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CULTURALLY INSPIRED PATTERNS FOR PHOTOVOLTAICS

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CULTURALLY INSPIRED PATTERNS FOR PHOTOVOLTAICS

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Abstract:

This paper reports the results of an investigation into applying the inventory of local cultural heritage, here Japanese traditional family crests, as an inspiration for technological innovation, here alternative patterns for solar photovoltaic (PV) panels. It presents some architectural, parametric design proposals. **Aim** To improve the versatility of light-transmissive PV panels used for architectural integration into building skins (BIPV). **Study Background** With the kind of PV panels called 'light-through', translucency is achieved by spacing the opaque crystalline solar cells, so that light can penetrate through the resulting gaps. The usual design alternatives offered by the PV industry are mostly restricted to an equal spacing of the cells throughout the grid pattern. **Methodology** Cultural individuality, essential for local and global sustainability, provided the basis for inspiration. The inherent geometric qualities of traditional Japanese family crests are analysed and applied to generate alternative light-transmitting PV patterns. **Conclusion** Without impeding on manufacturability a wide range of innovative design variations are possible. Furthermore, a flexible change in the level of transparency enables the architect to set the visible connection between the interior space and outside of a building into a complex relation, reflecting the local tradition. It is made clear that family crests belonging to Japanese tradition combined with new technologies is not antithetical, they proved to be an ideal source of inspiration for the design of innovative, light-transmissive building surfaces integrated with PV.

Keywords:

culture for architecture and sustainability,
nuances of depth,
low-resolution design,
multi-layered patterns,
light-transmissive photovoltaic (BIPV)

1. Introduction

Building in the 21st century is driven by the need to embark on the paradigm of sustainable energy use and supply. This includes reducing the need for energy, maximising energy efficiency, saving non-renewable as well as harnessing renewable energy sources, to ultimately replace today's reliance on non-renewable energy sources[i]. Zero-energy and carbon-neutral architecture are the goal (Guzowski, 2010). Photovoltaic (PV) systems are one way of energy generation from renewable sources, which can be easily integrated into buildings (BIPV[ii]), thus underlining a sustainable energy supply, which *"implies a local scale for energy sourcing"* (Acres, 2007, p102).

This paper focuses on **light-transmissive PV** systems for their unique flexibility to regulate the transmission of light and heat into the building while allowing for shade and views. Such functional requirements have been driving forces for the design of well-tempered buildings for centuries (Behling & Behling, 1996). Now coupled with the possibility to generate electricity, technological innovation has resulted in a truly multifunctional, environmentally responsive and highly architectural building material. However, the major focus of manufacturers has been on technological and manufacturing issues rather than on the issue of integration into the built environment. Integrated renewable energy generation is still all too often viewed as an added element stacked or patched on top, rather than as inherently belonging to and part of our environment.

> *"Energy is all. We are still largely unconscious of it, but our entire lives (both urban and rural) are driven by our access to energy (how we use it, why we use it, what sort of energy we use)."* (Webb, 2005, p75)

In the words of Cedric Price[iii], technology is maybe an answer, but we must not forget the question. As the answer, the technology of renewable energy generation, is readily available nowadays, a possible question was indirectly stated by Webb: *"our culture needs to internalise a new valuation of energy"* (2005, p75), hence the question for a cultural view on energy. While technology is a global phenomena, culture is rooted in the local, human scale.

> *"The essence of culture is in locality. There's any such thing as a global culture."* (Sen, Caltroni & Hara, 2009, p94)

Structure of this paper:

Section 2 explores the importance of culture for architecture and sustainability.
Section 3 analyses cultural differences of light and shadow, as well as nuances in the perception of depth.
Section 4 introduces the current debate on the relation between patterns, parametricism and performance in architecture.
Section 5 explores recent architectural low-res pixellated design strategies, and the affine and inherent qualities of solar photovoltaic cells.
Section 6 provides case studies, results of an investigation into applying the inventory of local cultural assets, here Japanese traditional family crests, as an inspiration for technological innovation, here alternative patterns for solar photovoltaic panels.
Section 7 records the main conclusions of this paper.

2. Culture for Architecture and Sustainability

The struggle to shift the focus of current developments towards a sustainable one is happening with undiminished intensity in all fields and in architecture as well, both in the theoretical discussion and in the building industry. To visualize the concept of sustainability in its manifold depths, it is helpful to think of layers. The generally established three main pillars or layers without hierarchy are economy, society and environment. However, *"[...] the meaning of sustainability depends on the context, in which it is applied"* (Kajikawa et al., 2007, p222).

The theoretical framework for architecture, that we are going to use, was suggested by Namba[iv] (2006). While evolving the concept of architectural designs for his box-house series, Namba developed a theoretical approach that he calls the 'Four Layers of Architecture' (Tab.1).

