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Between integration and expression: BIPV façades in Basel – a comparative study

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Abstract: The global energy transition necessitates integrating sustainable technologies into the urban environment, positioning Building-Integrated Photovoltaics (BIPV) as a key element of contemporary façade design. Although the evolution of photovoltaic technologies has broadened architects' vocabulary, implementing BIPV in European cities remains challenging due to contextual constraints, heritage protection, and the need for public acceptance. This study examines how distinct photovoltaic technologies influence the formal, material, and symbolic dimensions of façade design. A comparative case study was conducted on two public buildings in Basel, Switzerland: the Office for Environment and Energy and the Novartis Pavillon. Primary data were collected from on-site observations and photographic surveys (2025) and complemented by scientific and technical sources. Results show that BIPV façades can function simultaneously as energy systems and distinctly expressive architectural media. Sharing a focus on sustainability and innovation, the analysed cases represent contrasting approaches to BIPV design – one defined by architectural restraint and contextual harmony, the other by an expressive and interactive character. By juxtaposing these approaches, the paper highlights the expanding spectrum of solar architecture – from camouflage to expression, from integration to performativity – demonstrating how technological progress shapes both aesthetic meaning and symbolic communication.

Keywords: building-integrated photovoltaics, façade design, solar architecture, sustainable building design, BIPV façades

1. Introduction

Technology, like art, is a soaring exercise of the human imagination. — Daniel Bell

Architecture consistently responds to the technological, social, and environmental conditions of its time. In the current era of energy transition and the pursuit of sustainability in urban areas, this relationship is expressed through photovoltaic (PV) building envelopes [14]. Building-Integrated Photovoltaics (BIPV), in particular, are gaining significance as multifunctional systems that serve both as energy generators and architectural materials [10, 11]. Beyond meeting ecological imperatives, they aspire to aesthetic quality and symbolic meaning.

In contemporary cities, where rooftop PV systems are already widespread, façades are emerging as the next significant field for renewable energy deployment. BIPV convert the passive skin into an energy-active one, offering new potential for architectural expression and discourse. Depending on the design strategy, solar façades may integrate harmoniously with their surroundings or assert visual distinctiveness, becoming carriers of environmental and cultural values. The diversity of approaches makes BIPV façades a particularly compelling subject of architectural research.

PV technologies today encompass a wide spectrum of aesthetic and technical solutions. First-generation crystalline silicon (c-Si) remains dominant for its high efficiency and reliability, although rigid cell formats, visible structures and standardised colour tones (typically black or blue) often restrict architectural expression [3, 10]. Meanwhile, third-generation materials such as organic photovoltaics (OPV) are being developed. Despite lower efficiency, the combination of low weight, flexibility, partial transparency, and broad chromatic range makes them particularly promising for façade integration [12, 15, 19].

Against this background, the present study examines two exemplary BIPV façades—the Office for Environment and Energy (OEE) and the Novartis Pavillon—both completed within the same period in Basel, Switzerland, and serving prominent public roles in the city. Although differing in technology, material systems and architectural language, they exemplify how contemporary BIPV design can move beyond purely technical performance toward visual refinement and symbolic communication. Such innovations are particularly needed in European cities, where new architectural interventions must coexist with both modern and heritage-protected structures. Despite the growing technological maturity of BIPV systems, their broader implementation continues to face contextual and perceptual challenges, highlighting the need for design versatility and public acceptance [14]. The study aims to examine how distinct photovoltaic technologies shape formal, material, and symbolic strategies of façade design in contemporary urban architecture.

2. Methodology

This study employs a comparative case study approach to analyse strategies for integrating PV into contemporary urban façades. Two buildings were selected according to the following criteria:

- location within the same urban area (Basel);
- similar completion period (2021−2022);
- public function;
- exemplary façades featuring distinct PV technologies.

The projects are treated as demonstrative and communicative examples of BIPV within the European context, whose relevance lies in the architectural application of solar technologies in shaping form, material expression, and relationships with the urban fabric, rather than in maximising energy performance.

The analysis focuses on identifying both convergences and divergences across three main dimensions:

- urban and architectural aspects – context, form, integration;
- technical aspects - photovoltaic system, materials, energy role;
- aesthetic and symbolic aspects – visual perception, communication, cultural role.

The research combines primary data—on-site observations and photographic documentation conducted in Basel in 2025—with secondary sources encompassing scientific and grey literature, project databases, manufacturers' data, technical reports, and the websites of architects and companies involved.

