THE ART OF PHOTOVOLTAICS

Klaudia Farkas[1]

[1] Department of Architectural Design, History and Technology, Faculty of Architecture and Fine Art, NTNU Trondheim, (Norway)

1. Abstract

The principal task of the building skin is to create a comfortable shelter. However it has also been a platform of art and expression of symbolic meanings. Lately a contemporary and innovative function of the building envelope came into focus: the building skin as a responsive component of a low energy concept (Schittich 2001). Several building surfaces are suitable for solar products, especially for photovoltaics that generate electricity.

Lately a variety of products have been developed to match building integration and architects' needs. The basic aim is to produce clean electricity. However while the solar module becomes part of the building skin, it has multiple structural functions and requires aesthetical integration into the overall design concept.

There are several barriers that keep away architects from using the potential of this technology. Economy and lack of knowledge are crucial issues, while the perception of and prejudices against these components play important roles as well. There is a need to find the architectural language of PV products to enhance future developments and change the perception from a technical device to a building component.

Architectural projects that use photovoltaics visible to the public have even further roles than the ones mentioned above. Photovoltaics integrated visually into the building skin have a representational role of demonstrating the owner's care about the environment (Röpcke 2010). These projects have also an educational role to spread the knowledge and possibilities of solar technologies used in architecture. A further symbolic role is to raise the observers' awareness of environmental issues.

Architecture and art can be a mediator to enhance people's consciousness about the environment (Röpcke 2008). Some artists and architects have realized this and have started to experiment with PV on facades and public objects.

The paper discusses the symbolic aesthetics of photovoltaics and presents projects where art, architecture and photovoltaics create an integrated union.

2. Symbolic aesthetics of photovoltaics

2.1. Theoretical background - Formal and symbolic aesthetics

Environmental aesthetics is a discipline that focuses on the aesthetics of everyday objects, like public art and buildings. Therefore it provides a theoretical background to discuss this issue. Certain researchers in this field define symbolic aesthetics in a slightly different way.

According to Nasar, the aesthetic appreciation of environmental influences has two basic components. These are the formal and symbolic (*associational*) aesthetics. He defines the formal analysis of aesthetics as the attributes of the object that contribute to an aesthetic response (Nasar 1998). The focuses of the analysis are the formal characteristics of the object: size, shape, color, complexity and balance. Meanwhile in Nasar's definition the symbolic analysis focuses on the *connotative meaning* that is produced through the experience (Nasar 1998).

In Lang's definition a symbol is something that is standing for something else, it makes the observer *associate to something* (Lang 1998). Steven Holl, on the other hand, discusses that the built environment is not only giving a phenomenal experience (like space, light, color, geometry, detail, materials) but also *expresses meanings* (Holl 1994).

As a summary we can define symbolic aesthetics that focuses on connotative meaning, gives associations and expresses meanings.

In the perception of symbolic aesthetics of the built environment Lang distinguishes between the signified and signifier. The signified is the meaning or thought that is associated with the object, which is the nature of the aesthetic symbol. (Ballard 1953) While the signifier (the mode of signifying its referent (Ballard 1953) consists of a structure of physical variables, like color, materials, volume, illumination, and non-physical variables, like the architect, the place, the name of the project (Lang 1998).

2.2 Photovoltaics-material aesthetics, building integration, integration into public art

Several architects and artists have realized the symbolic potential of photovoltaics, a visible medium of energy conscious and environmental friendly design and the possibilities of combining art, architecture and solar design in buildings and public art. Before going into a detailed description of signifiers, signified meanings and exemplary projects, there is a need to shortly discuss PV materials, PV integration in buildings and public art.

