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Material Balance
A Design Equation

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Contents

Chapter 8
Future Façade Systems. Technological Culture and Experimental Perspectives

Massimiliano Nastri

Abstract 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, according to the procedures of integrated operations with regard to the interaction with environmental, climatic and energy loads. In this respect, the study focuses on the dynamic and reactive behavior, mediation and interchange practices in relation to the control and conveyance of thermal, light and air flows, along with the calibration of components according to energy performances. The study is developed in accordance with the procedures of dematerialization, interconnection and permeability of building façades, by deepening the constituent practices of textures aimed at spatial, perceptual and evocative connections. The examination of façades relates to conceptual and experimental practices according to the development of plastic, organic and kinematic morpho-genetic processes, extended to a three-dimensional digital modeling and topology optimization aimed at calibrating performances and physical and geometric characteristics. In addition, this research considers the development of façade surfaces in communicative and interactive form as a medium for visual and mediatic transmission.

Keywords Building envelope and façade systems · Environmental and energy design of façade systems · Dematerialization and interconnection of façade systems · Computational design of façade systems · Topology optimization of façade systems · Mediatic and communicative design of façade systems

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8.1 Morpho-Typological, Productive and Constructive Constitution of Advanced Façade Components

The design, production and manufacturing of building envelope systems, aimed at performing morpho-typological, perceptual, physical and environmental functions within the *Material Balance Research*, are dealt with the evolved *curtain wall* configuration (known as "outer curtain") and with the geometric and material continuity of "light façades" (or "curtain walls"), located outside the main structural apparatus (Giordanino et al. 1963, tr. it. 1967; Nardi 1961, 1976; Schaal 1961; Nastri 2008a, b, c). 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 (already defined by *components approach* or *componenting* processes, using "aggregation rules" for the assembly of "pieces"), which identifies an area characterized both by the multiplicity of combinations and by synergies between technical and material elements of different productive origin (Murray 2009; Nastri 2017).[1] This supports the "flexible" relationship criteria between structural and envelope elements, connection and functional devices and assembly modes (Daniels 2003; Herzog et al. 2008) (Fig. 8.1).

In general, the technical and executive design of façade systems focuses on the selective and "customized" use of the results derived from the current production and performance offer. This is done considering the opportunities of choosing between "series solutions" and "prototype solutions". In this respect, the convergence between design culture and industrial culture is defined by the versatility of production lines, the innovation aimed at the flexibility (but also to the specialization) of products and the offer of new performances, while considering the purpose of "multi-material" relationship and specialized stratification (Herzog et al. 2004, tr. it. 2005). This determines the development of functions according to specific needs and of products showing morphological neutrality and variety of use, articulation and joining procedures (Boswell 2013) (Fig. 8.2).

Within the design, productive and constructive scenario, the study considers the building envelope systems in relation to:

- the role of "transition" between internal spaces and external spaces, in an autonomous (morpho-typological) way towards the intended uses and in combination between performance contents (such as *useful skin*) and external aspects (such as *ornamental packaging skin*);
- the "integrated" constitution of components, characterized by "specialization" processes aimed at taking overall quality at different levels, in accordance with structural and connective, geometric and dimensional coordination procedures, to

[1]The scientific framework of this subject is dealt within the training course: Nastri M, «I sistemi di involucro. Facciate continue» (Tecniche Nuove S.p.A., Training and Retraining Division). Website (online course): http://www.tecnichenuove.com/argomenti/edilizia-e-architettura/i-sistemi-di-involucro-facciate-continue-12030.html.

Fig. 8.1 Selective and "customized" use of "series solutions" and "prototype solutions", according to specific needs and products showing morphological neutrality. Building Design Partnership, Marks & Spencer Building, Manchester © Courtesy of Focchi S.p.A.

allow both the application to multiple construction types and mechanical assembly modes (Watts 2010) (Fig. 8.3).

In accordance with this approach, the study examines the composition of building envelope systems (complying with the use of planar, modular or "customized" elements) by:

- the use of morpho-typological "rules" through prefabricated components, where their connection modes determine both the expressive and executive correlation strategy (Gulinello 2010);

Fig. 8.2 Role of "transition", in combination between performance contents and external aspects, and "integrated" constitution of components, characterized by "specialization" processes. Sidell Gibson Architects, One Snow Hill Building, Birmingham © Courtesy of Focchi S.p.A.

- the "construction poetry" finalized to define the semantic criteria of frames and envelopes in accordance with the expression of principles and modes of relationship between the pieces and the materials (Knaack et al. 2007).[2]

[2]The design of building envelope systems, in relation to the references of morpho-typological and traditional connective composition, considers:
• the tendency of rationalization and "reinvention" of both components and technical interfaces, in an integrated way according to the variety of expressive possibilities;
• the hybridization of traditional materials, in order to legitimize the "solid" and "massive" presence, within the growing "virtuality" and the ephemeral, dynamic and "metamorphic" configuration of façade curtains (Schittich 2001, tr. it. 2003).

