VISUAL IMPACT THRESHOLDS OF PHOTOVOLTAICS ON RETROFITTED BUILDING FACADES IN DIFFERENT BUILDING ZONES USING THE SALIENCY MAP METHOD

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ABSTRACT

The saliency map is a tool to describe the visual attention of human eye within a certain visual field. It is based on neurobiological and psychological principles. On a scale from 0-1, the lower the calculated value of a particular spot on the map is, the lower the probability of the human eyes to notice this spot. The authors have used this tool to quantitatively measure the visual change on heritage architectures before and after the Photovoltaic (PV) installation [1]. In this paper, the authors used a similar methodology to investigate the domains of allowed visual change caused by PV installation in different building zones. One existing building was used as an example and the PV color was used as the changing parameter. First, we found out how different visual changes and their quantification look like. A photo of the building in the original situation was taken, and named as the image "as is". This image was then run through about 5000 simulation iterations, each time the building façade on the image was equipped with PV with a different glazing color. After that, we investigated the visual changes that were caused by different PV color compared to the "as is" situation, and quantified them with the help of the saliency map. In the end, which amount of visual change is suitable for which type of building zone was discussed. Domains of allowed visual change were proposed. The benefit of the results could limit the negative visual impact caused by building integrated PV installation on urban buildings, retain the aesthetic balance in urban spaces, and could be integrated as thresholds in laws or regulations to guide the appropriate trend of building integrated PV installation in urban environments.

Keywords: visual assessment, solar architecture, façade retrofit, visual impact threshold

INTRODUCTION

Until today, people are still learning to deal with the combined qualities of PV that are quite unconventional: energy production and building material in one. Architects and engineers are still trying to find the balance between these two qualities. Experienced architects [2] compiled a report summarizing the experience of involving PV in architecture design. One chapter was dedicated especially to the decorative/architectural aspect of building integrated PV (BIPV), pointing out that especially in renovation projects, a careful coping with the existing façade is crucial.

Even though the new RPG clause 18a [3] and RPV clause 32a [4] were revised, only the importance of roof-integrated PV was paid attention to, façade-integrated PV was not mentioned at all. It was also stated that the installation of roof-integrated PV have higher probability of being installed in new buildings due to lower aesthetic requirements [5]. Nevertheless, façade integrated PV will gain more attention, as their daily electricity production profile fits a building electricity consumption profile better than the peak-oriented

PV power plants on roofs, and as a matter of fact, facades are not covered by snow during the winter season.

Others mentioned the importance of national policies [6]. According to this paper, different policies and regulations can lead to different results in BIPV adoption. For example in France, 59% of all PV systems are considered BIPV, in Italy 30%, Switzerland 30%, Austria 4% and Germany 1%.

Suggestions were made to assess the integration quality of BIPV [7]. The two main decisive parameters were the sensitivity of the zone where the building/building complex was located, and the visibility of the BIPV system itself. The latter one was again decided by the appearance of the PV (obviousness of size, material, color, texture, form and joints), whose obviousness was decided manually with +, +/- and – symbols. Thresholds for different quality levels of BIPV were given. This methodology allowed for quality categorizing and fast decision, but in terms of using descriptions with qualitative nature, there is still room for improvement.

PROBLEM STATEMENT

Due to lack of experience in using PV as an architectural element, at present mostly roof-integrated PV are mentioned in national laws and regulations, even though façade-integrated PV and roof-integrated PV both belong to the BIPV category. Also in current standards concerning BIPV, the laws and regulations only make vague separation between requirements in different kinds of building zones, even though different building zones clearly have different architectural standards, e.g. industrial zones would have a much lower architectural requirements compared to residential zones.

In order to prevent inappropriate BIPV designs, laws and regulations use mostly qualified and semantic descriptions to express how the expected BIPV installation should look like. This gives the responsible local authorities certain freedom in their approval process for BIPV projects. While the authors basically agree this is a successful way to prevent inappropriate BIPV designs, we must admit that façade-integrated PV has huge potentials in meeting the requirements of Energy Strategy 2050, therefore very possible to become more popular. Thus it is necessary to include the architectural requirements of not only the roof-integrated PV, but also of façade-integrated PV into regulations or laws, so that it can generally guide PV engineers, architects and other stakeholders with the “do-s” and “don’ts” when designing a BIPV project. The authors would therefore to make a proposal of another solution concerning the above-mentioned aspects.

SALIENCY MAP

The saliency map is a neurobiological and psychological tool to predict human visual attention. For every point in a certain human visual field, the probability of human paying attention to this particular spot can be calculated. These probabilities (on a sale from 0-1) can be presented on a saliency map. The Judd Saliency benchmark has evaluated the Harel & Koch [8] method as one of the most accurate algorithms available today. Their algorithm considers certain features (such as colour contrast, hue and object edge) and weights it according to position within the view for the processing of one final saliency map. Compared to other saliency algorithms, their algorithm has the advantage that the spots in the centre of the visual scene are prioritized, and also the area that are far away from the object edges are also being paid appropriate attention to. Figure 1 is an example of the saliency map application. One can see that the flower is the most salient spot in the image, meaning it has the highest possibility of being noticed by the human eye within this image. The farer away the object is from the centre of the image (e.g. the leaf down-left), the more it tends to be suppressed.

