural identity preservation. Authors explore a possible way to sustain the fundamental functions of urban fragments, city quarters or, eventually, city as a whole. Human survival in coherence with a healthy environment implies the survival of culture, which is otherwise unthinkable. Sustainability is sought in the reduction of energy demands in the building sector as one of major emissions contributors and resource consumers.

The authors seek to approach alternatives relevant for the architecture of the city, having in mind a new possible aesthetic paradigm of urban architecture. The concealed technology aspects remain in the second plan while the impact of solar radiation on urban fabric is of primary importance. This approach to urban and architectural design is, then, naturally reflected in the educational methodology of a specifically targeted department.

RIGHT TO THE SUN IN HISTORY

According to Lucretius, state, right, and law rely on the mutual consensus amongst people. The *Right to the Sun* was also made by consensus. From history one can mention *Codex Justinianus Leges Duodecim Tabelarum, De architectura libri decem* - representing Roman right, in England - *Doctrine of Ancient Light, Law of Ancient Lights,* or in the US *Doctrine of Prior Appropriation.*

All the political establishments are characterised by the need for regulation - democracy is no exception. The city as a political body is controlled by the force of law applying to its territory. The best example of hyper-regulation is Manhattan. In New York City the aspect of sunlight access to the city fabric was historically covered by *Zoning Law* (1916). Rem Koolhaas references this *perfect autopilot* of its age in his project at the 23 East 22nd Street [4]. This famous law initiates origin of the iconic *wedding cake* (set-back) skyscraper. In his publication *The Metropolis of Tomorrow* Hugh Ferris analyses the volumetric normativity of Zoning Law which has created a legal framework for today's *Zoning Codes* in diverse modifications. In a sense, solar rights are different from *solar access*. Solar access is a functional ability of solar energy conversion systems within a locale to receive or access solar gains across the property lines without shading or other obstruction caused by buildings, trees, landmarks set in a nearby property [5].

Quality and amount of sunlight, which can reach the structure is also extremely valuable for passive solar gains. *Solar rights* give the option to install a specific solar energy system within residential or commercial properties otherwise subject to private restrictions. They simply describe the ability to make use of solar energy in a locale. Systematic research and education must be performed in this field with the aim of implementation of similar solar principles in European policy and laws.

SOLAR URBAN DESIGN - CONCEPT

The sustainability of the building sector is closely linked with the *lifecycle costs*. Buildings have to be designed with a vision of their future integration into the urban structure while considering their operational claims and re-use opportunities. According to the legal documents supporting the strategy *Europe 2020*, the nearly zero-energy building is defined as:

> *(…) a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby* [6].

The shift of these requirements to the city level needs an innovative approach in urban planning within the integration of renewables into the urban structure. Thomas Herzog also confirms this fact by saying: *Cities, buildings and their various elements must be interpreted as a complex system of material and energy flows* [7]. In this way, cities and urban structures can manage with energy converted from renewable resources more efficiently.

An essential basis for designing solar architecture and solar urbanism is the direct use of solar energy based on the solar access principle. History has already confirmed the great importance of solar energy.

> *Even in the form of physical energy, the agricultural revolution, through domestication, was the most fundamental step forward in harnessing the sun´s energy: not rivalled again until the series of inventions that began with the water mill and reached its climax in nuclear power* [2].

Thanks to numerous inventions and innovations people can now return to clean, safe solar energy which may partially compete with nuclear power, but not only as a supplementary energy source. Could one be speaking of a *solar revolution*?

One way to improve solar utilisation is by passive solar gains (using energetic interspaces such as winter gardens), and another is by converting solar energy into thermal, chemical or electrical energy by devices such as photovoltaic panels, to generate electricity and solar collectors for domestic hot water production and for heating. Nevertheless, solar town planning incorporates much broader aspects of the sustainable city issue. One can speak of technological renewal of the city's technical infrastructure, the creation of cooperative and intelligent energy networks - *Smart Grid*/*Smart Infrastructure,* or the implementation of new urban regulations in relation to the Right to the Sun, etc. One can also think of a new philosophy of the life quality.

To support this strategy of the sustainable city, some shining examples can be put forward. Linz-Pichling, Austria, is home to *solarCity,* an energy-saving district based on a collaborative architectural master-plan by Prof. Roland Rainer (continued by T. Herzog, N. Foster and R. Rogers). Other examples include the city district Vauban in Freiburg, Germany; Daegu in South Korea; the Australian city Adelaide; Santa Monica in the USA; Oxford in the United Kingdom or Copenhagen in Denmark. Larger cities, such as Vienna, Berlin, etc, with smart urban vision have developed a publicly available *solar cadastre*. These on-line documents display solar photovoltaic and/or thermal potential of certain city districts or particular buildings, usually roofs. Such IT tools provide residents, developers and investors with an indicative estimate of the solar gains potential; thus, stimulating the increased use of renewable energy sources.

