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Building Envelope Engineering and Typologies for Complex Architectures: Composition and Functional Methodologies
Massimiliano Nastri

HELSINKI, FINLAND

JULY 19-20, 2022

Building Envelope Engineering and Typologies for Complex Architectures: Composition and Functional Methodologies

Massimiliano Nastri

Abstract**—**The study examines the façade systems according to the constitutive and typological characters, as well as the functional and applicative requirements such the expressive, constructive and interactive criteria towards the environmental, perceptive and energy conditions. The envelope systems are understood as instruments of mediation, interchange and dynamic interaction between environmental conditions. The façades are observed for the sustainable concept of eco-efficient envelopes, selective and multi-purpose filters, adaptable and adjustable according to the environmental performance. In particular, the study examines the contents and the methodological and systemic guidelines concerning building façades, which are expressed in terms of morpho-typological, environmental, interactive and energy characters: the design, production and manufacturing of building envelope systems, aimed at performing morpho-typological, perceptual, physical and environmental functions are dealt with the evolved curtain wall configuration and with the geometric and material continuity of "light façades". The evolved configuration of curtain wall is achieved according to the conditions arising from the widespread "technical opening" offered by the contemporary industrial production of façade systems.

Keywords**—**Typologies of façades, environmental and energy sustainability. interaction and perceptive mediation. technical skins.

I. Introduction

THE The study around the field of envelope elements considers the surfaces applied to façade systems in their characters of morphological expression and interaction with external environmental loads, observing, above all, the procedures for controlling thermal and luminous transmission. Therefore, the study of the envelope explicates the physical, material and performance contents according to the criteria of action towards both energy and environmental conditions, and ergonomic conditions through the procedures of reflection, capture and diffusion of stresses external or internal to the built spaces. This is done through "passive" transformation, aimed at accumulating and distributing the energy produced by solar radiation without the use of plant equipment, or "active" transformation, with the contribution of devices (in the form of "collectors") aimed at integrating and conveying heat, natural light or convection phenomena related to air flows. The technologies applied and, in particular, the components and devices of the envelope are assumed with respect to the processes of "permeability" (determining the criteria of energy, environmental and perceptive control of a "selective" and dynamic type), with the possibility of regulating the flows and conveying them in the overall operation. The envelope, as an apparatus of mediation and reaction towards external loads, is structured in the combination with the calibration of properties and performance (according to a "selective" orientation), with the technical design and with the coherent application to settlement needs and requirements (as an environmentally conscious design activity). Enclosure systems are specified in the constitution of integrated functional components with the objective of receiving, guiding and selecting environmental stresses to realize calibrated ergonomic conditions in built spaces. For this, the systems are endowed with engineering performances (such as multiple environmental performances), are articulated in the form of environmentally responsive walls (capable of actively "responding" to environmental stresses through perceptual and "organic contact" with climatic conditions) and engineered walls (such as equipment that can be operated by mechanical devices), aimed at regulating the transmission of heat, light and natural ventilation, together with the attenuation of wind and acoustic loads.

II. The Typological, Functional and Operational Definition of Envelope Systems

The study deals with the envelope systems conceived as light prefabricated external walls (made in the laboratory and assembled on site), identified within the perimeter walls, in the form of homogeneous and uniform vertical enclosures in the external surfaces. The envelope systems are examined according to the flat vertical composition and the combination of a series of functions, such as the delimitation and protection of built spaces, visibility, regulation and control of thermal incidence, natural lighting and ventilation, with respect to climatic conditions and stresses (mechanical, thermo-hygrometric, wind and acoustic). The envelope systems (which do not contribute to the main load-bearing performance) are considered as external enclosure units of the architectural organism, built by frames (mainly produced of metal, but also of wood or plastic materials) made of vertical and horizontal structural elements (which themselves are connected and anchored with interface devices to the main load-bearing structures, which are generally frame structures). These units, established as non-load-bearing external walls (and, therefore, supported by a vertical and/or horizontal support grid), consist of technical elements (with a modular production base)

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prefabricated and joined to the load-bearing structures of the architectural organism through mechanical assembly techniques, aiming at separating the interiors from the external environment.

The envelope systems are composed within structural frames capable of supporting, accommodating, combining, engaging and hooking the subordinate arrangements defined by the formulation of enclosure components. Therefore, the elaboration of contemporary envelope systems relates to curtain walls and to the extension of the curtain wall applied to vertically developed buildings. This typology indicates an external non-load-bearing enclosure made of panels, of glass or other material, connected to a support frame that is assembled to the main structural elements (vertical and horizontal) of the architectural organism. The composition of the façade systems through the design, production and application of lightweight prefabricated components is outlined in the form of the external curtain wall made on steel or reinforced concrete framed structures, as a unit that can be separated from the whole construction and has no load-bearing function (Fig. 1) [1].

Fig. 1 Pierpaolo Ricatti, *Diesel* Headquarters, Breganze (Vicenza) (©Courtesy of Schüco).

According to the general definition, concerning the vertical perimeter enclosures executed by means of light prefabricated components, the envelope is mainly made up of closing elements of the voids between the elements of the load-bearing framework, its morphology essentially depends on the materials and products used, on the laying methods and on the possible

forms of surface finishing. Furthermore, during the construction of the building envelope, different types of connection can be used between the parts making up the envelope itself (internal connections) and between this and the load-bearing structure of the building (external connections). The types and methods of connection vary according to the materials and products used, the structural typology of the building, and the number of functional layers of which the envelope is composed. In general, in contemporary construction, the elements of the envelope may be inserted between the grids of the buildings external structure, or they may be leaning against the exterior, directly attached to the beams and columns, or tied to a different, specially prepared support structure. The evolved configuration of the *curtain wall* takes shape according to the conditions, the impulse and the supply deriving from the widespread technical openness of the window and door industry for façade systems (already defined by the processes of *components approach* or *componenting*, with the use of aggregative rules for the assembly of pieces), which identifies a sphere characterized both by the multiplicity of combinations, and by the synergies between technical elements and materials of different productive origin, which must support the criteria of flexible relationship between the contents referring to the structural and closing elements, to the connection and functional devices, up to the assembling methods (according to the environmental and technological performances that are going to be examined and obtained). Within the design, production and construction scenario, the envelope systems are examined with respect to:

- the role of transition between internal and external space, independently, on a morpho-typological level, with respect to the intended uses and according to the combination of performance contents (as *useful skin*) and external aspects (as *ornamental packaging skin*);
- the constitution of the components in an integrated form, characterized by specialization processes aimed at assuming the overall quality at different levels, according to the procedures of structural, connective, geometric and dimensional coordination, in order to allow both the mechanical assembly methods and the application to multiple building types (Fig. 2) [2], [3].

Fig. 2 EFA - Esperienze Forme Architettura, *Chiesi Farmaceutici* Headquarters, Parma (©Courtesy of EFA).

Therefore, the envelope systems participate in the assignment of the expressive contents of architecture, so that the external composition of the architectural organism coincides with the functional and constructive solutions adopted for the vertical enclosures, through the reduction of material incidence, the perceptive dematerialization and the enhancement of the meanings related to lightness and transparency. Moreover, in relation to the results of

contemporary research, the examination of the technical and executive configuration of the envelope systems also addresses the innovative opportunities of morpho-typological expression correlated to aspects of a functional nature. This leads the design and application scenario to constant experimentation and considers the closing elements in their progressive acquisition of tools and performance solutions aimed at increasing performance with respect to mechanical and environmental stress as well as energy, light and air exchanges. The concept of envelope systems made from prefabricated components, therefore, includes the development of membranes separated from the supporting frames, with the necessary performance to provide protection and improve the ergonomics of interiors.

The building envelope is determined, on a conceptual and executive level, in the building façade, understood as:

- the external boundary with a representative function in the urban space with respect to the procedures of spatial composition: This is done through the (structural or formal) frameworks constituted by the frames and the corresponding backgrounds that are included;
- the integration tool towards the fruition and functional characters of both the context and the environmental, atmospheric and perceptive characters (Fig. 3) [4].

Fig. 3 OMI Architects, *Anaconda Cut* Building, Manchester (©Courtesy of Focchi).

