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Construction of the Façade Systems

Production and Assembly Procedures of the Advanced Building Envelopes

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Preface

The study, developed inside the experimental laboratory *Material Balance Research* within the Architecture, Built Environment and Construction Engineering-ABC Department at the Politecnico di Milano, examines the advanced façade systems according to the productive and constructive contents. The work is determined in the form of a knowledge and design concept tool for the construction of advanced façade systems, used for the realization of multiple types of envelopes. The book is configured in a cognitive and operative form, with the aim of providing researchers, technicians and professionals with the contents to proceed with the analysis, design and constitution of façade systems with the aid of the components, materials and assembly methods typical of the advanced and experimental contemporary scenario.

The purpose of the book is to provide operational guidance for the technological design, production planning and site executive coordination for the realization of façade systems. Moreover, the work goes into detail on how to form, connect and plan for the construction of the advanced façade systems, specifying itself as a manual text to provide guidelines for professionals in charge of design, production and construction.

The work involves the building characters of the envelopes with respect to both the range series (determined by the basic profiles) and the customized or "outside system" components. The scenario under consideration accommodates, in the range series, the types of envelopes transferred by complex, large-scale interventions, with the inclusion of appropriate tools and accessories aimed at widespread use: therefore, the components are proposed in the form of "integrated" elements, characterized by "specialization" processes. Then, the contemporary experimental production observes the application of the archetypal and tectonic properties of envelope systems and the hybridization of established façade typologies through the use of profiles and frames of different material, mechanical and connective invoices.

The study deals with the main building elements and technical interfaces, explaining the anchoring structures and their connections to the load-bearing structures, examining the criteria for the assembly between the mullion and transom profiles. The study of the façade systems focuses on the methods of collecting and draining rainwater, considering the execution of the sealing and the criteria of vapour pressure compensation and drainage for glass enclosures. The analysis of framing is completed with an explanation of the methods of mechanical and structural fastening of the enclosures, noting the criteria for pressure and structural silicone assembly. In particular, the text examines the technical interfaces of the main advanced envelope systems with respect to the functional, constructive and applicative coordination procedures of the mullions and transoms framing, of the structural sealant glazing façade system, of the unit façade system, of the suspended façade system and of the double skin façade system.

The technical and manual character of the book is also expressed through the analysis of the functional and application procedures of the gaskets with respect to the façade systems in order to prevent the transmission of air and water loads: the analysis focuses on the connections between the framing and the enclosure elements of the envelope, in accordance with the compensation of height differences in order to guarantee impermeability, airtightness and insulation. The study observes and investigates the types of framing elements in which the gaskets are inserted, emphasizing the specific function with respect to the connection interfaces.

Then, the study examines the assembly and interface conditions between elements of different composition and production within the façade systems: in particular, the examination of the technical interfaces involves the development and application of sealants, based on the loads exerted on the jointing devices, in order to fulfil the requirements of sealing and tightness with respect to mechanical, thermal and hygrometric, water, air and wind stresses. Moreover, the study of the envelope systems examines the methodologies directed towards fulfilling the requirements with respect to the actions caused by fire loads, considering the contents related to both components and connections and fixing surfaces. The design study involves the specific sections of separation with respect to the fire compartments: this is to limit the propagation of a fire originating inside the building, the fire of a façade and its propagation, the fall of the façade elements.

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Contents

Chapter 1
The Productive, Constructive and Expressive Articulation of the Advanced Envelope Systems

Abstract The study examines the context of the façade systems characterized both by the confirmation and progression of the range series, and by the possibilities of performance increase based on the basic profiles, according to the paradigms of versatility and relational flexibility. Moreover, the context of envelope components is expressed according to the acquisition in its own production of technical solutions "outside system": this considering the current component design strategies focused on production and combinatory procedures, or on criteria of integrated aggregation between elements and semi-finished products arranged "in catalogue". The scenario under consideration accommodates, in the range series, the types of envelopes transferred by complex, large-scale interventions, with the inclusion of appropriate tools and accessories aimed at widespread use: therefore, the components are proposed in the form of "integrated" elements, characterized by "specialization" processes, as finished products, dimensionally coordinated, capable of providing mechanical assembly possibilities and applicable to different building types. Then, the contemporary experimental production observes the application of the archetypal and tectonic properties of envelope systems, through both the elaboration of external enclosures defined by the use of products belonging to the construction "tradition", and the hybridization of established façade typologies through the use of profiles and frames of different material, mechanical and connective invoice. The alternative typologies are arranged with respect to the tendency towards rationalization and "reinvention" of the components and of the canonical application and interface methods, in an integrated manner with the multiplicity and variety of expressive possibilities: this is 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.

