Solar Energy 184 (2019) 672–687

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Criteria and policies to master the visual impact of solar systems in urban environments: The LESO-QSV method

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ARTICLE INFO

Keywords:
Urban acceptability
Solar policies
Architectural integration quality
Visual impact
Solar map
Criticity

ABSTRACT

Increased use of solar collectors in buildings is necessary but poses major challenges in existing built environments, especially where architectural quality is an issue. The large size of solar systems at the building scale requires careful planning, as they may easily end up compromising the aesthetics of buildings, threatening the identity of entire contexts. A new method named LESO-QSV(for Laboratoire d'Energie SOlaire – Qualité-Sensibilité-Visibilité) has been developed to help authorities promote solar energy use while preserving the quality of pre-existing urban areas. The vision underlining the approach is that solar integration is possible also in delicate contexts, if appropriate design efforts and adequate cost investments are made. The issue is then no longer to be in favour or against the use of solar systems in cities, but rather to define appropriate local levels of integration quality, and to identify the factors needed to initiate smart solar energy policies able to preserve the quality of pre-existing urban contexts while promoting solar energy use.

The LESO-QSV method helps tackle these issues with clear and objective proposals:

First it clarifies the notion of architectural integration quality and proposes a simple evaluation method, based on a set of criteria derived from pre-existing literature.

Then it helps authorities set and implement local acceptability requirements, introducing the notion of architectural "criticity" of city surfaces (LESO-QSV acceptability). The concept of "criticity", at the basis of the whole approach, is defined by the Sensitivity of the urban context where the solar system is planned, combined with its Visibility (close and remote) from the public domain. The more sensitive the urban area and the more visible the system (high "criticity"), the higher the need for integration quality. In practice, authorities will be in charge to set the desired integration quality levels for each of the defined "criticity" situations, considering local specificities (energy context, available energy sources, political and social considerations, city identity and topography, among others). To help authorities set these quality expectations, the software LESO-QSV Grid has been developed. It illustrates the acceptance impact of pre-defined sets of quality requirements, using a large number of integration examples (150 emblematic cases). These detailed examples are provided to show authorities how to objectively evaluate integration quality, but they also constitute a large set of learning examples, good and bad, for architects, installers and building owners.

Finally the method proposes a way to tailor solar energy policies to local urban specificities by mapping the architectural "criticity" of city buildings surfaces, and crossing this information with a city solar irradiation map (LESO-QSV crossmapping), hence completing the characterization of the building surfaces with the potentially required effort of integration.

1. Introduction

In the last decade global warming has become a major concern for the community, leading political authorities to take increasingly drastic actions in order to achieve energy savings and encourage the use of renewable energy sources. In the built environment these new concerns have led to the introduction of strict energy standards whose requirements continue to rise.

In Switzerland, many standards and regulations have been established, both voluntary (Minergie, Minergie P, Eco, A) and mandatory (SIA 380/1), clearly indicating a trend towards a zero energy balance of buildings.

In Europe, the framework is equally strict. A recent directive of the European Parliament rules that from 2020 onwards, each and every

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https://doi.org/10.1016/j.solener.2019.03.031
Received 21 September 2018; Received in revised form 26 February 2019; Accepted 10 March 2019
Available online 17 April 2019

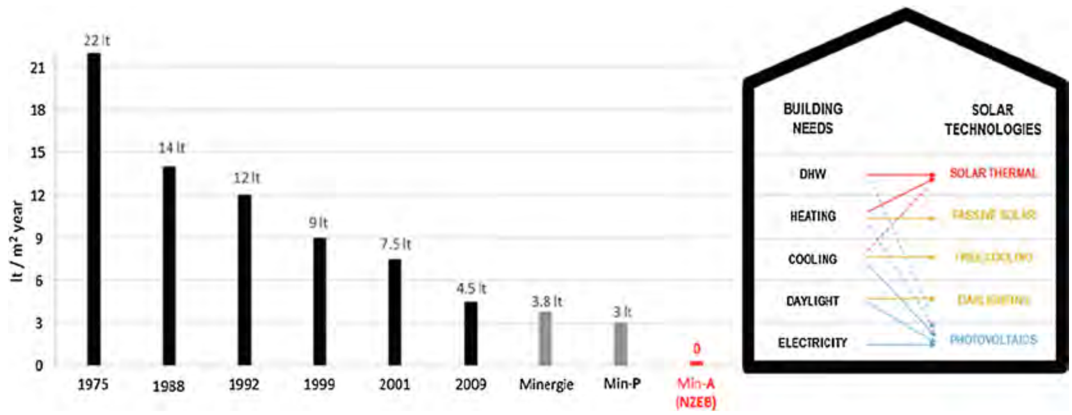

Fig. 1. Left: Building energy evolution (Switzerland); Right: Available solar technologies in relation to the different energy needs.

new building will have to meet the requirements of the NZEB standard (Nearly Zero Energy Building). For public buildings these requirements will have to be fulfilled starting January 2019. As stated by the Commission, "Nearly zero-energy buildings need to have very high energy performance", and "The low amount of energy that these buildings require has to come mostly from renewable sources". (Directive 2010/31/EU European Union Parliament).

In order to meet these new standards, it will no longer suffice to cut heating needs through an effective insulation of the envelope – it will also be necessary to plan and enforce new, long-lasting strategies for the production of operational power.

Its abundant availability and flexible use makes solar energy naturally one of the resources that we will turn to in priority (Fig. 1, left).

A combination of passive and active solar energy is in fact able to meet the various energy requirements of buildings in an effective and economically sustainable way (Fig. 1, right):

– appropriate daylighting strategies are able to decrease artificial lighting needs to a minimum;
– passive collection of solar energy through windows can cover a very large part of heating needs;
– solar thermal collectors are an excellent solution to produce hot water, for domestic use and space heating.
– photovoltaic modules can provide the power for household appliances and lighting, and can also operate a heat pump.

Clearly though, a consistent implementation of all these strategies will not be possible without a global architectural reflection. On the one hand, the position and size of openings play an essential part in lighting and passive heating strategies; on the other hand, the size of active solar systems is such that these systems have a major impact on building appearance (Dessi, 2013). As much as new insulation requirements have changed the way the materiality and language of the envelope are conceived, the use of solar technology will have a radical influence on the layout of buildings' exposed surfaces. Without the skills needed to integrate these new elements in a consistent design, the result will fail to be satisfactory from an architectural point of view.

2. Energy versus architecture?

The new energy regulations and mandatory solar fractions for electricity and domestic hot water are introducing new materialities and geometries in buildings, which are leading to new forms of architectural expression that will slowly modify our city landscapes. NZEB designers most often choose a compact geometry (optimizing the *heated volume/envelope losses* ratio) and then need to artificially expand the envelope surface to intercept a higher amount of solar radiation and convert it through dedicated solar devices into electricity or heat (Fig. 2).

This increased use of active solar collectors in buildings is clearly necessary and welcome, but brings major challenges, especially in already existing built environments. The large size of solar systems at the building scale asks for thoughtful planning, as these systems may end up compromising the quality of the building, threatening the identity of entire contexts (Fig. 3).

Accepting to sacrifice architectural quality to promote solar spread can be very counterproductive, leading right to the opposite effect in the long term. Animated discussions are already ongoing in most cities between "solar pros" on one side, concerned by the urgency of maximizing renewable energy use and asking for total freedom to install,

Fig. 2. New Solar Buildings (left: 3M office building, Milan, M.Cucinella; right: Endesa pavilion, IAAC, Barcelona).

