Smart Skin. Individualising the form of an ecological building

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The subject of the analysis are façades – the element with the greatest impact on the shape of the building. One of the tasks of the article is an attempt to determine whether, in relation to the mentioned technologies, it is possible to assess their direct impact on the health of the inhabitants. Final conclusions were drawn on the basis of a comparison of the characteristic parameters and the environmental impact of smart skin façades.

Do contemporary ecological buildings feature formal attributes that distinguish them from so called "standard" architecture? The requirements of the construction law – regarding energy efficiency – oblige most of the contemporary buildings to incorporate technologies or elements that may be referred to as ecological. Research indicates though that the standard claim that an ecological building is supposed to feature a compact form while aiming for a cubic or spherical shape [1, 2] – does not find a straightforward reflection in the world around us [3].

Such terms as: ecological, sustainable, green – in relation to architecture tend to be used interchangeably while comprising a variety of divergent issues – from technical to sociological. In the article, the wording "ecological" is narrowed down and refers to the definition of an "ecological" building created by the World Green Building Council[1]. The first three out of eight features that distinguish an ecological building include those most often associated with technological solutions: efficient use of energy, use of renewable energy and reduction of pollution.

The buildings certified in the LEED or BREAM systems (which objectively confirm many ecological features of the cubature) are formally diversified in the extreme, and it is rather difficult to notice their common characteristics. However, when designers aim to achieve an educational or advertising effect or simply draw attention to solutions designed as ecological, they often accentuate such intentions by means of unusual forms or non-standard locations. Such a tendency is evident in buildings dating a dozen or so years back, when the "eco-friendliness" in a building was still something of a novelty[2].

BedZed (Beddington Zero Energy Development) designed by Bill Dunster (built in 2000–2002) greatly influenced ecological architecture, and thus became a prototype for the One Planet Communities program, whose aim was to create a global network of eco-housing estates. While working on BedZed, the emphasis

Exhibit 1. A classic example of ecological architecture. BedZed estate in London, very characteristic design (chimneys), technologically and functionally innovative. Photo by A. Drapella-Hermansdorfer

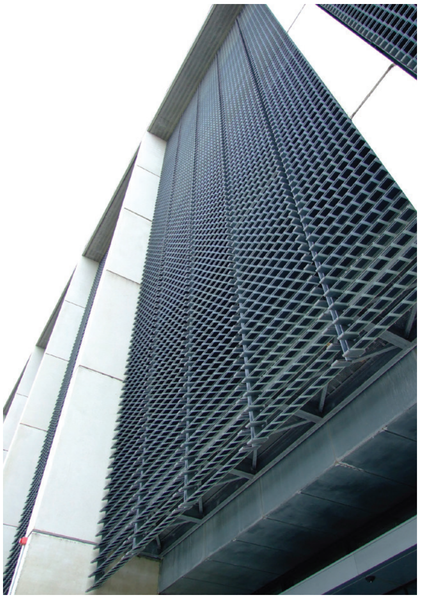

Exhibit 2. Photovoltaic cells as an off-grid installation. HOFOR office building, Copenhagen. Photo by Author

was not only on developing sustainable architecture, but also on creating a sustainable local community. The construction and technological aspects were as important for the designers as the sociological ones. Even now, BedZed – despite the failure of its many design elements [4] – it has been one of the best examples of ecological design many years on. It is worth adding that the failure of the project has been pointed out both in terms of innovative technologies (abandoning the idea of local CHP heating, inefficient living-machine type sewage treatment plant, parched green roofs, overheating of apartments in summer) and its sociological aspect (after partial "replacement" of its residents, the new tenants did not turn to the ecological lifestyle as set forth in the BedZED guide; what may be striking is the amount of air travel of BedZED residents – significantly higher than the Sutton average – [5].

One of the elements of the building that is currently the subject of technological peregrinations by designers is the construction and finishing of the facade – the so-called *Smart Skin*[3]. This most visible part of the building offers great opportunities to create something more than just the covers for cubature[4].

Smart skin, in addition to its standard function – i.e. protection against external conditions – can also fulfil other roles related to ecology – and sometimes rather surprising ones. This type of structure is more integrated with the building – not only structurally; it also affects the amount of energy consumed, and it is an integral element of the building's technical infrastructure.

