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Towards solar urban planning: A new step for better energy performance

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Abstract

The aim of this paper is to explore the concept of Solar Urban Planning with the goal of developing an operative methodology to achieve the best conditions towards Zero Energy Building (ZEB). In the last two centuries there has been a transformation in the form of cities, from being relatively compact to a confused urban sprawl. By 2020, all new buildings constructed in the European Union will have to be "nearly zero energy" in response to the Energy Performance of Building Directive. The ZEB goal is technically achievable but dependents on various conditions of the urban structure. By 2050, the population will grow from 7 to 9 billion, the facts are clear and the time to act is now. The task to provide high solar performances buildings could be attained in a better way if the urban planning process integrates a solar energy approach to both new and existing urban environments. A "new step" that determines the solar potential of an urban area, implements a model connected to the needs of buildings and their capacity to produce energy from solar resource integrating solar analysis with parametric urban design, represents a useful tool to be added into the conception phase of urban planning. The methodology has been applied to a case study in Portugal to plan the correct orientation and form of new buildings to guarantee the optimal efficiency of photovoltaic roof and façade systems and calculate their solar energy production. Considering the importance and the complexity to minimize the use of cooling system and reduce the buildings energy consumption, multiple actions are required. Solar urban design is a "new phase" of sustainable urban planning, a phase that has wide horizons of development and could provide new solutions to the worlds energy problem by reducing its consumption and improves the performance of future buildings.

Keywords: Solar analysis and parametric urban design; photovoltaic systems; sustainable urban planning; ZEB

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1. Introduction

Almost all population growth in the next 30 years will occur in urban areas in developing countries and it is projected that by 2050 seven out of every ten people on earth will live and work in a city [1]. Many cities around the world have started to develop sustainable urban plans to guarantee that their expansion processes lead to desired sustainable outcomes [2]. These cities focus on the sustainability of urban areas as a strategy to generate growth and drive economic development while protecting valuable environmental resources from degradation. The existence of a sustainable urban process that guides the actions and interventions to achieve efficiency both in temporal (short, medium and long terms) and territorial (local, regional and global levels) dimensions is the objective of the sustainable development applied to urban territories [3]. On the other hand the concentration of human activities in urban areas requires the availability of huge amounts of energy. By 2020 the European Union has set out, in its Performance of Buildings Directive (EPBD), the goal that all new buildings and a considerable number of existing ones be nearly zero energy. In this context it is appropriate to mention Girardet's (2005) concept that "a sustainable city is organized so as to enable all its citizens to meet their own needs and to enhance their well-being without damaging the natural world or endangering the living condition of other people, now or in the future" [4]. Then the City is the principal field where solutions of emergencies, closely connected to energy consumption, can be tackled and ultimately solved. Solar urban planning is a current topic stemmed from the inadequacy of the traditional urban planning process regarding the use of solar potential: a determining factor to reach smart energy cities formed by zero energy buildings. Le Corbusier's vision for the modern city wasn't carried out but constituted an innovative impulse to consider urban planning as the first field in applying the logic of solar design [5]. Ildefons Cerdà, developing the concept of the "compact city", provided a solution to reorganize the districts structure of Barcelona and take advantage of the solar potential [6]. The new urban pattern and build environment were based on some spatial factors such as streets orientation, parcels shape, ratio between buildings height and distance considering then the solar access as a structural design parameter. Le Corbusier and Cerdà have inspired the current research into combining the parametric urban design with the need to exploit solar energy in order to develop a Sustainable Solar Urban Planning Process and reach the utmost efficiency in buildings.

2. Background

The literature review methodology has involved the following five areas: 1 – sustainability and sustainable development; 2 – planning and urban planning; 3 – planning processes; 4 – solar energy and solar analysis; 5 – solar simulation. The phenomenon of climate change is today recognized as one of the most urgent problems facing mankind [7,8,9]. The Brundtland Report "Our Common Future" places the issue of sustainable development and the core of urban planning and all disciplines related to it [3,7]. The concept of sustainable development in turn gave rise to new "green" approaches in urban planning and integrated new fields into the planning process guaranteeing a better and more effective coordination among economic growth, environmental protection, social development and technological innovation [3]. In this sense the planning process could deliver much more positive results if integrates other knowledge fields into its procedures that already study issues of low energy consumption in buildings and cities. The developed world consumes half of energy production in the building sector and most of its activity is in urban areas. This situation has become an opportunity to introduce policies as for example "20-20-20" targets defined by the European Union, which aim to reduce the overall consumption and produce more energy from renewable sources on a national scale [9]. In theory, urban planning and design are fields where a huge progress can be achieved but to integrate the above mentioned issues they require the assimilation of expertise and technology. Land-use planning has to improve knowledge and tools that enhance the planners' capacity to address the spatial problem and simultaneously ensuring the best conditions for solar energy use. The photovoltaic systems integration in buildings and the achievement of an efficient solar energy production is facilitate if the urban context assures the necessary condition to improve solar access. Sustainable urban forms can only be achieved if supported by an operative process and policies that consider global sustainability goals and define local strategies to set the energy issue as a determinant factor for the quality and functional character of future cities. In this context the pursuit of the ideal conditions and solutions for better production from solar energy must require the identification of the critical factors for it. Several authors have applied GIS techniques to link urban planning and energy [8,10,11,12,13,15]. This link occurs because integrated in the planning process there are various steps where site analysis is a major factor. Other approaches have identified several key aspects: solar radiation on ground; levels of solar access related to urban density; solar potential on existing roof surface areas [6,9,10,12,13,14,15]. So the relationship between urban context and buildings is one of the key factors in the search for an efficient solar energy production process and has been noted as one determinant contributor to the NZEB goals. Other important factors to obtain a high level of performance are [16]:

