AIPV VISUAL ASSESSMENT FOR ARCHITECTURE RETROFITTING

R. Xu; S.K. Wittkopf

Competence Centre Envelopes and Solar Energy, Lucerne University of Applied Sciences and Arts

ABSTRACT

Typical architecture designers convey through vague and qualified notions. With the increasing number of PV installations on buildings, architects are forced to corporate with technicians and engineers in the design processes. However, the communications between them are often hindered because unlike architects who communicate through semantic descriptors and visual images, engineers are used to interact with quantified terms. One way to solve this problem is adapting visual impact assessment for PV installed on façade so that one can foresee and evaluate its final overall effect in a way that is comprehensible for both sides. The visual impact assessment is a method mainly used in landscape design for evaluating the influence manmade changes caused on natural landscape. Now it is vastly used on aesthetic assessment for wind farms being built on open landscapes all over the world. Comparing with wind farms, the relevant researches for Photovoltaics are rather underdeveloped. The estimation of visual effect created by integrating solar energy components on open landscape is rarely investigated, let alone on architecture where it is more complicated because more aesthetic factors are involved. With the increasing number of Photovoltaics installed or to be installed on architecture facades, it is necessary to develop a rational visual assessment tool to better evaluate the appearance outcome of the final installation. Based on summarizing research experiences and literatures from former visual impact assessments, this paper tries summarize the possible factors that are relevant for AIPV installation, and changes and extensions on existing theories are being made when necessary. The final results will benefit architects, engineers during the planning process, and eventually for law regulator in laying down clear and reasonable urban planning regulations regarding installing PV in urban areas. In the end, the author will apply the visual impact theory on a retrofitting project where AIPVs are assigned to be installed on a church in Lucerne, Switzerland.

Keywords: AIPV, Architecture Integrated Photovoltaics, Visual Assessment, retrofitting, Visual Impact

1. INTRODUCTION

Solar energy production is a booming technology and is welcomed especially among private investors in cities and suburbs. The government tries to encourage this trend by authorizing legal and bureaucratic simplification [1]-[4], but often the process is hindered due to administrational obstacles such as from historical preservation department, claiming many of them to be visually destructive to the existing architecture/environment [5]-[7]. Traditional architectural design process uses very vague notions, participants mostly communicate semantically to explain their pictorial demonstrations, as is the case when the historical restoration department explains their rejection reasons to the applicants, who are often even more confused after the explanation where mostly qualitative descriptors are used. Also architects and engineers often have very different understandings of certain words and what a good combination of PV on architecture is, which sometimes leads to bi-poled opinions on same subjects [8]. Survey shows that the main problems of solar architecture today can be summarized as following: the lack of diversity in solar panels; the professional tools that are available for solar energy assessment are mainly oriented to the engineers instead of to architects or to both [9]. The blockage between architects and engineers needs to be counteracted and one of the solutions would be to transform these vague notions into parameters and to lay clear defined physical features to those semantic descriptors in the design process. Visual impact assessment is one way to quantitative the evaluation on the effect of renewable energy, with practices done on wind energy in open landscapes substantially outnumbering the practices done on solar plants on open landscape, let alone on solar panels on architecture. This is why this paper would like to dedicate the research to develop a tool to appropriately evaluate the visual fitness of PV on architecture, to both lay a sound and sophisticated foundation for urban planning guidelines and regulations regarding solar energy, and to clear the communication barrier between architects, engineers and other stakeholders.