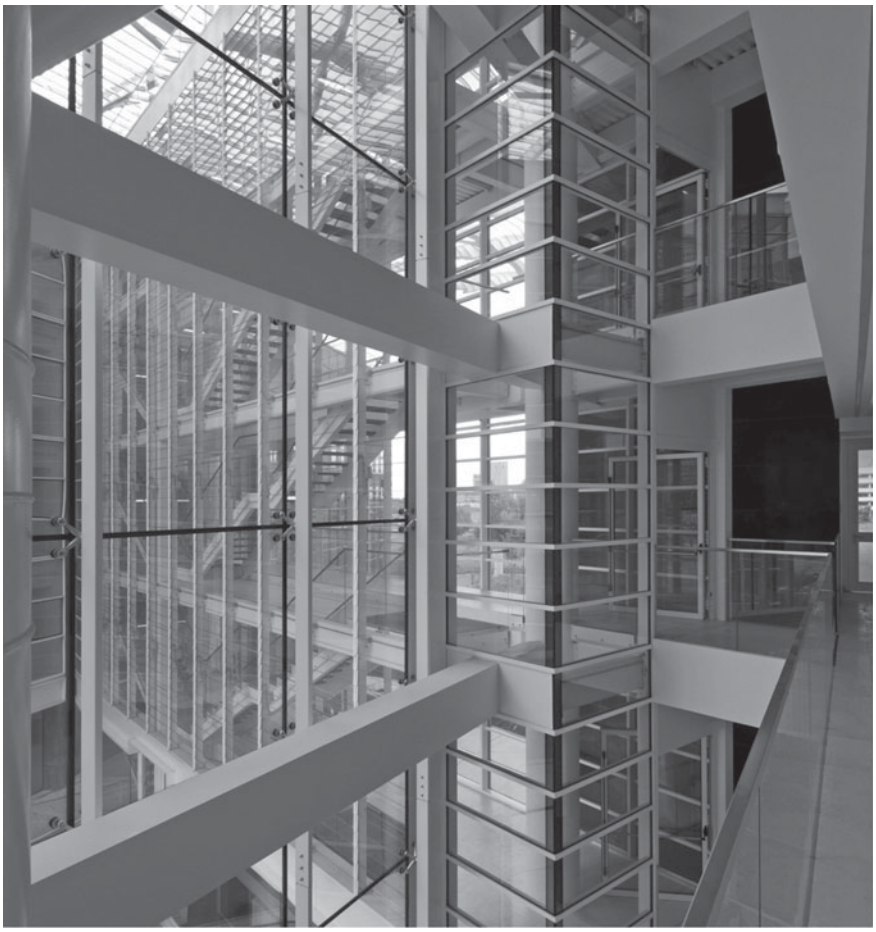

Fig. 8.3 Use of morpho-typological "rules" through prefabricated components and "construction poetry" finalized to define the semantic criteria of frames and envelopes. Goring and Straja Architects, Perseo District, Pero, Milan © Courtesy of AGC Glass Italia

8.2 Environmental, Functional and Integrated Design of Building Envelope Systems

The study of building envelope systems, within the *Material Balance Research*, is defined by the constitution of integrated functional components with the purpose of receiving, guiding and selecting environmental loads in order to achieve ergonomically "calibrated" conditions for internal spaces. The definition of building envelope systems considers the analogy with the concept of "machine-envelope" as a support and as an integrator of functional elements (Banham 1976, tr. it. 1980), expressed in formal, perceptual and performance terms: façade components are composed as

"mechanical bodies", "active diaphragms" and membranes which foster or prevent heat, light, acoustic and aerial flow transfer with the external environment, playing a visual and energy adjustment role (Schittich 2001, tr. it. 2003). The examination focuses on the development of the *engineering performances* (in particular, intended as a combination of multiple "environmental performances"), of the *environmentally responsive walls* (which actively "react" to the environmental loads through the perceptual and "organic" contact with weather conditions), and of the *engineered walls* (intended as mechanical equipments) which regulate thermal, light and air flow transmission, together with the mitigation of wind and acoustic loads (Daniels 1994; Syed 2012). On this basis, the analysis considers:

- the specialization and combination of "passive" and "active" functioning procedures leading to "self-regulating" building envelope systems sensitive both to external weather changes and to the need for thermal and light, air and acoustic comfort in internal spaces (Wigginton and Harris 2002);
- the environmental and "adaptive" strategy aimed at developing building envelope systems according to their metabolic efficiency and "instinctive" reactive capacity, as *intelligent skins* with "automatic" performances (using functional "autonomous adjustment" criteria) and as membranes defined as *biological skins* (effective towards external agents, by activating some "sensors" and protective devices). The biological reference identifies, inside the regulatory systems (such as the *computerized management systems*, *BMS*) and their environmental integration, protection and shading possibilities, the "hypothalamic" function able to react to external and internal loads (Atkin 1988) (Fig. 8.4).

