Urban Planning for Solar Energy – IEA SHC TASK 51

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Abstract

An increased use of solar energy is a key ingredient for forging resilient cities. This recognises the importance of the urban fabric being able to use renewable energy sources to become increasingly self-sustainable. In that regard, the integration of active solar energy systems in the built environment will allow cities to reach a high level of sustainability. In this framework, the main objective of the IEA SHC Task 51 Solar Energy in Urban Planning, was to provide support to urban planners, authorities and architects to develop urban areas with architecturally integrated solar energy solutions. The scope includes solar energy issues related to new and existing urban development areas and sensitive solar landscapes. This paper presents an overview of the Task's results from 11 countries including reviews on legal framework, barriers and opportunities, on planning processes and on educational issues. Approaches, methods and tools are presented as well as a collection of case stories with lessons learnt and a web-based learning platform.

Keywords: solar energy, urban planning, solar landscapes, methods, tools, education, case stories, IEA

1. Introduction

A large portion of the potential for energy efficiency in existing buildings and potential to utilize solar energy still remains unused. Globally, goals and specific targets are set up to reduce our environmental impact on climate and secure future supply of energy. The built environment accounts for over 40% of the world's total primary energy use and 24% of greenhouse gas emissions (Hegger et al, 2008). A combination of making buildings more energy-efficient and using a larger fraction of renewable energy is therefore a key issue. Political statements and directives are already moving towards zero-energy buildings and communities (Sartori et al, 2010; Voss and Musall, 2011). An increased use of solar energy, enabling renewable energy supply, is firmly acknowledged as a key ingredient for forging resilience and future proofing of our cities on the one hand. On the other hand, it is an important part of the development ahead, where the urban fabric strives to utilize passive solar gains and daylight to reduce the energy use in buildings and for lighting outdoor environments, as well as to improve the inhabitants' comfort (Compagnon, 2004).

The main objective of the IEA Solar Heating & Cooling Programme, Task 51 Solar Energy in Urban Planning, is to provide support to urban planners, authorities and architects to achieve urban areas, and eventually whole cities, with architecturally integrated solar energy solutions (active and passive). The objective contributes to urban planning by providing guidance for urban planners and policy makers on a large fraction of renewable energy supply. This includes approaches, methods and tools capable of assisting cities in developing a long term urban solar energy strategy. Heritage and aesthetic issues are carefully considered. Also, the goal is to prepare for and strengthen education at universities on solar energy in urban planning, by testing and developing teaching material for programmes in architecture, architectural engineering and urban planning. The material will serve a dual

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purpose by being inclusive for postgraduate courses and continuing professional development (CPD).

The scope of the Task includes solar energy issues related to 1) new urban area development, 2) existing urban area development and 3) sensitive and protected landscapes (solar fields). Both solar thermal and photovoltaics are taken into account. In addition, passive solar - as passive solar heating, daylight access and outdoor thermal comfort - is considered in the urban environment. Solar energy integration in existing and in new city districts are two different contexts with different opportunities and constraints. Furthermore, ground based active solar applications are interfacing with urban environments, creating solar landscapes that juxtaposition with the existing urban form with varying levels of aesthetic acceptance. In open landscapes, solar fields need to harmonize with the rural landscape and nature. Understanding the existing parameters under which planners operate and the challenges this presents is a key consideration of this Task.

2. Objectives, materials and methods

The Task's work started in 2013 and ends in 2017: it involved a consolidated scientific collaboration between researchers and practitioners from Australia, Austria, Canada, China, Denmark, France, Germany, Italy, Luxembourg (observer), Norway, Sweden and Switzerland. The Task was structured in four Subtasks:

Subtask A: Legal framework, barriers and opportunities. Lead: Australia.

Subtask B: Processes, methods and tools. Lead: Sweden.

Subtask C: Case studies and action research. Lead: Norway.

Subtask D: Education and dissemination. Lead: Germany.

Subtask A sets the current boundary conditions for solar integration, deals with the assessment of available potential and elucidates opportunities. Subtask B deals with processes, methods and tools and developments for the applied phase related to specific situations (new development areas, existing urban areas, landscapes). Subtask C focuses on implementation issues e.g. tests of processes, methods and tools, through case stories and showing relevant examples as case studies. Finally, Subtask D covers the dissemination focused on tertiary education and continuing professional development (CPD). The whole Task was led by Sweden.

Although Task 51 is organized in different subtasks, most of the work has been collaborative across subtasks. A central part of the work was carried out as action research. Action research is a reflective process of progressive problem solving led by individuals working with others in teams or as part of a "community of practice" to improve the way they address issues and solve problems (Stringer, 2014). Action research involves the process of actively participating in an organization change situation whilst conducting research. In Task 51, this was reflected in the participants' collaboration with urban planners and other key actors within local urban planning developments in each participating country. In this way information about important issues to address was identified. The goal has then been to develop knowledge that is useful for practicing urban planners and for education of architects and planners.