Fig. 3. Solar renovation at Schloss Walbeck-Castel, Germany (XVIII century).

and architects and building heritage institutions on the other side, expressing their worries about the urban impact of such systems and asking for a restriction of their use to certain urban contexts only.

3. The LESO-QSV mediation solution

De facto, both concerns of maximizing solar energy spread and protecting the architectural quality of the built environment are justified, and both should possibly be satisfied at the same time.

This is even more true when *considering* that good architectural integrations can often be possible even in very critical contexts, under the condition that appropriate design and cost investments are made (Fig. 4).

Starting from these considerations, and convinced that the development of solar energy in cities is one of the prominent challenges of the near future, we looked for an "inclusive" solution adressing Energy and Architecture.

As the issue is then no longer to be in favour or against the use of solar energy systems in cities, we propose to define minimal local levels of integration quality, and to identify the factors needed to establish smart solar energy policies able to preserve the quality of pre-existing urban contexts while allowing solar energy use.

The **LESO-QSV(Quality-Sensitivity-Visibility)** approach (Munari Probst and Roecker, 2011, 2015) gives clear and objective answers in this debate:

(a) First it introduces the innovative notion of "Architectural criticity" of city surfaces, in relation to their need for integration quality (see Section 4).
(b) Then it clarifies the notion of "Architectural integration quality", proposing a simple and objective evaluation method (see Section 5);
(c) Based on a) and b) it helps authorities set and implement precise "Local acceptability requirements" ("*LESO-QSV acceptability",* see Section 6);
(d) d) Finally it proposes a way to tailor "Solar energy promotion policies" to local urban specificities by combining architectural "criticity" and solar irradiation information ("*LESO-QSV-crossmapping*",

Fig. 4. Photovoltaic system integrated on the roof of Aula Pierluigi Nervi, Vatican.

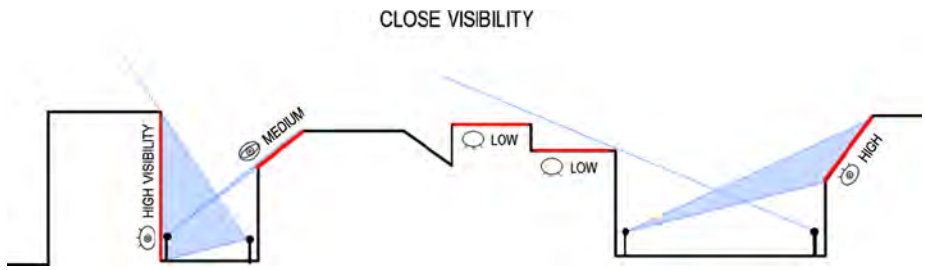

Fig. 5. Visibility of city surfaces from the public domain.

see Section 7).

4. Architectural "criticity" of city surfaces

Good integration quality is always desirable, but not always crucial, or even necessary. To facilitate the spread of solar energy, expectations toward integration quality may be reduced where the perceived impact of the installed system on the urban quality is lower.

In order to structure this idea, the new concept of "*criticity*" of city surfaces is introduced, which is at the basis of the whole LESO-QSV approach. The "criticity" of a surface defines the impact that modifications on that surface can have on the perceived global quality of the context.

Two main factors are defining the criticity of city surfaces: the architectural sensitivity of the building/urban context of the surface location, and the visibility of that surface from the public domain.

4.1. System visibility

The visibility of the surface from the public domain is one of the two factors influencing criticity. The higher the visibility of the surface from the public domain, the more important its impact on the perceived context identity. As for the context sensitivity, visibility is articulated into three levels *High*, *Medium* and *Low*. The visibility has two components: visibility from close range (*close visibility*) and from far away (*remote visibility*) (Figs. 5 and 6).

For the first one, the determining elements will be the geometry of the buildings and of the public space, while the second will be influenced by the topography of the city and its surroundings.

A detailed description of the practical ways to assess the visibility of city surfaces and the impact various city configurations have on this factor is given in Appendix A**.** An automatized geometric calculation tool is also under development at Ecole Polytechnique Fédérale de Lausanne (EPFL). The first promising results are presented in a PhD thesis just completed at EPFL (Florio, 2018).

4.2 Context sensitivity

The pre-existing quality of an urban context/building clearly influences the level of quality we can expect an integration to fulfil. If the pre-existing context has no clear identity, nor other specific architectural qualities, it is not pertinent to ask for a perfectly designed and integrated solar system. By contrast, it seems very important to push for integration quality in valuable areas or buildings.

To practically structure the issue, the QSV method proposes to classify the sensitivities of existing contexts into 3 categories:

- ***High*** sensitivity (heritage protected or meaningful contexs/buildings);
- ***Medium*** sensitivity (contexts/buildings with no specific architectural/urban qualities, but with a meaningful identity for the community, like most post world war residential or tertiary urban developments);
- ***Low*** sensitivity (contexts with poor urban/architectural qualities, and no specific identity, like many recent industrial/commercial urban developments) (Fig. 7a–c)

This categorization is meant to be coherent and coordinated (even if simplified), with both the city zoning defined in the building regulation codes, and the official categorization of protected areas and buildings released by national and regional Heritage commissions (Fig. 7d).

In a situation of rehabilitation or new affectation of a neighborhood the sensibility categorisation should clearly refer to the *projected* quality level planned by the authorities, and not to the present status.

4.3. Derived "criticity" matrix

To structure the issue of architectural criticity of city surfaces and related needs for integration quality, a matrix**,** called "*criticity grid*", is established by crossing the three identified levels of visibility (low-medium-high, Figs. 5 and 6) with the three identified levels of sensitivity (low-medium-high, Fig. 7), defining nine different criticity situations for which quality expectations will have to be set (cf. chap. 6). As shown in Fig. 8, the matrix displays a "criticity gradient" of increasing sensitivity, from the top left corner to the bottom right.

5. Assessing architectural integration quality

Requesting a certain level of integration quality implies being able to assess quality. Often this is considered a matter of personal taste, but recent studies have confirmed the existence of implicit criteria shared by the architects community and actually leading architectural

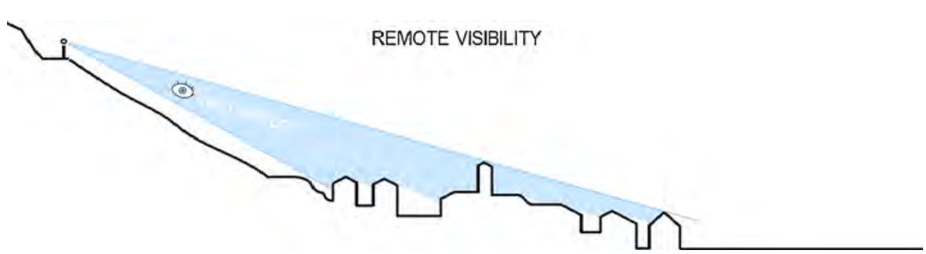

Fig. 6. Remote visibility is influenced by city topography.