8.2.1 Study of Dynamic Interaction Procedures

The examination explains the building envelope systems considered as "organic" compounds, adaptable and adjustable as *biological skins* and as *multifunctional skins*, that is as absorbent, radiant, reflecting, filtering and transferring devices (of thermal, light and air flows; Romano 2011). In particular, the use of dynamic and "reactive" elements takes the form of solar radiation control surfaces consisting of filtering or shielding sections capable of adjusting their transparency according to the level and distribution of natural brightness required in the interiors. The design of systems exposes the "technorganic" qualities (Welsh 1994), by interpreting and assimilating the environmental conditions in combination with the use of advanced techniques (in *organitech* form; Jencks 1995). This way, the study includes the experimentation concerning "artificial" (or "organic") systems integrated with "natural" systems, such as storage and conveyance, protection and calibration of "passive energies" devices that can provide buildings with heating, conditioning and ventilation. In this scenario, the study investigates:

- the development of building envelope systems intended as "dynamic interfaces", that is as a mediating and interchanging structure between the environmental

Fig. 8.4 Specialization and combination of "passive" and "active" functioning procedures, environmental and "adaptive" strategy according to metabolic efficiency and "instinctive" reactive capacity of the intelligent skins. Studio 44, Federal Almazov Heart, Blood and Endocrinology Centre, Almazova Medical Centre, Saint Petersburg © Courtesy of Lilli Systems

loads and the needs of indoor spaces, with "evolutive plasticity" and "adaptive" properties to environmentally differentiated loads (Altomonte 2004);

- the experimentation of advanced building envelope systems in order to integrate the climate conditions and convey them to indoor spaces, according to established procedures and levels, and to build components in the form of "biomechanical prototypes" where different parts specialize in a specific function (Hausladen et al. 2008) (Fig. 8.5).

8.2.2 Study of Functional and Energy Formulation Procedures

The examination defines building envelope systems as a means of mediation and response to external loads, in conjunction with the calibration of energy properties and performances (according to a *selective approach*), with the contribution of technical design and the consistent application to settlement requirements (as *environmentally*

Fig. 8.5 Development of "dynamic interfaces" as storage and conveyance, protection and calibration of "passive energies" devices that can provide heating, conditioning and ventilation. Schneider + Schumacher, Braun AG Building, Kronberg, Frankfurt am Main © Schneider + Schumacher

conscious design activity).[3] The performances of building envelope systems are processed in relation to "single-layer" systems (as *single-skin façades*) and "multi-layer" systems (as *multiple-skin façades*), whereby the fitting of planar surfaces generates "greenhouse effect", "chimney effect" and natural ventilation devices (in the form of *double skin façades*; Oesterle et al. 2001) (Fig. 8.6).

Moreover, performances are based on thermal, chemical and surface treatments, on stratification and cladding treatments (acting on the transmission of visible, solar and thermal radiation, especially in relation to the spectral field of infrared), on

[3]The study of façade elements focuses on the physicality of the combined and multi-layered surfaces, which the experimental research tends to transform into something "thick" and into an "interface of intelligent systems" (Altomonte 2004, p. 42). The main materials of external surfaces are composed in relation to their change processes from "stable entities" into "plannable entities" according to a particular "performance program" (ibid.). Their application is structured in relation to the outcomes of solutions where the functions tend to become "complex" (in "controlled" and "managed" ways) and articulated between them (in a *solid state* form).

Fig. 8.6 Examination of "multi-layer" systems in order to generate "greenhouse effect", "chimney effect" and natural ventilation devices in the form of double skin façades. Progetto CMR, Garibaldi Business Centre, Milan © Courtesy of Progetto CMR

coloring and deposition treatments in relation to the enclosure (Konis and Selkowitz 2017). In this scenario, the study investigates:

- the physical, material and performance contents of building envelope systems developed according to criteria of efficiency considering both energy and environmental conditions and ergonomic conditions through the reflection, collection and diffusion of external or internal loads. This is achieved by "passive" procedures, which are intended to accumulate and distribute the energy produced by solar radiation without the use of implantation equipment, or by "active" procedures, with the addition of technical devices (in the form of "collectors") aimed at integrating and conveying heat, natural light or convection in relation to air flows (Argiolas 2005; Aksamija 2013);
- the technologies related to building envelope components and devices able to activate the processes of "eco-efficient interaction" and "permeability" in relation to the thermo-hygrometric, light and air loads (by determining the energy and environmental control of "selective" and dynamic criteria), with the possibility of adjusting their flows and conveying them into overall functioning (Lovell 2010).