For Subtask A, a historical reflection was completed in parallel with sourcing country information regarding the legislative frameworks and voluntary initiatives that impact on the uptake of solar energy in urban areas. This included a review of legal cases that define the treatment and judgement of decisions where solar energy implementation was claimed to have created conflict or where urban development threatened solar access of existing systems. Whilst the treatment of passive solar protection is well defined, the research looked to review how active solar technologies are applied to urban environments and the planning controls that might promote or constrain their use. It also investigated the cultural and aesthetic sensitivities and parameters directly affecting technological choice and the acceptable application of urban solar systems.

The main topic in Subtask B was the planning process descriptions. Through collecting and sharing knowledge among experts in Task 51, the local planning prerequisites, including legislation and praxis, have been analysed in order to find commonalities to describe a generic planning process valid across countries in Subtask B. This work was carried out first on a national level by the experts collecting and describing the formal and informal planning processes through the steps of 1) short interviews during the Task definition phase, 2) analyzing legislation and 3) expert participation in urban planning projects in the form of action research. The aim was to explore when and how knowledge on solar energy (passive and active strategies) could enter planning processes.

The work on collecting local legislation and praxis has been reported in a common report between Subtask A on Legislation and Subtask B on Processes, Methods and Tools. In Task meetings, workshops were held where the experts analyzed national planning process similarities between different countries. The experts then agreed upon a common generic planning process described at different spatial scales, showing what actually is taking place in urban planning in all these cases. The scales found in all countries were 1) comprehensive/strategical planning scale 1:2000-1:100 000, 2) urban and landscape design scale 1:1000-1:5000, 3) detailed development plans 1:500-1:2000 and 4) architectural design stage 1:10-1:500.

Another objective in Subtask B was to identify supportive instruments that can assist planners during the planning process. These supportive instruments were defined as *Approaches*, i.e. means of incorporating solar methods and tools, *Methods*, i.e. planned procedures to assess and evaluate solar in relation to other aspects in urban planning (including landscape planning) and *Tools*, i.e. a rule of thumb, a calculation or a modelling software giving geometrical or numerical results; e.g. solar maps, solar potential software, GIS software, etc. This definition also implies a hierarchy where approaches include methods that incorporate tools in a planned procedure. The identification of existing as well as the development of new approaches, methods and tools was carried out during the action research work within national planning contexts and is presented in a report on *Approaches, methods and tools for enhancing solar energy* targeting urban planners. The approaches, methods and tools within the scope are instruments to support decision-making and to combine qualitative and quantitative aspects of relevance for spatial concerns in urban planning.

Bringing the generic planning process and the existing and new approaches, methods and tools on active and passive (daylight, solar gains and micro climate) solar measures together creates the base for the guidelines, developed as a homepage. The aims are to inform and support decision-making, orienting on existing and new approaches, methods and tools to inspire planners to find new ways of developing the planning process to enhance solar energy in the urban and landscape context.

The main objective of Subtask C was to stimulate successful practice and facilitate its replicability, by documenting experiences, helping cities avoid pitfalls already encountered by others, and creating arenas for mutual interaction between researchers and city managers. In that regard, the work was focused on case stories of new, existing urban areas and landscape planning related to active solar systems (both photovoltaics and solar thermal) and interrelated technical (i.e. solar potential, cost investment, product technology, energy production, daylight, quality of visibility etc.) and non-technical aspects (i.e. planning process, right of light, policy and legislation, etc.). More than 30 case stories from 11 countries have been analysed and compared in extensive reports (Lobaccaro et al., 2017). Lessons learnt for different targets groups have been condensed into guidelines for solar energy in urban planning (Fig. 1). Finally, a webpage of case studies linked to a world-map has been established. This serves as a user-friendly consultation and dissemination instrument: it is a sort of case stories' platform from which the users can download dedicated brochures where detailed information related to both single case stories and/or the case study comparisons have been collected.