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1.1 The Contemporary Characters and Paradigms in Advanced Envelope Systems

The study of the design and production sector of envelope systems is realized, in the current scenario, according to the confirmation and progression of the range series, with respect to the constant in-depth studies, refinement and improvement. The context offers situations of punctual analysis directed to reconfigure certain interfaces, to make explicit the possibilities of performance increase within systems and frames "hybridized" on the basis of the basic profiles. Or else, the context manifests the capacity to support, within its own research and development lines, the elaboration of "sub-components" that are themselves endowed with functional and applicative complexity, characterized by versatility and relational flexibility with respect to the basic frames. Furthermore, in some cases, there is a willingness to take on, channel and acquire in its own production the "out-of-system" technical solutions, increasingly present in the field of façade applications and ready to present themselves in the form of "system proposals". This, ensuring the expression of consolidated and updated paradigms according to the building's energy management and range expansion needs [5, 12].

The evolved expression defined by the productive sphere is characterized by innovative solutions at system or component level, affirming the correlation with the energy needs and the combined association with the entire architectural, plant engineering and functional set-up of the building, in the case of new construction as well as in the case of interventions on the building. In this regard, the evolution of production finally demonstrates the potential to go beyond the development of façade systems as an apparatus directed exclusively at new buildings, involving the technological transfer of functional procedures (above all in the field of bioclimatics and new materials, also studied for some time by techno-science) and experiments (for the most part already adopted and supported at a regulatory level in the Central European field) towards the use on vertical enclosures to be upgraded (Fig. 1.1).

The study of the building envelope made up of prefabricated components is specified as an actualization of the principles of functional architecture, of ergonomic performance combined with the morpho-typological conception of the building, through the use of technical solutions and contemporary materials of an evolved character: the current *component design* strategies focus essentially on the production and combinatory procedures, serial and modular, of enclosure and cladding materials belonging to the building tradition according to "hybrid" and "allusive" forms, or on criteria of mechanical, "tectonic" and integrated aggregation between elements and semi-finished products arranged "in catalogue". At the same time, the *component design* of envelope systems examines ways of environmental, functional and adaptive design with respect to climatic stresses, as well as proposing new scenarios in the "interactive" and "communicative" constitution of building surfaces. The envelope, disengaged from the load-bearing function and in the form of a "curtain", assumes the role of "transition" between interior and exterior space, questioning both the rigorous paradigms, sanctioned during the Modern Movement, of "formal purity"

Fig. 1.1 Christoph Mayr Fingerle, *Cascade* Swimming Centre, Campo Tures (Bozen). Role of “transition” between internal and external spatiality of the envelope, understood as a modular apparatus warped from the load-bearing framework towards the glazed surfaces, inserted in the horizontal perspective composition. © Courtesy of Schüco

and "material functionalism", and the formulation that the external expression of architecture should reflect the internal uses, as a "harmonic" relationship between form and function [1].

The correlation between the envelope and architecture specifies a specific and multidisciplinary field in design and construction, in which converge and relate:

- the notions and the practices relating to structural mechanical engineering, physics-technology, *component* and *industrial design*;
- the fine-tuning of support, interface and specialized "micro-systems";
- the production logic (now enunciated by "light" industrialization, characterized by versatile manufacturing processes for small series and special requirements);
- the "component" processing of enclosure systems that requires skills in "strategic invention" and the "art of connection", as a procedure of establishing connections for assembly sequences [2] (Figs. 1.2, 1.3).

The scenario appears mature and willing to welcome, in the range series, the types of envelopes previously the prerogative only of complex, large-scale interventions, with the inclusion of appropriate tools and accessories aimed at widespread use and also for contained interventions: these are façade systems conceived in flexible form, or systems in *multilayer* combination, in some cases investigated and offered with significant design features on the technical object. The systemic evolution, consolidated in the combination with environmental emergencies, sustainability and climatic balance, is determined decisively through the diffusion of domotics and the typological, functional and executive analysis of façade openings, solar capture and shading devices [10].

In this scenario, the complexity of the technical solutions is "hidden" in the apparent simplicity and immateriality of the envelope, for which specialized skills, at the same time scientific and craftsmanship, are involved. The field in question is proposed in a sophisticated way, the contents and knowledge to be made available require responsibility and figures with high technical preparation: this is so that the applications to the architecture correctly express the expected performance, connect to the other technological sub-systems in respect of the structural, thermo-hygrometric, acoustic and lighting functions, and correlate to the executive instances according to coordinated and studied procedural modalities in relation to the appropriate type of façade. Through the contribution of designers and technical experts, now protagonists in the experimental and evolved scenario, the thematic, operational and exemplary contributions are arranged for the understanding of the main methodological, functional and constructive aspects that define the correlations between the envelope and architecture [9, 11].