8.3 Permeable and Diaphragmatic Design of Building Envelope Systems

The study of building envelope systems examines the development of façade curtains in accordance with "dematerialization" and "interconnection" procedures, considering external, light-constitution surfaces, aimed at defining the relationships that support environmental and spatial interaction. The "dematerialization" procedures, which involve the application of "differences" of density and of "diaphragmatic porosity", are part of the contemporary design, productive and constructive experimentation, which takes, as a field of research and poetic development, the criteria, exercises and paradigms of "fusion" between architecture and context. The study of building envelope systems examines, in particular:

- the application of vertical enclosures according to the environmental and spatial "dissolution" of "boundaries" (considering them as losing their meaning of border between that which is "contained" and "external" spaces). This is done through the "dematerialization" of façade and cladding components (open to spatial, perceptual and evocative flows), by means of "filters", "diaphragms" and "mediated transparencies" (Premier 2012);
- the examination of physical and material characters of surfaces in relation to the "loss" of their tectonic consistency, expressing their permeability conditions, both functional and related to their use, and towards the random articulation inside the conceptual and visual steps.

The analysis focuses on the development of vertical enclosures which, in carrying out their purpose of enveloping and delimiting, are conceived as "revocable sheets", such as "intangible" and "movable" elements, in order to generate the dialectical relationships between internal spaces and the external context, and to emphasize the interactive and "organic" logic of architecture. In particular, the enveloping apparatus shall be determined by means of differentiated or calibrated "densities", according to the "cross-linking" principle by using "cuts", pixels and openings, inscribed and interposed on the curtain wall (Fig. 8.7).

8.3.1 Study of Perceptual and Connective Articulation Procedures

The field of interest, which includes the management of symbiosis practices in an "incorporeal" and "intangible" way applied to the context, entrusting to the fluidity of perceptual instances and external membranes the "loss" of texture and the enhancement of the diaphanous character (according to the detection of morphological, functional and visual permeability), defines:

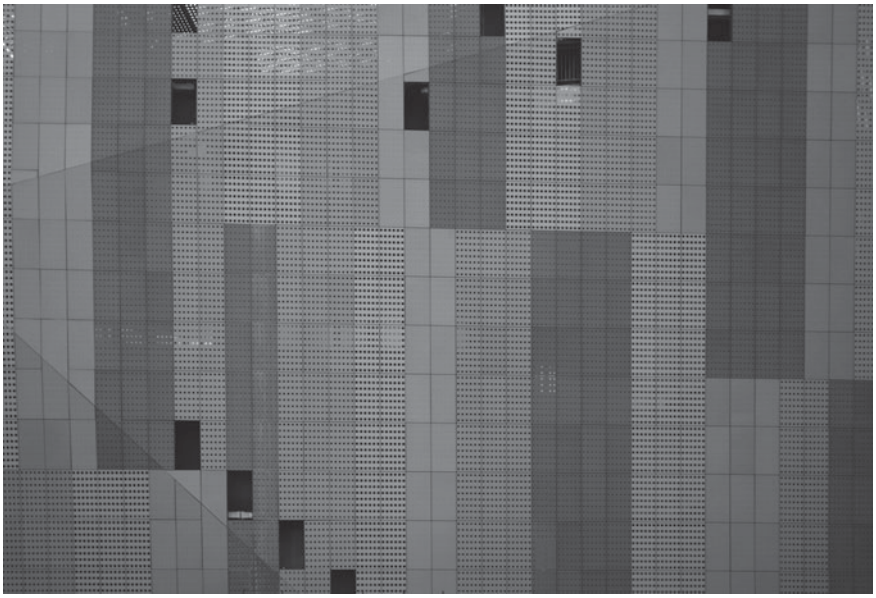

Fig. 8.7 "Dematerialization" and "interconnection" procedures with application of "differences" of density and of "diaphragmatic porosity", according to the environmental and spatial "dissolution" to generate dialectical relationships between internal spaces and external context. Cino Zucchi Architetti + Park Associati, Salewa-Oberalp Headquarters, Bolzano © Courtesy of Park Associati

- the concept of "deformed" and "impalpable", "metamorphic" and "unstable" surfaces, in relation to their properties of transparency, reflection and opacity (Prina 2008);
- the procedures of "organic deformation", aimed at defining the façade curtains as "fabrics" that pierce space through their "porous" and "vibrant", sensitive and interactive constitution, adaptable to the urban and "immaterial" context (Fortmeyer and Linn 2014) (Fig. 8.8).