- Building must be designed to consume the minimum energy possible
- Occupants must be willing to conserve energy in the operation phase
- Monitoring of performance must be known by occupants
- Adequate location and orientation of building roofs and façades areas must be available for renewable energy system installation

The capacity to fully utilize the solar potential in an urban context depends on street orientation, urban morphology and the area available for solar energy production. Site analysis, design phase and implementation processes have the ability to integrate various criteria that can lead to a clearer definition and representations of the properties of the territory being studied [3]. To introduce the energy factor in the urban planning process, both solar and planning design has to be connected. Parametric models on urban and building scale which implement interdependencies between factors and knowledge represent an innovative tools contributing to sustainable design integrated with solar strategies. In this sense the methodology to apply has to take into account the analysis of energy efficiency system of cities and is relationships with zoning and density regulations will provide orientation provides a comprehensive vision of the current and possible energy use of different urban "designs" and shapes. This will be paramount to create more efficient solutions as high densities may reduce solar access to lower floors. This data is integrated utilizing GIS, which can integrate both qualitative and quantitative data.

3. Methodology

The methodology for Sustainable Solar Urban Planning (fig.1) is based on determining the solar potential in existing urban area and comparing it to the possible gains if the area is transformed using actions from the sustainable urban planning process [3]. This new approach results from relating economic, social, and environmental and governance factors with solar energy use. It is a method that guarantees the effectiveness and prosecution of the sustainability principles and accurately predicts the solar energy production in urban areas subjected of renewal or regeneration processes.

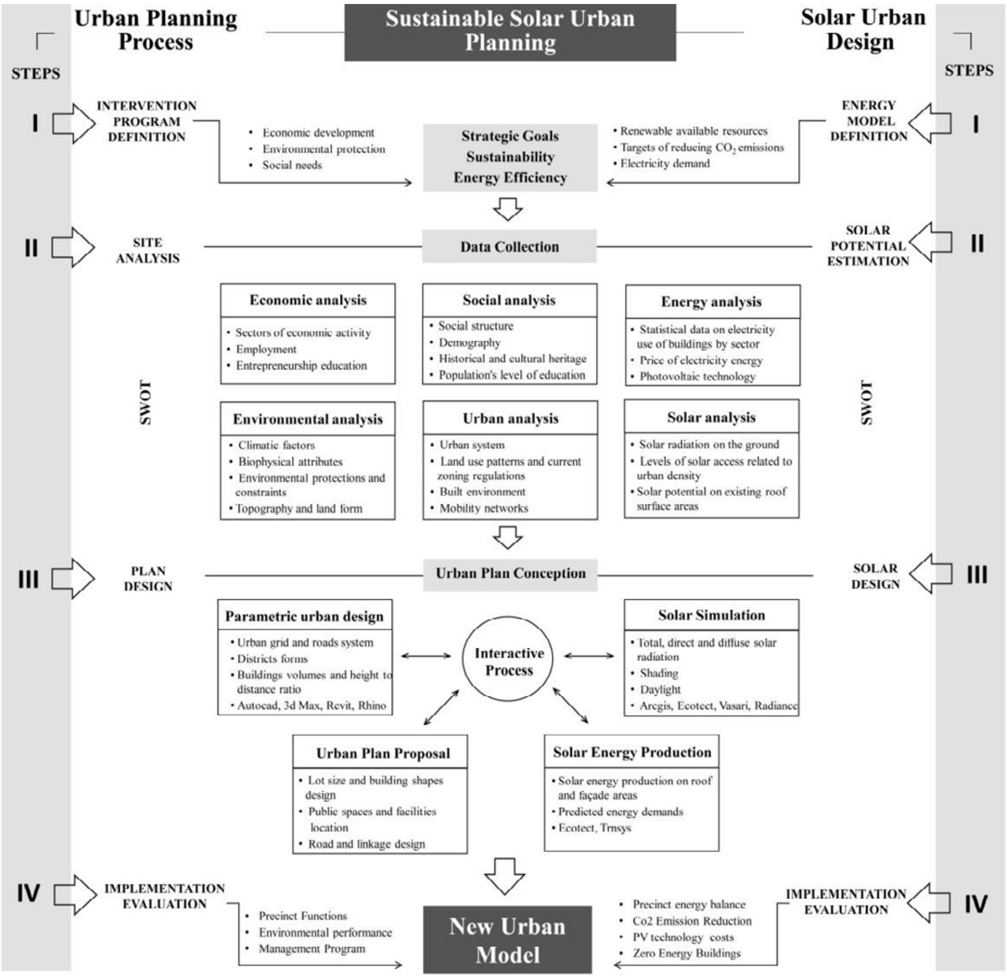

Fig. 1. Sustainable Solar Urban Planning Methodology

4. Description of the case study

The case study shows the operative application of the methodology and the assessment of the obtained results are described in the following sections.