Photovoltaic cell – material – high-tech

A photovoltaic module is a composite product that consists of various basic components and coatings, therefore it is not easy to speak about material aesthetics. (Weller et al 2010) The PV surfaces are primarily determined by the solar cells and the antireflection coating, and we can talk more about product aesthetics. Due to its high tech manufacturing process it highly differs from traditional materials. The high degree of prefabrication rules out its modification on site, the active solar component part is basically imperceptible to the observer, since it is encapsulated in protective cover. This level of material artificiality already contains a symbolic meaning in itself for some people (Lang 1998). The high-tech appearance is mainly associated with building types like office buildings, even though photovoltaics are suitable for all types of buildings. However, the choice of products and their integration should be carefully chosen not to have a clash between technical sensibleness and symbolic aesthetic requirements in design (Lang 1998).

Forms of expression: buildings and public art

Photovoltaics can be integrated into every part of the building skin becoming a multifunctional component by replacing other materials. Still the most common integration is on the roof. However, to make it visible, façade integration got into focus especially in public buildings. The facade is like the “face” of the building that always has represented and mediated symbolic meaning throughout history.

Public art refers to works of art that are placed in a public open space and are accessible by the community. Recently several artists integrated photovoltaics into their public art objects. The location and environment, the people to whom the art object is addressed plays important part in the symbolic aesthetics of the object.

Further characteristics may differ regarding buildings and public art. These will therefore be discussed in detail separately.

3. The art of photovoltaics in buildings

3.1. Signified - nature of aesthetics symbol

We can distinguish between three different signified meanings of photovoltaics used in architecture, these are the following:

- enhancing the observer’s environmental awareness
- educating the observers
- demonstrating the owner’s/developer’s/architect’s care about the environment

There are several design concepts and technologies that are used in environmental design. Most of them are invisible or not recognizable for the observers. Photovoltaic systems can become an architectural component by integrating them into any part of the building skin. Therefore they have the potential to visually show an environmental conscious design. Public art is also a possible “way of raising the citizens’ awareness of the possibilities of solar technology” (Röpcke 2008). Consequently art and building integrated photovoltaics that are visible to the public can *enhance the environmental awareness* of people through expressing this meaning.

There is a great potential in using PV in architecture. However, a great barrier is that there is still a lack of knowledge among architects and clients. Representative projects have an *educational role* to spread the understanding of the potential and possible solutions. Several educational institutions have integrated photovoltaics into their buildings in such a way that it is visually accessible for the students and employees. This way children learn to know about these solutions from an early age, they become familiar with it.

The reputation of several large companies and architects is an important marketing issue. Many would like to *demonstrate their care about the environment* through including environmental design visible for public in their buildings. Many office buildings and high-rise buildings that have mixed reputation due to the high energy demand have recently been designed with building integrated photovoltaics to show that the owners care about the environment (Röpcke 2010).

3.2. Signifiers - mode of signifying its referent

Lang defines five main signifiers that carry symbolic meanings (Lang 1998) which can be adapted to building integrated photovoltaics using their formal characteristics. These are presented in Table 1.

Tab. 1: Signifiers of building integrated photovoltaics

Signifier's (Lang)	characteristics of building integrated photovoltaics
NON-PHYSICAL VARIABLES	- the architect - the place - the name of the project - an event that takes place there
MATERIALS	- PV module in relation with other materials
PHYSICAL VARIABLES (the volume, degree of enclosure, and proportions of enclosed spaces)	- form of building - surface composition - shape and size of module - composition of cells
THE NATURE OF ILLUMINATION (the effects of the directionality, source, color and level of illumination)	- added elements – lighting
PIGMENTATION (the color of buildings, surfaces, and smaller artifacts)	- color of cells and module
OTHER	- added elements – glass painting

Another signifier can be added to the list. That is art combined with PV in the form of glass painting.

We have already discussed the symbolic meanings of photovoltaics as a material. The other properties will be discussed in more detail through presentation of exemplary projects. This gives a palette of solutions in current architectural practice.