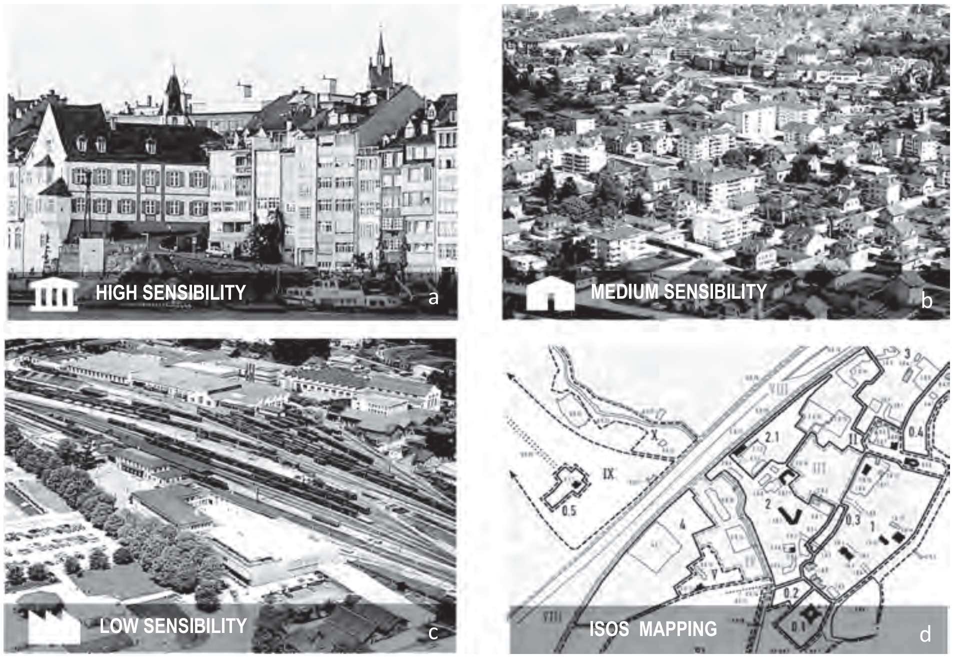

Fig. 7. (a, b, c) different degrees of sensitivity of existing urban context – (d) Swiss ISOS offcial mapping of heritage protected enclosure.

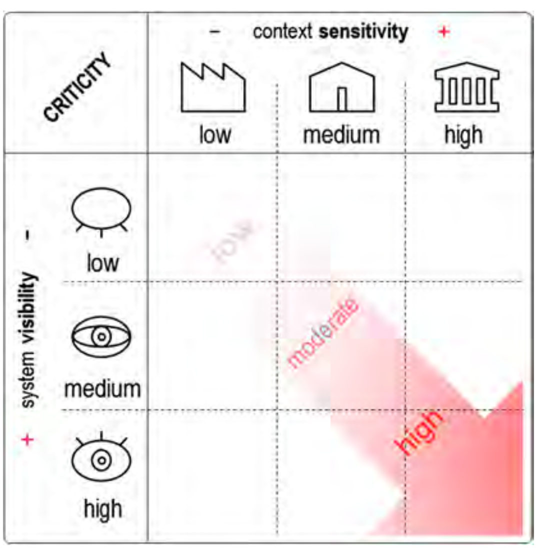

Fig. 8. Criticity matrix and gradient.

integration quality perception (Krippner and Herzog, 2000; Munari Probst, 2008; Munari Probst and Roecker, 2012).

To be perceived as integrated, the system has to be designed as an integral part of the building architecture. This means that all the *formal* (i.e. visual) *characteristics* of the solar energy system, have to be coherent with the global building design logic (Munari Probst, 2008):

- ***collectors field size and position***
- ***visible materials***
- ***surface textures***
- ***colours***
- ***modules shape/size***
- ***jointing system***

Identifying these key characteristics opens the way to an objective evaluation procedure.

5.1. Evaluation procedure

Based on these findings the LESO-QSV approach proposes a simplified qualitative assessment method, grouping the above described integration characteristics into three global sets of characteristics, leading to three integration criteria. This makes the procedure lighter while keeping the evaluation as objective as possible (Fig. 9).

The quality evaluation consists then in assessing separately the level of coherence of the three sets of characteristics with the global building logic – coherence of the *System Geometry*, the *System Materiality* and the *Modular Pattern* - using a three-level scale (fully coherent - partly coherent – not coherent).

This allows to concentrate sequentially on the specific characteristics of the integration while evaluating their level of coherence:

- First the *system geometry* is evaluated, considering the size of the collectors field, its shape and its position in relation to the building.
- Second, the coherence of the *system materiality* is evaluated, considering mainly the colour, texture and reflexivity of the modules.
- Finally, the pattern formed by the juxtaposition of modules and their jointing system is considered, to rate the coherency of the *modular pattern.*

(In the cases where the most critical visibility situation is the *remote visibility* (§ 4.1, Fig. 6) this last criteria can often be validated as *fully coherent*, as the *modular pattern* is no longer perceived from afar.)

This being a global qualitative evaluation, the partial results cannot be expressed by numbers and cannot be synthesized in a single mean value; hence the choice to represent each partial evaluation as a coloured arc of a circle (green, yellow or red, according to the level of coherency) to be combined with the others to form a complete three sectors circle expressing the global system quality (Fig. 9).

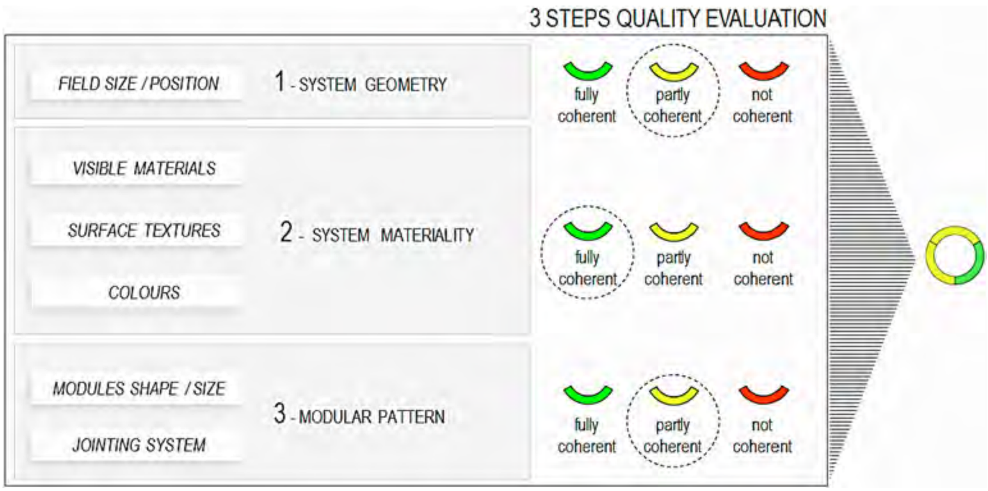

Fig. 9. Integration quality evaluation method: criteria grouping – sectors evaluations– resulting quality circle.

Fig. 10. Different levels of "**System geometry**" coherency.

5.2. Criteria evaluation examples

The following examples show the system evaluation principles applied to existing cases, demonstrating the idea of separate evaluations for each of the three global criteria (see Figs. 10, 11 and 12).

Fig. 11. Different levels of "**System materiality**" coherency.

Fig. 12. Different levels of "**Modular pattern**" coherency.

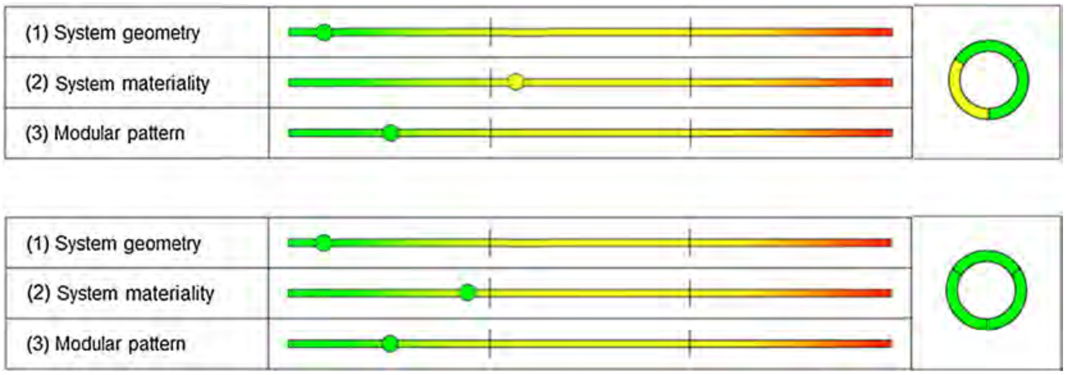

Fig. 13. Continous vs discrete scale evaluation: explaining apparent discrepancies.