The components are concretized in the form of "integrated" elements, characterized by "specialization" processes that intervene to define the overall quality at different levels (e.g. through the configuration of material layers, which become composite or result from the assembly of multiple elements). These components, then, are understood as finished products, dimensionally coordinated, capable of providing mechanical assembly possibilities and applicable to different building types: they are simple or elementary components, complex or composite, i.e. formed

Fig. 1.2 MDN Marco Visconti & Partners, *Ferrari* Restaurant, Maranello (Modena). Articulation for double-glazed façade components inserted beyond the stringcourse banding marked by the stainless steel sheet metal casing (externally pronounced) and, in the upper part, by Rheinzink vertical slat cladding. © Courtesy of Wicona

Fig. 1.3 Construction of pre-assembled modules. System designed according to the execution of serial units, which are mechanically assembled on the steel-framed decks and by means of the insertion of the upper enclosure on the open cells of the mullions. © Courtesy of Reynaers

by simple products combined into a unitary whole. In these terms, the assembly structure constitutes the geometric, morpho-typological and functional composition and relationship procedures. The systems are composed within structural "frames" capable of supporting, accommodating and combining the functional endowments of various destinations: the morphological and performance composition thus occurs through frames capable of grafting and "hooking" (according to the meaning of the English verb *to plug in*, hence the name of Archigram's *Plug-In City*) multiple elements coordinated in a unitary system [6] (Figs. 1.4, 1.5).

The figurative and constructive order results from the arrangement of:

- the frames corresponding to the structural elements and the frames enclosing the different envelope components;
- the composition as the result of analyses of functional, perceptive and connective character, as the implementation of a poetics of the "fragment", of the "situation", aimed at detecting the characters of the context, often with a metaphorical process with respect to environmental emergencies [14].

With respect to the studies supported by the main manufacturers of systems and components, the typological evolution is turning towards the increasingly decisive contribution of experimental applications: these welcome the results of research and are increasingly configured as "system proposals". The morphological, expressive

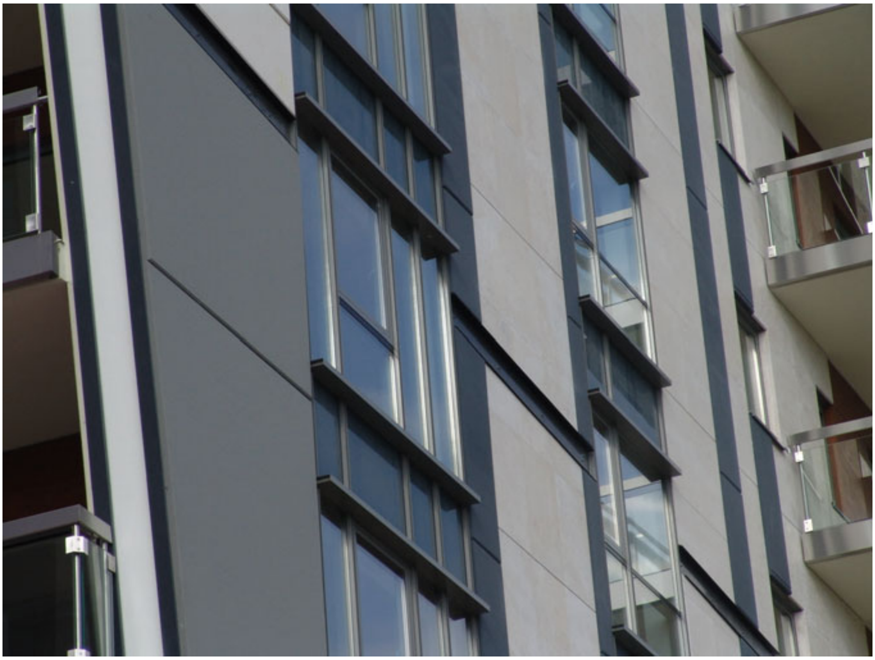

Fig. 1.4 Gergely Paulinyi and András Reith (Mérték Építészeti Stúdió), *Prestige Tower*, Budapest. Definition of the components according to the use of finished products, dimensionally coordinated and combined according to a homogeneous texture. © Courtesy of Mérték Építészeti Stúdió

and functional conception of façade systems is outlined according to the consolidation of *component design* procedures, brought up to date with respect to contemporary production and combination methods: such as, for example, the opportunity to act on the range series through the action of numerically controlled equipment, the arrangement of profile sections "open" to the aggregation and addition of both "pieces" and technical devices, the constitution of frame apparatuses suitable for the insertion of shielding or external cladding compounds.