3.3. Exemplary projects

The Solar Ark of SANYO (one of the world's largest solar energy systems producer) in Japan is one of today's most impressive building integrated photovoltaics structures promoting solar energy (Hirshman 2002). The aim of SANYO was to symbolize and demonstrate their goal of achieving a "clean energy society". The focus of the Solar Lab (museum with information on solar energy and exhibition for children) and the Field Lab (outdoor exhibition) is to create an interest in global environmental issues and has an important educational role for the younger generation.. The Solar Ark is a curved structure with a length of

315 m (Figure 1) . The south-facing façade contains PV modules on a surface of 7500 m2. The Solar Ark uses salvaged, less efficient modules that have been taken back from customers in exchange for normal ones. This made it a symbol of pragmatism (Hirshman 2002). The arc form of the building is eye-catching also for people passing by on high-speed bullet trains.

Figure. 1: Exemplary buildings. Left: Solar Ark, Anpachi Town, Gufu prefecture, Japan, 2001, Right: Main Solar Stadium for the World Games 2009, Kaoshiung, Taiwan, Toyo Ito, 2009

The Dragon-shaped Solar Stadium (Figure 1) as it is called by its form is the Stadium of Taiwan built for the 2009 World Games, designed by Toyo Ito. The Arena has 50,000 seats that are clad with 8,844 solar modules on a surface of 14,155 m2. This amount of modules is able to cover the energy needs of the stadium (lights and vision screens). The name of the famous architect Ito is already a symbol of quality and innovation amongst architects. Through its function, form and composition of modules it demonstrates the care about the environment of the developers, and through its publicity it enhances the awareness about environmental issues among the visitors.

Figure 2.: Exemplary buildings. Cité du Design, Saint-Etienne, Loire, France, LIN, 2009

Situated in the historic site of the National Arms Manufacture in Saint-Etienne, the “Centre International du Design” (Figure 2) is an international center for communication, research and education in design. The complex designed by LIN consists of several renovated historic buildings and a new facility called the “platine”. The “platine” is a scaffolding of triangular shapes. The skin is composed of 14,000 triangles that are made of different materials for light, temperature and air control. One type consists of semi-transparent photovoltaic modules with crystalline silicon cells. The function of the building and the composition of the building skin is strongly connected. The specific shape of the modules and the surface composition innovatively demonstrates and awakens environmental awareness encapsulated in art.

The Hotel Industrial (Figure 3) is a retrofit project of a listed building. It was originally a power station that now has been converted into an office building. The challenge for the architect was how to treat the façade, since that could not be altered. Finally, 330 photovoltaic modules have been integrated into the glazing of the openings with 45 different layouts: patterns created by removing a certain number of solar cells from the modules. The result of this composition gives a good balance of light for the interior. Moreover, this texture copies the texture of the brick surface pattern.

Figure 3.: Exemplary buildings. Left: Hotel Industriel, Paris, France, Emmanuel Saadi Architecture,2008, Right: Wind Tower, Regent College, UBC, Vancouver, Canada, Sarah Hall, 2007

The Wind Tower (Figure 3) is part of the environmental design of UBC Regent College's natural ventilation in Vancouver. Glass painter Sarah Hall was asked to design a composition on the Southern façade which combines her unique glass painting and solar cells. Even though the wind tower has its environmental function, the new composition on the façade still makes this awareness visible, illustrating the environmental conscious design of the College. The façade combines not only solar cells and painting, but colored crosses and writings from the Bible with lighting from the back in the night. The Wind Tower is in a public place, visible for the students and employees, hence it also enhances environmental awareness.

The Green Pix Wall in Beijing (Figure 4) is a Media façade that combines the artistic composition of the cells with changeable lighting images. The "Media Wall" is the largest colour LED display in the world. The frameless glass modules contain 4x4 or 5x5 polycrystalline photovoltaic cells with a certain distance between. The building is a self-sufficient system, which uses the energy collected during the day for the LED lighting at night. The lighting system provides several variations of color in the night. The façade demonstrates the developer's awareness of environmental issues and it becomes a landmark in the city. An interesting issue is that in traditional Beijing, bright colors were used for temples, palaces and buildings hosting rituals, while other buildings were as colorless as possible (Lang 1998). In this context color symbolizes status, which also appears in this contemporary project.