In this perspective, the conception, production and construction of the envelope systems, by using semi-finished elements or small finished components to be assembled on site, is configured as an activity of selection, adaptation and connection of products. In this regard, the convergence between design culture and industrial culture is outlined according to the flexibility of the production chains, the innovation oriented to the flexibility (but also to the specialization) of the products and the provision of new performances, while respecting the principles of multi-material relationship and specialized stratification: This, on the whole, determines the fine-tuning of functions according to specific needs, compared to products that manifest morphological neutrality and numerous possibilities of use, articulation and joining. According to this approach, the compositional elaboration of the envelope systems (in the form of orders and rules conforming to the use of planar, modular and often industrially manufactured elements) is examined through:

- the application of traditional materials, on the basis of references and allusions to the physical properties of their

surfaces, grading and modulations on the façade level;

- the use of morpho-typological rules which are mediated with respect to the prefabricated components, the connection methods of which establish the logic of correlation both expressive and executive;
- the poetics of construction aimed at defining the semantic criteria of the frames and enclosures in conformity with the expression of the principles and modes of relationship between the parts and the materials. In this regard, the elaboration of the envelope systems considers the procedures of mechanical assembly as a strategy aimed at specifying the design and executive practice no longer according to a fixed and immutable configuration, but rather as an activity that identifies a series of feasible solutions, allowing, in some cases, the reversibility of the construction (Fig. 4) [5].

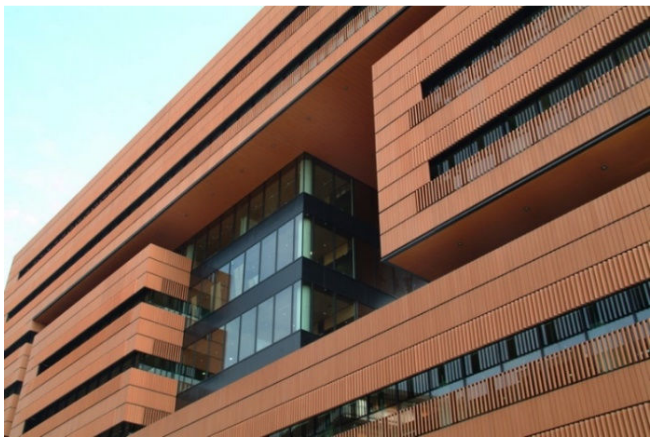

Fig. 4 Mario Botta and Giancarlo Marzorati, *Campari* Headquarters, Sesto S. Giovanni (Milan) (©Courtesy of Giancarlo Marzorati).

The characteristics of building envelope systems implies the following conditions:

- the adaptability of building products, within industrial logics characterized by high flexibility and construction strategies capable of encompassing different execution techniques. In particular, adaptability refers to the degree of variability of the technical elements, proportional to their degree of aggregation flexibility, that is, to their degree of autonomy in modifying their interactions with those belonging to other elements, which are conceived in an open manner through the use of solutions designed to allow subsequent integration;
- modularity, which, as a design and construction strategy, requires interchangeability and the possibility of combining technical elements, based on operational and procedural references such as standardization and modular coordination. In particular, modular coordination constitutes a method for determining the dimensions of technical elements and the structures they create, also in order to realize the conditions for a market of interchangeable and dimensionally selected building products. The module, therefore, is no longer the exclusive function of the measure, but becomes a function of the object understood not as a finished element, but as a basic element, moving from the "module-measure" to the "module-object" for both the frames and the enclosure apparatus;
- flexibility, which proposes the adaptation, by means of extension or convertibility, of characteristics already present in the system or in the technical elements, both structural and enclosure (Fig. 5) [6].

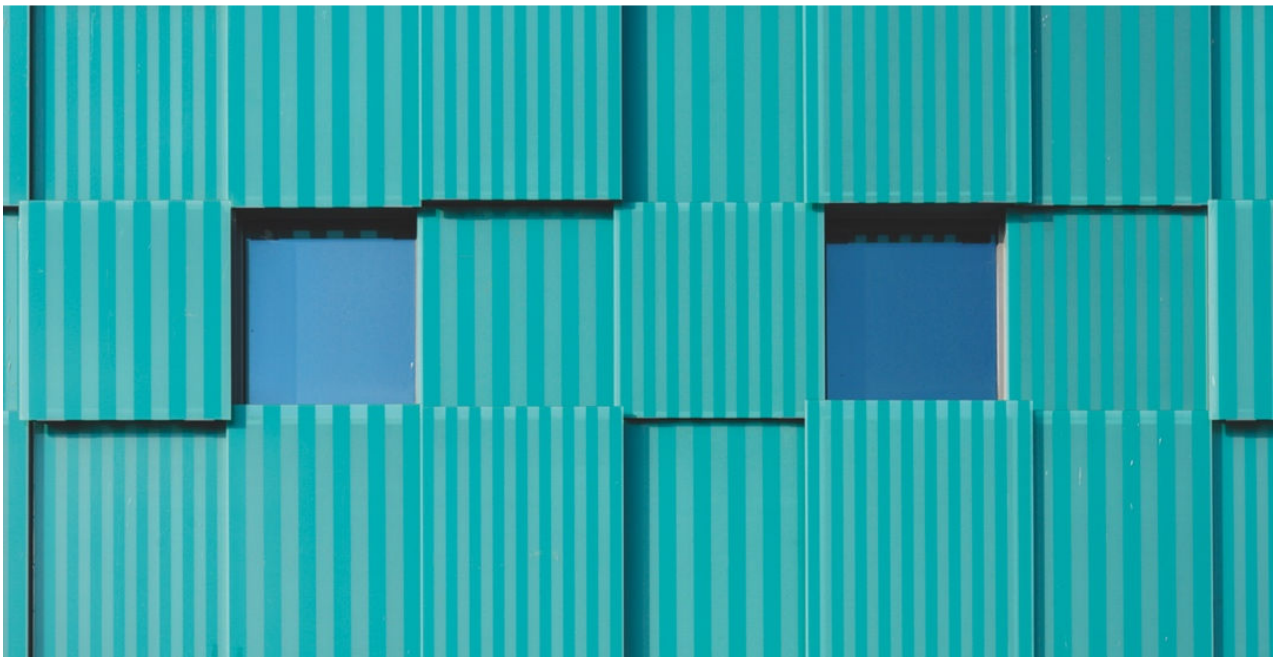

Fig. 5 Giancarlo Marzorati, *Barceló Hotel*, Milan (©Courtesy of Giancarlo Marzorati).

III. The Productive and Executive Articulation of Envelope Systems

The façade systems, designed and produced according to general needs, requirements and performance or for individual applications, are defined as light prefabricated external walls, executed in the form of curtain walls, cellular curtain walls, double skin curtain walls, structural curtain walls, suspended curtain walls and curtain walls with point fixing. In particular, both mullion and transom metal frame and structural and cellular façade types are specified by fixed and/or openable transparent closing elements, also combined with opaque elements (or *spandrels*, consisting of stratified panels, covered with pre-painted metal laminates, or panels with a ventilated air chamber and covered with glass or stone).

The façade systems are mainly considered with respect to the formulation of the structural apparatuses and connection devices, capable of resisting static and dynamic loads (such as wind stresses) and the deformations of the main load-bearing structures of the architectural organism (in order to support the movements due to differential settlements, to the inflections of pillars and beams, to horizontal loads). The structural apparatuses and connection devices are also identified in relation to their ability to respond to expansion and contraction phenomena, such as:

- thermal type, in order to absorb the stresses caused by temperature differences between indoor and outdoor, which can lead to deformations of the closing elements;
- hygroscopic, in order to allow differential movements of the enclosure elements due to humidity variations.

The load-bearing structural apparatus (consisting of the vertical and horizontal frames), the interface and connection devices, the components and the technical enclosure elements are then specified with respect to the requirements relating to:

- thermal resistance, so as to prevent the passage of heat by conduction, avoiding thermal bridges (especially in the case of metal profiles) which can cause localized condensation of water vapor on the internal surfaces of the enclosures;
- resistance to oxidation, exposure to ultraviolet rays and corrosion of metal parts;
- water tightness, by providing connective solutions (through the correct application of joints) capable of waterproofing situations of accumulation (e.g. in the interstices and along the projections) and of infiltration (e.g. in the joints);
- air-tightness, providing connective solutions capable of preventing infiltration of high flow rates into the interior, combined with the need to avoid the phenomena of water vapor condensation and acoustic transmission. This is achieved through the correct application of sealants, gaskets (for closing and filling joints) and drainage methods;
- vapor-tightness by providing direct solutions for the evacuation of condensation water;
- fire resistance;
- durability and maintainability, providing solutions capable of allowing periodic cleaning, repair and replacement of technical elements [7].