RESEARCH AND EDUCATION IN SUSTAINABLE SOLAR URBAN DESIGN

The authors of this article conducted research on two platforms of energy efficient urban planning. The first one is the *Energy Efficient Urban Structures Generating, and* the second is entitled *Energy Cooperativeness of Urban Structures.* The basis for both strategies constitute information technologies which enable today's architects, urban planners and other professionals to analyse urban structures *in silico* - by simulations in virtual space. Another advantage is the ability to program new software of *first design* for volumetric and spatial interpretations of urban structures. Virtual space is preferred for conceptual design, verification of spatial relations and urban compositions of building volumes with regard to existing structures. It becomes an integral part of the real creative process and inevitably penetrates into the architectural education in order to maintain competitiveness. Contemporary IT tools contribute significantly to the sustainable development of cities with nearly zero-energy impact based on analyses of orientation to cardinal points, relative rate of shading, ratio of transparent facades, as well as their capacity to generate optimal urban volumes in terms of solar radiation. The simulated energy performance of buildings and entire urban structures becomes an automatic pilot, using the aforementioned Rem Koolhaas' words.

ENERGY EFFICIENT URBAN STRUCTURES GENERATING

The strategy of Energy Efficient Urban Structures Generating is focused on searching for the optimal urban volumetric leading to maximisation of solar energy gains [8]. In this context, one can mention Ralph Knowles' *solar envelope* [9]. An IT geocentric model of the movement of the sun has been fundamental to determine the proposed generative algorithm written in Rhino-script Grasshopper. This algorithm can be useful in better understanding and proper implementation of solar access principles in urban design. It is based on the theory of radiant flux that enables the user to propose urban structures optimised for maximum yield of solar energy according to pre-set conditions. It grants access of direct sunlight to adjacent plots. In this manner, optimal conditions for active or passive solar energy utilisation are provided.

According to Juhani Pallasmaa, *creative process is taking place through the connection of hand and mind* [10]. The designing process considers many aspects, like mutual spatial relations within the city, traffic, walkways, views, plazas, promenades, etc. Therefore, the crucial input parameter for the generative process - *urban layout*, remains in the hands of an architect or a town-planner. The designer's creative hand remains unaffected in the widest possible way.

The user of the proposed algorithm inserts specific data such as plot dimensions, climatic data of the set region, and the build-up area of the plot. Finally, the time interval of insolation is defined (e.g. from 20 March to 22 September and from 9 am until 3 pm). The intervals can be optimised in order to achieve urban density and volume. The IT program generates the maximum shape that should be adapted according to aesthetic and static parameters. There is an option to select the shaded area, which has a cardinal impact on the generated volume. Final building shapes can be reduced by a south oriented cutting plane as the optimal orientation and inclination of photovoltaic and solar thermal systems. This principle supports the European strategy *Europe 2020* in terms of required energy covered by renewable sources produced on-site or nearby.

The proposed software algorithm generates urban structures volumes which must be subsequently evaluated by an energy performance in some other software (e.g. Autodesk Revit Energy Analysis, Eutodesk Ecotect, etc). This generative tool may also open up new aesthetic possibilities in architecture and urbanism as shown by three case studies on a virtual 4ha area (Figure 1).