Layer	**Mode** (Standpoint)	**Program** (Design requirements)	**Technology** (Means of solutions)	**Theme of sustainability design** (Program of contemporary architecture)
1st layer	physical thing	material parts structure construction	production assembly	reuse and recycling long-lasting lightweight
2nd layer	energy-controlling device	environmental energy	electric machinery climate control	energy conservation high performance
3rd layer	social function	purpose building type	planning organization	family community lifestyle urbanity
4th layer	symbol meaning	form space	representation criticism	virtual reality ephemeralization

Tab.1 Namba's 'Four Layers of Architecture', English source: http://www.kai-workshop.com/boxhouse/boxhouse01.html

The waging debates about environmentally friendly or 'green' architecture very often focus on the issue of energy (Wines, 2008, p226), *"a tendency to give top priority to the 2nd layer"* (Namba, 2006), while ignoring the similar importance of the other three layers.

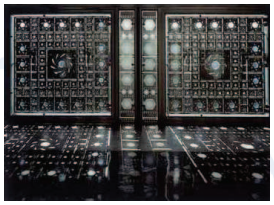
To briefly explain this, we have to go back in history. Builders in the pre-modern times were aware of the importance of solar energy for the human well being and applied this knowledge for well designed housing, as exemplified by Socrates' Megaron house (Schittich, 2003, p14). Wigginton (1996, p23) demonstrated, that the climate in England with often cloudy skies and generally less sunny weather entailed an appreciation for largely glazed façades by the English aristocracy until the end of the 16th century, but were replaced in later erected buildings by small-scale window openings more appropriate to the light-intense Mediterranean climate. Wigginton (1996, p24) attributes the cause for this shift to the spread of Renaissance writings originating from Italy and the reappraisal of the studies on mathematical laws and proportion by Vitruvius[v], the antique father of architectural engineering and theory, to the disadvantage of environmental and climate considerations. The result of this shift is well known, as the debate became dominated by Vitruvius' triple canon of *firmitas, utilitas, venustas*[vi]. A reference to climate only reappeared with Banham's 'The Architecture of the Well-tempered Environment' (1969), at a time when the sophisticated state of climate independent air-conditioning systems and its impact on the development of modern architecture could not be ignored any longer.

But what had been ignored in the analysis of historical architectural morphology for a long time, has always been present in vernacular design, one can even say that it must have been present to fulfil the Vitruvian principle of *utilitas*. Behling & Behling (1996) demonstrated that the world's native, vernacular design has been the truly environmental design: by skilfully

adapting to climate and local micro-climates; by utilising locally available building materials which gave rise to the necessary craftsmanship; as well as by allowing for the cultural desire for representation, like preferred spatial orders, separating and connecting transitions, and material, decorative or spiritual ornamentation.

What had been ignored in the conventional analysis for so long, suddenly entered the debate so forcefully, that environmentally friendly design or 'green' architecture focused strongly on the 2nd layer (Tab.1), "*[h]owever, properly speaking, sustainable design should involve all four layers",* as Namba (2006) pointed out.

Tab.2 is a short comparative analysis using the 'Four Layers of Architecture' framework, of traditional Arabic *mashrabiya*[vii] with two contemporary architectures, that translate the visual pattern of the local traditional craft into a design approach for a cultural distinctive adaptation of a modern technology.

	traditional Arabic mashrabiya local craftsmen	Arab World Institute, Paris, France architect: Ateliers Jean Novel, 1987	Menara airport, Marrakech, Morocco architect: E2A architecture, 2008
	 Fig.1 © Cora Edmonds	 Fig.2 © Ateliers Jean Novel	 Fig.3 © Brigit Varenkamp
1st layer	Wooden latticework	Mechanical devices between glass panes	Photovoltaic glass laminates
2nd layer	Daylight transmission, shading, cooling and air conditioning	Daylight transmission, shading, transparency	Daylight transmission, shading, energy generation
3rd layer	Privacy and views in residential houses	Representative street façade of the Arab World Institute	Skylight at an international airport
4th layer	Geometrically crafted patterns in accordance with Islamic laws	High-tech image, modern interpretation of the traditional mashrabiya	Green energy, modern interpretation of the traditional mashrabiya

Tab.2 Comparative analysis with Namba's 'Four Layers of Architecture'

Even though the aspect of culture is not explicitly mentioned in either of the layers nor any of the examples, it is inherently present in all of them. Architecture itself is an essence of culture, the cultural process of inhabitation.

> *"At its highest level of significance, architecture is the fusion of culture and the need for enclosure made material in physical form; it is the meeting point of the need to build and the innate urge to communicate."* (Wigginton, 1996, p10)

If culture is so essentially important for architecture, the same should be true for sustainability. Even though culture is often not explicitly mentioned when speaking about sustainability, distinctive cultural approaches are essential for local and global sustainability. It is one of the most important keys for achieving the sustainability objective (Nadarajah & Yamamoto, 2007).