Figure 4.: Exemplary buildings. Left: GreenPix Media Wall, Beijing, China, Simone Giostra & Partners, 2008, Right: Valby Gable, Copenhagen, Denmark, Anita Jørgensen, 2007

The Valby Gable (Figure 4) is a solar art project situated in the Valby district, Copenhagen. The original building is part of an industrial complex that has been renovated using energy conscious principles. Originally the photovoltaic modules were planned to be integrated on the roof. However the roof structure was not able to carry the extra loads, so it was decided to place part of the array on the gable facing the train

station. Anita Jørgensen, a Danish artist was asked to design an art facade using photovoltaic modules. The composition became a landmark, demonstrating the solar urban project in the district. It also symbolizes the dynamic movements of the city with the red lighting around the black panels representing the map of the city.

Figure 5.: Exemplary buildings. Left: Grass Valley Elementary School, Camas, Washington, USA, Sarah Hall, Right: Solar Illumination I: Evolution of Language in Pearl Avenue Library, San Jose, California, USA, Lynn Goodpasture, 2008

Solar cells can be integrated playfully into colored glass. This is especially impressive for children, who like bright colors and playful images. The Grass Valley Elementary School (Figure 5) is another project of glass painter Sarah Hall (the artist of the Wind Tower façade), where the pixelling image of the cells is integrated into the colored glazing of the school's stairway. The energy generated by the cells lights a small colored neon tube, educating the children of its use and enhancing their environmental awareness as they pass by this façade every day.

The "Solar Illumination I: Evolution of Language" corner (Figure 5) of the Pearl Avenue Library has similar symbolic aesthetics. The colorful artistic concept uses colored glass, characters from the Latin, Russian, Vietnamese and several Indian alphabets (the first writings of humankind) and solar cells. The project is part of the Silicon Valley city's Green Vision program demonstrating environmental protection and economic development. The four artistic glazings generate electricity to light a suspended glass LED lamp. "Art and technology intersect in a creative and inspiring way, recognizing our community's diversity, celebrating the history of innovation, and highlighting the great strides we are making with the San Jose Green Vision," says San Jose mayor Chuck Reed (Waggoner 2009).

Figure 6.: Exemplary buildings: Holy Family Church, Saskatoon, Canada, Architect: Friggstad Downing Henry Architects, Artist: Sarah Hall, under construction

Throughout history artists have been asked by the Catholic Church to present their contemporary works of art in churches. The Holy Family Church (Figure 6), planned to be finished in spring 2012 in Saskatoon, had two goals for an artistic element, a stainless glass installation and somehow to showcase the new cathedral's environmental sustainability, which is otherwise mainly invisible. They chose Sarah Hall artist to design their window installation, entitled "Lux Gloria", that combines colorful windows with some 1000 solar cells on the southern façade. The 54 large glass panels will collect approximately as much energy as is needed for five households in a year. The windows, in three large groups, are placed according to colour (red, gold and blue), reflecting the colour of the prairie sky. Non-solar stainless glass windows will be installed also in the interior as decoration. The solar window will "showcase both art and science".

In the projects described above colorfulness has been achieved by additional elements, like glass painting or lighting. However, there is a potential to use the palette of colors of the solar cells themselves. This is achieved by different antireflection layers. The efficiency in these cases is appr. 75-90% of the original cell. Sarah Hall made variations of an urban façade (Figure 7) where she combined a composition of colorful cells and painting for innovative and inspiring facades that could enhance the environmental awareness of people passing by.