The building envelope study examines the typological and productive, functional and executive articulation of:

- the curtain wall system (*stick system),* consisting of a load-bearing frame of mullions and transoms (generally made of aluminum or steel, as well as PVC) arranged according to structural, morphological and enclosure requirements using glass elements (generally double-glazed) and/or panels (such as the *panel system*, in the form of prefabricated two-dimensional elements with an outer covering surface and thermal and acoustic insulation layers). This system, both for flat or polygonal development, involves installation on site after preparation of the frame elements, which consists of cutting and machining the profiles (mainly extruded aluminum) to allow assembly procedures (using scaffolding at the perimeter of the building). These procedures concern, in particular:

- the execution of the vertical elements (mullions) to the main supporting structure;
- the execution of the horizontal elements (transoms) to the mullions;
- the application of the vertical enclosures (in double glazing or *spandrel* form, these with monolithic glazing and panels behind or with steel, aluminum, composite or stone cladding elements) (Fig. 6);

Fig. 6 GaS Architects, *Campus Milano Internazionale*, Milan (©Courtesy of Pichler Projects).

- the structural façade system (*structural sealant glazing* or *glass curtain wall*), determined by the load-bearing frame (defined as adaptation and, in general, made of aluminum or steel) assembled in the laboratory and applied on site to the load-bearing structure of the architectural organism (with the use of scaffolding at the perimeter of the construction), where the closing elements (generally, monolithic glass panes or double-glazing) are made using structural silicone (without mechanical constraints, inside the profile grooves). The structural façade system consists of:

- the *strip window* or *two-sided supported system*, also known as "two-sided glazing", where the closing elements are applied to the frame by means of the structural silicone sealant, on the two opposite vertical sides of the mullions and by means of mechanical retaining flaps on the horizontal sides;
- the *total wall* or *four-sided supported system,* also known as "four-sided glazing", in which the closing elements are applied to the frame using structural silicone sealant on all sides of the profiles (Fig. 7);

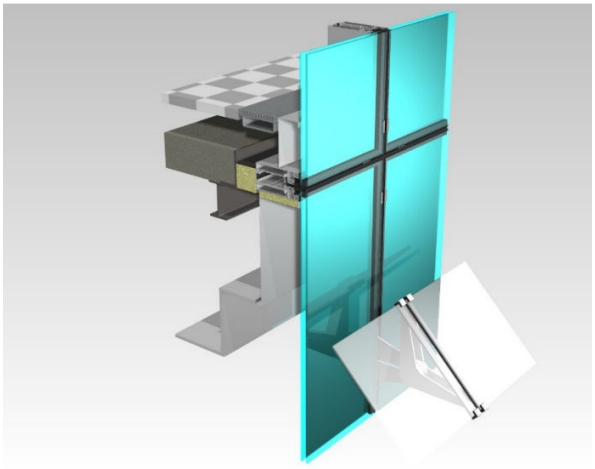

Fig. 7 Sidell Gibson Architects, *One Snow Hill* Building, Birmingham (©Courtesy of Focchi).

- the *unitized façade system*, determined by the load-bearing mullion and transom frame (generally in aluminum or steel) with a vertical extension that includes the height of the compartment and the stringcourse section, with closing elements. This system, preferred for vertical constructions

requires that the unitized façade system components are structurally independent and that they are connected to each other with telescopic or plug-in joints: these are capable of allowing, after installation, the movements for calibration on the façade level, carried out by means of the vertical and horizontal configuration profiles for performing the contiguity connections (Fig. 8);

Fig. 8 Park Associati, *U 27* Building, Assago (Milan) (©Courtesy of Focchi).

- the *double skin façade system*, determined in the transition from the continuous curtain to the multilayer type and articulating the specific performance of the layers and the relative technical elements. This involves the possibility of creating the cavity between the two walls for thermal and acoustic insulation, for ventilation and for housing functional devices as well as for plant ducts. The double-wall involves the use of a glass screen outside the vertical enclosure, with the aim of optimizing the functions of the ventilation in the cavity. The double skin system can be divided into the following types: façade with continuous cavity, without division, with discontinuous cavity and active façade (Fig. 9);

Fig. 9 5+1AA with Jean-Baptiste Pietri Architectes, *Fiera Milano* Office Building, Rho (Milan) (©Courtesy of Pichler Projects).

- the *suspended curtain wall* or *point fixed curtain wall* (or structural glass façade), determined by the use of glass sheet enclosure elements (made of vertical groups) by means of punctual constraints (in the form of mechanically supported fixing devices). These in turn are connected to steel cable frames anchored to the main load-bearing structure of the architectural organism (or to steel frames, usually tubular). Moreover, the *point-fixing façade system* is determined by the assembly of the glazing elements (with or without perforation) on metal supports (generally made of steel) (Fig. 10) [8], [9].

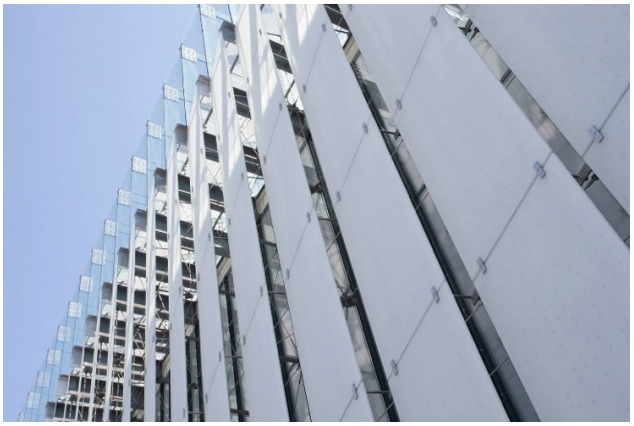

Fig. 10 Stelmach & Partners, *CSK* (*Centrum Spotkania Kultur*), Lublin (©Courtesy of Lilli Systems).

The composition of the envelope systems, constituted by the use of transparent enclosures, considers the surfaces applied to the façades in their morphological expression and interaction with the external environmental stresses, considering especially the procedures of control of the thermal and luminous transmission. The explanation concerns the productive, functional and use modalities of the techniques and materials aimed, in general, at the reduction of the loss or accumulation of heat (due to solar radiation), as well as the dynamic selection of the solar rays and the calibration of the natural light, in

observance to the types of use required. On this basis, the composition of the envelope systems is outlined with respect to the types, compatible solutions and procedures of use expressed in relation to the main references of a thermal, luminous and radiant nature. This is done through the definition of performance (at the mechanical, thermo-hygrometric, lighting and acoustic levels), execution (according to the relationships with the frames and joints) and the in-depth examination of the main factors of a physical, functional and applicative nature. In addition, the treatment detects the contributions of studies referring both to materials and devices from the experimental research sectors, and to the possibilities of being transferred from the advanced technology sectors. These contributions support, in the context of the systems under examination, the methods aimed at optimizing the physical, mechanical, chemical and thermal characteristics of the transparent surfaces, in order to calibrate the comfort conditions in the built spaces and the energy management criteria. In this case, the study exposes high-performance materials and compounds, indicated in the principles of both mediation between light transmission and thermal conduction (in order to reduce thermal dispersion without affecting transparency), and control of incident solar radiation (also with the adoption of selective coatings or shielding devices) (Fig. 11), [10].

Fig. 11 John McAslan & Partners, *Vitro* Tower, London (©by the Author).

In this respect, transparent enclosure elements applied to façade systems are established by:

- the passive use and transformation of solar radiation, using technical solutions aimed at capturing, accumulating and distributing the energy produced without the need for plant equipment. These solutions take on the functions of controlling the microclimate of the built spaces and the energy balance, according to the basic principles of solar heating and lighting;
- the use and active transformation of solar radiation, involving the use of technical solutions aimed at capturing, accumulating and distributing solar energy. These solutions involve the contribution of devices (in the form of collectors) capable of integrating the exploitation of heat, natural light or convection phenomena related to air flows.

Moreover, the area under examination addresses the visualization of alternative types for façade systems and is part of the progressive and linear developments in the construction sector and functional deepening. This is done with respect to a scenario where adaptable products and materials are used, simple, finished and small sized elements are marketed and diffused within the industrial logics characterized by high flexibility, capable of including and combining different solutions. The use of opaque enclosures expresses the façade systems with respect to:

- the tendency to rationalize and reinvent both the components and the conventional modes of application and interface, in an integrated approach to the multiplicity and variety of expressive possibilities;
- the hybridization of traditional materials, in order to legitimize the maintenance of the solid and massive presence, within the growing virtuality and ephemeral, dynamic and metamorphic configuration of the envelope (Fig. 12) [11].