Moreover, the analysis focuses on the composition of building envelope systems according to the ethereal constitution, such as a light and "impalpable", "metamorphic" and "unstable" simulacrum (within environmental, interactive and perceptual variations) by differentiated or calibrated "porosities" defined by:

- the application of rules aimed at considering building envelope systems as an "overlapping landscape", in a tension-sensitive relationship with the tectonics structures and the spaces. This is achieved by formulating a balance and a combined syntax between the specific characters of the context and the architecture (carried out as a "provisional" and "immersive" expression; Murray 2013);
- the work on the curtain wall according to the appropriate compositive and functional intents for the constitution of "diaphragmatic textures" (with the possibility

Fig. 8.8 Constitution of "deformed" and "impalpable", "metamorphic" and "unstable" surfaces, according to the procedures of "organic deformation" of the façade curtains adaptable to the urban and "immaterial" context. Cino Zucchi Architetti, U15 Building, Assago, Milan © Courtesy of Cino Zucchi Architetti

of grading and modulating the façades), in order to emphasize the "temporary" and ephemeral aspect including the "hypermedial perception" characters (by reference to languages aimed at interacting with the complex realm of sensoriality) (Fig. 8.9).

8.4 Complex and Optimized Morphology Surfaces Design

The study of building envelope systems examines the organization of two-dimensional and three-dimensional geometric structures in accordance with plastic, organic and kinematic morpho-genetic processes resulting both from "dynamic balance" levels and from constant fluctuations and mutations. The study is associated with the experimental design of *architectural compounds* where the combination of "tension" and "distortion" stimulation determines the spatial and volumetric configuration. This field of study considers the façade surfaces shaped as continuous

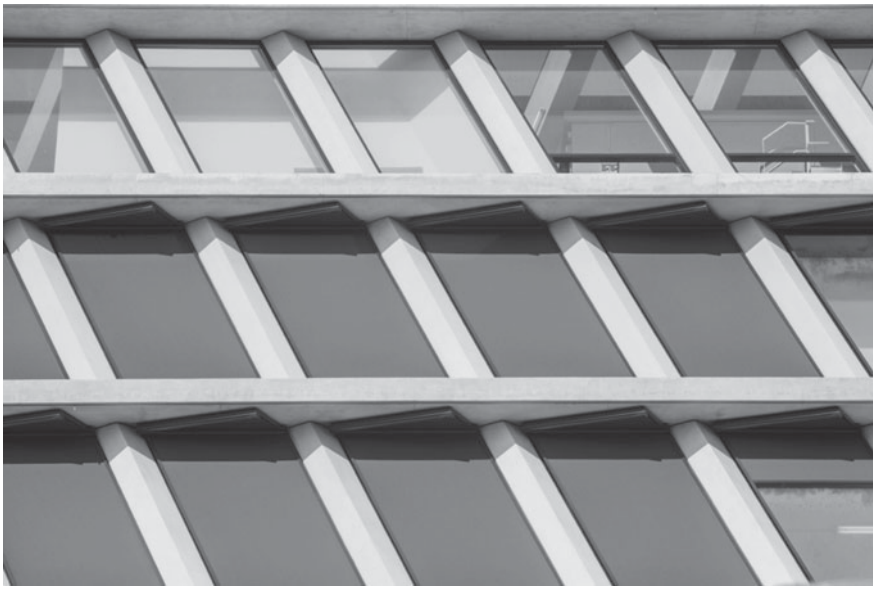

Fig. 8.9 Constitution as light and "impalpable", "metamorphic" and "unstable" simulacrum by differentiated or calibrated "porosities", as "provisional", "immersive" and "diaphragmatic textures". Jacques Herzog and Pierre de Meuron, Giangiacomo Feltrinelli Foundation, Milan © Courtesy of Resstende s.r.l.

"masses" or as intersections and transitions, according to "indeterminate" and relational forms (Block et al. 2015). Specifically, the study observes the composition of curtain walls (whereby the frames create the "sculptural" conception of the three-dimensional model, determining the rules of the "morphological configuration") through:

- the generative tension aimed at destructuring the "multi-linear" morphologies (capable of incorporating multiple variations and directions) and producing the prospective distortions geared towards multiple focal and functional points;
- the kinematic, permeable and osmotic organization in relation to the environmental, urban and perceptual conditions, in order to allow a multi-directional integration with the context;
- the constitution of metaphorical, analogical and dynamic morphologies, defined by the transfiguration and articulation of *flows* and *networks*, the view of "force-fields" of urban and "intangible" spaces (where the surfaces achieve the "connection-transition" ratio between the built-up densities and the external, environmental and urban spaces; Nastri 2009) (Fig. 8.10).