The applied methodology entails limitations inherent in qualitative architectural research, as it partly relies on on-site observations and perceptual assessment involving interpretative subjectivity.

3. BIPV façade case studies

The following case-studies of two selected buildings illustrate how BIPV façades reconcile architectural intent, material innovation and energy performance within varied urban contexts.

3.1. Office for Environment and Energy, Basel (2021)

The Cantonal Office is located in the city's historic centre, within a dense fabric of heritage-protected buildings (fig. 1). The combination of a public function and a sensitive urban context required both architectural restraint and advanced sustainability strategies. The result is Basel's first office building certified to the Minergie-A-ECO standard, meeting the highest criteria of energy efficiency, user comfort, architectural quality as well as contextual integration [13].

The compact rectilinear volume, ranging from six to eight storeys, features a hybrid timber-concrete structure supporting a prefabricated modular envelope [4]. The highly insulated façades with closed-cavity windows and opaque BIPV cladding on all sides, are key elements of the comprehensive sustainable concept. Although the north façade contributes marginally to energy generation, the 360° configuration enhances overall performance and visibility as an urban model of solar architecture, enabling the building to achieve a nearly zero-energy standard [13, 17].

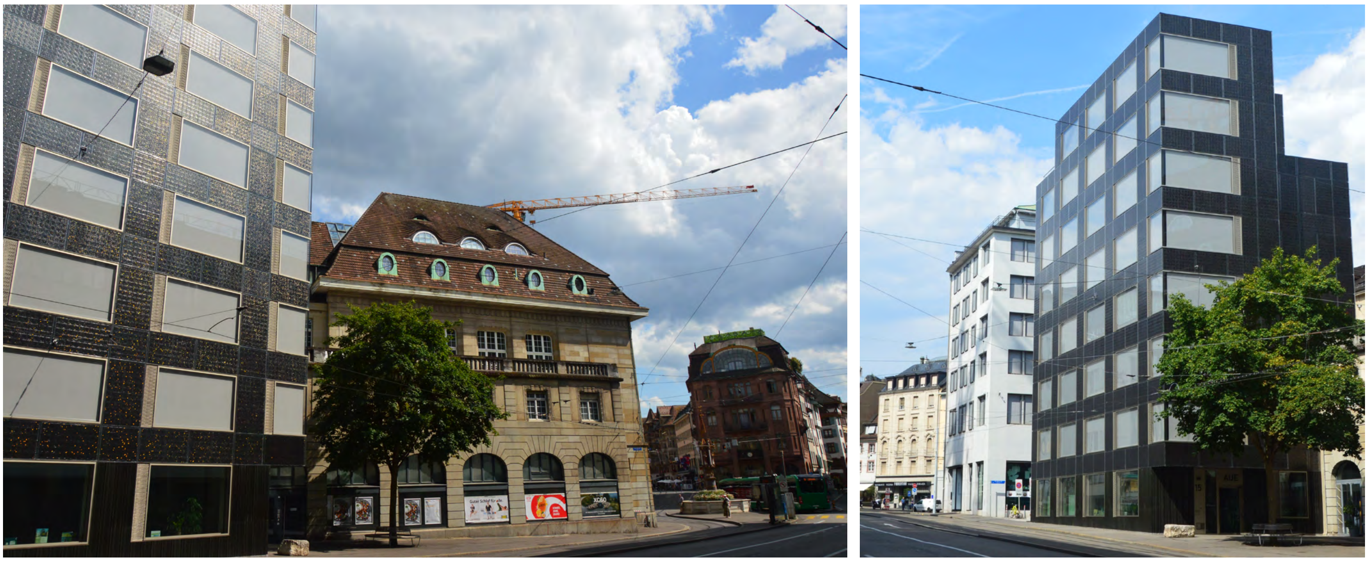

Figure 1. BIPV façades within the historic urban context of Basel's city centre. *Photo: M. Muszyńska-Łanowy (2025)*

Over 600 PV modules are integrated on aluminium subframes within a ventilated rainscreen cladding system. During construction, the BIPV design was revised, replacing the initially planned polycrystalline (p-Si) technology with high-efficiency monocrystalline (m-Si) PERC cells [16]. The interdisciplinary collaboration between designers, manufacturers, and façade engineers resulted in a project-specific material [9]. Each glass-laminated module was custom-made to align with the façade grid and window layout, featuring a textured fused-glass front surface developed specifically for this project (fig. 2). A titanium nitride (TiN) dot pattern was applied to mitigate bird collisions while enriching the visual character of the glass surface. Despite the technical complexity of multi-layer lamination required to compensate for glass surface irregularities, the BIPV modules achieve high durability and recyclability, with most components recoverable at the end of life [16].