2. LITERATURE REVIEWS

The importance of visual impact caused by using renewable energy technology is getting more recognized by the public over the years. Especially the subjective evaluation of wind farms on open landscape, both theories and methods are already well established [10]-[14]. In the paper of Tsoutsos [15], even though no evaluation methods were discussed, the author states that the trend of "hiding" solar elements is fading and that the architects are beginning to realize the aesthetic appeal of solar elements and use them in attractive and visible ways. Work by Torres Sibille et al [16] is one of the very few works done on scientifically evaluating the visual impact of solar plants in open landscape. This work was carried out on the basis of their former work [17] on evaluating visual impacts on wind farms in open landscape. They have developed a parameter called Objective Aesthetic Impact of a Solar Power Plant installed on a landscape (OAIWF), which is dependent on the following sub-parameters: visibility, color, climatology coefficient, fractality and concurrence parameters of the technology and site. With the reference to and some modifications on the work of Torres Sibille et al [16] mentioned before, Chiabrando [18] applied the similar theory on the visual impact assessment of solar power plants (can be both solar thermal collectors or photovoltaic) with the term OAISPP, which varies between the value 0 – 1 (0 being the least, 1 the most effective impact), decisive by the following sub-parameters: the visibility of the plant (Iv); the colour of the plant compared to the colour of the immediate surrounding (Icl); the shape of the plant (If); the concurrence of various forms and types of panels in the same plant (ICC). However, it is undeniable that the solar energy implementation on buildings requires more care and caution as compared to installing renewable energy farms on open landscape, as architecture is a small scaled and delicate work of art itself. Probst and Roecker [19] evaluated the architectural integration of solar thermal systems by dividing them into functional (integrating solar heat collection function and other envelope functions), constructional (mainly constructive issues) and formal aspects. Formal aspect refers to how well the equipment is integrated architecturally with the building and can be graded with three progressive levels: basic, medium to advanced level. The advanced level means that beside offering flexibility in terms of the solar collectors' shape, size, module jointing, color, visible surfaces textures and finishes, dummy modules and complementary interface elements (jointing/finishing/angular components) should also be provided by the producers. The theory developed is mainly based on acceptance surveys on different stakeholders. The methods of the above mentioned visual assessment theories vary from strictly parametric analysis to doing acceptance surveys and to merely semantic descriptions. These theories and methods can be used as foundation as references for assessing visual impacts of AIPV.

3. DISCUSSION

In this part, the author will discuss about the aspects that are important to the formal aspects of implementing AIPV (Architecture Integrated Photovoltaic) on building facades. Hereby the technical aspects, such as efficiency of the PVs, are omitted and the focus will be solely on the architectural formal integration, and theories from related architecture design aspects will be introduced and referred.

3.1 Location

Often during the design phase, it is difficult to decide where exactly to locate the PV panel that is the most efficient and at the same time will lead to the most appropriate visual impact. The method of setting up a 3D digital model in helping to visualize the design is a routine in architecture branch. Several practices show that Ecotect to be an efficient tool in solar optimizing of the digital 3D model [20]-[22]. Compared to wind farms on open spaces, AIPV will stay still for the most of the time, therefore Ecotect combined with 3D renderings will be used to balance the most probable locations for gaining sufficient solar radiation and architecture aesthetic.

3.2 Silhouette and Detail

To install AIPV on the façade of a building, it is important to know ahead how its size, detail and texture are going to affect the overall appearance of the building. There had been precedents in investigating the silhouette and complexity effects.

According to Van der Laan's [23] theory, if one form is intended to appear to be part of the other form, its respective dimensions have to be in the range of 1–1/7 of the latter form. If the ratio falls between 1/7 and 1/49, then it will be the ornament of the latter, and below 1/49, the form will come out as trim, detail and texture. Stamps III [24] tested this theory and his results suggests that trim and ornament affect the architecture detail more than texture does. He [25] also states that surface complexity would make the most in the architectural façade, followed by silhouette complexity and façade articulation. Therefore it is meaningful to seriously consider the different size of the AIPV as it will cause different impacts on the overall appearance on the building façade. When necessary, the details of AIPV should be handled thoughtfully, which means that e.g. the gaps between the panels should not be defined arbitrarily but with regard to the architecture details. Also module jointings should be chosen carefully such as the material (EPDM or metal), color (same or contrast color as the absorber) and size (large jointing width or rather as a slim embroider) (Fig. 1).