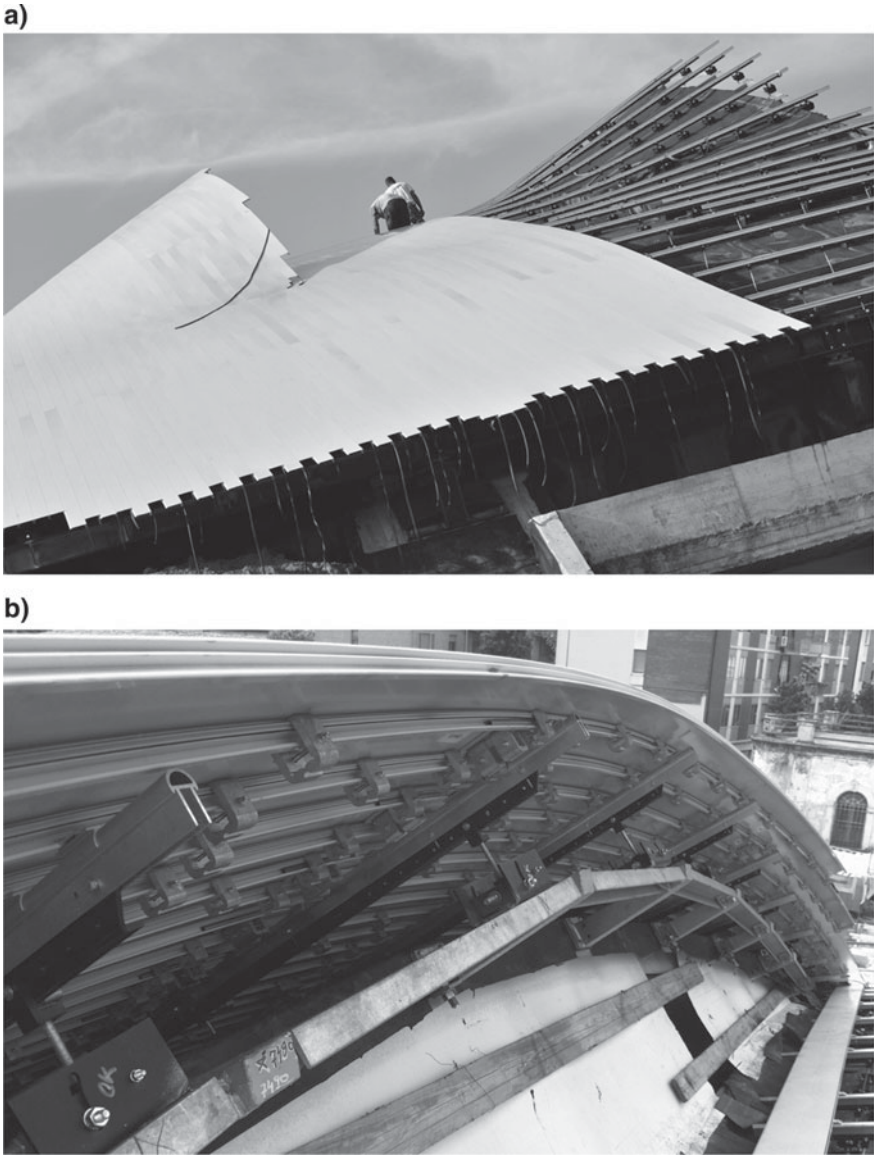

Fig. 8.10 Plastic, organic and kinematic morpho-genetic processes through the generative tension aimed at destructuring the "multi-linear" morphologies (**a**) in order to build the façade surfaces shaped as intersections and transitions (**b**). Future Systems and Andrea Morgante, Enzo Ferrari Museum, Modena © Courtesy of Cooperativa di Costruzioni di Modena

8.4.1 Study of Calibrated and Multi-dimensional Composition Procedures

The study of building envelope systems is part of the research regarding the application of *Automotive Manufacturing* procedures into the experimental design, production and construction scenario, aimed at the constitution of complex architectures defined by the overcoming of limits related to geometric, structural and connecting feasibility conditions. The study, using the operating methodologies acquired and transferred from the industrial sectors with the support of advanced technologies (such as automotive, aerospace and medical), in the expression of computational design practices, considers the cognitive and application guidelines for the implementation of multi-dimensional technical solutions, according to:

- the development of the three-dimensional digital configuration, the subsequent optimization related to the requirements and the physical printing (as *3D printing*), often reducing post-production and finishing phases;
- the geometric and physical, chemical and material calibration, determined in relation to the performances needed (by simulation and virtual modeling);
- the development of complex geometry integrated components, avoiding the critical issues caused by the combination of elements and joining devices according to traditional solutions (Naboni and Paoletti 2015) (Fig. 8.11).