Figure 2. View of the OEE's front façade showing the modular envelope with closed-cavity windows and opaque BIPV cladding. *Photo: M. Muszyńska-Łanowy (2025)*

3.2. Novartis Pavillon, Basel (2022)

Located at the southeastern edge of the corporate campus within a landscaped area along the Rhine, the pavilion forms part of the regeneration of the former St. Johann industrial district. Set in a broader ensemble of buildings designed by internationally recognised architects, it was conceived as a public forum promoting dialogue between science, art, and society [1, 7].

The compact, ring-shaped structure employs a hybrid timber-steel system. Both the outer and inner façades are enclosed by an experimental BIPV envelope, which merges organic photovoltaic (OPV) technology with an interactive media membrane (fig. 3).

Figure 3. Novartis Pavillon in the landscaped setting of the Campus, with contemporary office and laboratory buildings in the background. *Photo: M. Muszyńska-Łanowy (2025)*

The façade system comprises more than 10,000 custom-made OPV modules mounted on a tubular steel-mesh structure fixed to a lightweight aluminium subframe. The BIPV structure is suspended approximately 40 cm in front of the underlying sheet-metal shell, forming a ventilated double-skin envelope (fig. 4). Each rhomboidal module, printed on flexible organic film and laminated in polycarbonate, adapts to the pavilion's curvature through five geometric variations. Embedded within the OPV module surface are approximately 30,000 LEDs, nearly half bi-directional, connected via bayonet joints.

Figure 4. View of the main entrance. The double-skin façade is composed of a steel-mesh structure with diamond-shaped organic (OPV) modules integrated with LEDs. *Photo: M. Muszyńska-Łanowy (2025)*

The hybrid solar-media façade is self-sufficient: during the day, the modules generate electricity, while at night, the stored energy powers dynamic light projections, transforming the building into an illuminated communicative surface [7, 18]. At ground level, the semi-transparent OPV layer ensures daylight penetration and moderates solar gain while maintaining visual connection with the surrounding landscape.

Table 1. Summary of key parameters of the analysed case study buildings. *Own elaboration*

Case study building	Office for Environment and Energy	Novartis Pavillon
Address	Spiegelgasse 15 4051 Basel, Switzerland	St. Johanns-Hafen-Weg, 5 4056 Basel, Switzerland
Building typology	Office / Public Administration	Exhibition and Education Pavilion
Construction type	New	New
Year of construction	2018–2021	2022
Architecture	Jessenvollenweider Architektur	AMDL CIRCLE / Michele de Lucchi
Façade planners	gkp Fassadentechnik; Megasol Energie AG; SEEN AG (PV)	Emmer Pfenninger Partner; iart (media system)
BIPV façade system	Rainscreen cladding	Double-skin curtain wall
BIPV area	1,140 m^2	1,333 m^2
BIPV orientation	Multi-orientation N/E/S/W	Multi-orientation N/E/S/W
BIPV tilt	Vertical (90°)	Curved (0–90°)
PV cell technology	monocrystalline (m-Si) PERC	Organic (OPV)
Module construction	Custom glass laminate	Custom polycarbonate laminate
Module quantity	641	10,680
Installed power	163 kWp	36 kWp
Annual yield	~50 MWh/a	~1.3 MWh/a

4. Comparative analysis

Both case studies exemplify advanced and unique approaches to BIPV façade integration, yet they diverge in technological, aesthetic, and communicative intent. Developed within the same city and timeframe, they represent two distinct paradigms of contemporary solar architecture.

4.1. Urban context, form and integration

The Office for Environment and Energy demonstrates how BIPV can be harmoniously embedded within a dense historic urban fabric through restrained composition and muted aesthetics. Its compact, rectilinear volume with subtle height variations, aligns in scale, rhythm, and colour with the adjacent buildings, achieving visual continuity within a heritage-protected context. The building's modular, planar façades and carefully proportioned window openings reinforce a sense of balance and coherence, reflecting a deliberate architectural restraint appropriate to its civic function. This integration strategy shows that BIPV can become an unobtrusive yet expressive element of contemporary architecture without compromising historical character or urban harmony.