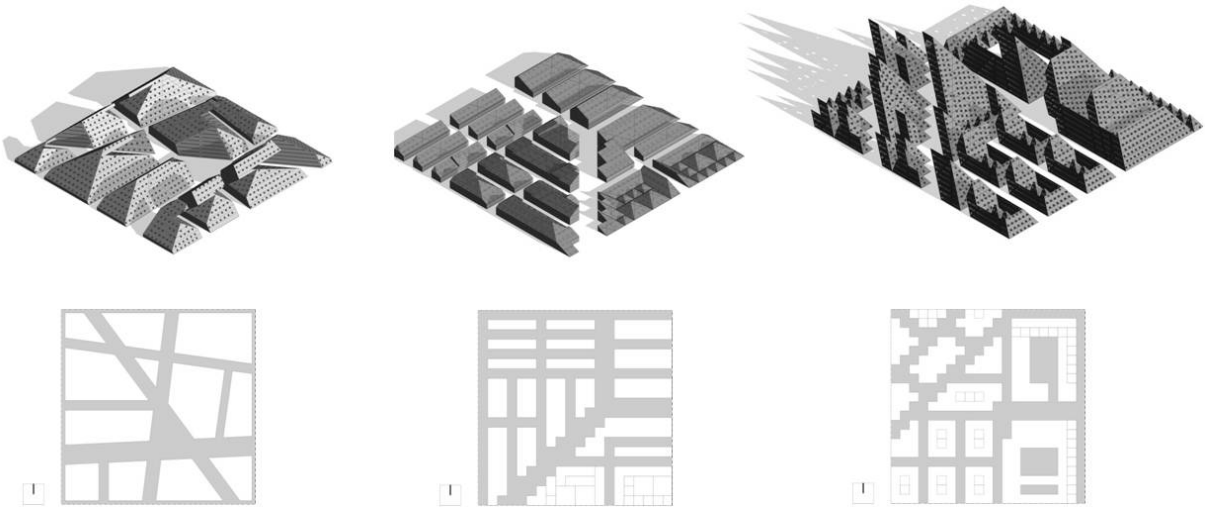

Figure 1: Generated urban structures based on set built-up areas (down: streets are grey, buildings white) and set condition for insolation (Bratislava, Slovakia). Generated volumes/buildings should be construed as solar generators.

A specific issue is represented by a superficial and random application of photovoltaic technology that would likely result in the risk of generic expression of the city across cultures. The rigorous solar design can provide a new principle of regulation represented by a new aesthetic paradigm. Shall one codify it or modify it?

Simulations of energy performance have shown that it is possible to design energy self-sufficient urban structures or even energy-over-productive structures. The energy profitable urban blocks subsequently subsidise the energy deficient urban blocks (with higher energy consumption) over the power grid. The second strategy examines the energy flows.

ENERGY COOPERATIVENESS OF URBAN STRUCTURES

This strategy analyses a possible energy performance and energy potential of basic residential urban typology. Using proposed urban energy indicators, there is a system of synergic relationships between the structures (new or historic) to optimise the energy efficiency of energy flows [11]. The *Smart Grid* theory has already acquired a solid research base. The authors just deal with it in the context of cultural identity and its sustainability.

To preserve our culture, it is necessary to teach the future generation to recognise the historical values of the city. The city character and identity have been formed for centuries by overlaying components of tangible and intangible nature. Nowadays, the urban interventions in the existing cities cannot be done in such a way as known from history, for example, Haussmann's renovation of Paris in the second half of the 19th Century.

An adequate *upgrade* of the building substance allows the city to implement energy sources directly at the place of consumption while preserving cultural identity. The natural implementation of renewable energy sources into urban fabric has already been happening in the city of Ieper, Belgium. Future developments are arguable (Figure 2). Urban structures with a different solar potential could form an equilibrium network of resources and consumers. The most valuable segments of the city can be maintained without any intervention because their energy requirements are covered by new energy-efficient city fragments.

Figure 2: City of Ieper in Belgium. The historical values encounter manifestations of energy sustainability. Presentation of the tension between culture and green sustainability. Is this really the right way? left: current state; right: possible future development (original photo by R. Špaček).

This concept of energy cooperativeness has led to verification of the basic urban typology and its solar potential characterised by proposed urban indicators - *solar index* and *cooperative indicator*. Their application at the city level provides the potential for deploying them as effective urban planning tools.

The Solar Index describes the amount of total solar radiation incident on a specified area (related plot) that can be captured and potentially utilised by the surface of urban structure (or neighbourhood, district, city quarter). The purpose of solar index, expressed in percent values, is to increase the urban density, while maintaining optimal access of solar energy in order to provide its utilisation.

The Cooperation Indicator of an urban structure (or neighbourhood, district or city quarter) is a quantifier of the negative or positive energy balance of a particular urban fragment contributing to overall synergy within an urban structure. It expresses either the structure's capability to offer its energy surplus, or its energy demands, towards adjacent structures or city quarters in creation of a smart local energy network utilising available renewable energy sources in actual time (Figure 3).