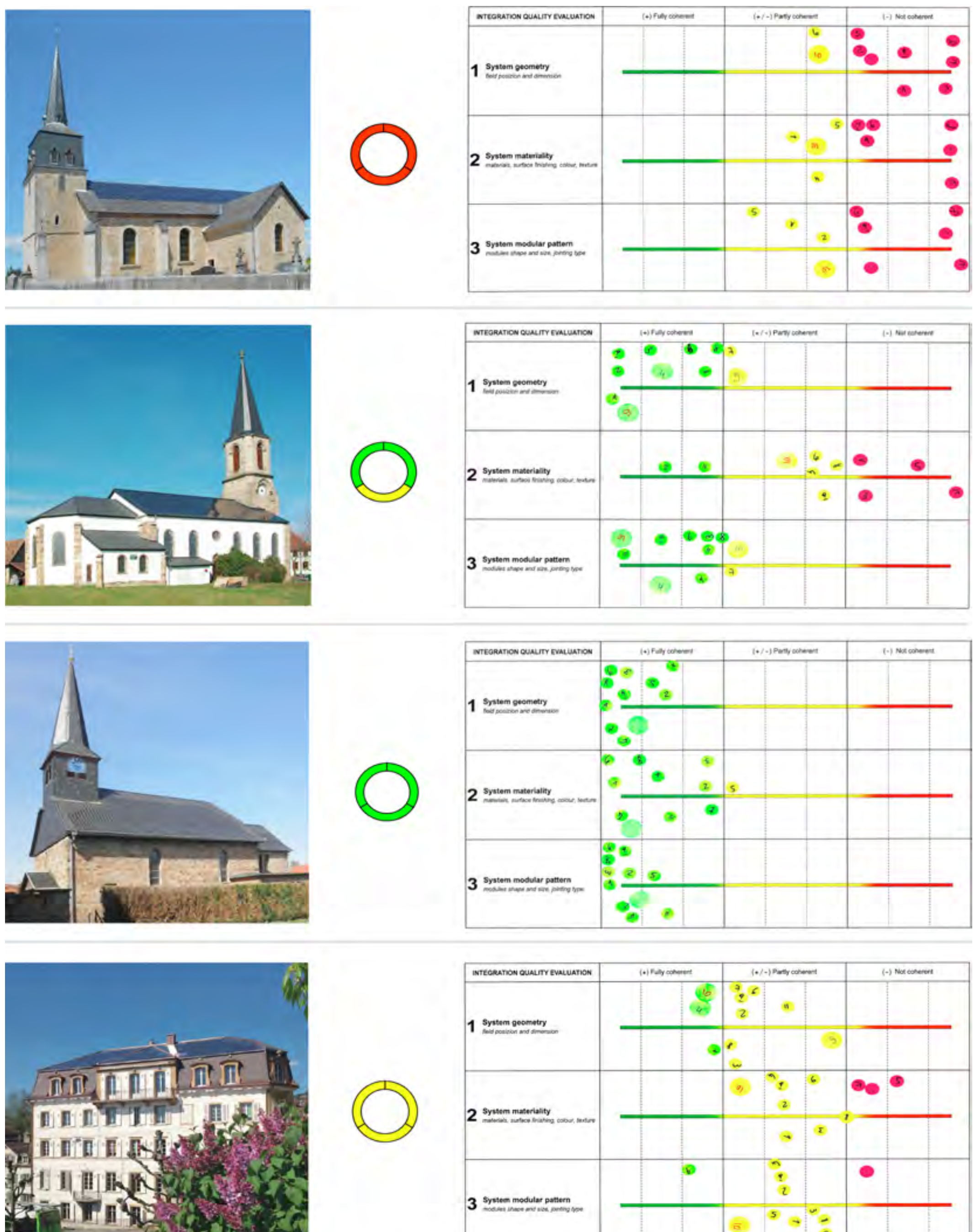

Fig. 14. Discrete vs continous evaluation scale and examples of cross evaluations by MAS students in Architecture.

5.3. Evaluation scale, discrete vs continuous

Proposing only three discrete values for qualifying the integration has the major advantage of greatly simplifying the tool, but it somehow reduces the possibilties of nuancing the appreciation**.**

To evaluate the impact of this simplification a continuous scale has been proposed to take this aspect into consideration (Fig. 13). This allows to evaluate the integration using the continous scale and to then read the result considering the three coloured "zones", giving the discretized evaluation score.

The continous scale helps evaluators set the discrete values, and can also explain why two expert's evaluations, once discretized, can slightly differ on particular cases.

The closer the "linear" evaluations are to a limit, the higher the risk of getting different discretized appreciations. For example, the closer a green evaluation is to the yellow zone for an expert, the higher the chances of getting different results (green or yellow) when the case is analysed by a different person (Fig. 13 *System materiality*). The approach was effective, as shown in the validation section below.

5.4. Validation

To validate the process of quality evaluation, the approach has been tested in several academic courses and seminars dedicated to solar integration and has been used as teaching material (Munari Probst and Roecker, 2009; Munari Probst, 2015a,b).

Participants were asked to individually evaluate integration cases, placing coloured stickers on the linear scales. As shown in the examples in Fig. 14, while not totally uniform, the participant's evaluations showed a very good general coherency, well validating the approach. A relatively low spread due to subjectivity and to the qualitative character of the evaluation process still does exist, but it indicates rather a variability in the intensity than a fundamental difference in perception. This procedure can be very useful when operating within specialized commissions having to find a consensus over the evaluation of delicate situations/objects.

Altogether this shows that the method can be considered reliable, and the discretization into a three-value scales a satisfactory practical choice.

A complete "case description and evaluation" sheet has also been developed, which uses the adapted version of the continuous-discrete evaluation scale (Section 6.2, Fig. 17).

These sheets are used within the Grid Software (Chapt. 6.1) and for education purposes (Chapt. 6.2)

6. "LESO-QSV Acceptability"

With a reliable method to evaluate integration quality finally available, quality expectations can be set for each criticity situation (see Chapter 4).

However, the quality level to be required for each criticity situation of the matrix is neither absolute nor constant, but depends on many local and temporal factors, such as city identity and image, energy context, availability of other renewable energy sources, quality and availability of market products for good integration solutions, political orientation, economic structure, etc.

For this reason the method does not provide one set of absolute quality requirements, but offers flexibility.

A specific tool, the LESO-QSV GRID software (§6.1) is provided to support authorities in establishing their own grid of local quality expectations, which will be more or less severe depending on the local reality. Three predifined grids, of different "severity levels" are proposed (Fig. 15), and the application provides the possibility to elaborate a *custom grid*, to adress specific situations.

Note that in the acceptability phase, as only the number of sectors of each colour is relevant, no specific position in the circle is attributed to each criterion.