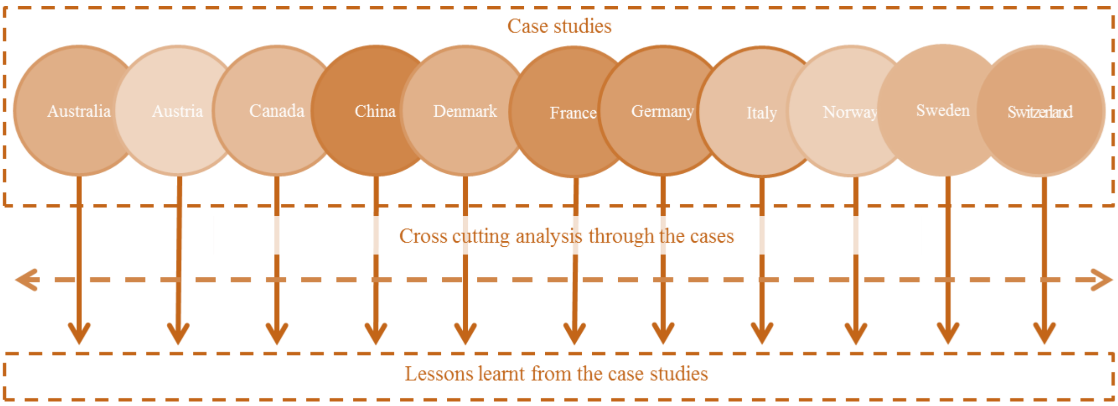

Fig. 1: A scheme of the methodology used for the case studies analysis

The work on education and dissemination in Subtask D started with a review of the present situation (Fig. 2). As a first step, existing courses and software tools in nine countries were surveyed and evaluated. The applied methodologies were based on a developed questionnaire handed out to a broad range of international institutes of urban planning and direct interviews with researchers and academics were undertaken.

An overview of existing software tools within solar energy was generated. These tools where tested and evaluated by students through an urban design task. Various criteria were applied such as usability, integration into other popular 3D modelling software and readability of results. Based on the results, it became evident that there was a lack of existing courses on solar energy in the urban context for students. This formed the basis for the development of an e-learning platform including a software package. This platform was then tested and evaluated during a series of symposia with experts and practitioners.

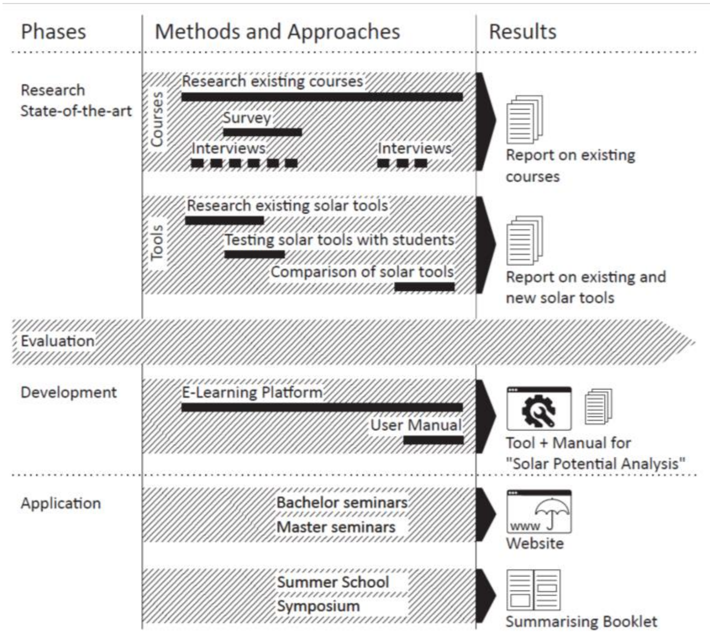

Figure 2: Overview of the methodology and approach concerning education and dissemination (Source: Subtask D, K. Simon)

3. Results

The Task is now in its final stage with some results already published. All results will be available as soon as they go through the review process within the IEA SHC programme. Main results are presented and discussed below.

3.1 Legislation and voluntary initiatives

The current status of solar energy in urban planning regarding legislation and voluntary initiatives were documented from 11 countries. As a starting point, recognition was given that many ancient civilizations have purposefully harnessed the sun's energy to add comfort to living spaces (Butti and Perlin, 1980) and incorporated into the rule of law safeguards to protect its practical inclusion as evidenced by ancient lights proclamations and Greek philosopher Hippocrates's air light treatise enshrining the sensible use of sunlight along with clear air and water. These well-founded learnings have witnessed significant upheaval through the technological innovation of electricity and urban densification pressures and consequently changing planning values and priorities. Urban plans and building widths, building heights, story heights, façade design and window heights did, until the early 20th century, comply with the physics of daylight distribution and natural ventilation (Lechner, 2008). This meant a certain limitation in widths and heights already on an urban level. When electricity and mechanical ventilation started to support the indoor climate as a standard, these limitations were broken and significant knowledge was lost during the second half of the 20th century.

The increased population growth in combination with the environmental gains of walkable and public transport cities, as well as higher real estate prices in the city centre work towards increased density. Increased density will at certain points at different latitudes be counterproductive for energy use, since both electricity demand will rise due to low winter daylight levels and summer cooling loads increase when natural cooling is diminished. The contrasting relationships between building energy use and transport energy use after certain levels of density and urban form have been eloquently presented by Steemers (2003). Research has shown that the relation between density and lower daylight is not linear, but relates to urban and building design. This pinpoints the important role of urban planning in harnessing daylight as a natural source instead of using electricity and also utilising building integrated solar structures for onsite energy generation and thermal shading that does not prohibit natural light entering buildings.