4.1. Step I: Intervention program and energy model definition

The selected urban area of approximately 1.88 ha (tab.1,Fig.2) is located in Alcabideche, a small town belonging to the Cascais Municipality (Portugal). In 2006, the precinct had been affected by a municipal renewal. The intervention program has been defined addressing the local authority policies and sustainable factors such as economic development, environmental protection and social needs directly related to the given urban area [3]. According to the local energy available resources only the solar potential has been considered and the methodology develops a new approach to focus on this factor in each its operative steps.

4.2. Step II: Site analysis

Before of every energy considerations, the existing urban model has to be analyzed under other different perspectives. Thus, in order to apply a sustainable planning approach, data on the economic, environmental, social and urban factors that characterize the given area have to be rigorously collected [3]. By means of Arcgis®, a complete data framework of the site has been collected; the most relevant information on the built environment is resumed in Tab.1.

Table 1. Land-use coverage system, Lots and buildings quantification

Urban area	Total intervention area	18790 m^2	-	**Lot**	Nº of parcels	47
	Road and parking	4319 m^2	23%		Area Minimum	42 m^2
	Residential use	5455 m	29 %		Area Maximum	996 m^2
	Service use	424 m^2	2 %		Mean size	286 m^2
	Industrial use	532 m^2	3 %	**Building**	Nº of existing buildings	93
	Residential/Commercial use	624 m^2	3 %		Nº of dwellings	58
	Private exterior spaces	6424 m^2	34 %		Population	170
	Public spaces and sidewalk	1012 m^2	6 %			

By the social and urban analysis results, emerges a critic condition of the current urban pattern that doesn´t guarantee suitable parcel size to satisfy activities and population needs (fig.2). The buildings in precincts have inadequate relationships between the height and distance that don't respond to daylight, ventilation and solar access need. The same inadequacy has been found in the quality of the public space and activities that aren`t sufficient for the predicted demographic trend and the future population demands.

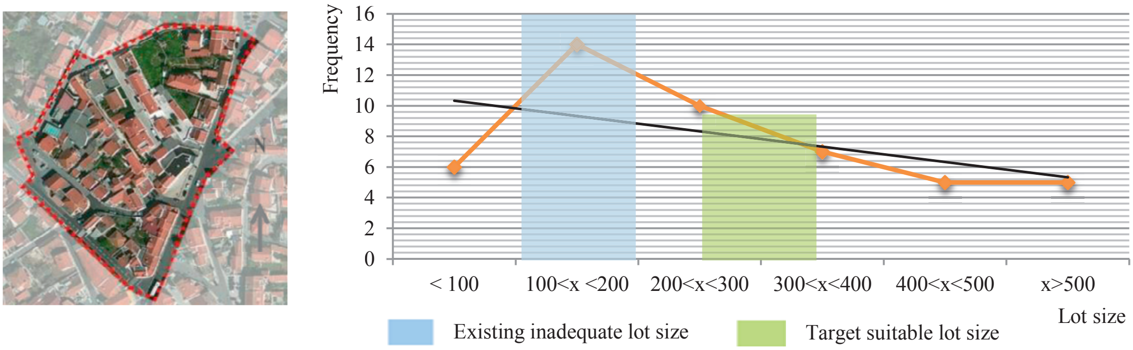

Fig.2. (a) Alcabideche precinct; (b) Lot size parameterization

4.3. Step II: Solar potential estimation of the existing roof areas

The energy analysis has to be conducted to evaluate what is the better photovoltaic system that could be utilized in the presents and future buildings according to the statistic date about price electricity and its annual consumption by each sector (tab.2) [18]. It's evident that on a urban scale the selected photovoltaic system has to be considered as simplified model but it's a determinant element for the whole solar urban approach [10,20].