Energy Generation
Photovoltaic module facade

The most obvious and popular solution is to cover the facade / roof with photovoltaic cells. However, this could be done applying a more sophisticated idea than simply mounting ready-made panels. One of such concepts is the use of an off-grid installation (a separate network otherwise independent from other elements of the building's electrical grid). Such solutions feature limited production capacity and energy storage capacity (space allocated to batteries); they usually serve to illuminate the facade, highlight information and advertising elements (Exhibit 2.).

Exhibit 3. Photovoltaic cells printed on glass (the so-called Sky Gardens in BedZED village). Photo by A. Drapella-Hermansdorfer

Exhibit 4. Soft House, design by Kennedy & Violich Architecture, Hamburg, 2013. Photo by Author

Exihibit 5. Building with bio-reactive facade, designed by Splitterwerk Architects and Arup, Hamburg, 2013. Photo by Author

[1] https://www.worldgbc.org/what-green-building.
[2] Cf. The Solar Settlement at Schlierberg (Solarsiedlung am Schlierberg, design by R. Disch), The Heliotrope (Freiburg, design by R. Disch), Greenwich Millennium Village in London (design by R. Erskine), Earth Centre (Doncaster, design by B. Dunster), Solarcity Amorbach (Neckarsulm, various designers), EVA Lanxmeer (Culemborg, design by M. Kaptein et al.), Ökokultureller Gewerbehof – Kühl KG (Frankfurt, design by J. Eble.
[3] The ability of a given structure to react to changes in the environment within which it is located [6].
[4] Contemporary buildings seem to reduce their essence to becoming the packaging; effective, attractive and [...] devoid of substance [...] [7].

Exhibit 6. Casa Albergo – a building with façade partially painted with catalytic paints, designed by Studio Costa and Partners, Turin, 2011. Photo by Author

Exhibit 7. Palazzo Italia, design by Nemesi & Partners Srl, Milano, 2015. Photo by Author

Exhibit 8. Decorative facade of Manuel Gea Gonzalez Hospital, Mexico City, 2013 (https://images.fastcompany.net/image/upload/w_596,c_limit,q_auto:best,f_auto/fc/1681660-inline-009-c009829-r1-00-0.jpg)

In the case of printing photovoltaic modules directly onto window panes, the effect is not only the production of electricity, but also protection of the building's rooms (most often the southern facade) against excessive insolation and overheating (Exhibit 3.).

A more innovative approach aims at attempting to provide artificial lighting to the rooms from the outside. An example of that is the facade structure of the Soft House building in Hamburg. Solar Sails – Flexible photovoltaic cells printed on fabric rotate towards the sun. During the day they generate electricity and serve as protection against overheating of the interior, while at sunset the sails emit light (from the outside – through the windows) thanks to the LED diodes built into them – somehow “delaying” the oncoming dusk (Exhibit 4.).

Bio-reactive facade

The BIQ building (Exhibit 5.) using this experimental technology was built as part of the IBA 2013 exhibition in Hamburg. The water-filled panels on the south elevation are bioreactors for the cultivation of microalgae, which gradually turn them green as they grow. As water flows through the panels, it is heated by the sun's rays. Thermal energy is recovered by a heat pump located on the ground floor of the building and is used to heat domestic water. Any excess heat is stored in the ground by pumping it into boreholes 80 meters deep. In turn, the biomass produced from algae is fermented in the local biogas plant. Compared to plants grown in soil, algae produce 5 times more biomass per hectare and contain a large amount of oils. This feature allows for alternative use of biomass in the cosmetics and food industry in the summer when growth is at its peak. It is also worth mentioning that while growing, microalgae decompose the carbon dioxide contained in the air, processing it, among other to oxygen.