As the deployment of active solar energy systems has grown in cities, the challenge of protecting sufficient solar access into the future becomes more prominent as urban consolidation and densification intensifies (Snow and Prasad, 2011). Within this context is also the critical pursuit of energy-efficient buildings as well as achieving comfortable urban environments (Samimi and Nasrollahi, 2014). Whilst the provision of solar access rights has historically focused on daylight (Lechner, 2014), there is an emerging need to revisit the legal framework and the extent to which it enhances or hinders deployment of sustainable energy technologies. Despite the need to establish a satisfactory legal regime for solar access protection was recognised many ago, the analysis from national perspectives is that the law on this issue is still unsatisfactory. There is considerable scope for legal reform in many countries and the typical subjective judgement of considering solar access under the characterisation of 'nuisance' creates significant investment uncertainty and barriers to uptake that could be remedied by more informed decision-making processes.

3.2 Solar energy in urban planning processes

Urban planning is a political process that exists to balance society's common interests against individual interest mainly when it comes to land use. The political process as well as the planning process differs between national, regional and local contexts (Newman and Thornley, 1996). The smallest common denominator is that all urban planning deals with land use regulation in some way.

The focus of urban planning and the power of land allocation differs somewhat between countries. This implies that the possibility to affect urban planning to implement solar energy to a higher extent differs as well. In some countries, the largest potential may be to influence local planners on the municipal level who have a large influence on the built environment while in other countries the potential may lie with influencing decision makers on a regional or national scale who can more directly influence policy and legal instruments on a wider scale.

A comparison between studied local processes has been carried out by experts which has shown that a generic planning process can be described using a spatial scale. Other aspects that relate to administrative and legal frameworks in planning, i.e. laws and regulations, policies, ambitions, voluntary initiatives etc. are too dependent on local contexts to generalize.

The generic planning process developed in Task 51 involves four stages; 1) comprehensive/strategical planning, 2) urban and landscape design, 3) detailed development plans and 4) architectural design (Fig. 3). Also, approaches, methods and tools (AMTs) have been collected, summarised and related to which specific stage of the urban planning process they are relevant. The AMTs can be divided into four types; 1) regulatory, policy and governance approaches, 2) integrated design and planning support, 3) assessment methods and tools and 4) awareness and consultation methods. Each type is exemplified with existing or newly developed AMTs and relate to the four stages of the urban planning process.

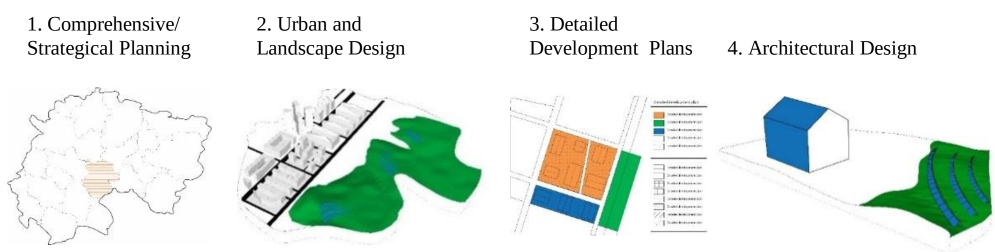

Fig. 3: Illustration of four stages of urban planning

Guidelines for comprehensive/strategical planning

Within comprehensive/strategical planning, visions and strategies to reach certain goals are developed and connected to land use and zoning. Plans can be regional and/or at municipal/city scale. Examples of key considerations and decisions taken at this stage are; visions for cities/municipalities, general land use, larger infrastructure etc.

Comprehensive and strategic planning are often visionary plans stretching 20-30 years, which gives a general direction for a city, municipality or region. They are used to identify potential development areas and the need for larger infrastructure but should also include a clear idea of how to provide the city, municipality and/or region with clean energy. Solar maps are one of the most common and efficient methods of integrating solar energy at this scale, which acts as an inventory of the solar potential in existing urban structures (Kanters et al., 2014). Solar maps can also be used to overlay solar potential with other aspects such as heritage concerns, energy infrastructure, future renewable energy goals and the impact of new urban developments on existing urban fabric. As active solar and daylight will become more and more present in urban planning, there is a need for targets, goals and assessments in early comprehensive and strategic planning stages.

Guidelines for urban and landscape design

In the urban and landscape design stages, the urban fabric and morphology is decided for a city district and for a landscape area. Examples of key considerations and decisions taken in this stage are street widths, volumes, typologies, spatial patterns and orientation.

New urban environments

Planning of new urban environments in the 21st century requires focus on the need for energy efficient design and an energy generating built environment. Urban planning is complex, and there is a need to bring in the relevant aspects at stake at the right stages of the planning process. This is in order to support spatial planning and energy, both relating to free energy such as daylight and to active solar, such as solar thermal and photovoltaics, for future urban development and renewal projects. In situations where new urban areas lack existing energy infrastructure, the possibilities for including solar energy are at their most favourable and the design scheme will be crucial.