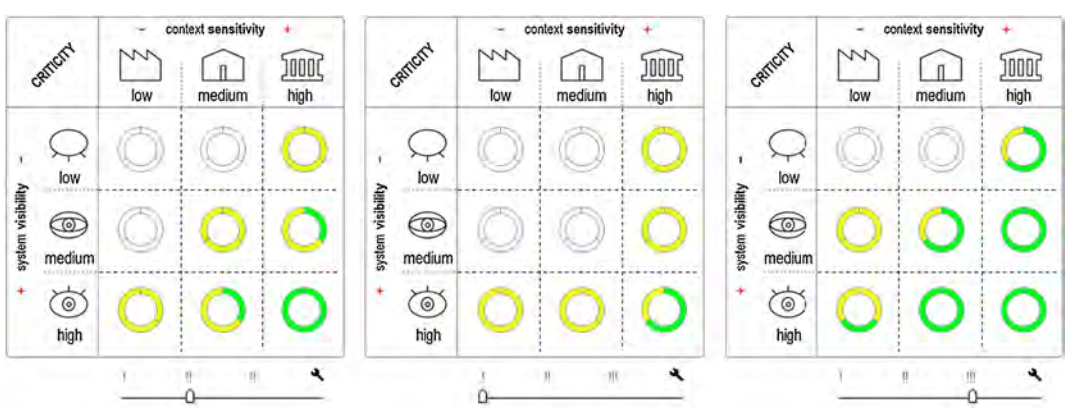

Fig. 15. Different possible levels of severity for the acceptability grid (from left to right : standard, permissive, demanding).

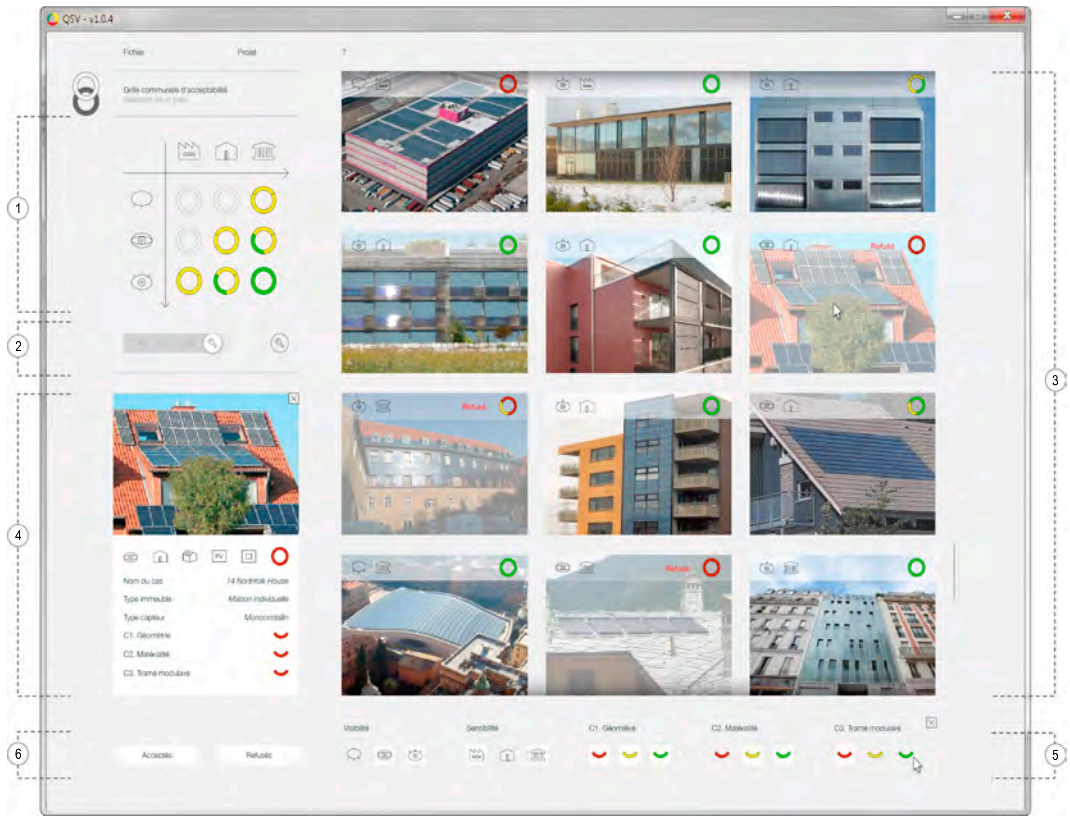

Fig. 16. Main screen of the LESO-QSV GRID program : 1 – Acceptability grid of the specific city: i.e. required integration quality for each criticity level f (system visibility; context sensitivity). These are the criteria to be met for the installation to be accepted; 2 – Acceptability grid setting 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 150 cases is shown according to a selected filter setting (5). This showcase is meant to: help Municipalities set an appropriate acceptability grid by showing the impact in acceptancy of pre-defined sets of quality requirements; present a model for authorities of 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.

6.1. LESO-QSV GRID software

To help authorities set these requirements, a multi-purpose software simulation tool has been developed, called LESO-QSV GRID (Fig. 16). Quality expectations are represented by the same three circle-sector symbols used for the evaluation of the integration quality described in Section 5. Three "standard" sets of quality requirements with gradual severity (demanding - standard – permissive, Figs. 15 and 16/1) are available for authorities to choose from, together with the additional option of setting a fully customized grid. As can be seen in the examples, most propsed grids will have a "severity gradient" matching somehow the criticity gradient.

To help authorities choose the most appropriate "acceptability grid", a large selection of integration cases is displayed (Fig. 16/3) that shows in real time which integration approaches would be accepted and which ones would have to be rejected with the selected settings. The examples database can be scrolled through, showing the effect of the acceptability grid over a very extensive set (more then 150 real cases) of integration approaches and criticity situations.

The same software is intended to be used, with minor adaptations, also as an education tool for architects, authorities, installers and building owners. The wide palette of examples provides inspiration from good examples, shows errors to be avoided or gives ideas on how to improve the quality of a project which would be rejected in its present state.

It can also help municipalities explain in an interactive and visually convincing way how the method works and justify to users possible project rejections.

Selection buttons are available in the bottom part of the screen to display a chosen subset of integration examples in selected situations (system visibility/context sensibility/integration quality level…) (Fig. 16/5)

Primary school in Geis - Swiss Solar Prize, 1996

Localisation	Niederteufen Switzerland
Architect	Gsell und Tobler, Niederteufen
Solar technology	Solar thermal collectors
Sub-technology	Glazed flat plate collectors
Product	Ernst Schweizer AG, Metallbau, Hedingen (CH)
Link-s	www.schweizer-metallbau.ch

Qualité d'intégration architecturale	(+) Fully coherent	(+/-) Partly coherent	(-) Not coherent
(1) System geometry I *Field position and dimension*			
(2) Modules materiality I *Materials, surface finishing, colour, texture*			
(3) Modular pattern I *Modules shape and size, jointing type*			

Even though the integrated collector system allows a very low level of formal freedom (fixed module size of 2081x 1223 mm), this building fulfils almost all sets of integration criteria, showing the great impact good architects can have even when dealing with formally limited products.
The integration of solar thermal was clearly considered at a very early project phase, so that the design of the south façade, of the spaces behind it, and of the roof structure have all been influenced by both the size of the collectors field, and by the fixed modular dimensions of the collectors.
The collector field (63m2) occupies the whole parapet area of the façade; its modular dimensions respect the rhythm of the window opening and of the vertical wooden structure carrying the sun shading; the glazing of the collector and its dark colour match the glass and dark colour of the window, in contrast with the lateral blind facade in concrete bricks. Even if not ideal, the rubber joints are acceptable. Their colour and thickness are not very different from the ones of the window frames.
This example presents a new building project, that could be developed around the solar system. For building renovations the integration of a fixed dimensions module is clearly more problematic.