3. Light and Shadow – Nuances of Depth

> *"In the thousands of years since he learnt to build, man has had to try to meet two particular, and often conflicting needs: on the one hand, the need to create enclosure for shelter, protection and privacy; on the other, the need to transmit light to provide illumination and view."* (Wigginton, 1996, p10)

The different regional and cultural perception of light and shadow has been recognised in the architectural debate. An example from Wigginton (1996) was given in chapter 1. But light is more than the presence of it, and shadow more than its absence. The manifold nuances and meanings of shadow were beautifully described by Tanizaki in his book 'In Praise of Shadows'.

> *"And so it has come to be that the beauty of a Japanese room depends on a variation of shadows, heavy shadows against light shadows - it has nothing else."* (Jun'ichiro Tanizaki, 1933, p18)

From whatever side the issue of light and shadow is approached, important are not the ends, but the superimpositions that occur on the path towards each other, where the dichotomy essentially merges. Neither of them is eradicated, both are present. However, the cultural difference of the starting point can be traced easily. An example may be the Gothic stained window in comparison to the Arabic *mashrabiya*. The feature of the Gothic mosaic glazing is coloured light entering the nave of a church, its material expression is the translucent, colourfully stained glass. The feature of *mashrabiya* is shaded privacy, its material expression the wooden latticework. The difference of focus can be seen not only in the dualism of light and shadow, but in the attention of the craftsman, on the light transmitting material versus the shading material. What both approaches have in common are the variations of gradation.

> *"The theme of light […], the blurring of contours, the superimpositions, in reverberations and reflections and shadows."*
>
> (Jean Novel about the Arab World Institute, Fig.2)

To better understand different ways to perceive depth, let's look at an example, at the tools of writing and building in Western/European and Eastern/Japanese tradition, instruments that are different in substance and intent. Where historically the West wrote with a chisel and erected temples and obelisks in stone, the East used the brush, wood and paper to create its own landscape. Where the West has expressed ideas related to eternal life, to the permanence and immutability, the East declared its preference for the transience of existence, for the decentralised pluralism and the impermanence of time. It is immediately visible that the two systems are based on cognitive tools and very different materials. Where the West has historically practised the art of the inscription, the East has preferred description. In one system there is a vigorous activity that is expressed through the tension of the muscle strain, in the other system there is a relaxed physicality that manifests itself in softness. In the West, the practice of sharpening the tools of writing to get the precision of the sign refers to what might be considered as an art of aggression. In the East, the practice of softening, scrubbing and waxing to make the gesture of the brush fluid refers to reflection and peace. Where European and American architects metaphorically build by inscribing, their Oriental colleagues - build by describing. Rather than impose themselves on a place they perceive it and bring it to light. While in the West, in architecture and art, the sense of depth is created by the distance from a focal point through the perspective[viii], in the East, it is given by the ink gradation. Even though fundamentally different in their tools, both approaches

strive for the depiction of spatial degrees of depth, or the gradation of depth.

The contemporary architectural output and the materialisation of light/shadow gradations within the layers of the building skin were analysed by Beccu and Paris (2008), who call it a "new" opaqueness, a paradoxical *"accumulation of different kinds of transparencies"* (p37). What had been a clear composition of opaque and subordinated transparent areas during the European Renaissance turns into an ambiguous playground of *"infinite variations in its degrees of transparency"* (p47). The true newness may not be so much the layering of the façade itself, but the eventual consideration of light as a form of energy, that has multiple spectra and can be preserved, dispersed, transformed, temporarily stored and inversely distributed during night time. With the help of photovoltaic devices, natural and artificial light respond in a newly found dual, dialectic relationship. Where, seen from the outside during daytime, a darker interior appears flat, this changes dramatically when the inside is illuminated. The degrees of transparency are enriched with spatial degrees of depth. However, what appears so novel when seen from the point of light, was already described by Tanizaki from the point of shadows in 1933.

4. Patterns, Parametricism, Performance

> *"[Patterns] have been covering architectural surfaces since time immemorial, in the same way that they have been spread all over manmade objects. The human body was perhaps the first surface to receive designed patterns. Architectural patterns thus have a broad and deep lineage, and one should not expect them to have any well-defined, unitary function. As patterns evolve they acquire new functions and lose their prior functions, or new functions are superimposed upon older ones."* (Schumacher, 2009, p30)

Patterns have always been present in the architectural debates. In his 'De Re Aedificatoria', Leon Battista Alberti, an architect and polymath of the European Renaissance, defined the patterns as the final component added to the volumes for producing beauty. In his book VI, architecture is defined as a process which starts from the naked volumes of the building, passes through the structures, and ends with the addition of the ornaments. Modernist architecture banned the use of any type of decoration, but today thanks to the advent of new technologies and design tools (such as parametric design), patterns have become once again central in the architectural debate[ix].