Pollution absorption

There is a growing popularity of buildings with façades whose additional feature is aimed at reducing air pollution. This is accomplished through the selection of innovative building materials that may absorb and bind air pollutants within. This may also be done through technologically unsophisticated solutions – painting (soaking) the facade with appropriate paints (Exhibit 6.), or such advanced solutions as mounting biologically active elements. The latter solution is more spectacular, it affects the form of the building itself and may be utilised in both existing and newly designed buildings. Prefabricated panels can be an integral part of the building's facade – an example is the remarkable Palazzo Italia, a facility designed to be the dominant feature of the EXPO exhibition in Milan. The façade is covered with Biodynamic concrete active panels with TX Active technology that captures pollutants and transforms them into neutral salts[5] (Exhibit 7.). In the case of existing buildings, it is possible to attach elements forming the outer skin to the facade. One of the producers of such devices (the Prosolve370e system) is the German company Elegant Embellishments Limited. The created structure consists of repetitive interconnected prefabricated elements. The modules are covered with titanium dioxide. The technology requires little moisture and sunlight to reduce nitrogen oxides and volatile organic compounds to innocuous amounts of carbon dioxide and water. The 2,500 square meter facade of the Mexico City hospital (Exhibit 8.), cited as an example, naturalises the pollution produced by 1,000 cars daily.

Exhibit 9. Smart is Green is an example of a three-layer façade building. Railing panels are filled with a phase change material (dark elements in the photo). Photo by Author

Thermal Energy Storage

Modern construction technology while allowing for perfect thermal insulation of the interior of the building from external conditions, has made it impossible to accumulate heat obtained from solar energy in the walls. Thanks to technologically advanced solutions, such a function can now be fulfilled by such facade elements as balustrades. An example is a building called *Smart is Green*[6]. The façade was designed as a complementary three-layer system (1 – a wall of creepers shading the windows in summer, 2 – thermo-saving windows, 3 – balustrade). Yet its focal element is the balustrade, the filling of which is made of panels filled with a phase change material[7]. They make use of a process similar to that observed in common hand warmers. The difference is that the PMC in the railings is kept in a permanent aggregate state between solid and liquid. The panels are capable of cooling the building's surroundings during the day by absorbing heat while emitting it back at night, thus heating the surrounding air.

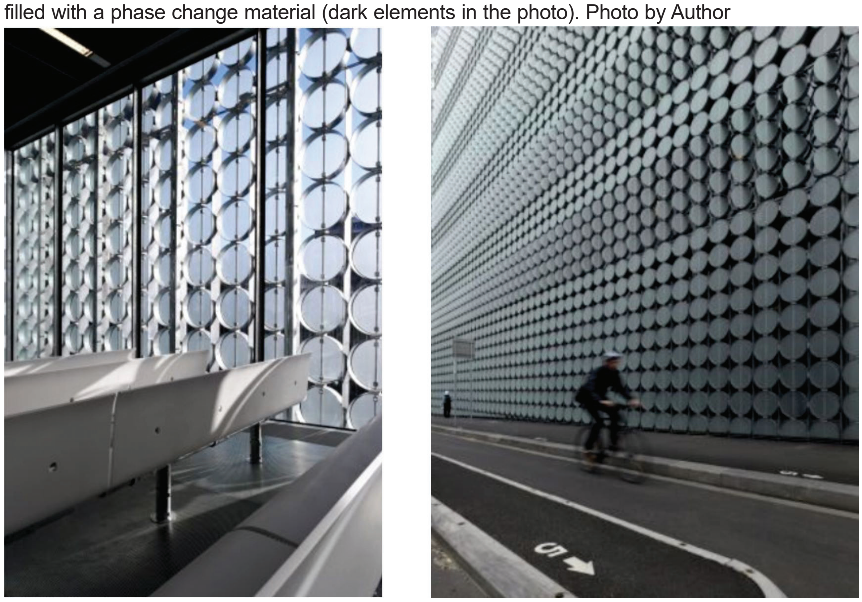

Exhibit 10. RMIT Design Hub facade from inside and outside. Design by Sean Godsell Architects, Melbourne 2012 (https://static.designboom.com/wp-content/uploads/2013/07/sean-godsell-architects-RMIT-design-hub-designboom02.jpg)

Active Response to Environmental Conditions

One of the buildings whose façade adapts to the sunlight is the Design Hub, a building of the RMIT University (Royal Melbourne Institute of Technology) design school. Its cubature has become an icon of style; it has won many awards, and the building has been equipped with the facade that enables to control both ventilation within and the level of interior insolation. Round plastic "throttles" mounted on a common axis are rotatable. The solution is not technologically advanced and was classified as low-tech. Depending on the position of the sun, the panels arranged in sets regulate the lighting and ventilation of the rooms. In 2017, the facade panels on the southern side of the building were replaced with photovoltaic ones, and the facade gained an additional pro-ecological function. It has become the university's testing ground for photovoltaic cells with an innovative design. A prototype of a graphene-based cell and a prototype electrode model is to test the possibilities of developing a flexible thin-film system for capturing and storing solar energy in a single device.