Figure 1. An example of the saliency map application. It is possible to use a photo as an import into the saliency map tool. The photo is considered to be a snapshot of the human visual scene. Even though the proportion of the Harel & Koch map's default setting is 900 x 1200 pixel, but in reality the proportion does not matter due to saccade movement in the human eyes.

METHODOLOGY AND APPLICATION EXAMPLE

In order to find out the visual changes and their corresponding quantified descriptions, representative heritage views was chosen for the investigation. Visual changes in this paper always referred to the difference of the view perception of the scene in figure 2 ("as is" situation) before and after the PV installation. Figure 2 shows the Kapellbrücke in Lucerne Old City as an application example because it could best demonstrate how a scenic view is very sensitive to an extrinsic PV installation that did not belong here originally. The sensitivity was also amplified by the fact that the PV was installed on a precious heritage building.

Figure 2. The image "as is" (left) and its saliency map "as is" (right).

As seen in figure 2, the Kapellbrücke consists of a water tower and a wooden bridge. However, the heritage site is not defined by the Kapellbrücke alone, but the surrounding architectures (e.g. the church in the background) also play important parts in defining the aesthetic balance of this view. The image left in figure 2 was named image "as is" and imported into the Harel & Koch algorithm. A saliency map was then generated from it (see figure 2, right). One can see that in original situation "as is", human attention is drawn to the water tower and the white church in the background first, which are the dominant attention-drawers. This was due to their colour contrast with the environment, central location and the unusual edge directions in the visual scene. Then the attention goes to the other white building with a triangle roof in the background and the roof of the bridge. The surrounding objects such as the white architecture on the right, and the swan in the down-right corner are not salient in the map, even though they are in very heavy colour contrast with their environment. That is because they are very far away from the centre of the visual scene and are suppressed in the normalization processes.

This paper studies the visual changes caused by differently coloured PV modules in this view, as purely hypothetical installations. A square PV module was painted into the image region showing the tower, indicated as the white square in figure 3. Other parameters than the colour such as location and details (joints, mounting, cables etc.) were omitted.

Figure 3. The white square represents the locations where Photovoltaics of different colors were added.

Through an automatic image processing script, the white area was filled with different colours, which were represented by different RGB values (each 0-255). With increments of 15 for each colour channel, the output was 4913 "new" images (each with a different glazing colour) in total. Then the images "new" were imported into the Harel & Koch algorithm, resulting in 4913 saliency maps "new".

In order to find out how different PV colour affected the overall visual perception of the scene, each saliency map "new" was compared with the map "as is". The results were named Delta Saliency maps (see formula (1)).

$$\Delta Saliency\ map = |Saliency_{As\ is} - Saliency_{New}| \quad (1)$$

On Delta Saliency Maps, we have the locations marked where the saliency values of saliency maps "new" were different compared to saliency maps "as is" by an absolute value of more than 0.1 (differences under 0.1 were considered as noise). The sum of the pixels with different values were counted together, and then divided by the total pixel number of the map (in this case 900x1200). This was calculated by formula (2) and presented in figure 4.

$$Percentage_{\Delta Saliency\ map>0.1} = pixel\ number_{\Delta Saliency\ map>0.1} / (900 \times 1200) \quad (2)$$

DISCUSSION

With the different PV colour as the changing parameter, the results could provide us an insight how different visual changes and their corresponding quantifications look like.

Throughout figure 4, we can see that the white church in the background and the water tower still belonged to the most dominant objects in the image. This was especially the case with a visual change of within 30% in the scene. If the PV colour was grey-brownish that is similar to the original colour of the water tower, as seen from the images on the first row, then the overall perception of the visual scene stayed basically the same.