Table 2. Energy analysis

Specification of the PV system	Module	Martifer Solar PV modules 210p
	Dimension	1639 x 982mm
	Maximum Power	210 Wp
	Nominal Module Efficiency	0,13
	Orientation	SE (45º) < S < SW (45º)
	Minimum usable roof area to produce 1kWh/ m^2	20 m^2
	Optimal PV tilt	38º (latitude)
Electricity building consumption by sector	Residential (consumption per capita)	4587 kWh/inhab/y
	Mixed-use: Residential/Commercial	200 kWh/m^2/y
	Industrial and other specialized structures	312 kWh/m^2/y
Electricity price	High consume hours	0.1925 €/kWh

To determine the net roof area for PV installation, some reduction factors have to be assumed to analyze existing suitable roof areas and predict future roof typologies and façade orientation [10,12,15,19]. In this way the PV system has to be considered as a solar urban design parameter that has influence on the methodology from the site analysis stage till the end of the planning process and then continuing with a more detailed consideration in the building process. To gather solar radiation data it has been used ArcGis® combining local geographic information and topographical features [15]. The obtained maps (fig.3, tab.3) describe the annual solar radiation features on the ground and are a useful tool to provide the best location for buildings and open spaces within the case study area.

Table 3. Solar analysis

Solar radiation on the ground (mean values/year)	
Location	38°44' - 9°24'
Global radiation	1340 kWh/m^2
Direct radiation	1007 kWh/m^2
Diffuse radiation	326 kWh/m^2
Direct radiation duration	3670 h

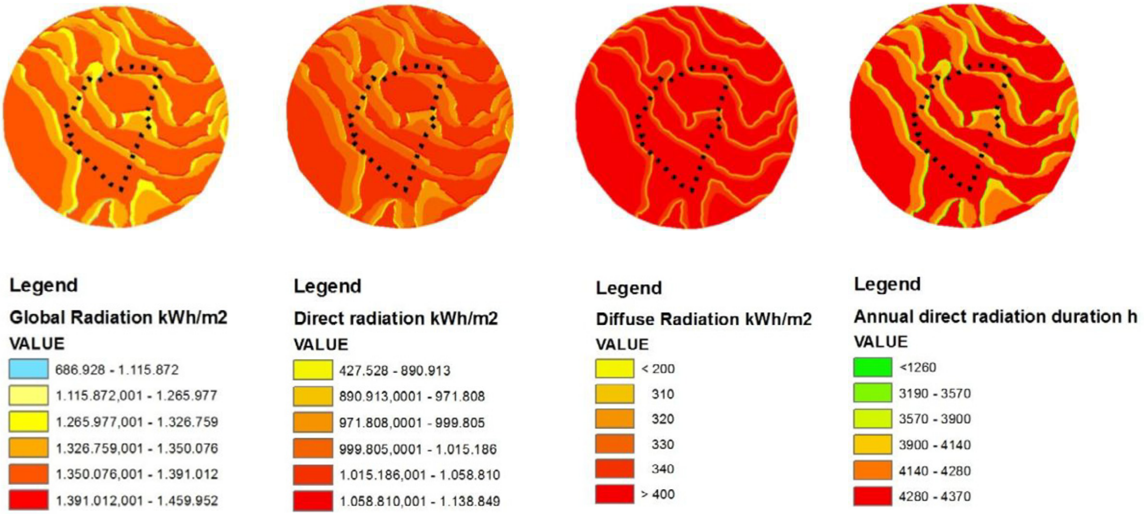

Fig. 3. (a) Global solar radiation; (b) Direct solar radiation; (c) Diffuse solar radiation; d) Annual direct radiation duration

0An urban renewal plan is a process much more complex and delicate than planning a new urban area in a context without existing built forms and the associated restrictions. The actions on an existing urban area have to deal with social and economic factors that can results mandatory and have to be supported by valid and functional justifications. Therefore, in order to design a new urban model, it's always necessary to consider and respect the existing positive potentialities and features that are worth to be maintained. In this context, the estimation of potential energy production of existing rooftops represents a strategic step to obtain an energy feedback comparing local activities and their energy demands and the current built form and its potential energy efficiency. The approach for the solar estimation has to integrate all the urban, energy and solar analyses information which are necessary to build the 3d urban model and realize the solar simulations. By mean of satellite images and Arcgis® has been conducted a roof types classification identifying 34 with flat solution and 59 pitched (fig.4). The graph in fig.4 shows that on a total of 93 existing rooftops corresponding to a gross area of 7137m^2, the more frequent size surface is between 50m^2 to 100m^2.