Figure 7.: Exemplary buildings: Variations for facades, Sarah Hall

4. The art of photovoltaics in public art

4.1. Signified - nature of the aesthetic symbol

Public art is another form of promoting contemporary thoughts in a symbolic way, where the artistic, hence associational meaning is more prominent. Contemporary public art has a potential to make powerful statements. Public art objects that integrate photovoltaics into their design have the role of enhancing the environmental awareness of people passing by.

4.2. Signifier - mode of signifying its referent

Due to the larger formal freedom of art objects (in the case of buildings functional and several other aspects have to be considered together), the modes of signifying the symbolic meaning has a wider palette. The formal freedom gives possibility to create sculptures or imitations of natural elements, like trees. Not only the lighting but also the shading of modules can be a tool for artistic expression. Furthermore the installations can be combined with movable elements and sound effects that enhance the experience of the public space. The additional characteristics of public art objects used for expressing symbolic meanings are presented in Table 2.

Table 2.: Additional modes of signifiers of public art objects with integrated photovoltaics

Signifier's (Lang)	characteristics of building integrated photovoltaics
NON-PHYSICAL VARIABLES	- the artist
PHYSICAL VARIABLES	- form of the object- sculpture, imitation
THE NATURE OF ILLUMINATION	- shading
OTHER	- sound - movement

4.3. Exemplary projects

The Giant Solar Cube (Figure 8) was designed to be an "icon of the future". With its 46 m height it was the largest building integrated photovoltaics in the United States when it was built in 1999. It is located in the Discovery Science Centre in Santa Ana, California. The PV system is placed on the south face acting as a conventional glazing of the cube and has a highly visible display to show people the efficiency of the system. With its tilted cubic form and huge size it definitely catches the attention of people passing by (Strong 2008).

Figure 8.: Examplary public art projects: Left: Giant Solar Cube, Discovery Center Sant Ana,CA USA, 1999, Right: Learning from Nature, Louisiana Museum of Modern Art, Humlebaek, Denmark, 3XN, 2009

The Learning from Nature (Figure 8) is another project that shows the potential of photovoltaics. It uses a flexible thin film laminate on the top that suits to the organic möbius shape of the object and that lights LEDs placed on the other side of the strip. The pavilion is made of biodegradable materials.

Figure 9.: Examplary public art projects: Solar Mallee Trees, Adelaide, Australia, Anthony Materne, 2005; Solar Tree, Rein Triefeldt, Hillsborough, California, USA, 2008

In the previous cases the form of the public art object was a dominating geometric element, however the form can also imitate natural elements, like trees. Lately several projects have appeared where the object copies the form of tree or flower, using the PV cells as the crown of the tree or petals of the flower. Like the leaves collect sunlight and through photosynthesis convert it to energy that can be used by plants, the solar crowns and petals collect energy that in most cases is used for public lightning.

Well-known examples are the Solar Mallee Trees (Figure 9) in Adelaide, Australia formally imitating the indigenous mallee trees. These objects were part of a solar city project with the aim to raise the citizen's awareness of the possibilities of solar technology through art. (Röpcke 2008).

Another tree imitation (Figure 9) is designed by Rein Triefeldt who has been creating sculptures with integrated photovoltaic elements for over a decade. His idea is that "solar artwork can generate public dialogue, addressing and even resolving community problems". The Solar Tree project grew into an educational project where the students learn about environmental issues while combining the education of math-science and art with social responsibility. This way art became a way to provide knowledge to the young generation about the potential of renewable energy.

Figure 10.: Examplary public art projects: Greeting to the Sun, Zadar, Croatia, Nikola Bašic, 2007

The Greeting to the Sun project (Figure 10) is designed by Nikola Bašic together with the Sea Organ installation in Zadar, Croatia. It is a paving that consists of three hundred glass panels that cover photovoltaic modules and LED lighting fixtures in a circle with a diameter of 22 m. The PV cells collect energy during the day that provides energy for the game of light in the paving during the night and for the lighting of the entire quay as well. This urban development attracts public attention and represents the contemporary values and awareness of the city.