Fig. 12 Maurizio Varratta, *iGuzzini Lab*, Recanati (©Courtesy of Pichler Projects).

The morphological and functional development that is outlined appears to be directed towards affirming the steady character of the unitary composition, by the expressive balance of the closing parts, as a response to the broken continuity of traditional languages and techniques, to the overlapping and integration of types and multiple fragments in the external constitution of architecture. This is achieved through:

- the application of elements capable of wrapping both the surfaces and the supporting and connecting apparatus, grafting themselves between the current processes of technical complexity and productive and linguistic articulation, often leading to the loss of the homogeneity and material congruity of the envelope;
- the assimilation of the characteristics of industrial production, aimed at overcoming the dichotomy between tradition and innovation, constituting an experimental basis both for the updating of sedimented practices and

techniques accepted as valid, and for the promotion of compatible solutions, of significant insertions characterized by the complementarity between consolidated and evolved materials and construction procedures [12].

IV. The Environmental and Energy Functioning of Envelope Systems

The envelope systems are defined as applications aimed at isolating, filtering or absorbing external climatic stresses (mainly thermal and luminous), in order to reduce the impact of technical devices. The systems are presented as instruments of mediation between the external environmental conditions and the ergonomic aspects of the built spaces, through specific performance reactions. These reactions are calibrated and variable according to the stresses and comfort requirements, highlighting the possible contributions to the reduction of energy use. In this regard, the systems are treated as interchange tools because of their ability to respond to external stresses, through the development of different functional levels (in terms of material, structure and thickness) and through the use of regulation means that allow to handle (in a natural, or passive form, and in an artificial, or active form) the interactions with the environment. For this reason, the enclosure elements behave as osmotic membranes acting according to processes of exchange of energy, light and air flows.

The typological examination introduces the identification of the closing elements that constitute the stratification of the envelope systems, according to the specialized functions developed with the precise subdivision of the performances assigned to the different materials and devices. The analysis then focuses on the perspectives of dynamic interaction between the envelope systems and the external environment. This is done by observing the criteria aimed at realizing built spaces in a steady and balanced way, with the possibility of transferring, modifying or repelling external stresses, according to the sustainable and low-energy concept of the components made up as reactive and sensitive surfaces to climatic stresses (Figs. 13, 14) [13].

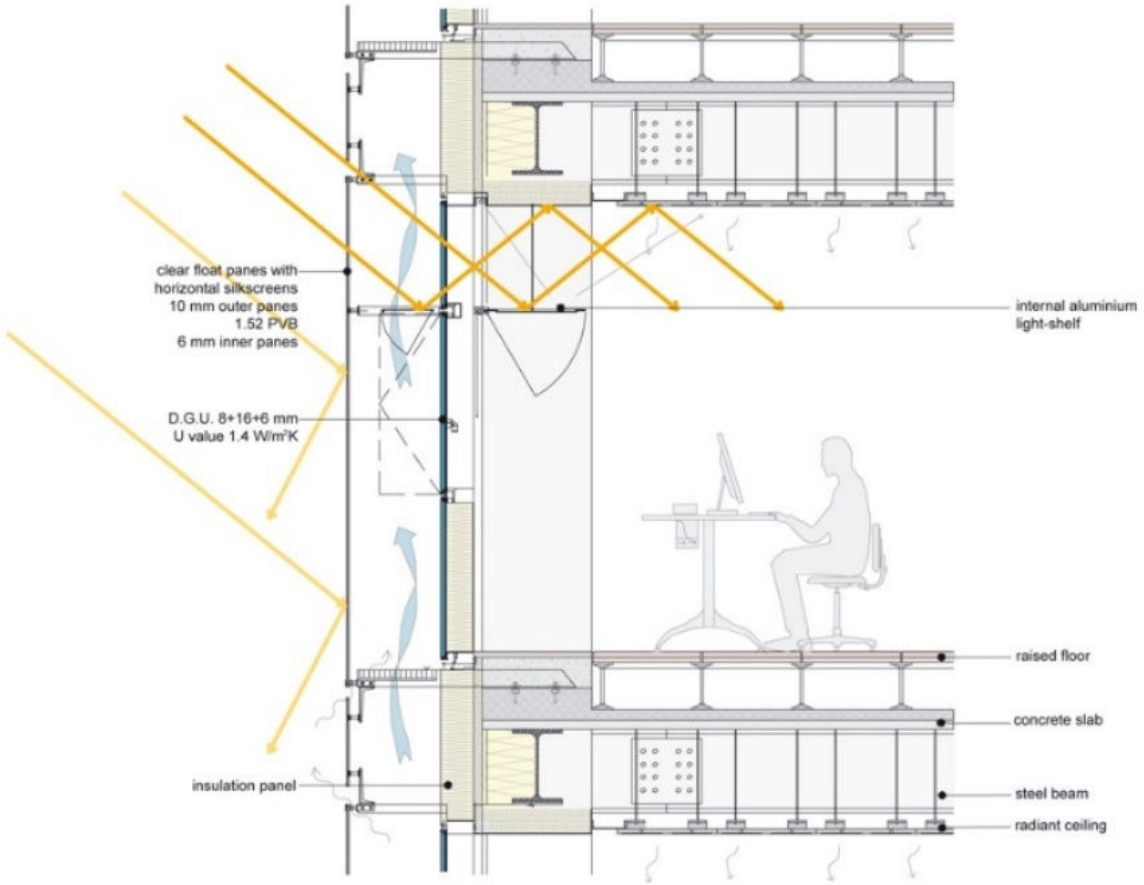

Fig. 13 Mario Cucinella Architects, *SIEEB* (*Sino-Italian Ecological and Energy Efficient Building*), Beijing (©Courtesy of Mario Cucinella Architects).

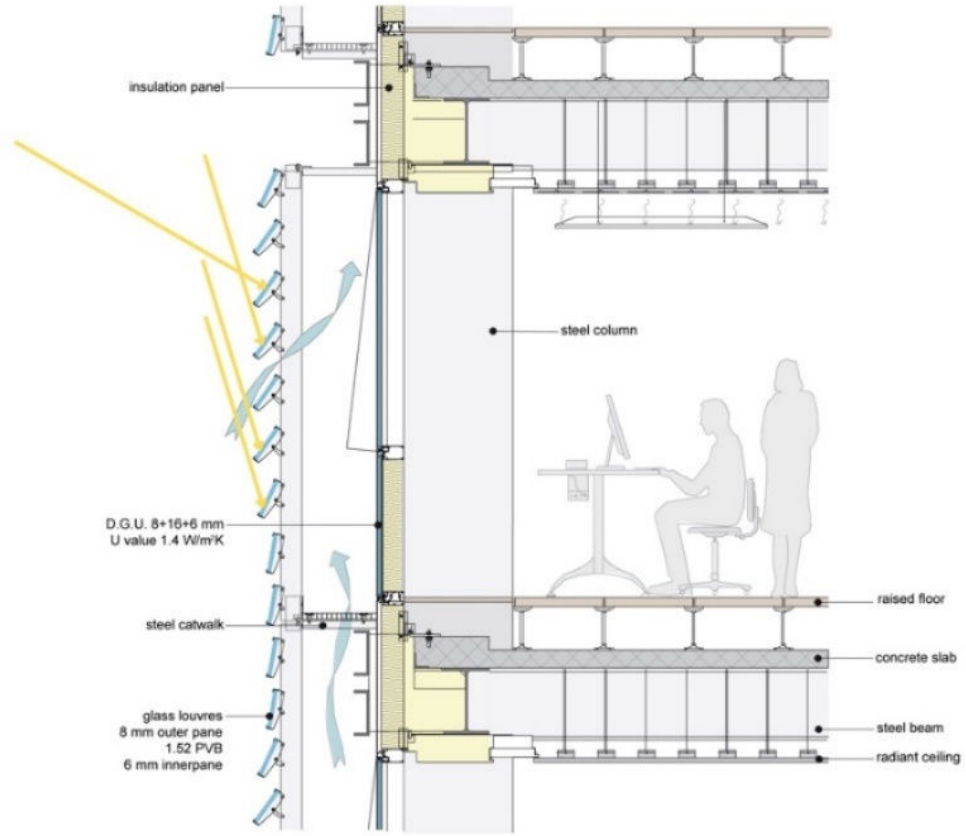

Fig. 14 Mario Cucinella Architects, *SIEEB* (*Sino-Italian Ecological and Energy Efficient Building*), Beijing (©Courtesy of Mario Cucinella Architects).