The role of the urban planner is to design areas that can be built to last. For different reasons, solar energy installations may not be feasible when the area is designed, but buildings change over time while typologies and the urban fabric tend not to. An urban design that does not include solar energy considerations today may effectively hinder it in the future.

Major aspects that have a large impact on solar energy potential are density, street widths, building heights, roof angles i.e. the typology of an area (Kanters, 2015). Today the solar energy potential can easily be estimated through rough simulations from early drawings to more detailed models. A rule of thumb is that the more complex the model, the more complex the simulation.

In urban areas, solar energy also needs to be considered from a load matching perspective. Load matching implies that the solar energy generation is compared to the energy use of buildings and neighbourhoods (Voss and Musall, 2011). This is meaningful because solar energy in urban areas is most relevant when the generated energy is used locally rather than exported to the electrical grid or a district heating system. Criteria for load matching evaluation annually can easily be estimated through a comparison between local energy performance standards and a solar potential study although it is also important to consider seasonal and daily variations in energy use and potential energy generation. In e.g. northern latitude countries this is imperative as energy use peaks at night and in winter while solar energy generation peaks during the daytime and in summer.

Urban typologies also have a huge impact on daylight access both inside buildings but also on streets and public spaces. Studies and research show that different urban design proposals for the same density give very different daylight conditions and that the daylight design aspect on urban and building design scales are crucial for daytime, sunlit areas in dense areas (Baek Pedersen, 2009; Sattrup, 2012).

Existing Urban Areas

The existing building stock will have the biggest impact regarding climate emissions from operational energy use for the foreseeable future due to the high energy use compared to new buildings. Currently, most of the attention is devoted to the reduction of energy needs, but the transition towards a more comprehensive renovation including localized renewable energy generation is imperative. Prices for solar technologies are dropping and regulations are encouraging local energy generation. More than half of the global PV capacity from now to 2050 will be installed on buildings (IEA, 2014), producing a little less than half the total PV electricity needed. There is a risk that such a massive deployment will sometimes lead to prioritising only the return of investment for private owners through a solar refurbishment, which is often riskier and less lucrative than early-design implementation for a new settlement.

This deep intervention on the urban morphology requires a rational method to properly organize the arrangement of installations according to site characteristics and a compromise between heritage protection, energy and spatial planning. A match between building energy needs, solar energy generation potential and site identity has to be aimed to tailor coherent strategies of solar refurbishment and define homogeneous zones with particular architectural integration quality requirements.

In order to deal with the local energy production, new methods and tools have been introduced into urban planning, such as assessment methods supporting urban planners and real estate owners in estimating the solar potentials of existing built surfaces. One major outcome of this Task is the LESO-QSV Method (Fig. 4), which is based on the above (Munari Probst and Roecker, 2015).