Banque de données LESO-QSV — Fiche A-1

Fig. 17. Case study description and evaluation sheet example, with continuous evaluation scales and final discretization.

6.2. Educational use of the LESO-QSV GRID database

To better valorize the education potential of the database, more then 150 cases can be accessed and downloaded as separate case sheets classifying and describing in some detail each installation example and using both the discrete and the continous evaluation scale (Fig. 17).

These cases were collected with the help of the the students of different courses at EPFL and at IUAV (Venice) who were asked to collect existing solar integration examples and use the sheets as learning material to classify and analyse each case (more than 500 examples were collected in three years of teaching in three different courses on the topic of *Architecture and Solar energy* (Munari Probst and Roecker, 2009).

The proposed selection is meant to give a significant and comprehensive outlook of the different approches available today to integrate active solar strategies in buildings. New, existing and historical buildings are equally represented with respectively 50, 62, and 44 cases each. For each category, different integration approches, solar products, integration qualities and criticity situations are proposed, all together

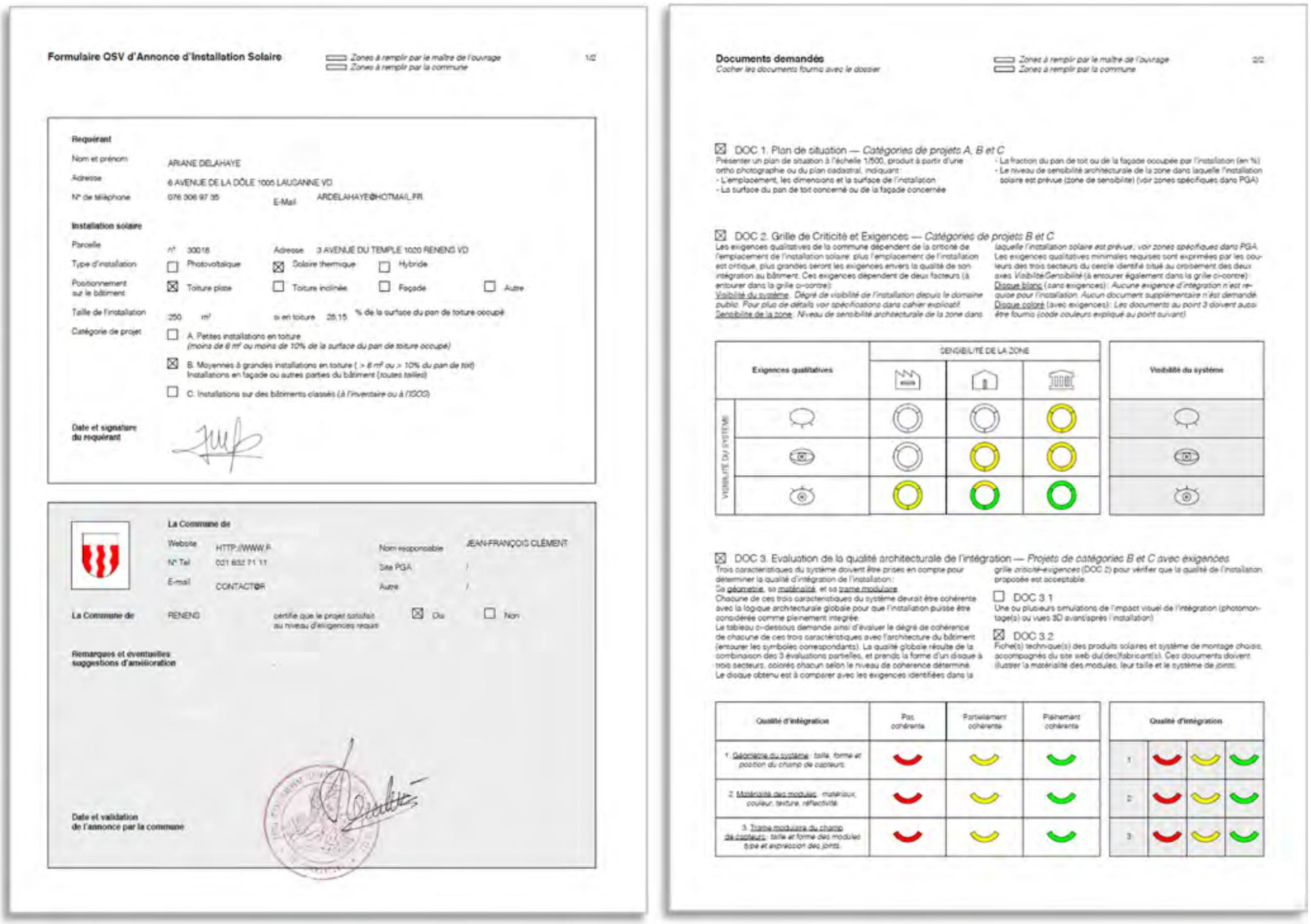

Fig. 18. Proposal of application form.

informing extensively on the state of the art of the topic.

The cases can then be used as unique education material, providing at the same time a collection of integration references and a set of educated evaluations.

The integration examples, good and bad, inform students, architects and building owners on present possibilities and limits in terms of products and technologies, within various architectural contexts.

To ease its use, the complete collection can be sorted according to various criteria of interest: building type; system size (small, medium, large), system position (roof or façade), solar technology (PV, solar thermal, hybrid), integration approach (basic to enhanced); etc.

6.3. Implementing the LESO-QSV method locally

As the main goal of the method is to help Municipalities manage the impact of active solar systems locally, all the needed practical elements to handle the acceptability have been prepared in the form of a "user kit". This kit includes a method implementation manual, a quality evaluation manual, the described GRID software and the set of example sheets. A customized "Application form" for approbation/rejection of new installations is also produced, using the "severity grid" established by the local authorities (Fig. 18).

Once an application form is filled by a citizen for a proposed installation, the local QSV commission can accept or refuse it, using the detailed quality evaluation to explain which aspect of the system needs to be improved in case of refusal, possibly allowing to correct the proposed system.

7. LESO-QSV "Crossmapping" tool

While the above described tools are reactive, and meant mainly for context protection and users education, another tool derived from the QSV criticity concept, called "LESO-QSV Crossmapping", is conceived as proactive and meant for energy policy planning.

Presently, the only information available to planners and authorities to make decisions on solar policies (promotion, regulations, financial incentives, among others) is the amount of solar energy received by the various city surfaces, usually displayed on solar maps (GIS). These maps vary in accuracy and detail levels but their only goal is to assess the gross solar irradiation potential of city surfaces, without concern for their urban specificities. As shown in Fig. 19, these integration related specificities do have a major impact on solar application real potential and should therefore also be made available to planners. To cover this need, the "LESO QSV-Crossmapping" tool proposes to map the architectural criticity of city surfaces, as defined in Section 4, and to superimpose this information over the available GIS solar irradiation

Fig. 19. LESO QSV Crossmapping tool (roof irradiation data from http://www.uvek-gis.admin.ch/BFE/Sonnendach?lang=fr; Sensitivity plan from ISOS: http://data.geo.admin.ch/ch.bakbundesinventar-schuetzenswerte-ortsbilder/PDF/ISOS_4397.pdf.

map. This allows to weight the pure irradiation potential of each surface with the expected architectural integration effort needed to collect it.