The advanced building envelope is considered as a *dynamic interface*, i.e., as a structure of exchange between the environmental stresses and the fruition needs of the internal spaces, having evolutive plasticity and adaptation qualities to the different loads coming from the environment. The experimentation here expresses the intention to integrate the climatic conditions and to convey them into the interior spaces according to established procedures and levels, to build components in the form of biomechanical prototypes in which the different parts specialize to achieve a certain function. In particular, the envelope systems are assumed as mediation and reaction apparatuses towards external stresses, considering their sensitive and organic nature (in the form of *technical skin*), their physical and material consistency, which is progressively determined towards integrated layers and performances that act, with adaptation and control capacity, according to the well-being requirements and reduction of energy consumption in built spaces. This assumption therefore focuses, on the one hand, on the aspects related to the adaptation and progressive control of thermal and energy exchanges between the internal micro-environment and the external macro-environment, identifying this area as a catalyst in the type-technological evolution of the building envelope; on the other hand, on the experimentation of technological and construction solutions aimed at optimizing these exchanges, as well as, obviously, on the expressive and communicative content that this experimentation implies. The definition of the envelope systems is thus carried out in the analysis of the dimensional consistency, which considers the building envelope as a system consisting of interacting parts, whose thickness varies according to the overall operation. Furthermore, the envelope systems are defined as external apparatuses capable of interpreting the functions and needs of their users as an *eco-efficient envelope*, as selective and multi-purpose filters, in relation to climatic conditions and ergonomic comfort requirements (of a thermo-hygrometric nature, relating to temperature control, humidity levels and ventilation. They also have a visual aspect, relating to perception towards the outside and control of lighting levels; an acoustic aspect, relating to insulation from sound stress; and an olfactory aspect, relating to control of air quality) (Fig. 15) [14].

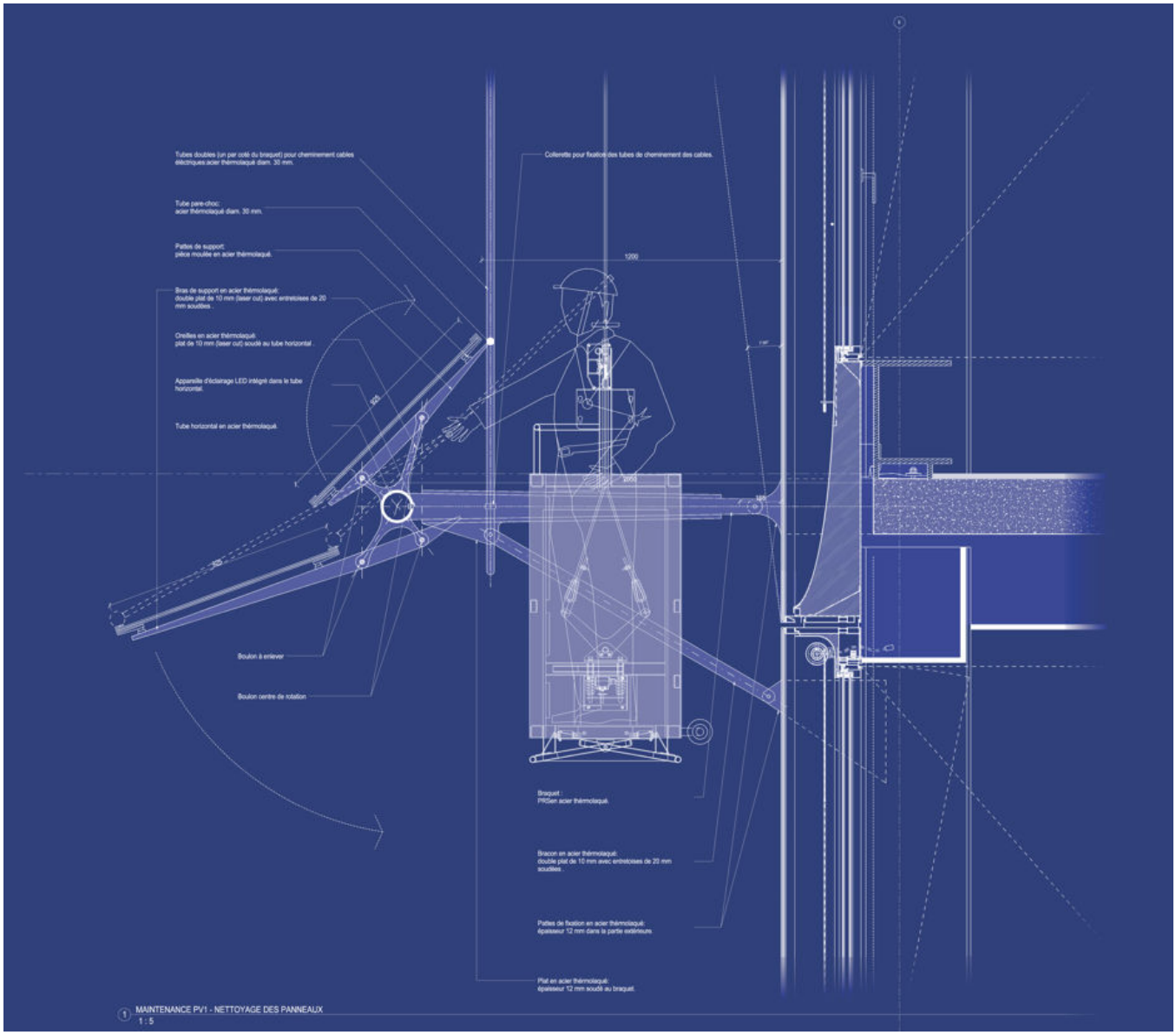

Fig. 15 Renzo Piano Building Workshop, *Courthouse*, Paris (©Courtesy of RPBW).

The analysis is then expressed through the investigation of systems as organic compounds, adaptable and adjustable as *biological skin*s and as *multifunctional skins*, i.e. as absorbing, radiating, reflecting, filtering and transferring (thermal, luminous, aerial) devices. In particular, the use of elements with dynamic and reactive behavior assumes the use of surfaces for the control of solar radiation, consisting of filtering or shielding sections able to modulate their transparency according to the level and distribution of natural light in the interior spaces. The closing elements of the envelope systems are especially investigated with respect to their character of modified physicality, which the experimental research tends to transform in thick and in *intelligent systems interface*. At the same way, also the main materials that constitute the external surfaces are analyzed with respect to their transformation processes from stable entities to designable entities according to a specific performance plan. In this case, the application of the envelope materials, in the form of designable entities, is examined with respect to the outcomes of the solutions in which the functions tend to become complex (in a controlled and managed way) and combined (in a *solid-state* form), achieving multiple performances through the correlation of different agents and layers. This is done by:

- the integration possibilities of functions related to enclosure elements, where relationships and interfaces (physical, performing) are arranged between individual parts and materials of a system or component;
- the development of custom-made enclosure elements, using materials specifically produced to perform certain functions and without having to adapt to the limits imposed by

original and predetermined properties. This is achieved by replacing composites made from multiple devices, assembled together, with elements resulting from the union of different surfaces within a single polyvalent layer;

- the systems capability to react to environmental stresses, according to passive or active regulation processes (by manual, mechanical or computerized commands) induced by electrical, thermal and lighting triggers that modify, through alterations in the physical or chemical structure, the disposition of the enclosing elements or the properties of materials (Fig. 16), [15].

Fig. 16. Norman Foster and Partners, *Greater London City Hall*, London (©by the Author).

The study of envelope systems is linked to research on sustainability in the construction industry, which considers the need to reduce energy consumption and polluting emissions with respect to the implementation of solutions that can establish high environmental performance. In this regard, the contribution of the envelope systems is related to the performance of technological systems, considering the operational procedures designed to balance the relationship between climatic conditions and well-being in built spaces. The design and application field of building envelope systems includes the evolution of conceptual and operational apparatuses referring to the foundations and requirements of environmental sustainability, addressing:

- the eco-efficiency of transformation processes, whereby the planning, production and construction process is determined, in its global form, both in the interaction with the eco-systems harmony, and in the acquisition of the appropriate levels of both environmental and urban quality;
- the paradigms of sustainability, defined by the principles expressed in a series of reports and protocols sanctioned internationally. These address the consequences of environmental impacts (caused to a large extent by management practices, especially energy management, of buildings) and are aimed both at protecting the environment and bio-ecological balances, and at preserving non-renewable (both material and energy) resources, as a basic condition for development (Fig. 17).