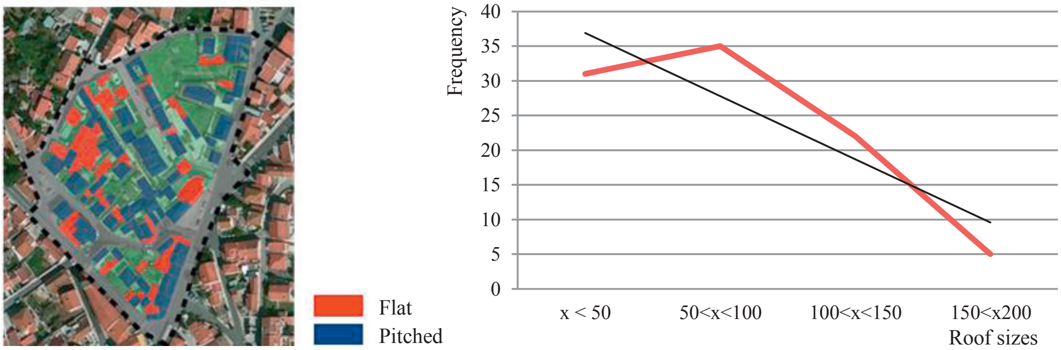

Fig. 4. (a) Flat and pitched roof classification; (b) Existing roof sizes

The minimum usable roof area for the selected PV system, determined by the relation between the photovoltaic module efficiency and the maximum power, is approximately 7.6 m². It is evident that not all the building roofs of the precinct have an adequate dimension for PV installation. In addition to this restriction and according to other related researches that study reduction coefficients to account geometric factors, shading effects and other roof uses [10,12,15,19] that can reduce the total roof area, a collection of reduction criteria has been elaborated. Statistic studies show that in Portugal the annual electricity consumption per capita is 4587 kWh/inhab [21]. Considering the selected PV system, a net roof surface of 35 m² is required to produce that amount which during this study has been defined as the minimum annual photovoltaic production that a roof surface has to guarantee. But the PV system layout also requires additional area to permit installation and maintenance works and spacing among the arrays to avoid shading [20]. These spatial conditions have been analyzed on a selection of more representative existing roof shapes and it has been estimated that the net roof surface before referred needs approximately 20% more of its area. From these considerations, the final minimum size value of 42m² has been considered as reduction factor during the analysis of the existing buildings. To achieve a positive balance between economic advantages by solar energy production and investment costs for the PV the available solar radiation has to be gathered in the most efficiency possible way. In this perspective the percentage shaded analysis has been simulated by mean of Ecotect® and an incidence of shadows by other building greater than of 30% reducing the total sunlight hours from 9 to a number inferior of 5 has been considered as another reduction factor (fig.5).

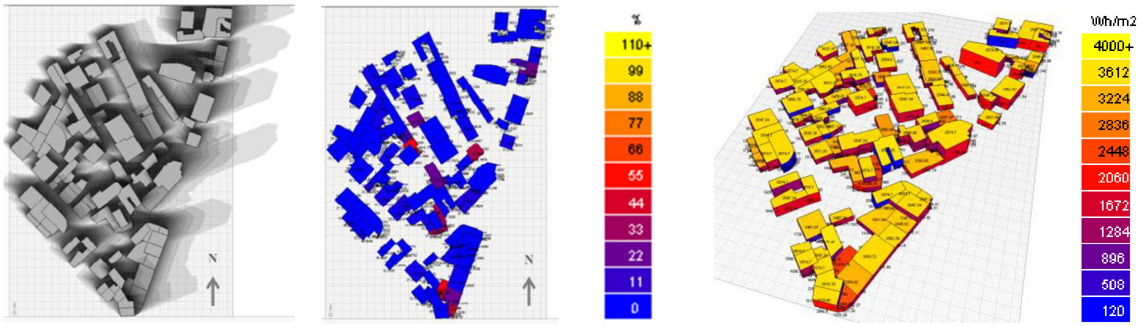

Fig. 5. (a) Global shadow range; (b) Percentage shaded on existing roof; (c) Global radiation on existing rooftops

Elements such as chimney or heating/air conditioning installations are another aspect with considerable influences on PV installation. *Isquierdo et al.* work on this issue estimates facility coefficients related to the available area per capita Aa/ca and building and population densities [15]. According to this study and considering that the case study has medium building density and low population density and the available area per capita amounts to Aa/ca= 50 it has been adopted a facility coefficient Cf=0.90. Another important consideration is that in order to reduce the time and the complexities for 3d modeling, the solar simulations have been done on a simplified parametric model that considers the flat roof type for all the existing buildings (fig.5). To limit the error that this approximation induces, a generic 3d model was studied with shape and height according to the most representative building typology in the urban area. Simulating the solar radiation on the same model construed with flat roof and pitched roof the results have been compared and an error of 9.7% is the results of the adaptation of the global radiation incident on a horizontal surface to a pitched one. The pitched roof typologies are another variable that has been analyzed during the process and the scheme in fig.6 shows the reduction coefficients for each representative roof area to consider only the optimal surface amount for PV installation.

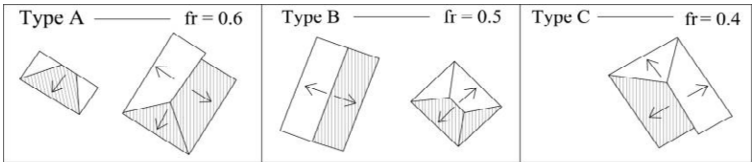

Fig. 6. Representative pitched roof and related reduction factor for PV

The PV array orientation have to face between SW (45º West) to SE (45º East) in order to achieve the most efficiency possible. The analysis of existing roofs has been done according to the diagram of the optimal orientation for solar PV panels [17] and considering that for a system, which utilizes solar energy throughout the year, the optimum tilt angle is taken to be equal to the latitude of the location (φ=38º for the case study) [12,22,23]. In this way roof areas facing SW and SE have been considered with 95% efficiency, those facing directly South with 100%. Pitched roof areas that don't follow these orientations will operate at about 60% and they weren't considered for the PV System application [23]. To calculate the predicted annual energy yield for PV systems it has been adopted the following equation [24]:

$$Annual\ PV\ energy\ production = PR \times Me \times Vst \times (A \times Gr \times 365) \qquad (1)$$