In contrast, the Novartis Pavillon, situated within a less dense, contemporary environment, follows a markedly different strategy: it asserts an expressive presence. Its circular geometry and lightweight construction symbolically evoke organic forms and the notions of openness and inclusivity, underscoring its role as a public cultural venue. While visually integrated into the riverside landscape, the low pavilion simultaneously distinguishes itself from the predominantly rectilinear campus buildings through its sculptural form and continuously changing BIPV-media envelope, reinforcing its identity as a landmark of future-oriented architecture and communication.

Together, these two case studies illustrate a spectrum of urban settings and architectural strategies for BIPV integration—from contextual assimilation to expressive autonomy—reflecting the adaptability of photovoltaic technologies to both historic and modern urban environments (fig. 5).

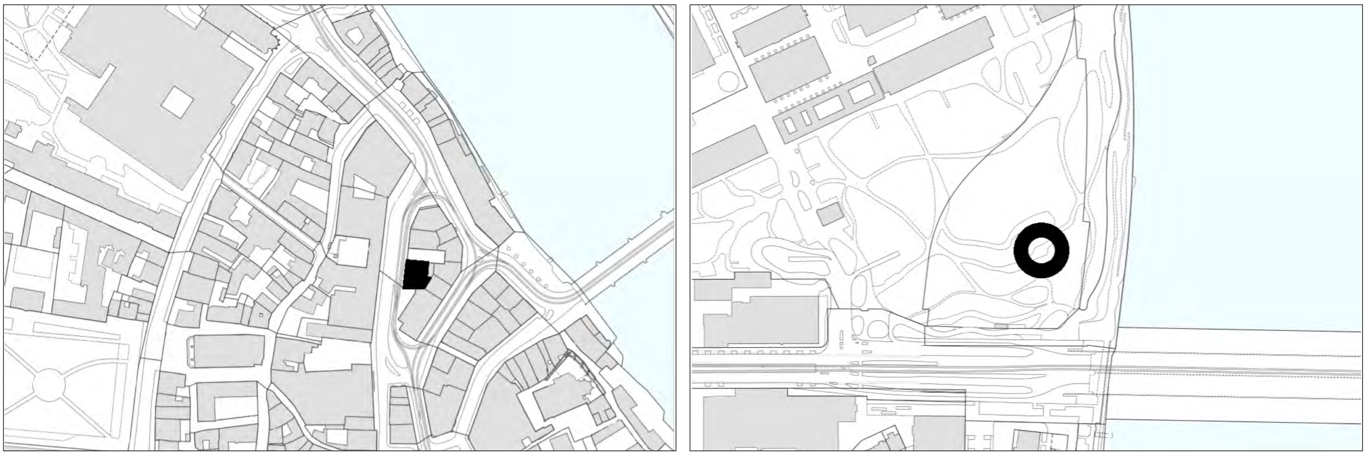

Figure 5. Comparison of urban settings: the Office for Environment and Energy embedded in the dense historic fabric of Basel's centre (left), and the Novartis Pavillon located in the open riverside landscape of the Novartis Campus (right). *Own elaboration*

4.2. Role of the façade in the energy concept

Environmental considerations are central to both architectural approaches, with BIPV façades playing a key role in the overall energy strategy. Advanced PV modules cover extensive surface areas across all orientations—including non-optimal ones—and collectively make a significant contribution to the buildings' overall energy balance. Such 360° orientation is relatively uncommon, as south- and west-facing façades are generally considered as most energy-effective; north-facing parts of the building envelope are rarely clad with BIPV materials.

The OEE's opaque BIPV façades, equipped with high-efficiency m-Si PERC cells, contribute substantially to achieving a nearly zero-energy standard. The energy generated on-site offsets a major part of the building's operational demand, complementing the highly insulated envelope and efficient mechanical systems.

The Pavilion's OPV–LED membrane, while using less effective cell technology, performs multiple functions. It embodies a self-sufficient energy loop in which the power generated during the day drives the nocturnal light display. Depending on external lighting conditions, the semi-transparent skin simultaneously functions as an energy generator, a daylight-modulating membrane, and a luminous display surface. This innovative integration of renewable energy production, light filtering and digital communication defines a new typology of self-sufficient media architecture.

4.3. Photovoltaic technology and material solutions

Both façades employ technically sophisticated, experimental BIPV modules based on entirely different photovoltaic cell technologies—first- and third-generation respectively. This technological contrast determines not only their energy performance but also their architectural expression.