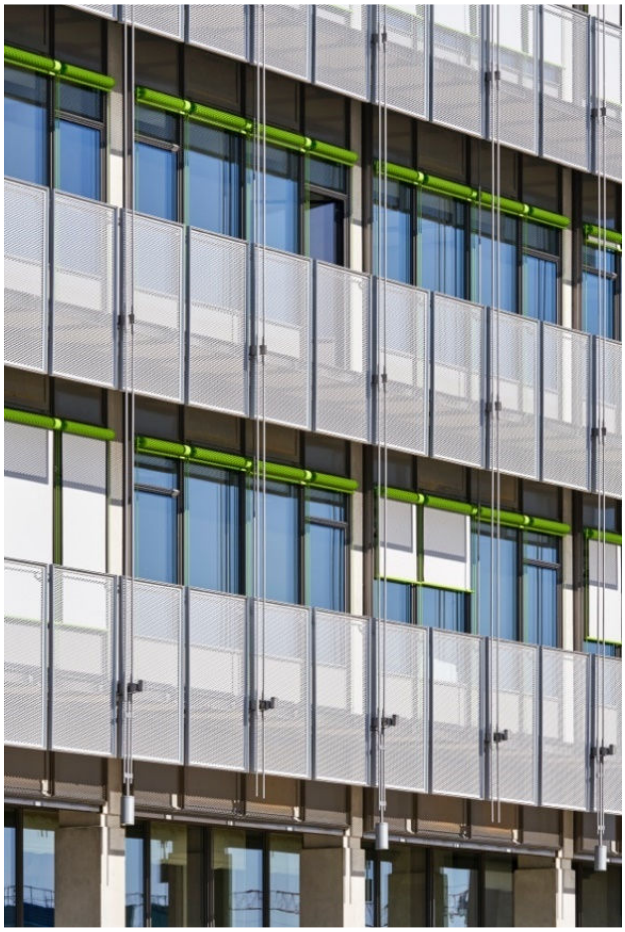

Fig. 17. Renzo Piano Building Workshop, *École Normale Supérieure*, Paris-Saclay (©Courtesy of RPBW).

In this sense, the analysis of envelope systems is linked to the way they interact with climate factors, thereby promoting the primary examination (aimed at the design, functional and application conception) of the external environmental conditions relating to:

- the (apparent) solar path and height above the horizon according to the specific context (latitude) and seasonal periods, which determine the intensity and angle of solar radiation;
- the intensity of solar radiation according to the orientation and inclination of the elevations;
- the solar radiation, either direct and/or indirect (according to the radiation being reflected from the celestial vault and the surrounding environment), according to the different wavelengths;
- the amount of energy input estimated according to the climatic conditions and the energy demand linked to the intended uses [16].

In general, building envelope systems are permeable to solar radiation, leading to the generation of energy inputs that can be accumulated, transmitted (by thermal conduction) and radiated into the interiors (depending on the thermal conductivity of the closing materials). The exposure, due to the different irradiation, affects the energy production of solar radiation,

contributing to solar gains following the heating of the built spaces and their structures. In this regard, vertical façades (facing east, west and south) have a high energy production (which is mainly derived from direct radiation) during the periods of highest exposure to sunlight, thus indicating the need for solar protection.
With regard to the requirements concerning indoor climatic conditions, in relation to the use of building envelope systems, it is considered:
the air temperature and relative humidity of the built-up spaces;

- the temperature and surface airstreams in the area around the closing elements;
- wellbeing requirements related to both the quality and quantity of light transmission and visual conditions (Figs. 18, 19).

Fig. 18. Gatermann + Schossig, *Capricorn Haus*, Düsseldorf (©Courtesy of Schüco).

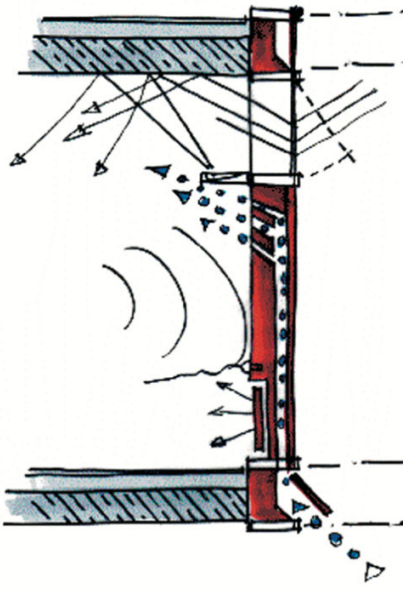

Fig. 19. Gatermann + Schossig, *Capricorn Haus*, Düsseldorf (©Courtesy of Schüco).

As far as the thermal quality of the envelope systems is concerned, which effects the possibility of energy saving through the exploitation of solar radiation, it is observed:

- the low thermal inertia, which provides sensitivity to cooling and overheating phenomena of built-up spaces due to prevailing transient thermal phenomena;
- the thermal dispersion due to infiltration losses, related to the joints between structural elements (i.e., with respect to frames) and closing elements.

At the production, design and construction level, it is necessary to define operational conditions of balance between conflicting requirements, such as the need to ensure a positive energy contribution during the winter period, reducing dispersion and providing thermal storage by transforming solar radiation into heat (according to the phenomena of thermal inertia) (Fig. 20), [17].

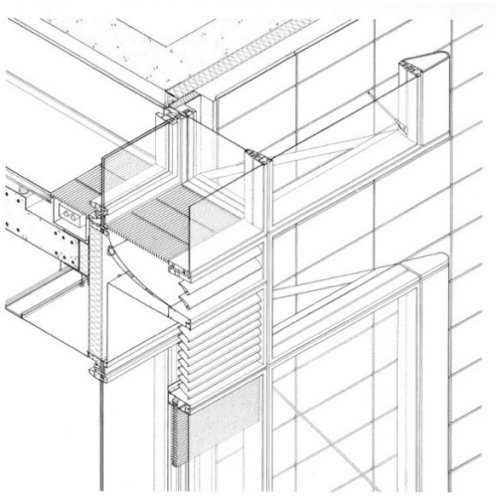

Fig. 20. Norman Foster and Partners with RKW (Rhode, Kellermann, Wawrowsky), *Arag* Tower, Düsseldorf (©Courtesy of RKW).

The combination of passive and active operating procedures regulates the creation of systems capable of self-regulation, sensitive to external climatic changes and to comfort requirements (both thermal and visual) and interiors ventilation. In this regard, the environmental and adaptive strategy develops the envelope systems according to their metabolic effectiveness and their instinctive reactive capacity, configuring themselves as *intelligent skins* endowed with automatic performance (by means of functional criteria of autonomous regulation) and membranes defined as *biological skins* (capable of reacting against external agents through the activation of sensors and protective devices). Furthermore the biological relationship considering the regulation systems (computerized building management systems, BMS) and the corresponding opportunities for opening and closing, protection, shielding and environmental incorporation, identifies the *hypothalamic function* reactive to external and internal stresses (Figs. 21, 22).

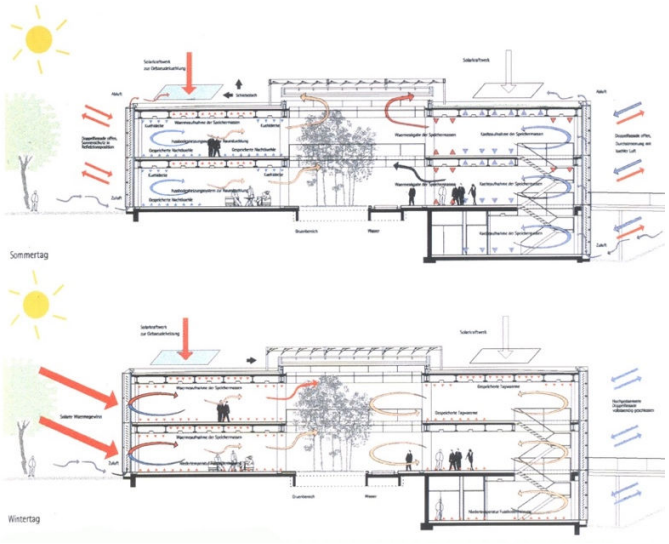

Fig. 21. Martin Webler and Garnet Geissler, *Götz* Headquarters, Würzburg (Germany) (©Courtesy of Götz).