The material itself or innovative technology may become a focus for designers. Façades that react to the ambient temperature make an interesting case. An example is the parametric coating of thermobimetallic steel panels, created at the USC[8]. The operating principle of the coating is based on biomimetics (i.e. imitation of the action of living organisms); each side of the panel reacts differently to sunlight, expanding and contracting at different rates – creating a tension between the two surfaces and ultimately a curling effect. So when the surface heats up, the thin panels in the shade curl up to allow more air to pass into the space below – and when it cools down, it closes again [8].

Façades made with recycled materials

While considering the problem of the building facade as a characteristic element that can emphasize the environmental aspect, it is diffi-

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[5] The salts are deposited on the surface of the panels and washed away by rain. Sunlight (UV) is required for the catalytic reaction. Additionally, the active compound – in this case titanium dioxide – can oxidize façade contamination and keep it clean for a long time.

[6] The building was erected as part of the Smart Materials Building theme exhibition for the IBA (International Building Exhibition) in Hamburg, design by Zillerplus Architekten und Stadtplaner München, 2013.

[7] Variable phase material or PCM (Phase-Change Material) – also known as a phase-change compound. It is a substance that is able to absorb, accumulate and then release a large amount of energy per unit mass in the range of the phase transition temperature (e.g. solid – liquid).

[8] USC – University of Southern California, a team of designers supervised by Prof. Doris Kim Sung.

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Exhibit 11. Bloom – an object demonstrating the properties of a thermobimetallic coating, located in the exhibition yard of Material and Application exhibition space. Los Angeles, USA (https://www.materialsandapplications.org/membership)

Exhibit 12. The building of the Swiss Museum of Transport, utilising old traffic signboards for the facade cladding. Design by Gigon & Guyer, Lucerne, 2009 (https://image.architonic.com/imgArc/project-1/4/5204924/GigonGuyer-Verkehrshaus-der-Schweiz%2C-Luzern-04.jpg)

cult to skip constructions that are not smart (as defined by [6]) in the technological sense, but are inventive and must never be denied their ecological character. The fundamental process used in sustainable development is material recycling [9]. As façades often make use of recycled materials, by doing so they contribute to the perception of such buildings as environmentally friendly[9].

Finally, let me draw your attention to the idea of DFD (*Design for Deconstruction*) – an unusual approach to designing façades – which, regardless of the construction material, form or structure, significantly increases its environmental friendliness. Even at the design stage, DFD takes into account the possibility of a disassembly[10] of the original facade and subsequent replacement of all or some of its elements with the new ones. Researchers indicate that it is the facade that is the most frequently rebuilt part in a building. Therefore, rendering it for possible disassembly at the start is the right, ecological and economically justified activity [10 p. 60].

Summary

An overview of some unusual features installed on the façades of buildings[11] is presented in the table below, in which the functional and structural relationships for the discussed solutions are indicated. Only the features of the façade that were considered the most important were compared. It is worth noticing the direct link between the degree of technological advancement and integration into the building infrastructure. This always applies to structures linked to energy production.

The examples described above clearly present how innovative functions are featured onto façades and provide an answer to the question posed at the beginning of the article – i.e. ecological buildings do not have a characteristic form; there are no distinguishing features (in terms of the form of the facade) that would automatically qualify the building as ecological without providing sufficient clarification. The distinguishing feature of the functioning of such structures should be indicated. Most of the systems described herein are inextricably linked with the building infrastructure. Therefore, the essential aspect – and a much more important one than in the case of traditional façades[12] – is their durability. In buildings with façade intelligent systems, it will be very difficult to replace such an element with another, in many cases impossible (e.g. BIQ building). Therefore, it is not possible to design them in the DFD system.