The OEE utilises high-efficiency monocrystalline silicon PERC cells (Passivated Emitter and Rear Cell), representing advanced first-generation PV technology. All modules were custom-manufactured in multiple formats to align with the façade grid. Their construction combines fused, textured glass with a titanium-nitride (TiN) dot pattern, ensuring both optical refinement and bird-collision protection (fig. 6). The modules achieve a balance between efficiency, durability, and aesthetic quality, demonstrating that even conventional cell technologies can yield architecturally distinctive results when innovatively reinterpreted. This approach reflects a trend toward material hybridisation, where high-performance photovoltaic components are treated as architectural finishes rather than technical add-ons.

In contrast, the Novartis Pavillon employs cutting-edge third-generation organic photovoltaic (OPV) technology (fig. 7). Based on carbon compounds rather than silicon, OPV modules are characterised by low embodied energy and high recyclability. Their light weight, flexibility, and responsiveness to diffuse light make them particularly suited for façades with complex curvature and multidirectional exposure. The semi-transparent modules, custom-designed and laminated into polycarbonate panels, adapt seamlessly to the pavilion's geometry. Despite lower peak efficiency under direct sunlight, OPV performs effectively under diffuse radiation typical of façade applications [5, 18]. This technological innovation exemplifies how next-generation photovoltaics can expand both the expressive and communicative dimensions of architecture.

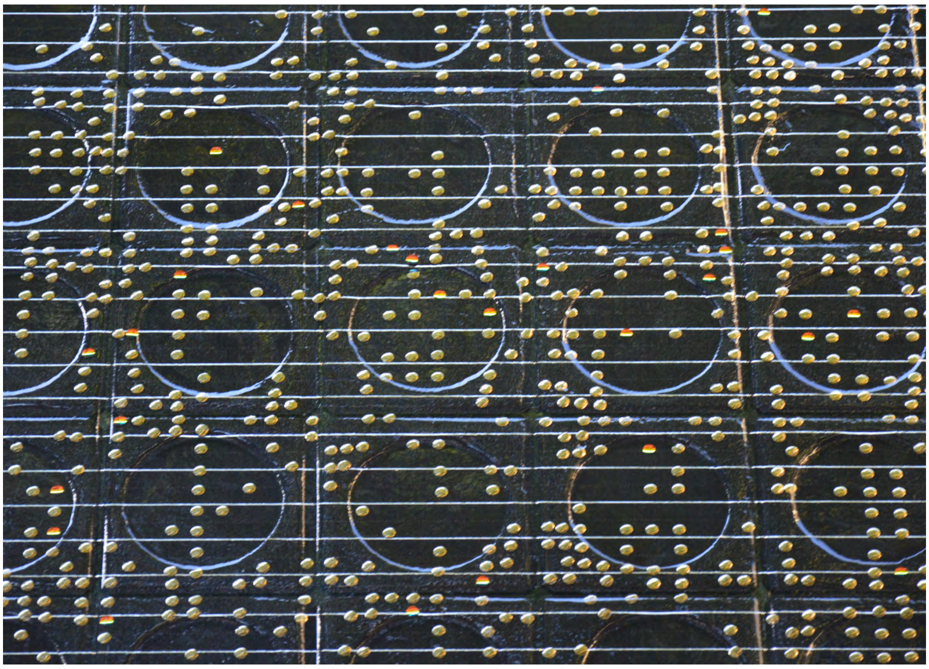

Figure 6. **Monocrystalline (m-Si) PERC cells laminated in 3D fused-glass with metallic TiN dots.** *Photo: M. Muszyńska-Łanowy (2025)*

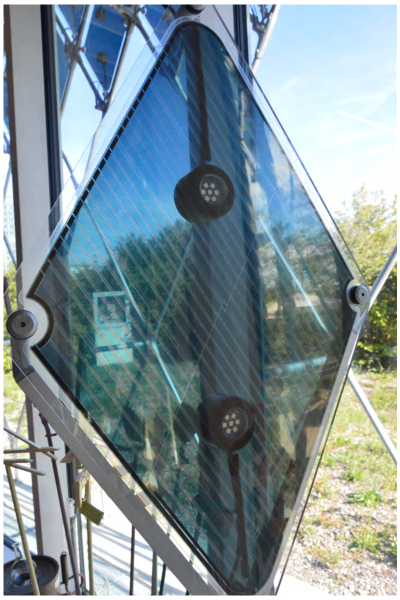

Figure 7. **Semitransparent organic cells (OPV) printed on flexible substrate.** *Photo: M. Muszyńska-Łanowy (2025)*

4.4. Aesthetic strategies and façade expression

In both projects, innovative and project-specific BIPV materials were developed, requiring extensive testing to achieve the desired visual and technical balance. Multiple prototype series were created through interdisciplinary collaboration.