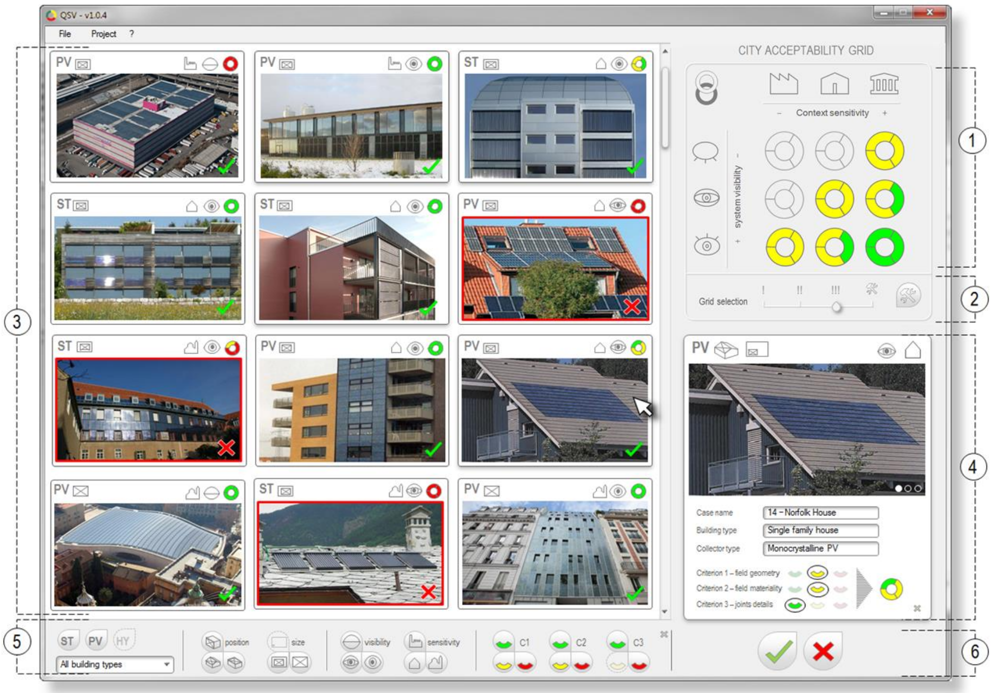

Fig. 4: Main screen of the LESO-QSV GRID program: 1 - Acceptability grid of the specific city: i.e. required integration quality for each criticity level (system visibility; context sensitivity). These are the criteria to be met for the installation to be accepted; 2 - Acceptability grid setting bar (for municipality use only): integration requirements can be selected by using pre-established grids (more or less severe), or built to measure; 3 - Integration examples showcase: a database of more than 100 cases is shown according to the selected filters setting (5). This showcase is meant to: help municipalities to set a convenient acceptability grid by showing the impact in acceptancy of pre-defined sets of quality requirements; work as a model for authorities for how to objectively evaluate integration quality; inspire architects, installers, building owners; 4 - Case details window: The window appears while clicking on a specific case. The detailed evaluation of quality becomes visible, together with other more precise information and additional pictures of the case; 5 - Filter bar: The case studies can be filtered according to solar system type, position, dimension, context sensitivity, system visibility, integration quality; 6 - Accepted / not accepted cases button filter. (Source: Maria Cristina Munari Probst and Christian Roecker)

Guidelines for detailed development plans

Detailed development plans set the implementation conditions for the urban design, and the land use is regulated into legally binding documents. Examples of key considerations and decisions taken in this stage are maximum building height, limitations on material choices and type of building (residential, office, school etc.).

Detailed development plans are legally binding documents that set the prerequisites for the building design in contrast to the more visionary process in the urban design stage. An important factor here is a meaningful dialogue between urban planners, the local authorities (both planning and building permit offices) and developers and real estate owners. Academic institutions and research institutes have proven to be front runners in driving and facilitating stakeholder dialogue and incorporating new solutions into urban planning. Since planning traditions vary and this is bound by local planning traditions and legal frameworks (Newman and Thornley, 1996), it is difficult to give general advice.

Experiences have shown that specific requirements often attached to land procurement deals have in some cases proven an efficient approach to introducing solar energy in urban areas. Also, since the interest for solar energy is growing rapidly the concept of “solar rights” or “right to light” will probably need to be considered by many urban planners in the near future. Solar rights work differently in different contexts but involves cases where an existing building becomes shaded by a new building which can affect either daylight and sunlight access or energy output from a solar energy installation.

Guidelines for architectural design

At the architectural design stage, new and existing buildings or landscape integrated systems are designed, new or altered. Examples of key considerations and decisions taken in this stage are architectural composition and pattern/surface/facade design.

New buildings

The integration of solar energy in buildings has been studied extensively through the completed IEA SHC Task 41 – Solar Energy and Architecture. More information about this can be found here http://task41.iea-shc.org/. Also, a webpage on innovative solar products is available showing examples for building integration as continuation from the project IEA SHC Task 41 (Munari Probst et al, 2012; Wall et al, 2012).

Existing buildings

The reduction of building energy use and the replacement of fossil energy by renewables have become priorities for authorities and planners. As active solar is entering, architectural alteration, materiality, geometry and detailing in buildings can be affected, resulting in new forms of architectural expression which are slowly modifying our existing city landscapes. The increased use of active solar systems in buildings is necessary, but clearly poses major challenges for existing environments. The large size of solar systems at the building scale asks for thoughtful design, as these systems otherwise may end up compromising the aesthetics of the buildings, and may affect the identity and the quality of entire contexts. Luckily, good architectural integrations are possible also in the most critical situations, but they clearly need appropriate design and economic investments. A good knowledge of basic solar physics, of simple dimensioning tools for early design phases and currently available products designed for building integration can be very helpful for this purpose.

Before aesthetic standards can be established, objective criteria need to be developed. While it is often thought that aesthetics is a matter of taste, recent studies confirm the existence of clear criteria against which the suitability of solar power installations can be evaluated. Solar installations can be made qualitatively, evaluated through three simple and objective criteria: the project’s geometry, materiality and modular pattern. These criteria provide a framework for assessing how harmoniously an installation fits into the surrounding urban environment. In several cities in Scandinavia, guidelines for stakeholders seeking building permits have been published with advice from IEA SHC Task 41 and in relation to the architectural guidelines regarding respect of existing qualities in the built environment. With additional support from the LESO-QSV method, several reference examples can be consulted. The method can also be used to create a “criticity” grid identifying different situations for which the municipal authorities will set quality standards in view of local considerations.