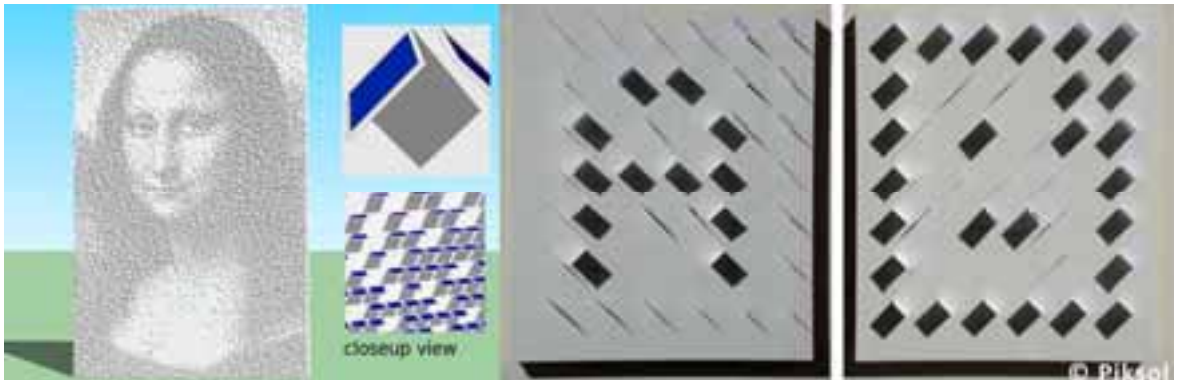

Figure 11.: Examplary public art projects: Piksol, Drzach&Suchy

The Piksol project (Figure 11) is one technique to create public art on buildings. The idea is to use tilted small solar modules for example on an empty gable of a building and by using the pattern of the shading and movement of the sun to create different images and a dynamic façade. The designers Drzach&Suchy declared in an interview that as art has always communicated ideas, an important function of solar public art can be "to raise people's awareness of the environmental challenges of our times".

The proposals of Thomas Lindsey for solar meditation gardens (Figure 12) are innovative projects to combine solar energy, art and deeper thoughts of our existence on this globe. His proposals are contemporary sacred places that consist of a kinetic slowly rotating wheel, cone or drum powered by a set of photovoltaic cells with a musical composition. The kinetic objects symbolizes the Buddhist prayer wheel and, through their motion, a focus point that helps the observer to experience its interconnection with the universe. Though the first aim of the artist is to create contemporary meditation gardens, this work of art promotes a higher awareness of our biological and spiritual connection with the environment. These installations present

a further possible symbolic meaning of photovoltaic art installation, i.e. spiritual awareness.