In the case of the OEE, all BIPV materials had to be approved by the Cantonal Commission for Aesthetics, ensuring compliance with Basel's strict heritage and design standards. The architects treated the modules as an architectural material in their own right—"equal to stone"—working with them to achieve harmony with the surrounding urban fabric rather than technological exhibitionism. This approach resulted in a tactile solar surface whose optical depth and golden sheen blend naturally with the sandstone hues of the old town, ensuring visual continuity while maintaining a contemporary character [13, 16]. Each module is unique: its fused-glass surface features circular reliefs with irregularities up to 4 mm, creating a play of light and shadow across the façade. Modules of varying dimensions form a mosaic aligned with the façade grid. Their matte finish minimises glare and softly modulates daylight, while titanium-nitride (TiN) metallic dots laminated onto the glass create a shimmering secondary layer (fig. 8). These micro-reflections enrich the perception of depth and colour, producing a slight iridescent effect reminiscent of water droplets in orange, red and green hues. The façade's appearance shifts subtly under varying light conditions and viewing angles, entering in a moderate visual dialogue with its surroundings [2, 17].

Conversely, the Novartis Pavillon façade adopts a more expressive and dynamic aesthetic strategy, in which technology is intentionally revealed. Diamond-shaped OPV modules—produced in size variations and arranged in a cellular lattice pattern—evoke biological and molecular structures, conceptually linking architecture and science. During the day, the semi-transparent OPV membrane appears as a translucent graphite-grey skin; after dusk, it transforms into a luminous media façade displaying animated light compositions (fig. 9). Embedded double-sided LEDs emit light both outward and toward the reflective metal shell beneath, creating a layered luminous depth that accentuates the pavilion's organic character [5, 7]. Light intensity and colour vary in response to ambient conditions, visualising the continuous flow of energy and information. The dynamic display presents curated works by tree international artists, developed in collaboration with scientists [1, 6]. The façade thus becomes a communicative interface—a performative architectural medium that merges renewable energy generation with artistic expression, redefining the relationship between technology, aesthetics, and public space.