Approaches, methods and tools for solar energy

Urban planners are typically generalists who have to consider many different aspects. It is important that methods, tools and approaches are designed to aid urban planners in their work rather than increasing their workload. There exists a large amount of software tools today where solar insolation of an urban area can be calculated and visualised, but there is a lack of approaches and methods of how to integrate the results from such tools into traditional urban planning processes. The software tools available also vary in complexity, user friendliness and quality of end result. Extensive work has been carried out in developing approaches, methods and tools that aid in understanding solar potential in an urban planning context as well as defining which level of detail potential studies need to be at in different phases of urban planning. Generally, in early phases, such as comprehensive and strategical planning as well as urban design on a city district scale, the potential studies can be quite rough as many parameters can change later on while in latter phases such as building design, the potential studies need to be more detailed.

3.3 Lessons learnt from the case stories

Case stories provide an international overview of different types of examples where solar energy in urban planning is applied in new, existing and landscape areas. The case stories reflect the objective of Task 51 with cases placing different emphasis on legislation, education and approaches, methods and tools. In addition, case stories indicate other influencing aspects for solar energy in urban planning such as economy and the role of stakeholders. Table 1 below outlines which cases emphasize the aforementioned aspects featured in Task 51.

Solar energy does not necessarily feature in legislation, but is often one of the options to help meet national energy reduction targets. Legislation played a key influential role in many of the case stories but also there were indications that legislation could go further to incentivize solar energy in urban planning. For example, solar landscape case stories offered creative opportunities to overcome restrictive legislation by exploiting the dual use of agricultural land as a cheap alternative for a common use of food production and to generate energy from large scale solar energy systems.

The use of public institutions to aid the take-up of solar energy other than legislative governing bodies is through educational institution. Education was important for case stories as a mechanism to ensure professionals of urban planning have the knowledge and skill to consider solar as an option for renewable energy solutions for a district. However, there is still some ground to cover in education in terms of raising awareness of how to implement solar energy into an urban area. There were indications in responding to the 'how' questions in the case stories. One approach are holistic approaches of involving all relevant stakeholders of urban planning. This involvement extends to citizen engagement, which is crucial in building agreements, understanding and achieving solutions. This approach ensures wide representation of stakeholders and increases the chances of reaching ambitious goals by overcoming barriers in developing solar energy in urban planning through an open communication forum.

Approaches, methods and tools are key instruments from which design and energy strategies can be formulated to achieve the optimum solutions for implementing solar energy in both new and existing urban environments. All case stories used both technical and non-technical approaches, methods and tools, thus highlighting the need for a multidisciplinary attitude to contemplate appropriate solutions of solar energy in the complex environment of urban planning. Indeed, case stories highlighted that the planning process for solar energy is complex with consideration on how solar energy can contribute to the development of the area as well as work within the confines of an allocated area where options for design may be limited. Examining the potential and use of design expertise are essential steps in the planning process and should include local conditions and context, in particular, the scale of the area, options for design layouts as well as technical knowledge.

Finally, economy is influential in developing different solar energy solutions, as there are diverse economic factors. These economic factors include affordability of urban areas; the energy market; available financial incentives; financial benefits of introducing solar as a single solution or an integrated solution. There are also solar group purchase initiatives which motivate small property owners to realize solar installations while reducing investment costs. Above all, the case stories exemplify the scope and possibilities for implementing solar energy in urban planning on a global scale, which is beneficial both for the environment and for the societies living in urban areas.

Tab. 1: Type of lessons learnt found in the case stories

Lessons learnt	Case stories
Legislation	Freiham Munich Nord, **Germany**; Lund Brunnshög and Malmö Hyllie, Uppsala Frodeparken, **Sweden**; Le Albere, Agrovoltaico, **Italy**; The Eco Neighborhood of Ravine Blanche, The sustainable city of Beauséjour, Agrinergie 5, Lyon Confluence, **France**; VerGe project - Lugano-Paradiso, **Switzerland**; Sarnia Photovoltaic Power Plant, **Canada,** Zero Emission Office Building, **Norway**.
Education	Øvre Rotvoll, **Norway;** Lyon Confluence, **France**
Stakeholder and researcher involvement	aspern+ Die Seestadt Wiens, Stadtwerk Lehen, Graz Reininghaus, **Austria**; FredericiaC and Gehry City Harbour, **Denmark;** Residential Plot B45, **China**; The Eco Neighborhood of Ravine Blanche, **France**; Dale, **Norway**; VerGe project - Lugano-Paradiso, **Switzerland**.

Economy	Energy Innovation Solar Purchase Group, **Switzerland**; Freiham Nord Munich, **Germany**; aspern+ Die Seestadt Wiens, **Austria**; Violino District in Brescia, **Italy**; Solar in Halifax Regional Municipality, **Canada**; Dale, **Norway**; Sarnia, **Canada**; Solar District Heating Brædstrup, **Denmark**; Agrovoltaico, **Italy** and Agrinergie 5, **Reunion Island, France.**
Planning process	Solar District Heating Brædstrup, FredericiaC, Gehry City Harbor in Sønderborg, **Denmark**; Lund Brunnshög, Malmö Hyllie **Sweden**; Photovoltaic Village in Alessandria, **Italy**.