The building requirements in force that pertain to energy-efficiency promote the use of many eco-technologies (e.g. photovoltaic solutions), which results in the perception of such solutions as a standard and they no longer indicate the "greenness" of the building. Apparently there seems to exist only one direction – further reducing energy consumption and using renewable energy, and buildings – gradually and imperceptibly, having visible and hidden eco-technologies, will bring about our acceptance for many elements. Gradually we will be able to define all of them as green – and this change is likely to happen without excessive bureaucracy.

Exhibit 13. A characteristic apartment building clad with a thousand battered doors. Design by Choi Jeong-Hwa, Seoul, 2011 (http://waveavenue.com/wp-content/uploads/2012/02/doors4600x800.jpg)

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[9] Cf. How to Make a Facade with Recycled Materials: 21 Notable Examples (https://www.archdaily.com/896930/how-to-make-a-facade-with-recycled-materials-16-notable-examples).
[10] There is an inherent different between such terms as deconstruction and destruction.
[11] As described in the article.
[12] In the case of a standard facade, it is possible to insulate it, paint it, replace the plaster, type of cladding, etc.

Table 1. Table of functional and design relationships of the described technologies

	cost[13]	The degree of interference with the building structure	The degree of integration with building installations	A standard, repetitive solution	The degree of technological advancement of construction elements
PV modules	+	0	+	+	+
Bio-reactive panels	+	+	+	-	+
Absorption of pollutants	+	0	-	+	0
Thermal Energy Storage (phase-change material)	+	0	+	-	+
Biomimetic coatings (shading effect)	+	0	0	+	0
Facades made with recycled components	-	0	-	-	-

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CORRECT QUOTATION FORMAT
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Abstract: Contemporary ecological buildings have no formal attributes that distinguish them from "standard" architecture. What is more – due to the requirements of the construction law regarding energy efficiency, currently designed buildings almost always are equipped with technologies or elements that could be described as "green" or "health promoting". The aim of the article is to check whether this thesis is indeed true. The subject of the analysis are façades – the element with the greatest impact on the shape of the building. The innovative functions fulfilled by these structures were analysed. The examples – depending on the function performed – were divided into groups: energy production, pollution absorption, thermal energy storage, response to environmental conditions and the use of recycled materials. Relatively common and experimental technologies were considered. One of the tasks of the article is an attempt to determine whether, in relation to the mentioned technologies, it is possible to assess their direct impact on the health of the inhabitants. Final conclusions were drawn on the basis of a comparison of the characteristic parameters and the environmental impact of smart skin façades.

Keywords: smart skin, ecological building, smart façades

Streszczenie: SMART SKIN. INDYWIDUALIZOWANIE FORMY BUDYNKU EKOLOGICZNEGO. Współczesne budynki ekologiczne nie posiadają formalnych atrybutów, dzięki którym można odróżnić je od „standardowej" architektury. Co więcej, ze względu na wymogi prawa budowlanego dotyczące energooszczędności projektowane obecnie budynki praktycznie zawsze posiadają technologie lub elementy, które moglibyśmy określić jako „zielone" lub „prozdrowotne". Celem artykułu jest sprawdzenie, czy rzeczywiście postawiona teza jest prawdziwa. Przedmiotem analizy są elewacje – elementy budynku o największym wpływie na jego formę. Przeanalizowano nowatorskie funkcje pełnione przez te struktury. Przykłady – w zależności od pełnionej funkcji – podzielono na grupy: produkcja energii, pochłanianie zanieczyszczeń, magazynowanie energii cieplnej, reakcja na warunki środowiskowe oraz wykorzystanie materiałów z recyklingu. Wzięto pod uwagę zarówno technologie stosunkowo powszechne, jak i te eksperymentalne. Jednym z zadań artykułu jest próba określenia, czy w odniesieniu do wymienionych w nim technologii da się określić ich bezpośredni wpływ na zdrowie mieszkańców. Wnioski końcowe sporządzono na podstawie porównania charakterystycznych parametrów i wpływu aktywności inteligentnych elewacji (ang. smart skin) na najbliższe środowisko.

Słowa kluczowe: ekologiczna fasada, ekologiczny budynek, inteligentna elewacja

[13] Simplified assessment – high, neutral, low (+, 0, -) – compared to standard façade.