> *"Patterns provide architects with a device to connect apparently incongruent categories and synthesize a multitude of performances, project requirements and informational types in a perception-based medium."*
>
> *(Anderson and Salomon, 2010, p14)*

Patterns have served different purposes, and what interests us are their flexibility and high degree of adaptation. When used along parametric software, patterns are similar to seeds. Aristotle would call them *dynameis*: they are to be seen not just as form, but as a generator (and problem solver) of performances (Liotta, 2010).

> *"Functioning both as process and image, graphic and code, they [patterns] are able to foreground the sensual while shaping matter and behavior."*
>
> *(Anderson and Salomon, 2010, p25)*

Patterns appear to be useful for rethinking some aspects of architecture, especially their potentiality as dynamic agents of synthesis and multiplicity is only rarely fulfilled. Thanks to the digital architecture paradigm shift, we foresee a new role for patterns. They might be used by architects to make a synthesis of different requirements of a project, as patterns belong at the same time to a conceptual and material state.

> *"The introduction of different surface effects, like different material textures, had already happened within the later phases of Modernism, but artificial, quasi-graphic techniques of surface treatment and surface patterning were now being deployed. […] Parametricism transforms this technique of parametric pattern design into a new and powerful register of articulation."*
>
> (Schumacher, 2009, p33-34)

While architecture during the 20th century focused on function and form, the current architectural debate is dealing more with relationships, boundaries and energies. In this regard, parametric photovoltaic patterns have the poetic and pertinent potential to precisely promote performance*, or in short: patterns promote performance.*

5. Low-res – Pixel and Solar Cell

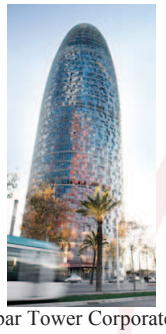
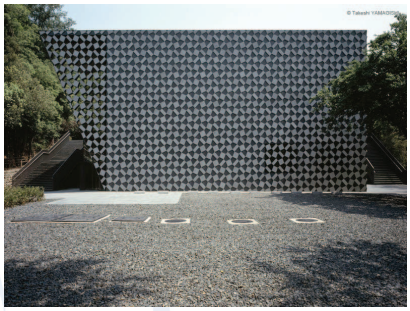
From the manifold pattern revealing or generating algorithms we want to focus on low-res strategies. Low-res, or low resolution, usually describes the insufficient amount of a pixellated screen or image, where instead of a smooth gradation of colours or levels of brightness, the individual pixels can be distinguished, thus revealing a "digital" origin. In the world of computers, screens and digital images or films, low-res has been seen equal or near to bad quality. In the field of product design (e.g. Ron Arad's pixel sofa Do Lo Res), the computer derived pixel art and architecture, however, it is seen as an inspirational approach for design and pattern generation. The appearance of façades or roofs as made up of smaller units is in itself nothing new to architecture. In fact, until the invention of monolithic concrete structures and surfaces, it was the only way to build, like bricks for walls, tiles for roofs and floors, stained glass pieces for windows of Gothic cathedrals, wooden pieces for *mashrabiyas*, etc.

So if it is nothing new, what makes it so compelling? Maybe the answer was given by Bullivant analysing the design approach of Ron Arad:

> *"[L]ow-res tactics in order to achieve appropriate, affordable, as well as poetic and more subliminal, effects, harnessing emotion rather than technology. At the same time, these tactics are programmed to be adjustable."*
>
> (Bullivant, 2005a, p6)

Low resolution as opposed to high precision, emotion rather than technology, or *"low-res, or on demand [and adjustable], rather than high-res or pervasive"* (Bullivant, 2005b, p60). In time, these kind of low-res tactics could be compared to the 19th century art movement Impressionism and Pointilism[x], that gave precedence to visual effects over minute details. Interestingly, then and now, an interest in and emphasis on light effects, its changing qualities, reflections, nuanced shades, and vibrating colours, can be observed.

In Tab.3 some contemporary examples are given, of which two, the GreenPix - Zero Energy Media Wall by Simone Giostra & Partners and the Hotel Industrial by Emmanuel Saadi Architects have integrated photovoltaic solar cells. The examples are split into three groups. The **illuminated and mediated** examples play with the reference to digital screens, low-res occurs in different scales due to the comparatively large size of the building. The examples of **fabric surfaces**, either static or dynamic, take reference to textiles and drapery folds. Here low-res is similar either to weaving as a structuring principle, or to dying and printing as a subordinate, overlaid principle. For **tectonic surfaces** on the other hand, low-res is the major structuring principle, with similarities to grains or structures in natural materials, that are intentionally exposed.