The equation (1) relates the performance ratio PR= 0.75 to consider the energy losses in the balance of system [25], the PV module efficiency Me=0.13 and the solar radiation values at standard test conditions of irradiance Vstc =1 kWh/m^2 reported by the manufacturer, the annual global solar radiation (Gr) incident on the available roof areas (A) for PV system installation. After all the described considerations the effective net area on the existing rooftops and the related values of solar radiation incident have been estimated and resumed in the table 4.

Table 4. Results of the photovoltaic energy production estimation on existing roof areas

Building current use	**Gross roof area of existing buildings (m^2)**	**Flat available roof area for PV installation considering reduction factors (m^2)**	**Pitched available roof area for PV installation considering reduction factors (m^2)**	**Total available roof area for PV installation (m^2) A**	**Mean annual global radiation on available roof area (kWh/m^2/y) AxGrx365**	**Predicted annual yield for PV systems on existing available roof area (kWh/m^2/y) PRxMexAxGrx365xVstc**
Residential	5455	564	1338	1902	2607083	254191
Industrial and other specialized structures	532	452	_	452	579326	56484
Service	424	242	46	288	381839	37229
Mixed-use: Resid/Com	624	88	36	124	157613	15367
Unclassifiable	102	58	39	97	128685	12547
Total	7137	1404	1459	2863	3854545	375818

4.4. Step III: Plan design and solar design

Accounting to the defined intervention program, the analyses outputs and solar urban design strategies, the new urban model has been planned. The approach to the new urban layout has been deal with population needs, related functional activities, public spaces and smart linkage for a more ecologically responsive mobility system obtaining a more functional and balanced global urban model (Tab.5).

Table 5. New land-use coverage system and lots and buildings quantification

Urban Area	Total intervention area	18790 m^2		**Lot**	Nº of parcels	23
	Road and parking	4613 m^2	23%		Area Minimum	200 m^2
	Residential use	6982 m^2	34%		Area Maximum	808 m^2
	Residential, commercial and service uses	2944 m^2	15%		Mean size	431 m^2
				Building	Nº of new buildings	27
	Service/Commercial use	579 m^2	3%		Nº of dwellings	127
	Public spaces and sidewalk area	5143 m^2	25%		Population	391

The global solar radiation on the ground has been used to provide the best location for new buildings and open spaces within the case study area [3,8,11]. A distribution of parametric volumes has been constructed in 3D Max to study the relationship between the height and distance of the buildings and their integration in the new urban model. Shading and solar radiation simulations conducted by Ecotect® have been supported the elaboration of different build forms during all the urban plan conception in the search of the best energy efficiency solution. Analyzing the new urban model from an energy efficiency perspective, several improvements have been obtained compared with the existing context. All the new buildings has been designed with flat roofs and size areas greater than 42m^2, two factors that permit optimal PV panels orientation and assure spatial flexibility for PV arrays installation and their maintenance. The new urban forms, respecting the 45 degree rule of the Portuguese Building code [26] between windows and walls facing them, guarantee solar access into the courts of collective buildings and minimize the shading by other building. In this way the façades that in the existing buildings don't have any potentiality, constitute a resource of the new buildings to implement photovoltaic integration (fig.7).