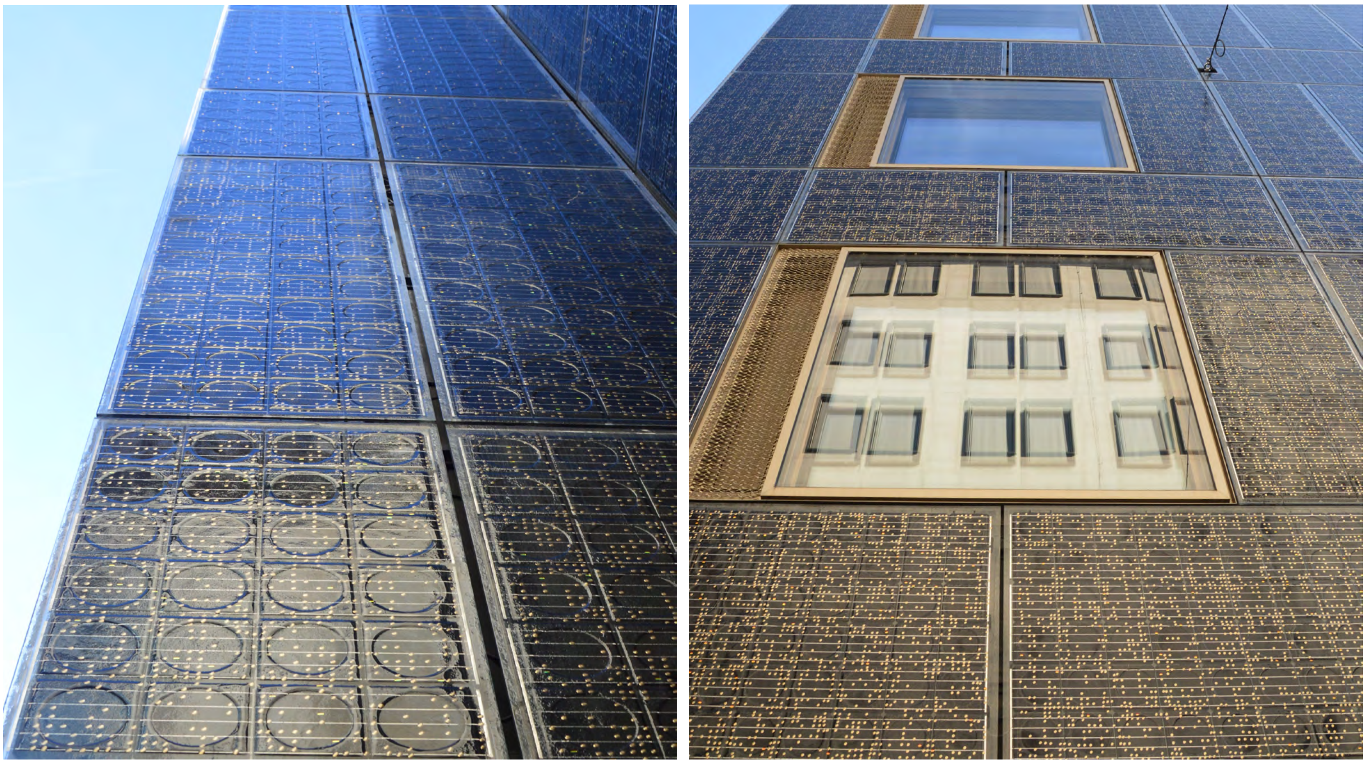

Figure 8. **Detail views of the office façade showing the tactile surface and subtle chromatic variations of the BIPV modules under changing daylight conditions and view angle.** *Photo: M. Muszyńska-Łanowy (2025)*

Figure 9. **Curved diamond OPV modules – left: the inner façade viewed from inside; right: visual effects on the outer skin – sunlight reflections and LED lighting. During the day, only white LEDs are activated, while after sunset, additional colours emerge.** *Photo: M. Muszyńska-Łanowy (2025)*

4.5. Communicative and symbolic dimensions

Both buildings function as instruments of environmental communication, yet they differ in their modes of expression and public engagement. The Office for Environment and Energy serves as an educational model of sustainable urban design. Its façades, merging photovoltaic technology with a historic setting, convey transparency, civic responsibility, and environmental awareness—values that reflect the institution's mission in advancing energy transition and ecological policy. The building communicates sustainability through material integrity, its message embedded in the coherence of form and detail.

The Pavillon extends this narrative toward public engagement and media interaction. Its BIPV membrane and integrated light system transform the building into an interactive medium connecting science, art, and society—symbolising openness, innovation, and dialogue. Here, energy and information merge into a shared visual language, accessible to the public through sensory experience (fig. 10).

Figure 10. The Novartis Pavillon's BIPV-LED media façade after sunset, displaying dynamic artistic installations that merge science, art, and technology. *Photo: M. Muszyńska-Łanowy (2025)*

While the OEE expresses sustainability through architectural restraint and symbolic clarity—its message embedded in the material coherence of a civic institution—the Pavillon embodies a performative and communicative approach, engaging visitors through its responsive façade and immersive experience. In the former, the façade's silent presence evokes credibility and responsibility; in the latter, its dynamic surface stimulates curiosity and interaction.

Both projects embody the convergence of technological innovation and cultural continuity. In the OEE, the encounter between BIPV glass and adjacent historic stone reflects the coexistence of past and future within the urban present [2]. In the Pavillon, the OPV membrane resting on rammed-earth walls (fig. 9 left) evokes the layered material memory of the site [8]. Through their distinctive façades, the two buildings articulate complementary messages: the OEE conveys institutional transparency and environmental responsibility, whereas the Pavillon represents openness and the power of science. Together, they exemplify how sustainable public architecture can turn façades into communicative interfaces between heritage, innovation, and environmental consciousness.

Table 2. Comparative summary of context integration, form, visual and symbolic characteristics of analysed case studies. *Own elaboration*

Case study building	Office for Environment and Energy	Novartis Pavillon
Urban context	Historic city centre	Contemporary riverside campus
Integration	Harmonious integration; restraint	Visually striking; expressive
PV cell colour; opacity	Black; opaque	Blue-grey; semi-transparent
PV cell visibility	Concealed behind textured front glass	Clearly visible in close-up view