Fig.1 Megaslate from 3S Photovoltaics, Suntech PV Module, First Solar PV Modules

The work of Attneave [26] suggests that for random polygons, the most important effect will be caused by the number of turns. Also Stamps [27] reports that the number of turns in the architecture silhouette has the most effect on shape complexity. Neither of the other parameters such as symmetry, the number of lengths of line silhouette segments nor the number of angles between those silhouette segments share comparable importance. Both cases indicate that for architectural silhouettes, the impression of complexity can be indicated very well from the turns in the form-outlines. Akalin [28] made experiments on the impressiveness and preference in residential architecture. The students will see a set of houses where they will decide their favor for the house with a changing variety on complexity details. It turns out that preference (fondness) was much stronger than impressiveness in both the minimum and intermediate complexity levels, but this relationship seems reversed at maximum complexity level, i.e. impressiveness was much stronger than preference (fondness). At present the PV panels can exist in many shapes thanks to dummy parts. These literatures suggest that special attention should be paid to the silhouette forms of the architecture and the PV panels (complexity, number of turns etc.), so that they share a certain connection with each other, and can exits harmoniously together, and that the PV panels will not be standing out boldly and conspicuously.

3.3 Style of architecture

Dalit Shach-Pinsly et al [29] argues that façade openings will link with human`s feel of privacy and comfort. [30] proposed a term called void-to-solid ratio, which is defined by the proportion of openings (such as windows or glasses) to the solid part (such as walls) on a façade. He believes that it can be an implication to the style and function of the certain architecture. Since PV panels are usually highly reflective and share the same reflectivity feature with window glasses, meaning that it can be treated as window components for observers. The ratio between window and wall ratio, or between the reflective and antireflective surfaces should be cautiously arranged, e.g. for historical architectures, it is the best to keep the ratio as original as possible, and for newer buildings, the ratio can be changed but should overall be kept in balance.

Architecture is also a design process that deals with ratio and proportion. Further literature studies should be made on theories about these areas. However, it is certain that e.g. if a building that was designed to have a horizontal trend and meant to give out a massive and stable atmosphere, then a single vertical PV panel component sticking out from the façade would certainly be inappropriate.

3.4 Material, Colour parameters and Light

[31] carried out the evaluation of the architecture façade only by changing the one parameter, namely the hue based on the similarity between the façade color and its natural surroundings. Torres Sibille et al [16], [17] and Chiabrando et al [18] deepened the definition of color contrast by using CIE color formulae to define the difference between the equipment and its surroundings. Here the color is identified by the colorimetric coordinates hue, saturation and brightness. L. Oberascher [32] claims

that perception of color in architecture is dependent on space and time, material and form, light and surface and the user itself. The last method might be the most appropriate for analyzing architecture integrated solar panels impacts, because unlike being on an open landscape, the color combination of architecture is more meticulous and is mostly comprised of multiple complex colors and materials where bumping and texture (based on their scale) can also be an issue. Thus same prudence shall be given to PV modules when choosing their color. Moreover, special attention should be dedicated to the unique feature of AIPV color that changes all the time with the shifting angle of the incoming light.

4. AN EXAMPLE OF APPLICATION

The following part is a progress report where it is the author's first attempt to design AIPV on a church façade by taking visual impact assessment into account. Due to time constraint, only location analysis and void-solid ratio theories are adopted. Further analyses are to come. Since the installing PVs on the roof of the buildings and hiding behind the parapet wall is clearly a natural choice without any effect on the façade, this option will be omitted from the discussion. Only options where the AIPV will take an effect the façade will be paid attention to.

The Catholic Church St. Michael lies in Lucerne, Switzerland and is required to be retrofitted with Photovoltaic. The church as a representative of 1960`s Brutalism and has an emphasis on the massiveness and horizontality, the installation requires extra care to be well integrated with the architecture, since for retrofitting projects that are under the protection of historical preservation, it is important to retain the original atmosphere. The suitable locations of the PV were carefully defined using simulations per Ecotect based on digital 3Dmodel made from sketch up. The findings in annual solar radiation analysis and shadow range in winter and summer are shown in Fig. 2 – Fig. 4.