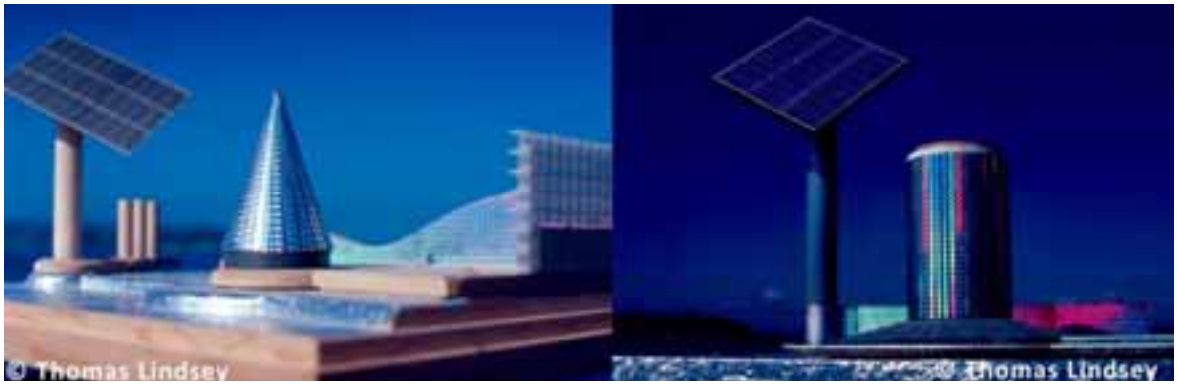

Figure 12.: Examplary public art projects: Meditation Gardens, Thomas Lindsey

5. Summary and Conclusions

Contemporary art is a powerful tool to express ideas and to mediate values. Through buildings and public art objects it can demonstrate the awareness of the owners, or even a whole region or city that has a solar urban project and care about the environment. It has a high potential to raise the awareness of people passing by through representing the importance of solar energy use in everyday life. Due to their publicity these projects have an important educational role by expressing the potential of photovoltaics in art and architecture and providing knowledge through displays, exhibitions and other media. With the combination of other signifiers PV art can even contribute in enhancing spiritual awareness.

The projects presented above show a palette of possible ways of symbolizing these issues by using the variety of physical and non-physical characteristics of photovoltaic installations (Tables 3 and 4). A distinction has been made between building integrated photovoltaics and PV integrated into public art objects, since these have different freedom in formal characteristics and provide different solutions in combining art and solar energy. Even if the main focus of architects is on building integration, public art objects have an important role in public spaces and can also be inspirations for building integration.

The variety of projects shows that basically every characteristics of the projects with PV integration can be used as a signifier for a symbolic meaning. In the case of building integration a certain characteristic of the PV cells or modules (like composition) is combined with non-physical variables or additional elements (like lighting or painting) to achieve the desired expression. In the case of public art objects, on the other hand, the place of the object is a dominating feature together with the formal design of the installation. This place can either be a science institution, an art museum, a busy public space, or a silent place for meditation. These different situations also show that there are wide possibilities of using solar energy in our everyday environment.

The vision of building integrated photovoltaics is that they will become a natural part of everyday practice and our built environment. Until that period using art as mediator is an important step to spread the knowledge and to make both professionals and others familiar with these solutions.

Table 3.: Summary of symbolic meanings of exemplary building integrated projects

BUILDING	SIGNIFIED	SIGNIFIER
Solar Ark	• environmental awareness • education • demonstration	• Event taking place inside • Form of building
Taiwan Solar Stadium	• demonstration • environmental awareness	• Architect • Form of building • Surface composition
City of Design	• demonstration • environmental awareness	• Event taking place inside • Shape of modules • Surface composition
Hotel Industrial	• demonstration	• Composition of cells
Wind Tower	• environmental awareness • education	• Glass painting • Composition of cells
GreenPix Media Wall, Beijing	• demonstration	• Lighting • Composition of cells
Valby Gable	• demonstration • environmental awareness	• Lighting • Surface composition
Grass Valley Elementary School	• education • environmental awareness	• Glass painting • Composition of cells
Pearl Avenue Library	• education • environmental awareness	• Glass painting • Composition of cells
Holy Family Church	• environmental awareness • demonstration • spiritual awareness	• Glass painting • Composition of cells
Variations Sarah Hall	• environmental awareness	• Glass painting • Composition of cells • Color of cells

Table 4.: Summary of symbolic meanings of exemplary public art objects with integrated photovoltaics

PUBLIC ART	SIGNIFIED	SIGNIFIER
Giant Solar Cube	• environmental awareness	• Form of the object
Learning from Nature	• environmental awareness	• Form of the object
Solar Mallee Trees	• environmental awareness	• Form of the object • Lighting
Solar Tree Project	• environmental awareness • education	• Form of the object
Greeting to the Sun	• environmental awareness • demonstration	• Lighting • Composition of cells
Piksol	• environmental awareness	• Composition of cells • Shading
Meditation garden	• environmental awareness • spiritual awareness	• Form • Movement • Sound

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