Differentiated policies and educated decisions can then be based on this more comprehensive information, keeping in mind that solar integrations are possible also in delicate situations (Fig. 4). In these cases though, design efforts and cost investments will probably be higher. If extra efforts cannot be afforded, it might be preferable to postpone the operation, as poor integrations usually end up just discouraging new users. By contrast, if well designed, such examples can be among the strongest driving forces for the solar change, repaying by far their extra cost.

7.1. Next steps

The criticity map mentioned above indicates for each city surface its visibility from the public domain, and its sensitivity in relation to the urban context. A process to automatically establish the visibility of the surfaces in the 3D models of cities is currently being developed at the EPFL LESO-PB Laboratory, as part of a PhD thesis (Florio, 2018). The information related to surface visibility should not only consider the purely physical visibility from the public domain, but should also take into account the hierarchy of the different points of view in relation to their importance for the perceived city identity (the view from a major city square being usually more crucial than the one from a secondary parking lot).

Possible crossed graphic representations of insolation and criticity are currently under development in the Laboratory.

8. Conclusion

As more and more pressure is building up to increase the use of solar energy as a replacement for fossil energies, there is an urgent need for new responsible ways to implement the solar collecting elements in urban contexts.

We have presented a new method able to concile the spread of active solar solar systems in buildings with the protection of existing urban environments. The method is based on the novel concept of city surfaces criticity, as a function of visibility from the public domain and architectural sensitivity of urban environments. Criticity is used to set the quality expectations for solar integrations in the different situations. The needed objective integration criteria have been defined and a simple qualitative evaluation method proposed.

A software program has been produced to assist municipalities in the practical application of the method. The program with its 150 commented integration cases will also serve as education tool for students, architects and the general public.

Finally, a new element for urban solar planning is introduced by combining criticity of city surfaces with their irradiation potential and finally establish smart solar promotion strategies.

We strongly believe that the concepts of *urban "criticity"* and *architectural integration quality* at the basis of the LESO-QSV method offer practical means to implement such responsible policies. We do hope that all together the inferred tools will contribute to the elaboration of valuable solutions to the problematic "Solar Energy Promotion *and* Urban Context Protection" equation.

The method has been used within the recent works of IEA SHC Task 51 "Solar Energy in Urban Planning" (IEA SHCP Task 51 2018; Munari

Probst and Roecker, 2016) as a basis to assess the quality and acceptability of the different solar integration approaches proposed by the set of case studies collected within Subtask C, and as core resources in three courses currently taught at EPFL (Ecole Polytechnique Fédérale de Lausanne, Switzerland) and University IUAV in Venice (Italy).

In November 2016 the method was rewarded by the Innovator of the Year Prize Årets Framtidsbyggare in Sweden (Prize Årets Framtidsbyggare, 2016), and recently the city of Malmö in Sweden and the village of Valangin in Switzerland have shown a strong interest to implement it as a pilot project.

A professional supporting structure to help municipalities and heritage preservation commissions implement the method is currently under finalisation with the support of the innovation transfer programs Enable and Innoseed of EPFL.

Acknowledgments

This work was financially supported by :

– The Swiss Federal Office for Energy(OFEN)
– The Swiss Federal Institute of Technology of Lausanne(EPFL).
– The Innoseed Incentive Program at ENAC/EPFL.
– The Enable Technology Transfer Program at EPFL.

The authors wish to thank herewith the following persons :

– Laurent Deschamps, Paul Becquelin, Sebastien Hausamann and Julien Grandin for their support in developing the software LESO-QSV GRID.

– Barbara Smith for revising and proofreading the english.

– Ariane Delahaye for her support in developing the graphic layout of the software and the example sheets.

– Professor Maria Wall for supporting the method and promoting its diffusion.

– André Catana from the Technology Transfer Office at EPFL for his continuous support.

– All the Innoseed commission members at EPFL.

Appendix A. Assessing visibility levels in standard urban situations

As presented in the main text, the visibility has two components: visibility from close range (close visibility) and from far away (remote visibility) (Section 4.1 Figs. 5 and 6).

While the second will be influenced by the topography of the city and its surroundings, for the first one, the determining elements are the geometry of the buildings and of the public space. It is therefore possible to pre-estimate the visibility levels for the most paradigmatic city configurations.

A first simplified estimation of the impact of city geometry has been done by calculating the variablity of the surface vision angle (β) according to viewer distance, building height and roof tilting (Fig. A1).

The table below (Fig. A2) shows the values both of β (degrees) and of the actual visibilty reduction (% of viewed surface) for different relevant city situations:

– Various roof types : flat roof - roof tilting at 25°- roof tilting at 40°- roof tilting at 60°
– Various building heights; from 1 to 6 floors (most buildings higher than 6 floors have flat roofs!)
– Various distances of view: across a street of 5 m. (medieval city street); 10 m. (medium city center carriage street); 20 m. (wide city center carriage street/suburb street with buildings located far from plot boundaries); 30 m. (small city square); 100 m. (large city square).

A series of visual simulations (Figs. A3 and A4) have allowed to establish that below 10% ($\beta < 6°$) the surface can be considered not critical at all (low visibility). Starting at around 40% ($\beta = 24°$) and up, the surface starts to become very visible (high visibility). Between these two limits, the visibility can be considered medium (the system details are not clear but the presence of the system is well perceived).

Analysis

Plotting on the same graph (Fig. A5), the visibility of roofs as a function of building heights, tilt angles and observer distances allows to extract very significant findings:

– in *narrow to medium wide city streets* (up to 10 m.) building roofs are invisible, unless the building is extremely low and the roof extremely tilted. In

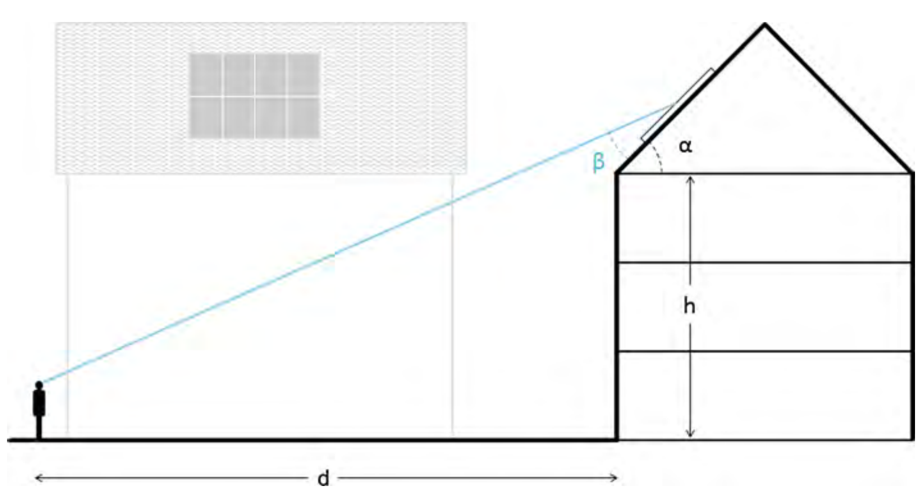

Fig. A1. Vision angle (β).