Illuminated / mediated surfaces association: translucent, video animation	**Fabric surfaces (static / dynamic)** association: textile, energy flow	**Tectonic surfaces** association: grained texture
Torre Agbar, Barcelona, Spain architects: Ateliers Jean Novel, 2005	Santa Caterina Market renovation, Barcelona, Spain architects: Miralles - Tagliabue | EMBT, 1997	Museum of Kanayama Castle Ruin, Kanayama Community Center, Ota city, Gunma, Japan architects: Kengo Kuma & Associates, 2009
 Fig.4 © Agbar Tower Corporate Marketing Department	 Fig.5 Miralles - Tagliabue | EMBT	 Fig.6 © Takashi Yamagishi
GreenPix - Zero Energy Media Wall (Xicui Entertainment Center), Beijing, China architects: Simone Giostra & Partners, 2008	Technorama Facade - Technorama, The Swiss Science Center, Winterthur, Switzerland architects: Ned Kahn, Durig and Rami, 2002	Hotel Industrial, Paris, France architects: Emmanuel Saadi Architecte, Jean-Louis Rey and François da Silva, 2008
 Fig.7 © Simone Giostra & Partners	 Fig.8 © Ned Kahn	 Fig.9 © Nicolas Borel

Tab.3 Examples of low-res facades

The **Torre Agbar by Ateliers Jean Novel** (Fig.4) has a multi-layered, pixel-like patterned façade. Some of these square pixels are opaque and coloured in a gradation from red at the bottom to blue at the top, some are openings that randomly perforate the load bearing shell. Some openings have coloured glass windows, others have clear glass. On the outside an enveloping layer of tilted louvres. During the day, the sunlight dances along the curved façade, and vibrates between and along the transparent louvres. It is the geyser Jean Novel is speaking of, a geyser of colour and reflections. During the evening and night, the building turns, illuminated by artist Yann Kersale, into a geyser of pulsating light and illusion.

> *"The surface of the building evokes water: smooth and continuous, shimmering and transparent, its materials reveal themselves in nuanced shades of color and light."* (Jean Novel)

The **GreenPix - Zero Energy Media Wall by Simone Giostra & Partners** (Fig.7) is an illuminated and mediated façade with integrated photovoltaic system. This time the surface is rectangular, not plane but with some protruding elements. At daylight the façade generates energy with the help of three differently dense populated PV laminates, that are arranged in a compositional template reminiscent to *"seascapes as an example of an ever-changing visual experience"* (Eakin, 2007, p48). During daytime the reflections on the bumpy façade. During the dark hours the façade changes into a huge video screen, while using the during daylight generated energy, each laminate becomes one pixel for low-res video animations.

The **Santa Caterina Market renovation by Enric Miralles and Benedetta Tagliabue of EMBT** (Fig.5) features a fluid, wavy, undulating roof covered with multicoloured ceramic tiles. Each hexagonal tile is combined in groups of 37 pieces to form a larger hexagon and to finally generate a tetris like pattern and collage, intended to *"reflect the polychrome art nouveau facades of the merchants' mansions and the public buildings those merchants sponsored"* (Riley, 2006, p25).

The **Technorama Façade by artist Ned Kahn** (Fig.8) is formed by an even grid of thousands of movable aluminium panels, but the slightest breeze excites them to flutter and *"reveal the complex patterns of turbulence in the wind"* (Kahn, undated), a huge real time animation of the natural flow of wind energy translated into reflections and reverberations.

The **Museum of Kanayama Castle Ruin by Kengo Kuma & Associates** (Fig.6) has a wall cladding made of thin rectangular stone slabs. The pattern is simple at first, but manifold when indulging in the building's deeper composition.

> *"The natural stone external wall is a signature feature of the building, a contemporary take on historic materials. Two sizes of rectangular stone slabs are set so that their corner tips touch. The resultant alternation of solids and voids on a sheet steel supporting frame creates a delicate screen. The dynamic, lightweight character of the design becomes even more evident when the sheet steel structure is replaced by a simple steel grid that allows greater passage of light. The same design is continued inside with the wood fibre and concrete panels of the false ceiling. Here the lay is slightly different with some panels overlapping so that in the exhibition section they turn into 3-D cells giving a greater sense of depth."* (Pagliari, 2010, p25)

Kengo Kuma generally operates with an approach fully without the computer derived, digital reference to pixels. He calls it *"particlization", "apertures",* and more recently *"gaps"* (Futagawa, 2009, p122), and his modus operandi yields results, that are more affine to the pre-digital age and low-tech architecture.

> *"[...] by reverting to an even more primitive condition, to search for possibilities in an area that can only be resolved by a new, contemporary technology."* (Kengo Kuma in Futagawa, 2009, p116)

The **Hotel Industrial by Emmanuel Saadi Architecte, Jean-Louis Rey and François da Silva** (Fig.9) is a renovation project, where windows were replaced with light-transmissive PV laminates. A reason for pixelisation is often the search for a pattern generating principle, here the pattern is predetermined by the manufacturing process of PV laminates and the size of a crystalline silicon solar cell. Pixelisation is used purely in its original, computer graphics derived sense, simply to alter a photography of limestone, the building's original cladding material, into a low-res image of positive and negative pixels (Demoustier, Martin & Zéro, 2007). But instead of designing the material, the approach is turned upside down by alloting gaps for daylight to penetrate between opaque cells, to leack into the architectural volume. By night the play is reversed by spilling light into the street and joining the galanty show of the urban nightlife.