8.4.2 Study of Topology Optimization Procedures

The study of advanced building envelope systems considers the experimental design, productive and constructive procedures aimed at the *topology optimization* processes focused on components and technical interfaces, according to:

- the method of shaping the geometric, structural and physical constitution in accordance with the desired performances in terms of strength (mainly mechanical) and material distribution related to the lowest possible weight, considering the feasibility constraints and thus complementing it with additive production practices (which can also foresee the extension of customized solutions into serial solutions; Bendsøe and Sigmund 2003);
- the method aimed at a "calculable" and "manipulable" constitution of components, the subsequent "empirical education" and "executive materialization" of data, through processes related to geometric, structural and parametric "calibration" of functions (as *shape-size-structural optimization* activities)[4] (Fig. 8.12).

[4]The analysis concerns the contents of the lecture: Paoletti I, Nastri M, Adaptive Façades and Topology Optimization, Conference Façade 2018—Adaptive, COST TU1403, Adaptive Facades Network. Lucerne University of Applied Sciences and Arts (Lucerne, 27.11.2018). Published in Luible A, Gosztonyi S, Ed. (2018) Façade 2018—Adaptive, Proceedings of the COST TU1403 Adaptive Facades Network. Lucerne University of Applied Sciences and Arts, TU Delft Open, Delft, 2018, pp. 473–485.

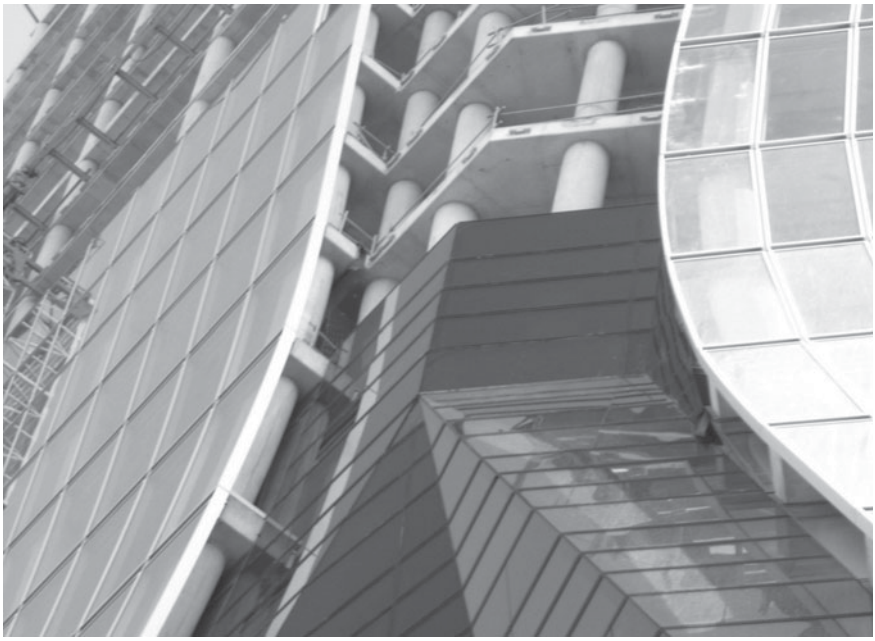

Fig. 8.11 Computational design practices of multi-dimensional technical solutions, with the development of complex geometry integrated components and joining devices. Zaha Hadid Architects, CMA-CGM Building, Marseille © Courtesy of Metalsigma Tunesi S.p.A.

8.5 "Mediatic" and "Communicative" Design of Building Envelope Systems

The study of building envelope systems is based on a part of contemporary architecture that displays, through its external skins, a desire of greater effectiveness in communication, establishing itself in a position of "discontinuity" compared to the urban context. The interactive façade design examines the composition of external surfaces considered as supports for information and as "irradiating macro-objects", as interactive choreographic tools at "infrastructural" scale (Gasparini 2009, 2012). The composition of building envelope systems is demonstrated by the acquisition of new visual and "virtual" potentials, which transcend material aspects and aim at the metamorphosis of curtains (which stand out as "bodywork" and "communicative devices") (Fig. 8.13).