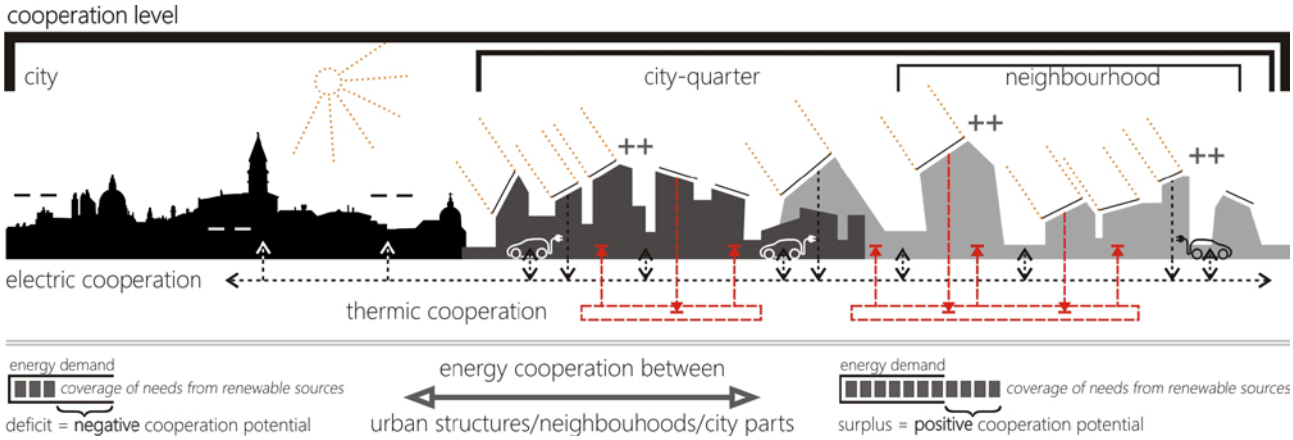

Figure 3: The concept of synergic energy cooperation of urban structures/neighbourhoods/city quarters.

The potential for overproduction or deficiency may be related to electrical energy as the *electric cooperation indicator - ECI* or to thermic energy as the *thermic cooperation indicator - TCI* (any other related commodity can be applied). Alternatively to the daily or yearly average specification of absolute energy amounts [kWh/d], the electric/thermic cooperation indicator offers the unitary value (uECI/uTCI) linked to the number of units (e.g. dwellings). In this way, the overproduction of solar energy systems per unit can be expressed or if the value is negative, the number of units which need to be supplied from external sources (other structures) [units/d]. Using this system, an urban neighbourhood or a city quarter can be evaluated in the context of its surroundings, helping architects in the sustainable redesign of cities.

Obviously, the synergic use of renewable energy sources requires intelligent infrastructure and a holistic approach to urban planning. All these aspects are incorporated in the concept of *Smart Cities*. Water supply and drainage, power supply and heat, transportation and mobility have to become gradually decentralised, but interconnected systems.

CONCLUSIONS

The application of these two strategies is closely linked to the local building culture. Utilisation of contemporary IT tools in the design process can, perhaps, evoke some negative associations with the generic principles that cannot be connected with the living environment for human beings, such as city and architecture. It needs to be explained that the generated architectural and urban forms are affected by local specificities - e.g. movement of the sun across the sky (through the season and day), the optimal orientation and inclination of active solar systems, urban context, urban layout and composition, distances between buildings, typology, topography, etc.

Designing *in silico* must be understood as a guide, automatic pilot, the first design tool. Generated volumes must be further transformed according to human needs and desires. The *Smart Grid* principle primarily counts with the existing building stock. The implementation of new urban indicators represents some soft solution that does not prescribe formalities, but rather stretch the architectural imagination. Setting of concrete rules in urban planning will strengthen the status of local building authorities, vis-à-vis commercial developers.

The urban environment, like architecture, forms its inhabitants. The inhabitants, reciprocally, form their environment - the city. Therefore, the cultural values of urban environment are very important for sustainable development, because they affect the perception of aesthetic and historical values of everyone, but mostly of young people. The crucial role in the reduction of energy consumption is also played by the user’s behaviour, education, research and innovation in this field. Life in the solar city becomes a specific choice, perhaps a philosophy of life. Solar city represents a healthier

space where a new generation grows up that regards the use of renewable energy sources for granted. One reference to the retroactivity of environment to citizen's awareness is a photograph that captures the *subcultural speech* in the solarCity, Linz-Pichling, Austria (Figure 4).

Figure 4: Life in the solarCity meets the subculture expressions, Linz-Pichling, Austria (photo by P. Morgenstein).

Finally, the inspiring quotation characterising authors' efforts need to be mentioned: *Teaching, may I say, is the noblest profession of all in a democracy* [12]. It is the duty to support sustainability by preserving continuity and culture of a man. One can do it only by transferring our knowledge and experiences to future generations and opening - not restricting - their possibilities.

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