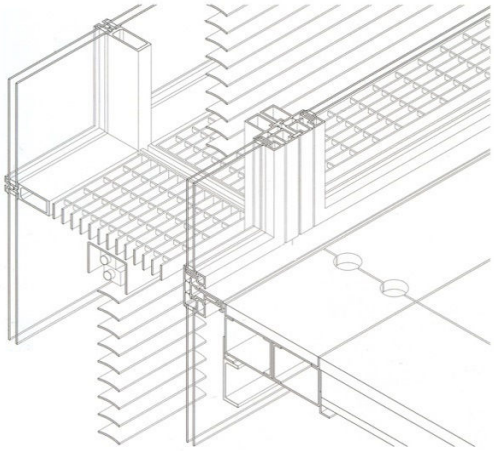

Fig. 22. Martin Webler and Garnet Geissler, *Götz* Headquarters, Würzburg (Germany) (©Courtesy of Götz).

The systems design thus exposes the *techno-organic* properties through the interpretation and assimilation of environmental conditions in a combination with the use of advanced techniques (in *organitech* form). In this manner, the study involves the investigation of artificial (or organic) systems integrated with natural systems, as tools for accumulation, channelling, protection and calibration of passive energies that can provide buildings with heating, air conditioning and ventilation. Consequently, the building envelopes are expressed by environmental diaphragms and by *neuronic façades*, built like "natural organisms", or rather like machines that aim to reproduce, manage and metabolize natural processes according to criteria of active understanding.

The design of building envelope systems is aimed at:

- securing natural lighting levels (according to reflection, absorption and diffusion criteria) in order to reduce energy consumption;
- controlling the overall transmission component of solar radiation (with particular attention to ultraviolet wave transmission), while not penalizing the transmission component within the visual field;
- controlling the perceptual-visual relationships and gradations;
- controlling air quality and humidity, especially through natural ventilation;
- reducing acoustic stress, through reflection and/or absorption of sound waves (Figs. 23, 24), [18].

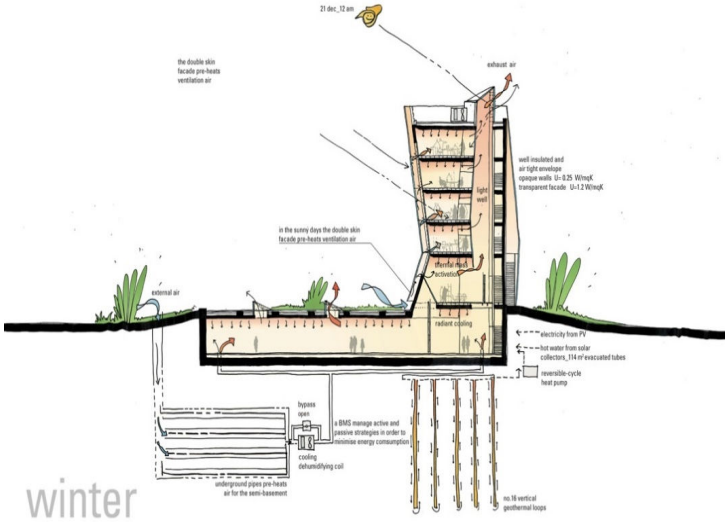

Fig. 23. Mario Cucinella Architects, *CSET* (*Centre for Sustainable Energy Technologies*), Ningbo (China) (©Courtesy of Mario Cucinella Architects).

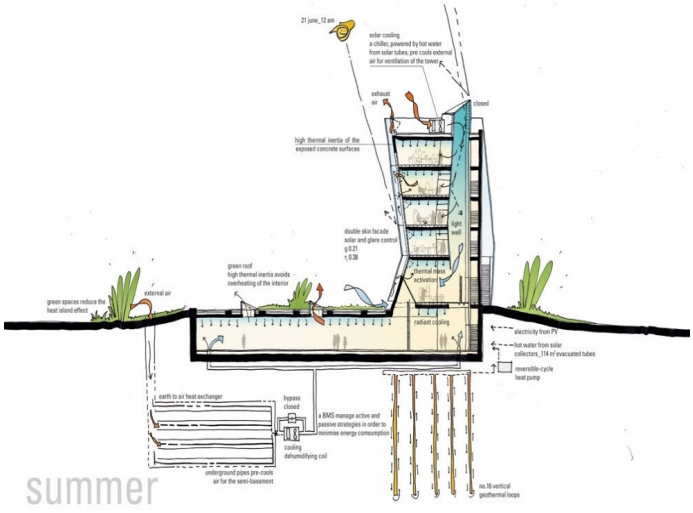

Fig. 24. Mario Cucinella Architects, *CSET* (*Centre for Sustainable Energy Technologies*), Ningbo (China) (©Courtesy of Mario Cucinella Architects).

V. Interactive Processing of Envelope Systems

The interactive design of the envelope systems analyses the constitution of façade surfaces as an information support and as a communicative tool, according to technological and multimedia business, along with the progressive dematerialization and immaterial transformation of architecture. In this respect, the composition of the building envelope is expressed through the acquisition of new visual and virtual potentials, which transcend the material aspects, which aim at the metamorphosis of curtains and which stand out as communicative devices. Within this scenario, the composition of envelope systems is configured both according to the loss of perspective stability and according to the emphasis on membranes and programmable surfaces (Fig. 25).

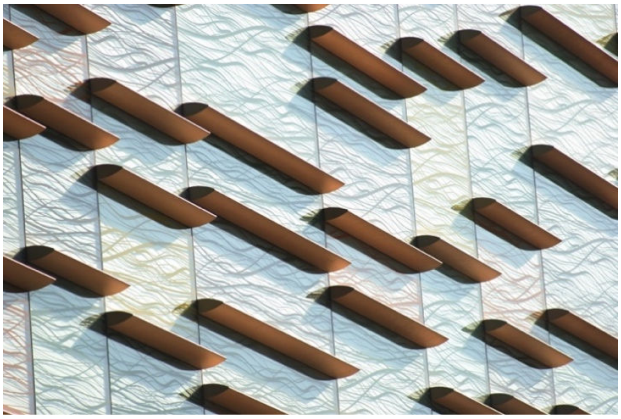

Fig. 25. Irene Sabato (Polis Engineering), Ivo Pellegri (DAGA Studio), *Guna Headquarters*, Milan (©Courtesy of Sipam).

The combination of expressive and performance opportunities, of working methods and morphological experiments, on which the composition of the interactive envelope is based, supports the evolution of stylistic features, so that the architectural works take on increasingly enigmatic aspects: the absolute essentiality of the interiors is matched by an exasperated sophistication of design and effect on the outward appearance, to the point of making us imagine the future landscape of our cities only as a continuous series of thin, changing envelopes. Such experimentation leads to alienation from the context in which the building envelopes are placed, in accordance with the desire to affirm that each work of architecture establishes itself through its own conceptual contents and its own principle of independent identity (Fig. 26), [19].

Fig. 26. Gianandrea Barreca and Giovanni La Varra, *"B5" Building, RCS - Media Group Headquarters*, Milan (©Courtesy of Focchi).

Specifically, the envelope systems are considered according to:

- the formulation of scenographic and catalyzing mechanisms open to multiple expressive and functional solutions, such as accumulators of pictures and as urban transmitters, assigning to the façade curtains the function of configuring themselves as an autonomous and communicative support;
- the elaboration of conceptual installations, through which the temporary, ephemeral and suggestive content of visual engagement is revealed, whose surfaces take in the suggestions of the media culture, thus asserting themselves as media façades, or hypersurfaces (as supports for the expressive potential of media);
- the modes of interaction and merging between the architectural work and the context, through the development of surfaces marked by discontinuities, foldings or stratifications, according to fluid and dynamic morphologies. The surfaces are examined as membranes, active and structured, connected to the concept of continuous movement and modulation. They are not identified by the necessity to produce thickness in the wrapping of the perimeter curtains, but with regard to the paradigms of immediacy and instantaneousness (Fig. 27), [20].

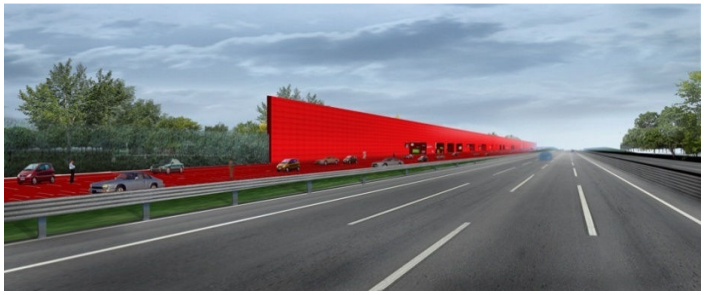

Fig. 27. Atelier Jean Nouvel + Studio Blast, Technological Scientific Park *Kilometro Rosso*, Stezzano (Bergamo) (©Courtesy of Studio Blast).