Module surface texture	Irregular fused-glass relief; tactile, matte finish	Smooth polycarbonate surface
Module transparency	Opaque	Semi-transparent
Module flexibility	Rigid	Flexible
Module shape	Rectangular	Diamond, triangle
Module colour	Warm golden-anthracite; pearlescent reflections (light depending)	Cool blue-graphite-grey; multicoloured luminous LEDs
Façade composition	Planar, grid-based, variable panel formats, modular repetition	Curved, cellular pattern, variable panel formats, modular repetition
Light interaction	Subtle shimmer; soft daylight modulation	Dynamic interplay of light and motion; double-sided LED illumination
Aesthetic strategy	Subtle integration; matte non-reflective glass; golden hue matching stone; colour and depth variability	Expressive dynamics; translucent by day, luminous display by night, colour variability
Symbolic and communicative role	Transparency, civic responsibility, sustainability model	Openness, innovation, dialogue; science–art interface

5. Conclusions

The comparative study demonstrates that BIPV can operate simultaneously as technical systems and architectural media, adapting their formal and symbolic expression to diverse urban and cultural contexts. Although both projects share a commitment to sustainability, they articulate contrasting yet complementary approaches to solar design—one grounded in contextual integration and architectural restraint, the other in expression, interaction, and performative communication.

Recent advances in first- and third-generation PV technologies have expanded the creative vocabulary of architects, enabling context-sensitive design approaches across diverse urban conditions. Conventional silicon photovoltaics, when reinterpreted through material and compositional strategies, can achieve refined visual integration while maintaining high energy performance. Emerging organic photovoltaic technologies, despite their lower efficiency, introduce new opportunities for architectural experimentation, particularly in terms of transparency, lightness, and communicative potential.

These divergent design attitudes may be understood within an integration–expression continuum, which provides a conceptual framework for interpreting contemporary BIPV façade design. At one end of this spectrum lies architectural restraint and contextual assimilation; at the other, expressive performativity and active public engagement. Positioned along this continuum, the analysed projects illustrate how technological choices, material articulation, and cultural priorities jointly shape the architectural role of BIPV façades within European urban environments.

The study also identifies a perceptual paradox characteristic of contemporary solar aesthetics: technologically advanced solutions may appear visually subdued, while seemingly neutral materials can become highly expressive through their interaction with light, context, and media systems. This observation underscores that architectural impact depends not solely on technological sophistication, but on the deliberate orchestration of materiality, form, and environmental conditions.

Ultimately, the two buildings delineate a broad spectrum of possibilities for solar architecture, operating between visibility and subtlety, restraint and performativity. Together, they signal a shift from photovoltaics as predominantly utilitarian infrastructure toward a cultural and communicative architectural medium, in which façades act as responsive interfaces between energy generation, architectural form, and symbolic meaning.

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Między integracją a ekspresją: fasady BIPV w Bazylei – studium porównawcze

Streszczenie: Globalna transformacja energetyczna wymaga integracji technologii zrównoważonych w miejskiej zabudowie, co czyni fotowoltaikę zintegrowaną z budynkiem (BIPV) kluczowym elementem współczesnego projektowania fasad. Choć rozwój technologii fotowoltaicznych poszerzył słownik estetyczny i techniczny architektów, wdrażanie systemów BIPV w miastach europejskich wciąż napotyka trudności wynikające z ograniczeń kontekstowych, ochrony dziedzictwa oraz potrzeby społecznej akceptacji. Badanie analizuje, w jaki sposób różne technologie fotowoltaiczne wpływają na formalne, materiałowe i symboliczne aspekty projektowania fasad. Przeprowadzono porównawcze studium przypadku dwóch budynków publicznych w Bazylei (Szwajcaria): Urzędu ds. Środowiska i Energii oraz Pawilonu Novartis. Dane pierwotne pozyskano podczas obserwacji terenowych i dokumentacji fotograficznej (2025), a następnie uzupełniono je źródłami naukowymi i technicznymi. Wyniki wskazują, że fasady BIPV mogą pełnić równocześnie funkcję systemów energetycznych i środków architektonicznej ekspresji. Analizowane przypadki, choć łączy je wspólne dążenie do zrównoważonego rozwoju i innowacyjności, reprezentują odmienne strategie projektowe – jedną opartą na architektonicznej powściągliwości i harmonii kontekstowej, drugą na ekspresyjności i interaktywności. Zestawienie tych podejść ukazuje poszerzające się spektrum architektury solarnej – od kamuflażu po ekspresję, od integracji po performatywność – dowodząc, w jaki sposób postęp technologiczny kształtuje zarówno estetyczne znaczenia, jak i symboliczne komunikaty współczesnej architektury.

Słowa kluczowe: fotowoltaika zintegrowana z budynkiem, projektowanie fasad, architektura solarna, zrównoważone projektowanie budynków, fasady BIPV