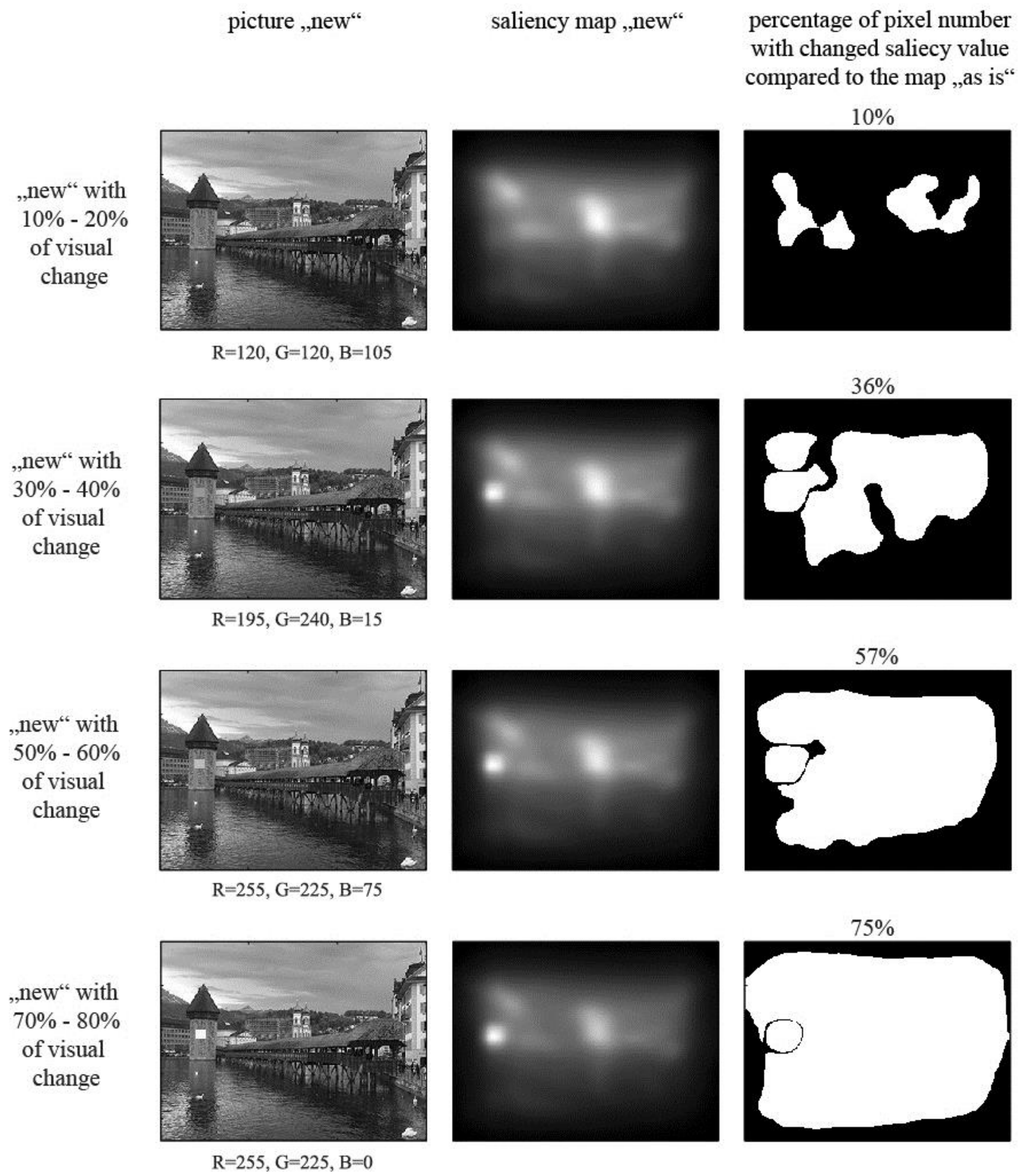

Figure 4. The saliency map and visual attention comparison for different PV module colors.

When the hue of the PV colour exceeded the one of the water tower, and the visual change went above 40%, the presence of the PV and its negative visual impact became inacceptable. It was also obvious that the more obvious the PV colour got, the larger the attention shift in the visual scene became. This is because human attention can only focus on one single object each time. Paying attention to multiple objects at the same time is not possible. So if the PV was installed on the water tower and its colour made it get attention probability of 1, then other objects will be “kicked out” of the original attention priority ranking. This is why when the visual change stayed below 40%, the colour of PV is still acceptable – the attention priority ranking in the original scene was mostly not destroyed. When the visual change went above 40%, the former attention priority ranking in the visual scene was shifted too much that the visual change became apparent to the human eye.

With the results above, the authors propose a mapping of visual changes to different building zones as summarized in table 1, for discussion.

Visual change %	Applicable zones	Preservation level	Reason
< 20%	Sensitive heritage zones.	High	The preservation value of area is high. PV and the change are almost unnoticeable to the human eye. The former visual attention ranking is mostly preserved
20% - 40%	Residential and business zones. Insensitive landscape zones.	Medium	The preservation value of the area is medium. PV is noticeable from afar. The moderate part of the former visual attention ranking is changed.
>40%	Industrial zones, renewable energy demonstration zone	Low to very low	The preservation value is low, visual changes are welcome. PV is very noticeable from far away.

Table 1

CONCLUSION

This paper investigated and quantified the possible visual changes caused by installing PV on an existing building façade using the saliency map method. Visual changes thresholds were proposed for different building zones. In order to simplify the experimentation, only one parameter was changed – the PV colour. Location and details (edge, construction joint etc.) of the PV were omitted. We found out that when the visual change stayed below 20%, the change was barely noticeable by the human eye. This range may therefore be a suitable as a threshold for sensitive zones with heritage protection. Within the range of 20%-40%, the visual change was noticeable by the human eye, but may not cause disturbance, because the major parts of visual attention ranking in the visual scene stayed the same. The visual change above 50% drew major attention to the newly installed PV panel. This range is therefore only suitable for demonstration zones where PV needs to be presented prominently.

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