After this short catwalk of contemporary architectures it seems obvious that patterns are regaining popularity.

6. Case studies – Japanese traditional patterns as an inspiration for BIPV

What we have described in the previous four chapters, was the starting point for an investigative approach into applying the inventory of local cultural heritage as an inspiration for technological innovation. The following case study translates the spirit of traditional Japanese pattern into a contemporary design and pattern generating approach, bridging global technology with local culture.

6.1 Aim and Study Background

Light-transmissive photovoltaic (PV) laminates provided the technological test bed and Japanese traditional family crests were the cultural ingredient for this case study. The aim was to improve the versatility of light-transmissive PV panels used for architectural integration into building skins (BIPV). Even though PV is in general highly appreciated to contribute positively to a building's energy requirement in a sustainable manner, their actual use and integration into the building skin is lacking far behind their full potential. From a cultural point of view this is a matter of acceptance of a product appreciated for its technology, but not its appearance. One of the main reasons given, is that the standard products offered by the PV industry are regarded as insufficient to pleasantly merge the technological product with the demands of contemporary architectural design (Scognamiglio et al., 2006; Mercaldo et al., 2009), thus rendering the appearance as 'added' instead of 'integrated'. In chapter 2, Tab.2 an example was given, that with the help of cultural referencing public acceptance can be achieved.

6.2 A condensed overview on PV

PV technology nowadays can be separated into two major groups with differing material and visual attributes, the first group of crystalline silicon technology and the second group of thin-film technology.

Crystalline silicon PV technology (Fig.10, façade) is characterised by distinctive square, semi-square or round solar cells with 100, 125 or 156 mm edge length or diameter, who are additively tiled and laminated between sheets of glass or film to cover larger areas. With this kind of PV panels translucency is achieved by spacing the opaque crystalline solar cells, so that light

can penetrate through the resulting gaps – a rather coarse approach. Such panels are often called 'light-through' due to the remaining view obstructions.

The second group of **thin-film PV technology** (Fig.11, roof) on the contrary are monolithic PV sheets of manufacturer dependent and varying, but usually much larger size than crystalline silicon cells. Transparency is achieved by laser scribing a light-transmitting pattern of thin lines or tiny holes, a subtractive process. As this pattern yields a much finer, much more uniform transparency, such PV panels are called 'see-through' and have an appearance similar to tinted glass.

Fig.10 © Emmanuel Saadi


Fig.11 © HBS Wolfhagen

6.3 Innovation for PV – Innovation with PV

Our case studies focus on crystalline silicon cells for two reasons: (a) the manufacturer independent standardisation of the solar cell, which allows for widespread utilisation of the design proposals; and (b) the affinity of the additive tiling of solar cells to contemporary low-res strategies, as described in chapter 5. In the context of other materials low-res strategies are often employed as an organisational and pattern generating principle, but in terms of crystalline silicon cells it is an inherent quality. Here the smallest 'pixel' or 'particle' is equivalent with a single square, semi-square or round solar cell. However, the usual design alternatives offered by the PV industry are mostly restricted to an equal spacing of the cells throughout the grid pattern. The reason for this can be attributed to the mostly opaque PV products, the lion's share of production. Light-transmissive PV is still a niche product with a lot of design potential yet to be explored. The GreenPix - Zero Energy Media Wall by Simone Giostra & Partners (Fig.7), the Hotel Industrial by Emmanuel Saadi Architects (Fig.9), and the Menara Marrakech Airport by E2A Architecture (Fig.3) are three of the growing, but still limited number of examples, were the designers embarked on the quest to discover the potential and de-materialise the ready-made industrial PV products.

6.4 The source of inspiration – Japanese family crests

In order to understand the importance of patterns in Japanese tradition and culture, it must be remembered that the Japanese/Eastern form of writing and building has most likely shaped the perception of the universe, as described in chapter 3. The initial theory of Japanese people has never changed: catch the cosmos as an image (Liotta, 2011, p38). That is probably the main reason why Japanese artisans have developed such a high skill in producing thousands of

different patterns, motifs and ornaments. Flexible enough to be adapted to numerous contingencies, patterns undergo radical changes without losing their aesthetic identity. They have been used by Japanese craftsmen for different purposes: from architecture to design, dyed on clothing and as family crest. Patterns are deeply rooted in Japanese culture and identity. However, patterns are present in all cultures of the world.