Within this scenario, the composition of façades is determined both by the loss of prospective "stability" (along with the progressive "intangible" transformation of architecture) and by the emphasis on their constitution as "membranes" and "programmable surfaces". The combination of the expressive and performance possibilities, the processing methods and the morphological experiments supports the evolution of the compositive characters, according to:

Fig. 8.12 Topology optimization processes focused on components and technical interfaces, through shaping the geometric, structural and physical constitution in accordance with the desired performances and parametric "calibration" of functions. Massimiliano and Doriana Fuksas, Former Unione Militare Building, Rome © Gianni Basso; Courtesy of Stahlbau Pichler

- the constitution of scenographic and "catalyst mechanisms", open to multiple expressive and functional solutions, such as "accumulators" of images and as urban "transmitters", by assigning to the "decorative curtains" (already theorized by Robert Venturi) the function of communicative support (from internal spaces and context) and by exposing itself to the interactive perception at an "infrastructural" scale (Henket and Heynen 2002);
- the development of *conceptual installations*, through which the temporary, ephemeral and evocative content of the visual involvement is detected, where the surfaces take on the stimulations from the mediatic culture by asserting themselves as *media façades* (i.e. as a "mediatized façades") or *hypersurfaces* (i.e. as media's expressive potential supports; Haeusler 2009, 2010);
- the way of interaction and "fusion" between the architecture and the context, by developing surfaces with fluid and dynamic morphologies, where the façade curtains are examined in the form of "active membranes" in relation to the paradigms of "immediacy" (Haeusler et al. 2012) (Fig. 8.14).

The interactive design of building envelope systems concerns the "dematerialization" of "containers", so that the surfaces are manifested as "mediatic skins", as "sensors" capable of reporting the reality and information instances, according to:

- the contribution of digital processing, which allows to represent the "organic", "dynamic" and "metamorphic" aspects of the "virtualization" of façade curtains;

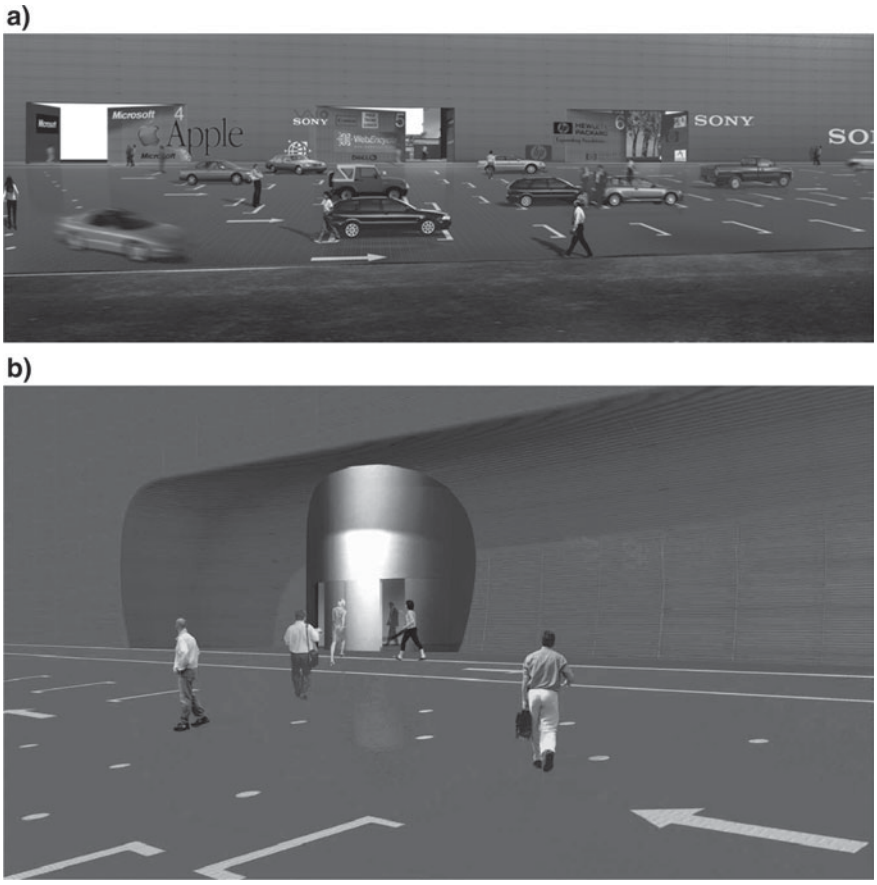

Fig. 8.13 Interactive façades as supports for information and as "irradiating macro-objects", characterized both by scenographic and "catalyst mechanisms" (**a**) and as conceptual installations or media façades (**b**). Atelier Jean Nouvel + Studio Blast, Kilometro Rosso, Scientific and Technological Park, Stezzano, Bergamo © Courtesy of Studio Blast

- the development of criteria of "hypermediate perception", aimed at intellectual, emotional and sensorial reactivity;
- the plastic tension of façade curtains brought to the extreme of its functions so that the closing "barriers" are exceeded by the inclusion and dilution of visual transitions (Moloney 2011).

Fig. 8.14 Interactive surfaces as "mediatic skins" according to the development of criteria of "hypermediate perception" and to the inclusion and dilution of visual transitions. Gianandrea Barreca and Giovanni La Varra, RCS Media Group Headquarters, "B5" Building, Milan © Courtesy of Focchi S.p.A.

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