3.4 From research to education

A state-of-the-art of education on solar energy in urban planning in nine countries was carried out and summarised in two different parts. Part 1 on approaches and methods in education showed through a survey that solar energy as it relates to urban planning was rarely part of the curriculum at universities. The identified courses are instead mostly offered in other disciplines. Technical aspects, especially on the architectural level, are taught in most of the courses, particularly in the undergraduate level. The main reason for these shortcomings is the short duration of the relevant courses during the studies. Due to relevant aspects in the planning of sustainable settlements, usually the subject of solar integration is only addressed on the periphery during urban development design assignments (Siems et al., 2017a). The identified continuing professional development (CPD) programmes generally dealt with key aspects, such as climate change, and not specifically with solar energy in urban planning. In Part 2 of the review, solar tools in education are discussed and experiences in using the selected software tools in university are compared. The differences among the analysed software tools are large, both in functional scope and operation. Only the software plug-in DIVA for Rhino3D achieved high marks of usability and precise calculation results. Its short initiation period for new users, its high computing power, and its visual results in the form of false-colour imaging makes this tool eminently suitable for use in training and continuing education. However, number-based output of the calculation results for further use in other software tools and a version for the Mac OS would be welcome.

The identified gaps and barriers in existing courses and pedagogy provide knowledge that can be implemented in relevant seminars, lectures and tools for educating the next generation of architects, urban planners and specialist planners by developing a web-based platform. Therefore, a tool, called Solar Potential Analysis for both students and life-long learning was created. The software tool itself is accompanied by a detailed user manual. The entire software package is free to use without limitations. The goal of this web-based platform is to help students to integrate solar energy in their design projects by providing relevant materials such as explanations, tutorials, illustrations etc. One part of this is the open source tool "Solar Potential Analysis" which allows for analysis of solar potentials and visualisation of the results as false-colour images. In parallel with the digital software tool, a set of manual tools such as "register cards" were designed for bachelor and master courses to aid exercises and seminars in relation to solar energy. The set will be freely available online to download.

The University of Wuppertal organised an interdisciplinary summer school to educate students from various disciplinary backgrounds. Such summer schools and courses provide valuable input to improve teaching methods and assessment tools for solar energy planning such as the tool "Solar Potential Analysis" and the developed manual set of tools. Teaching methodologies and results from the summer schools were documented in a booklet (Siems and Simon, 2017b).

4. Conclusions and outlook

There is considerable scope for legal reform in many countries as to solar access protection. Planners are increasingly calling for more sophisticated decision support tools to assess active solar energy potential and measures to determine the impacts of future development, the range of technological options that may more readily accommodate shade impacts as well as aesthetic solutions. This is becoming more important as solar energy targets are being pursued in an aim to transition to low carbon cities to build resilience. It also allows building owners utilise their solar access assets to harvest energy and reduce their exposure to external energy price variability and supply constraints. Ultimately, the research found that active solar systems have a critical role to play and their deployment will conflict with future development heights if there is not a more cohesive relationship between planning approval processes and building innovation.

There is more work needed that aims to help urban planners and designers in understanding the complexity in dealing with daylight, active solar and energy performance in cities that are rapidly densifying. The role of the urban planner is to design areas that can be built to last. Urban design that addresses the need for daylight and sunlight will not only contribute to a healthier urban environment, it will also enable photovoltaics and solar thermal technologies to be implemented if not now, in the future.

The case stories illustrate that while technical and non-technical aspects of solar energy are important, they are still often considered as separate entities. However, within the complexity of urban planning, these entities are part of a holistic picture. The development of urban areas takes into account social contexts, economic frames, legislative constraints/enablers and stakeholders' expertise and/or access to expertise. The integration of solar energy in urban planning requires taking into account complexity and the need for holistic approaches.

The research also illustrated the importance of introducing solar with systematic respect to the urban context to preserve heritage and avoid unnecessary aesthetic conflicts. There is a risk if these aspects are not taken seriously that the social acceptance of solar technologies may decrease and in the long run slow down the pace of solar utilisation.

With increasing global population growth, cities will require more resources while at the same time renewable energy sources are expected to expand rapidly and the needed land to support cities can be expected to increase. Renewable energy systems are set to be a major land use in the near future and more research is needed to understand the environmental and social impacts of these systems and how rapidly growing cities affect the land use in the immediate surroundings.

Teaching at universities and colleges cannot be considered separate from research or practice. Creating a connection between the areas of "research and teaching", as well as between "research and practice" is an essential integral objective for research projects. Therefore, research is used as a connective link between teaching and practice and/or the public with far-reaching impacts. Researching new insights is not the only important factor here, but also information exchange and dissemination. Education and dissemination need to be strengthened to rapidly ensure that knowledge and support are offered for present and future professionals and educators. The research results should be disseminated through a public and easily accessible platform. The work of Task 51 will hopefully support such developments and knowledge transfer.

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