For this study, *kamon* or traditional Japanese family crests were chosen as source of inspiration. *Kamon* depict plants, animals, natural or man-made objects. Some are very figurative, others are more abstract, but most inhere certain geometric qualities, and despite being monochrome exhibit a layered depth. We selected *kamon*, that are composed of square, rectangular or linear elements, which can be easily translated into single or groups of photovoltaic solar cells. Strong linear arrangement of PV cells is one of the requirements for an automated manufacturing process. Thus the selected *kamon* were applied to generate alternative light-transmitting PV patterns.

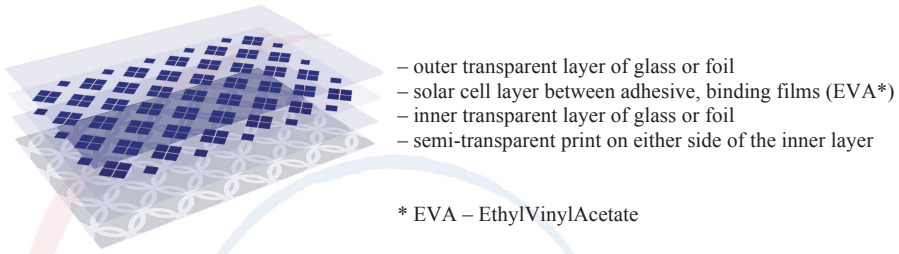


Fig.12 Layered structure of a light-transmissive PV laminate

Fig.10 shows the layered structure of a light-transmissive PV laminate with the addition of a semi-transparent print on either side of the inner layer. This feature is a common option for glazings, but hardly explored in the application of light-transmissive PV.

6.5 The case studies

Finally, four exemplary case studies are illustrated in Tab.4, showing the source of inspiration, the translation into two layers, and a rendered image of a possible façade application seen from inside the building.

We focused on crystalline silicon PV technology, as explained in chapter 5.2 and 5.3, but the approach is not limited to this technology. Fig.13 shows an example using thin-film PV technology.

"Transparent modules don't always have to look the same [...]." (Riedel, 2010)

Fig.13 © Schüco

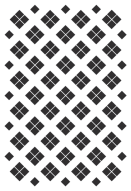
iafor

Case study A
Maru ni yottsu-wari-ishi

Family crest

Fig. 14
□□□□□□□□

Solar cells



Print

Interior rendering

Case study B
Nanatsu-wari sumi-tate yottsu-me + Tsunagi kokonotsu-me

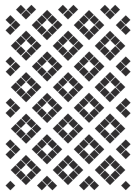
Family crest

Fig. 15
□□□□□□
□□□□

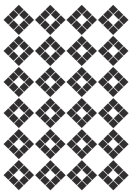
+

Fig. 16
□□□□□

Solar cells



Print



Interior rendering

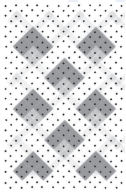
Case study C
Mittsu-me

Family crest

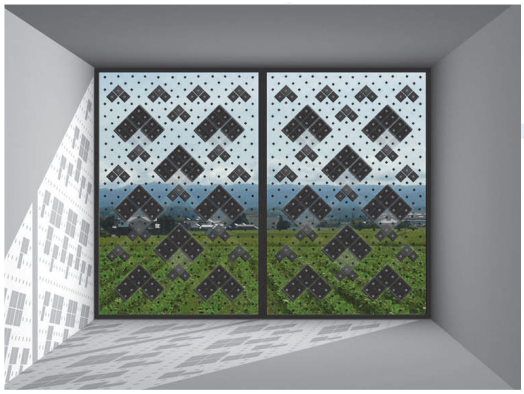
Fig. 17
□□□

Solar cells

Print



Interior rendering

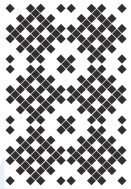


Case study D
Muttsu kumi sujichigai

Family crest

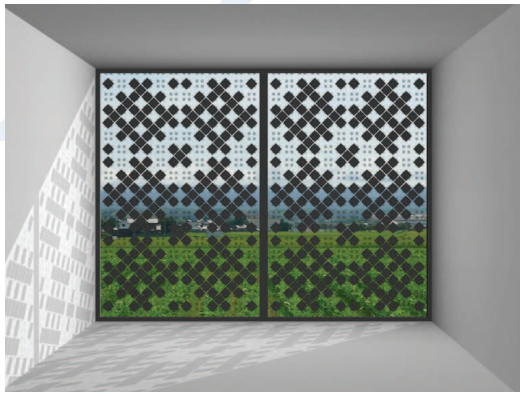
Fig. 18
□□□□□□□

Solar cells



Print

Interior rendering



Tab.4 Case studies, source of *kamon:* http://www.kamon18.com/index.html

7. Conclusion

This paper points to the importance of implementing into contemporary design not only present technologies, but also cultural uniqueness. It must be noted, that this is not an attempt of bringing traditional icons without thought into the context of modern design, but to highlight the importance of cultural adaptation of technology. Careful consideration must be taken to not cheapen the value of traditions.