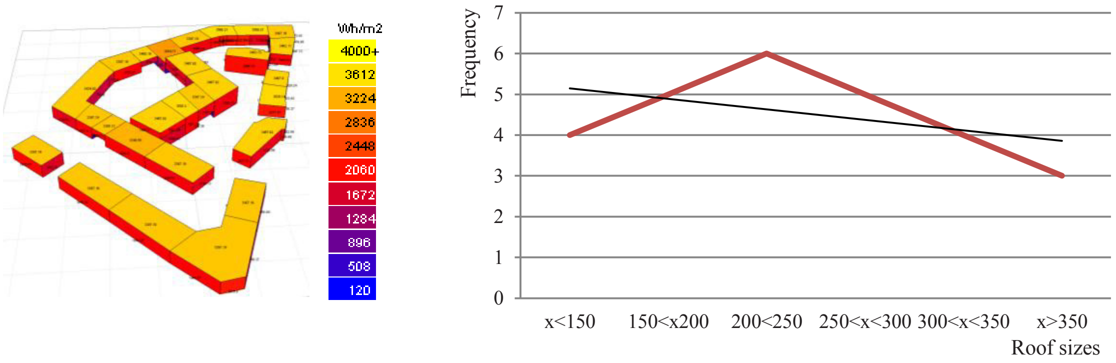

Fig.7. (a) Global radiation on new rooftops and façades (b) New roof sizes

4.5. Step III: Estimation of solar energy production on the new roof and façade areas

This estimation process applies the same approach used to evaluate the given urban area adding some further criteria characterizing the building facades and that are indispensable to obtain the solar energy estimation. The facility coefficient for the new urban area has been assumed Cf=0.80 according to the available area per capita Aa/ca= 17.3 and densities parameters [15]. The facades areas of size inferior than 35m² haven´t been considered according to the logic adopted to grant at least the annual electricity consumption per capita of 4587 kWh/inhab by each PV system. The façade areas also have to be affected by a reduction factor taking into account that the photovoltaic system has to be installed above the ground floor because of its commercial and service use. To exclude façade parts facing street, courtyard or private spaces and according to the two buildings typologies introduced by the urban renewal, a form reduction coefficient Fg= 0.5 (two-storey building) and Fg=0.67 (three-storey building) has been calculated by proportional ratio consideration (fig. 8).

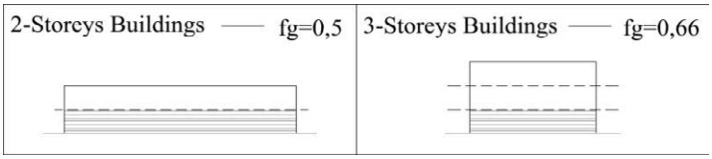

Fig.8. Façades reductions

The voids of windows also reduce the façade available area for PV integration. To consider this area it has been assumed a Window to Floor Ratio of 20% that respects the minimum reference value of 10% established by the Portuguese Building Code [26] and fulfils day lighting and natural ventilation needs of the building typologies object of study. Another important aspect is that photovoltaic systems in facades have mainly a fixed angle of 90º and a reduction amount nearly to 50% has been considered to calculate the solar energy power output [22,23]. The results of the solar energy estimation on roof and facade areas are resumed in table 6 and 7 and commented in the following "results and conclusion" section.

5. Results and conclusions

Tables 6 and 7 show that the new buildings roof and façade areas constitute a great potentiality to gather solar radiation and produce the electricity which can contribute for satisfying their own cooling and heating needs.

Table 6. Results of the photovoltaic energy production estimation on new roof areas

Building new use	**Gross roof area of new buildings (m²)**	**Net flat available roof area for PV installation considering reduction factors (m²)**	**Mean annual global radiation on new available roof area (kWh/m²/y) AxGrx365**	**Predicted annual yield for PV systems on new available roof area (kWh/m²/y) PRxMexAxGrx365xVstc**
Residential	4954	4211	1725305	168217
Service/Commercial	302	257	325403	31727
Mixed-use: Resid/Com/Serv	1605	1364	5216321	508591
Total	6861	5832	7267029	708535

Table 7. Results of the photovoltaic energy production estimation on new façade areas

Building new use	**Gross façade area of new buildings (m²)**	**Net available façade area for PV installation considering reduction factors (m²)**	**Mean annual global radiation on new façade area (kWh/m²/y) AxGrx365**	**Predicted annual yield for PV systems on new available façade area (kWh/m²/y) PRxMexAxGrx365xVstc**
Residential	7512	313	187541	18285
Service/Commercial	475	66	41682	4064
Mixed-use: Resid/Com/Serv	3177	291	189124	18440
Total	11164	670	418347	40789

Summarizing the results and conclusions, the methodology and its application in the case study show that the ZEB target is achieved if the urban design implements efficient solar orientation to future buildings and public areas in the way to increase a better solar access on building facades. The potential energy production of the existing built environment has been estimated in 375818 kWh/m^2/year (tab.4), to support the annual electricity consumption per capita of 4587 kWh/inhab and the current number of 170 residing people. The estimated output is able to demonstrate that are satisfied only the energy needs of 81 inhabitants, about 48% of current needs. The obtained results reflect the characteristics of the traditional architectures, unsuitable roof areas and inappropriate facade configuration (shading, lack of distances between buildings, fragmented dimensions,...) that don't allow the full exploitation of the solar potential in an efficient way. In another hand, the proposed solution of urban design supported in the new methodology provides conditions to a total production of renewable energy of 749324 kWh/m^2 supplying to a population of 391 inhabitants. In this context is clear there are guaranteed the conditions to realize a ZEB purpose where the consumptions of population and activities are supported from energy renewable source. In order to assure this goal and the ZEB target, future buildings will have to be design implementing solar passive strategies and educating users to adopt lower consumption behaviors. In this context, a question has to be posed: "Is an urban transformation possible that provides better energy performance and conditions towards the ZEB target?" We have a Yes for response. The obtained results confirm that by applying the proposed methodology to urban interventions is possible achieve better energy performance in urban context and better conditions to ZEB goal. Presented research also shows that with the methodology Solar Urban Planning is possible to improve urban areas, accommodate more people and areas and at the same time guarantee a better energy performance leading to the effective Zero Energy Precinct. In future developments of this research can be study the ideal percentage of the distribution of number of residential, commercial and services areas in order to provide an efficient balance of day and night energy consumptions in the way to reduces storage requirements and permitting that buildings be are part of a network of districts or neighborhoods.