The experimental elaboration of the envelope, then, examines the application of the enclosures on the basis of the

environmental and spatial fading of boundaries (intended as the loss of their role as a clear-cut boundary between content and exterior). This is achieved through the dematerialization of the facades (aimed at a free conceptual, spatial, perceptive and evocative flow), operating on filters, diaphragms and transparencies. The interactive processing of envelope systems concerns, then, the dematerialization of containers, whereby surfaces reveal themselves as a media epidermis, as sensors capable of connecting reality phenomena and information demands.

The physical and material characters of surfaces are examined in relation to the loss of their tectonic consistency, proceeding to the expression of the permeability conditions, both functional and fruitive, and towards the aleatory articulation in conceptual and visual transitions, through:

- the contribution of digital processing, which allows to represent the organic, dynamic and metamorphic aspects of the envelope virtualization; the development of hypermedia perception standards, aimed at the deep layers of intellectual, emotional and sensorial reactivity;
- the plastic tension of the enclosure, taken to the extreme of its functions, whereby the barriers of closure are bypassed by the inclusion and dilution of visual passages (Figs. 28, 29), [21].

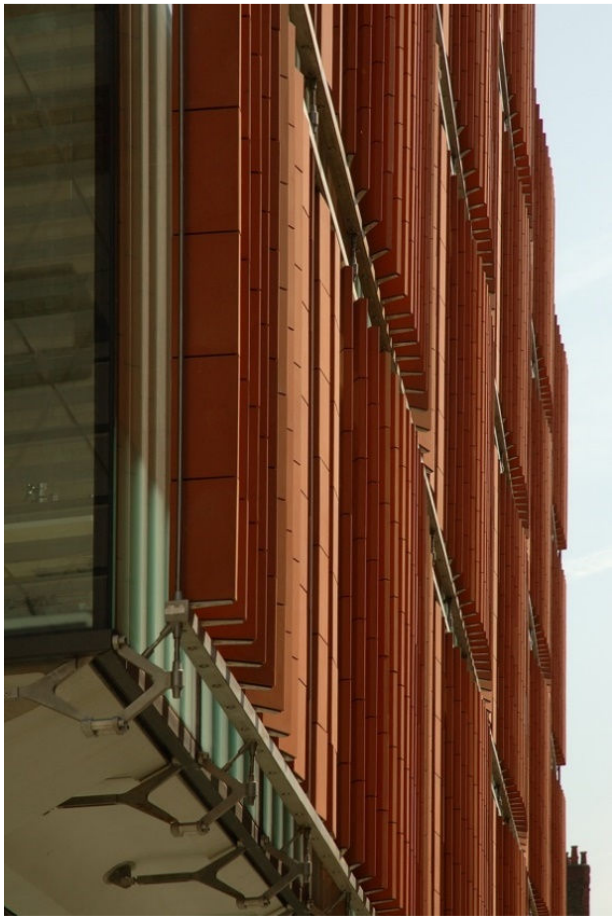

Fig. 28. Nicholas Grimshaw and Partners, *UCL Cancer Institute*, London (©Courtesy of Sannini Project).

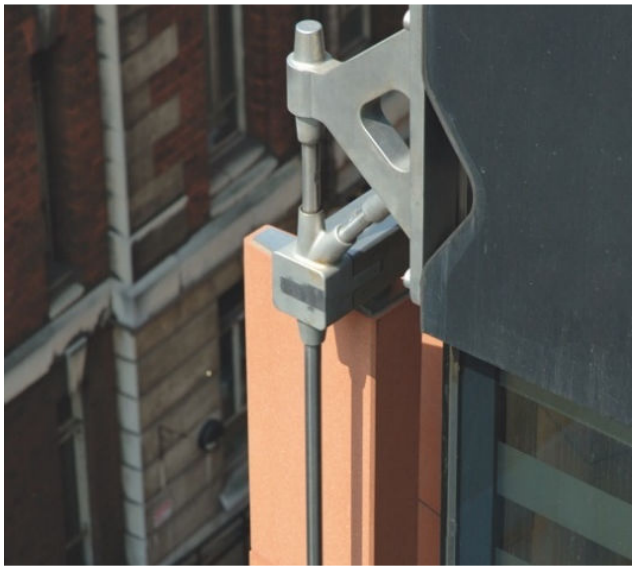

Fig. 29. Nicholas Grimshaw and Partners, *UCL Cancer Institute*, London (©Courtesy of Sannini Project).

Therefore, the enclosures in fulfilling the purpose of wrapping and delimiting, are conceived as removable slabs, as almost immaterial and mobile presences, in order to generate dialectical relationships between built spaces and the external context and to emphasize the interactive and organic logic of architecture. In particular, the wrapping of the building envelopes is determined through differing or calibrated densities, according to the principle of porosity and reticulation. This is achieved by using cuts, pixels and openings, engraved and interposed on the perimeter curtains. The enclosures are thus examined, in general, according to:

- the procedures of dematerialization and interconnection, both spatial and visual, considering the surfaces in their light, transparent constitution, aimed at specifying a symbiotic and engaging relationship with the external space. The envelope systems are thus conceived through flexible and reactive, metamorphic and unstable configurations, in relation to their transparency and opacity (Fig. 30);

Fig. 30. Valentina Bonato, Dario Cagol and Helmuth Niedermayr, *Alperia Tower*, Bolzano (©Courtesy of Oskar DaRiz).

- the organic deformation procedures, considering the curtains as textures that flow through space due to their porous constitution, perceptible and intelligible according to the temporality of movement. The envelope systems are then intended as a vibrant and changeable configuration, sensitive and interactive, adjustable to the urban and immaterial environment (Fig. 31).

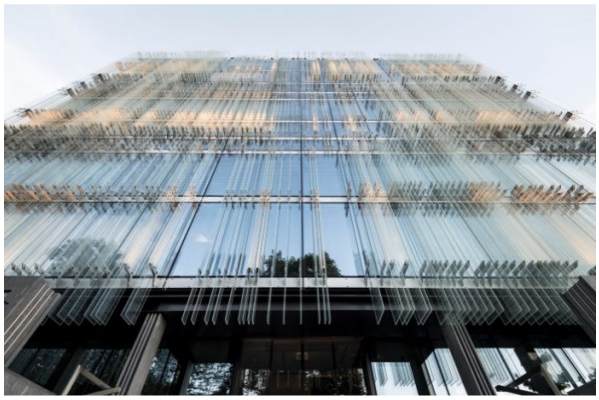

Fig. 31. Giovanni Vaccarini Architetti, *Société Privée de Gérance* (*SPG*), Geneva (©Courtesy of Alex Filz).

The envelope systems are therefore articulated through a number of observations on part of contemporary architecture that displays, through its own external sensitive films, through its own skin, a desire for effective communication, relating to a position of discontinuity with respect to the urban context: these are design researches that seek to introduce new image accumulators and place identities, according to complex aggregation devices and hierarchies, no longer capable of being identified and ordered according to the usual categories of urban analysis (Fig. 32), [22], [23].

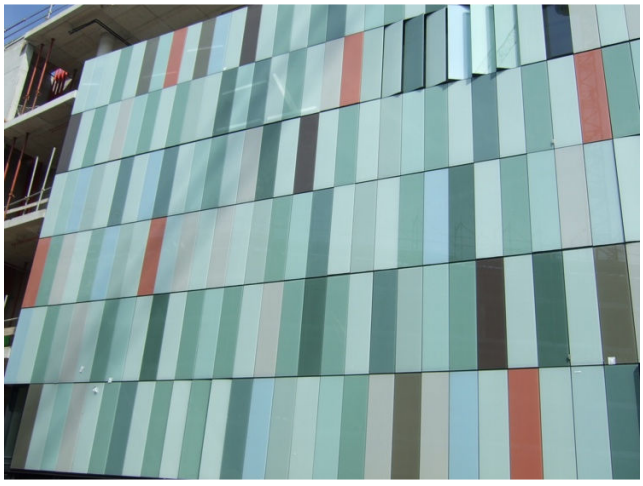

Fig. 32. Matthias Sauerbruch and Louisa Hutton, Area "Mac567", *Maciachini Center*, Milan (©Courtesy of AluK).

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