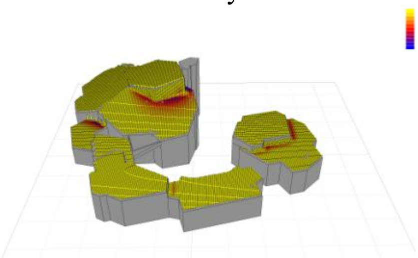


Fig.2 Annual Solar Radiation Analysis via Ecotect

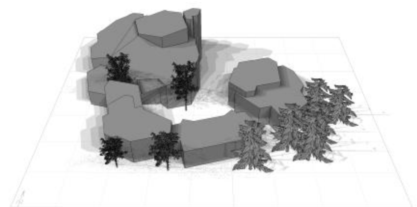


Fig.3 Shadow range summer via Ecotect

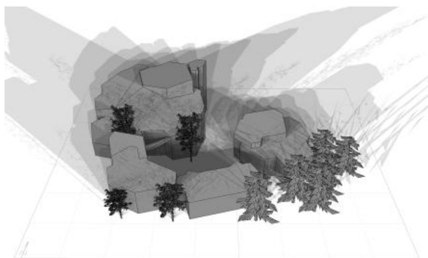


Fig.4 Shadow range winter via Ecotect

Since this church is under restoration protection, it will be very necessary to maintain its original style, and eventually its original solid-void ratio. As in this case, the solid void ratio refers to the proportion between the windows and opaque walls. Fig. 5 demonstrates the analysis of solid void ratio on different facades via AutoCad. The findings are that the main facades of the church possess an average ratio that is normally under 0.1, with less windows and a more sacral, monumental appearance; while on the side with residential function the ratio being much higher (0.15 or more) as there are more transparent areas.

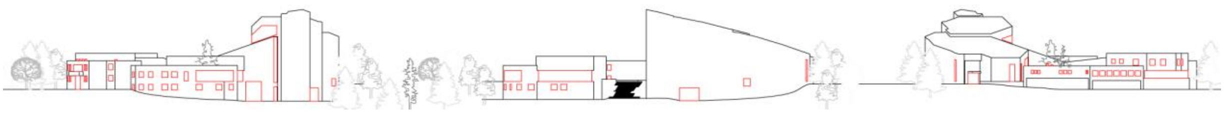
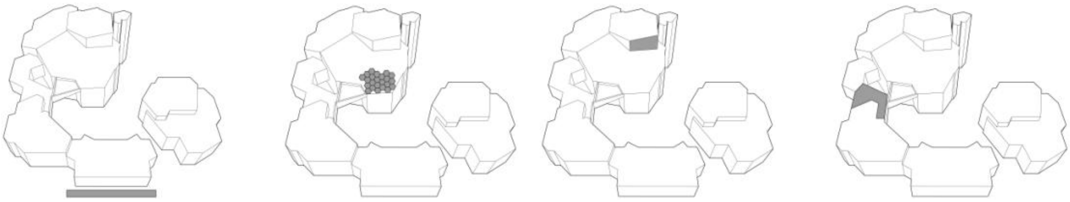


Fig.5 Solid-void-ratio

5. RESULTS

Based on the findings from above, it can be concluded that for large area AIPV installation, it can only be processed in the following 4 ways: (a) outside the church building complex (e.g. parking area) where the appliances are practically “invisible” and the ratio will not be affected, (b) on the sloping roof of the church where the ratio will only be very slightly affected, (c) on the original window area where the ratio will stay the same, and (d) on the residential part of the building, where the higher ratio will not do much harm to the original atmosphere. Do to the reflecting characteristic of the PV panel surface, a lowering of the ratio will not be feasible. The results are presented in the Fig. 6.