References

[1] United Nations. *World urbanization prospects: the 2011 revision*. New York: United Nations Secretariat, Population Division; 2012.

[2] Gideon D. P. A., Aschvanden, Haegler S, Bosché F, Gool L V, Schmitt G., *Empiric design evaluation in urban planning*. Autom. Const. (2010), doi:10.1016/j.autcon.2010.10.007

[3] Amado, M. P., *The Operative process in Sustainable Urban Planning*, in Sustainable Development and Planning II, A.G.Kungolos and others (eds): WIT Press, Vol. 1 (2005) pp. 181-191

[4] Girardet H., *Cities, people, planet*. Transcript from the Schumacher Lectures, Urban Sustainability, Liverpool (2000).

[5] Evans, J. M., Schiller, S., *The friendly city, the sun and Le Corbusier: Form, function and bioclimatic response*. In Environmentally and Friendly Cities, Proceedings of PLEA 98, James & James, London (1998) pp.221-224

[6] Curreli, A., Coch, H., *Solar access in the compact city: a study case in Barcelona,* A: Passive and Low Energy Cooling for the Built Environment. "PALENC 2010". Rhodes Island: 2010, p. 1-11.

[7] WCED, Our Common Future, UN-Report of the World Commission on Environment and Development, Oxford University Press, UK (1987)

[8] Rylall, M., Gadsden, S. Lamas, K., *GIS-based decision support for solar energy planning in urban environments*, Computers, Environment and Urban Systems, 25 (2001) 579-603

[9] Meijer, M., Adriaens, F., Van der Linden, O., Schik, W., *A next Step for sustainable urban design in the Netherlands*, Cities 28 (2011) 536-544

[10] Wiginton, L.K. H.T. Nguyen, J.M. Pearce. *Quantifying rooftop solar photovoltaic potential for regional renewable energy policy,* Computers, Environment and Urban Systems, 34 (2010) 345-357

[11] Appleton, K., Lovett, A., *GIS-based visualisation of development proprosal: reactions from planning and related professionals*, Computers, Environment and Urban Systems, 29 (2005) 321-339

[12] Armstrong, S., Hurley, W.G., *A new methodology to optimise solar energy extraction under cloudy conditions.* Renewable Energy, 35 (2010) 780-787

[13] Morello, E., Ratti, C., Sunscapes: 'Solar envelopes' and the analysis of urban DEMs, Computers, Environment and Urban Systems, 33 (2009) 26-34

[14] Ratti, C., Baker, N., Steemers, K., Energy consumption and urban texture, Energy and Bildings,(2005), article in press

[15] Izquierdo, S., Rodrigues,M., Fueyo, N., *A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations.* Solar Energy, 82 (2008) 929-939

[16] Kibert, C.J., Net-Zero Energy Buildings: The Next Shift in Green Building?, Proceedings in SB10: Sustainable Building Affordable to All, L.Bragança et al. (Eds) IOS Press (2010) 3-14

[17] Thomas, R., Grainger, G., *Photovoltaics in Buildings A Design Guide.* Produced by Max Fordham & Partners. (1999).

[18] Portuguese Energy Data, http://www.edp.pt

[19] Cellura, A. Di Gangi, S. Longo, A. Orioli. *Photovoltaic electricity scenario analysis in urban contests: An Italian case study.* Renewable and Sustainable Energy Reviews, 16- 4 (2012) 2041-2052

[20] Ordóñez, J., Jadraque, E., Alegre, J., Martínez, G., Analysis of the photovoltaic solar energy capacity of residential rooftops in Andalusia (Spain),Renewable and Sustainable Energy Reviews, 14-7 (2010) 2122-2130

[21] Portuguese National Statistic Institute (INE) http://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_main; 2009

[22] Gunerhan, H., Hepbasli, A., Determination of the optimum tilt angle of solar collectors for building applications.Building and Environmental,(2007), doi:10.1016/j.buildenv.2005.09.012

[23] Cheng, C. L., Charles, S., Sanchez, J., Meng-Chieh, L., Research of BIPV optimal tilted angle, use of latitude concept for south orientated plans. Renewable Energy, 34 (2009) 1644-1650

[24] Méndez,J., Cuervo, R., Energía solar fotovoltaica. FC Editorial, Madrid (2008) ISBN-3: 978-84-96743-45-8

[25] Nordmann, T., Clavadetscher, L., Jahn, U., Pv system performance and cost analysis. Proccedings of 22nd European Photovoltaic Solar Energy Conference and Exhibition, 3-7 September 2007, Milano, Italy

[26] Ministério das Obras Públicas. RGEU,Regulamento geral das edificações urbanas. Diário da República, Portugal; 1951