observer distance [m]		5		10		20		30		100	
n. of floors	Roof tilt [°]	β [°]	% of visibilty	β [°]	% of visibilty	β [°]	% of visibilty	β [°]	% of visibilty	β [°]	% of visibilty
1	0	-9	0	-5	0	-3	0	-2	0	-1	0
2	0	-27	0	-17	0	-10	0	-7	0	-2	0
3	0	-40	0	-28	0	-16	0	-12	0	-4	0
4	0	-50	0	-36	0	-23	0	-16	0	-5	0
5	0	-57	0	-44	0	-28	0	-21	0	-7	0
6	0	-62	0	-49	0	-33	0	-25	0	-8	0
1	25	7	13	14	24	19	32	21	35	24	40
2	25	-9	0	3	4	12	21	16	27	22	38
3	25	-21	0	-7	0	5	9	11	19	21	35
4	25	-30	0	-16	0	-1	0	7	12	19	32
5	25	-36	0	-22	0	-6	0	2	4	17	30
6	25	-40	0	-27	0	-11	0	-2	0	16	27
1	40	17	29	26	43	32	53	34	57	38	62
2	40	1	2	14	25	25	42	30	49	37	60
3	40	-10	0	5	8	19	32	25	42	35	58
4	40	-18	0	-3	0	13	22	20	35	34	55
5	40	-23	0	-9	0	7	13	16	28	32	53
6	40	-27	0	-14	0	2	4	12	21	30	51
1	60	30	50	42	67	50	77	53	80	58	85
2	60	15	25	30	50	43	68	48	75	56	83
3	60	5	8	21	35	36	59	43	69	55	82
4	60	-2	0	13	23	30	51	39	63	53	80
5	60	-7	0	7	13	25	42	35	57	52	78
6	60	-10	0	3	5	20	35	31	51	50	77

low visibilty | medium visibilty | high visibilty

Fig. A2. Values of β and of the actual visibilty reduction (% of viewed surface) for different vision distances, building height, roof tilting.

Fig. A4. Simulations of the visual impact of distance on a 3 floors building with a 25° tilted roof (upper numbers refer to situations in Fig. A5).

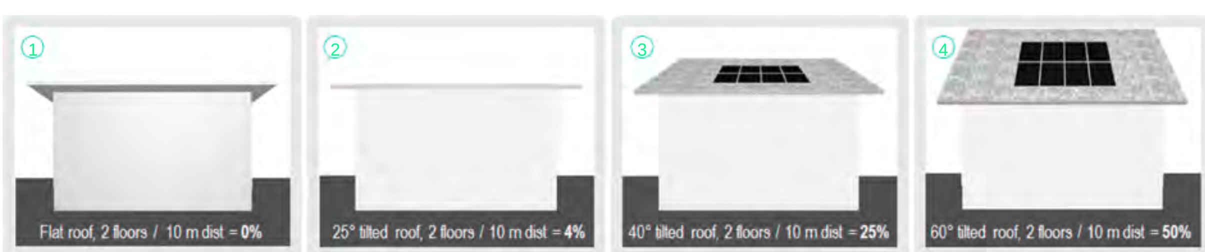

Fig. A3. Simulations of the visual impact of roof tilting on a 2 floor building seen from a 10 m distance (upper numbers refer to situations in Fig. A5).

these situations the only concern may be the remote visibility from the surroundings, mainly depending on the city topography.

– In *medium to large city streets* or in suburb areas where buildings are located far from the plot boundary (around 20 m. width), the visibility is still generally quite moderate, but steep roof tilting (40° or more) becomes a major concern; depending on the building height it will in fact induce a medium to high visibility.
– Finally , when the building is *in front of a large space* such as a city square (50 m. or more), the crucial factor for visibility becomes the roof tilting, while the building height starts to have a much reduced impact. Medium tiltings (around 20°) always result in medium visibility, while high tiltings (around 40°) always lead to a high visibility.

A more comprehensive calculation process, aiming at automating the calculation of visibility of city surfaces based on available city 3D representations (eg LIDAR) has been conducted at EPFL-LESO in the form of a PhD thesis (Florio, 2018). This work takes into consideration city topography, visual obstructions, as well as all the different angles of vision) (Munari Probst and Roecker, 2015; Florio et al., 2016, 2017, 2018).

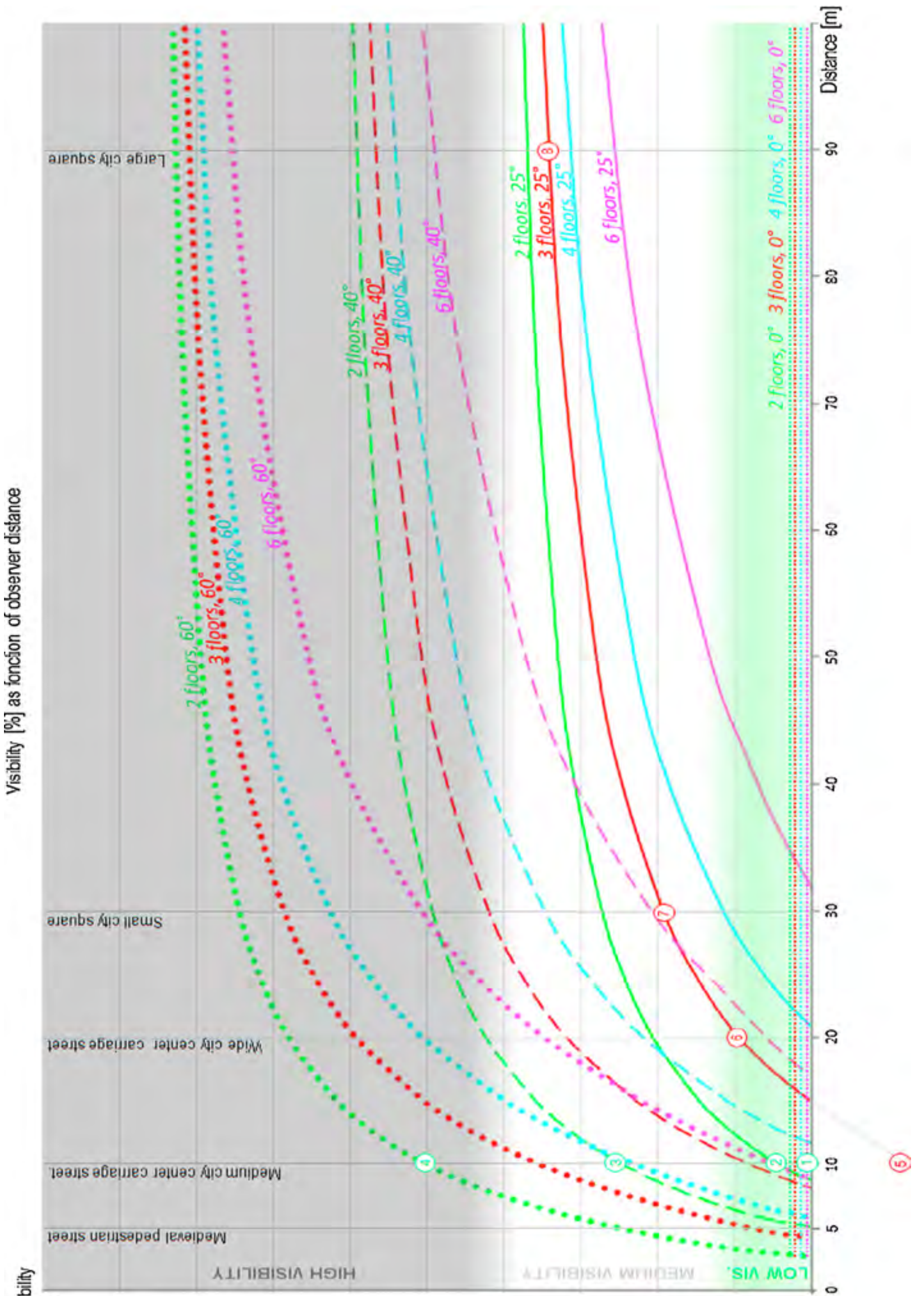

Fig. A5. Visibility [%]as a function of observer distance.

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