(a) (b) (c) (d)

(a)

(b)

(c)

(d)

Fig.6 (a) on the roof of the church, (b) on the parking space (c) on the original window area and (d) on the residential part of the building

6. DISCUSSION ON THE RESULTS AND OTHER PROBLEMS

This work is the author’s first attempt to develop a design methodology based on analyzing the visual impact of the AIPV on facades beforehand. Even though the results are developed on the basis of quantifying the parameters and rational reasons, there is still a lot of architectural design thinking involved. This kind of thinking needs to be clarified in the future so as to better serve the purpose of processing a rational design. Other problems also involve:

1. In this paper, only the existing theories are being looked into so far. In the upcoming future, crystallizing parameters that are fit for visual impacts of AIPV should be developed.
2. The energy production (which is proportional to the area of PV) of AIPV hasn't been taken into consideration yet. This is of course a crucial point that separates PV from any other architectural components.
3. For architecture observer, the height and viewpoint is decisive in the design process. Visual impacts strongly depends on the AIPV’s visibility to the observer, whereas different from the wind farms, the distance is by far not as pivotal as the observation angle. Thus theories about how to define the most suitable viewpoints should be investigated.

REFERENCES

[1] Schweizerischer Bundesrat, “Bundesgesetz über die Raumplanung (Raumplanungsgesetz, RPG)(Vom 22.6. 1979),” Bern, SR, vol. 700, 1979.

[2] Department Bau, Verkehr und Umwelt, Department Bildung, Kultur und Sport Kanton Aargau, “Merkblatt Solaranlagen,” pp. 1–5, Feb. 2012.

[3] Bau und Verkehrsdepartment des Kantons Basel-Stadt and Department für Wirtschaft, Soziales und Umwelt des Kantons Basel Stadt, “Richtlinie_Solaranlagen_BS_PDF.indd,” pp. 1–6, Dec. 2012.

[4] Regierungsrat des Kantons Bern, “Richtlinien - Baubewilligungsfreie Anlagen zur Gewinnung erneuerbarer Energien,” pp. 1–32, Jul. 2012.