Our case studies are an attempt to make clear that such traditional values combined with new digital technologies is not incompatible, as demonstrated in the case studies presented here. On the contrary, the use of Japanese traditional patterns as an inspiration for BIPV proves to be successful in the reinterpretation of the long established tradition and aesthetic of Japanese pattern design. Japanese sensibility retains its unique character even when it is used along with new technologies.

> *"Japanese architecture is a treasure trove of boundary techniques. […] Diverse screens (such as louvers and [curtains][xi]) and intermediate domains (such as verandas, corridors and eaves) are gaining attention once more as devices for connecting the environment to buildings."* (Kuma, 2010, p15)

As Arad observes, design has always evolved alongside technology (Bullivant, 2005b, p60), a mutually beneficial relationship. Thanks to the use of parametric design software, we were able to edit, and use the traditional aspects pertinent to Japanese patterns and transform them into contemporary possibilities of what a BIPV product might look like. Now it is the task for the PV industry to incorporate the demand for custom designs into their production processes.

> *"This is not a dream, because technology plus poetry equals architecture […]. All architects […] have to do is make it happen."* (Wigginton, 1996, p238)

To reflect once more on Cedric Price and his famous statement. Technology may provide answers, but as little as technology is a goal in itself, neither is sustainability.
Both are *"a constraint on the achievement of other goals"* (Kajikawa et al., 2007, p222).

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Figures

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Fig.13	© Schüco (Riedel, 2010)
Fig.14-18	http://www.kamon18.com/index.html

i In some rare cases, non-renewable sources may not be replaceable, but should be used as cleanly and efficiently as possible. For further information on the definition of sustainable energy see Acres (2007).

ii BIPV – building integrated photovoltaic

iii Cedric Price (1934-2003) was a British architect, teacher and writer, and one of his famous statements is "Technology is the answer, but what was the question?", for more information see Steenson (2007).

iv Kazuhiko Namba is a Japanese architect, born 1947. He etsablished his office KAI Workshop in 1977, and was professor at the University of Tokyo from 2003-2010. He became known throughout Japan with a series of one family houses, the first one, Ito house or box-house 001 finished in 1995. Until today he has designed more than 130 individual box-houses, exploring different social, spatial, material, structural, environmental and formal meanings in his designs. The results of this investigation into the design of eco-houses were condensed into a theory about sustainability in architecture, which Namba calls the 'Four Layers of Architecture', published in his book 'The Box-Houses: Towards a New Ecohouse' in 2006.

v Vitruvius (born around 70-80 BC, died after 15 BC) was a Roman writer, architect and engineer, and is best known as the author of 'De Architectura' (Ten Books on Architecture). This text deeply influenced Leon Battista Alberti (1404-1472) in writing his 'De Re Aedificatoria' (1452, On the Art of Building in Ten Books).

vi *Firmitas* is stability or durability. *Utilitas* is functionality. *Venustas* is beauty.

vii *"Mashrabiyas were veils drawn against the outside world and behind their cool shield of latticework those inside did recline in shaded privacy while gazing out at the tumult of the streets below. And yes, they were also a haven for women whose need for privacy in older cultures did give rise to the exotic, if exaggerated, legends of the hidden harem.*

Yet the origins and functions of the mashrabiya are far more prosaic – as their Egyptian name suggests. The word "mashrabiya" comes from an Arabic root meaning the "place of drinking," which was adapted to accommodate the first function of the screen: "the place to cool the drinking water."

As indeed it was. The shade and open lattice of a mashrabiya provided a constant current of air which, as the sweating surfaces of porous clay pots evaporated, cooled the water inside. This was such an important function that sometimes a small screened platform large enough to accommodate two or three pots of water was built out from the main screen to catch additional air and cool more water. From this beginning the mashrabiya developed into an eminently practical architectural feature that for centuries served, at one and the same time, as window, curtain, air conditioner and refrigerator. Shrewdly designed, it not only subdued the strong desert sunlight but also cooled houses, water and people in lands from India to Spain where, at certain times of the year, people hide from the sun as others seek shelter from rain." (Feeney, 1974)

viii It should not be forgotten that perspective is a law, a perceptive one, yet a law apt to build up -and geometrically control- the constitution of a state.

ix For further reading on this topic see Garcia (2009).

x Pointillism, or divisionism, is a technique of painting in which small, distinct dots of pure colour are applied in patterns to form an image, that relies on optical mixing by juxtaposing pigments instead of pigment mixing. George Seraut developed the technique, branching from Impressionism in 1886, anticipating the rasterised and optical mixing television image.

xi We deliberately replaced the Japanese term 'noren', which are in fact a kind of fabric dividers.