[5] “Ortsbild kommt Solaranlagen in Zunzgen nicht mehr lange indie Quere,” http://www.bzbasel.ch/basel/baselbiet/ortsbild-kommt-solaranlagen-in-zunzgen-nicht-mehr-lange-in-die-quere-124869377,7/ 2012
[6] “Familie Wildhaber ändert Rechtspraxis, 8890 Flums, SG,” http://www.solaragentur.ch/images/content/PDF/Seiten%20aus%20G-11-10-31%20Wildhaber%20def_KA.pdf?PHPSESSID=815a2ae977ea39ba06b642aa69ea6f03, Oct. 2011.
[7] “Keine Sonne über den Weilern,” http://www.aargauerzeitung.ch/schweiz/keine-sonne-ueber-den-weilern-5276784, Dec. 2009.
[8] M. Munari Probst and C. Roecker, “Towards an improved architectural quality of building integrated solar thermal systems (BIST),” Solar Energy, vol. 81, no. 9, pp. 1104–1116, Sep. 2007.
[9] M. Wall, M.C. M. Probst, C. Roecker, M.-C. Dubois, M. Horvat, O. B. Jørgensen, and K. Kappel, “Achieving Solar Energy in Architecture-IEA SHC Task 41,” Energy Procedia, vol. 30, pp. 1250–1260, Jan. 2012.
[10] J. HURTADO, “Spanish method of visual impact evaluation in wind farms,” Renewable and Sustainable Energy Reviews, vol. 8, no. 5, pp. 483–491, Oct. 2004.
[11] J. Molina-Ruiz, M. J. Martínez-Sánchez, C. Pérez-Sirvent, M. L. Tudela-Serrano, and M. L. G. Lorenzo, “Developing and applying a GIS-assisted approach to evaluate visual impact in wind farms,” Renewable Energy, vol. 36, no. 3, pp. 1125–1132, Mar. 2011.
[12] Jacob Ladenburg, “Visual impact assessment of offshore wind farms and prior experience,” Applied Energy, vol. 86, no. 3, pp. 380–387, Mar. 2009.
[13] T. Tsoutsos, A. Tsouchlaraki, M. Tsiropoulos, and M. Serpetsidakis, “Visual impact evaluation of a wind park in a Greek island,” Applied Energy, vol. 86, no. 4, pp. 546–553, Apr. 2009.
[14] G. B. Jerpåsen and K. C. Larsen, “Visual impact of wind farms on cultural heritage: A Norwegian case study,” Environmental Impact Assessment Review, vol. 31, no. 3, pp. 206–215, Apr. 2011.
[15] T. Tsoutsos, N. Frantzeskaki, and V. Gekas, “Environmental impacts from the solar energy technologies,” Energy Policy, vol. 33, no. 3, pp. 289–296, Feb. 2005.
[16] A. D. C. Torres Sibille, V.-A. Cloquell-Ballester, V.-A. Cloquell-Ballester, and M. Á. Artacho Ramírez, “Aesthetic impact assessment of solar power plants: An objective and a subjective approach,” Renewable and Sustainable Energy Reviews, vol. 13, no. 5, pp. 986–999, Jun. 2009.
[17] A. D. C. Torres Sibille, V.-A. Cloquell-Ballester, V.-A. Cloquell-Ballester, and R. Darton, “Development and validation of a multicriteria indicator for the assessment of objective aesthetic impact of wind farms,” Renewable and Sustainable Energy Reviews, vol. 13, no. 1, pp. 40–66, Jan. 2009.
[18] R. Chiabrando, E. Fabrizio, G. Garnero, “On the applicability of the visual impact assessment OAISPP tool to photovoltaic plants,” Renewable and Sustainable Energy Reviews, vol. 15, no. 1, pp. 845–850, Jan. 2011.
[19] M.C. M. Probst and C. Roecker, Architectural Integration and Design of Solar Thermal Systems, EPFL Press, 2011.
[20] E. Mark, “Optimizing solar insolation in transformable fabric architecture: A parametric search design process,” Automation in Construction, vol. 22, no. C, pp. 2–11, Mar. 2012.
[21] J. Kanters and M. Horvat, “Solar Energy as a Design Parameter in Urban Planning,” Energy Procedia, vol. 30, pp. 1143–1152, Jan. 2012.
[22] X. Shi and W. Yang, “Performance-driven architectural design and optimization technique from a perspective of architects,” Automation in Construction, vol. 32, no. C, pp. 125–135, Jul. 2013.
[23] H. Van der Laan, Architectonic Space: Fifteen Lessons on the Disposition of the Human Habitat. Leiden, The Netherlands: Brill Academic Publishers, 1983.
[24] A. E. Stamps III, “Architectural detail, Van der Laan septaves and pixel counts,” Design Studies, vol. 20, no. 1, pp. 83–97, 1999.
[25] A. E. Stamps III, “Physical Determinants of Preferences for Residential Facades,” Environment and Behavior, vol. 31, no. 6, pp. 723–751, Nov. 1999.
[26] F. Attneave, “Physical determinants of the judged complexity of shapes”, Journal of Experimental Psychology, vol. 53, no. 4, pp. 221–227, Apr. 1957.
[27] A. E. Stamps III, “Complexity of architectural silhouettes: From vague impressions to definite design features”, Perceptual and Motor Skills, vol. 87, no. 3, pp. 1407–1417, Dec. 1998.
[28] A. Akalin, K. Yildirim, C. Wilson, and O. Kilicoglu, “Architecture and engineering students• evaluations of house facades: Preference, complexity and impressiveness,” Journal of Environmental Psychology, vol. 29, no. 1, pp. 124–132, Mar. 2009.
[29] D. Shach-Pinsly, D. Fisher-Gewirtzman, M. Burt, “Visual Exposure and Visual Openness: An Integrated Approach and Comparative Evaluation,” Journal of Urban Design, vol. 16, no. 2, pp. 233–256, May 2011.
[30] M. M. Alkhresheh, “Preference for void-to-solid ratio in residential facades,” Journal of Environmental Psychology, vol. 32, no. 3, pp. 234–245, Sep. 2012.
[31] Z. O'connor, “Bridging the Gap: Façade Colour, Aesthetic Response and Planning Policy,” Journal of Urban Design, vol. 11, no. 3, pp. 335–345, Oct. 2006.
[32] L. Oberascher, “‘Luminos 3’: a new tool to explore color and light in 3D,” Proc. SPIE 4421, 9th Congress of the International Colour Association, vol. 4421, Jun. 2002.