Then, the design of the envelope components is obtained in the customized project, where the designer, together with the contributions of engineering and company potential, can conduct the morpho-typological study to "hybridizations", combinations and treatments on materials, integrations, projections and extensions of the profile pieces [3] (Fig. 1.6).

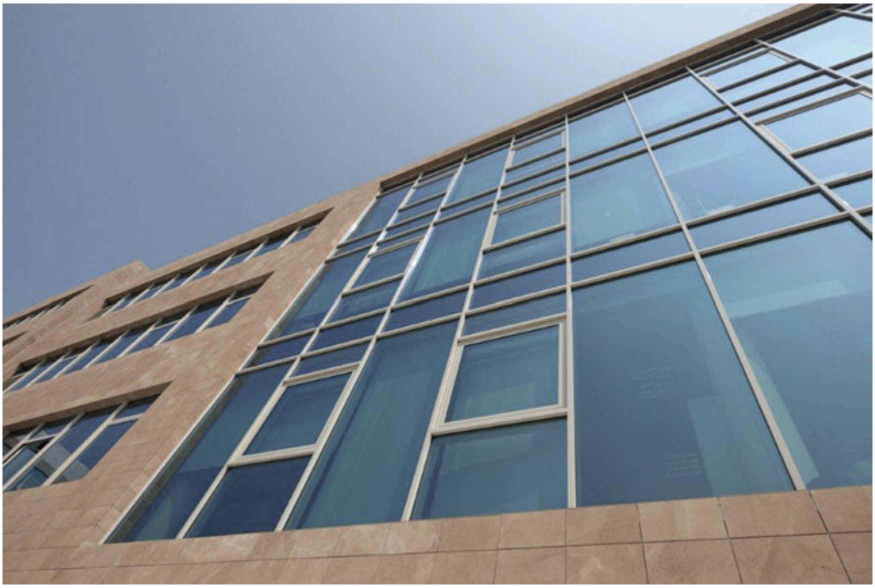

Fig. 1.5 Studio Bertonazzi Associati, *Metrocomplex*, Milan. Articulated modulation of the façade surface within the stone cladding curtain wall section, aimed at rooting with the urban context. © Courtesy of Schüco

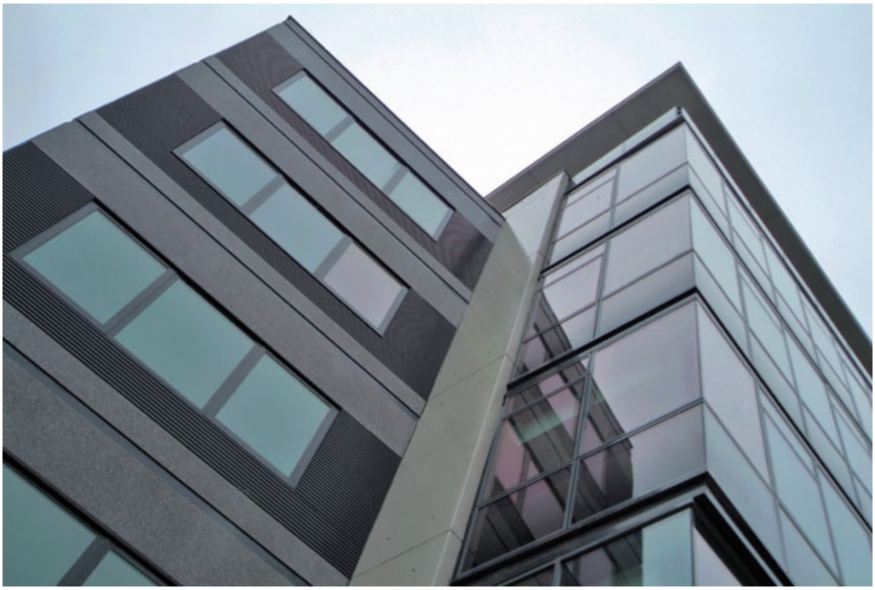

Fig. 1.6 "System proposals" and constitution of frame apparatuses suitable for the grafting of exterior cladding compounds: interface experiments, customized design procedures and "hybridisations" with material combinations and treatments. © Courtesy of Reynaers

1.2 The Customized, “Hybrid” and Integrated Envelope “System Proposals”

The typological characters of the range production are articulated, in the examination of the criteria of “style” and “form” proper to the “design of micro-architectures” afferent to the “technical artefacts”, on the basis of the structural compositions of the profiles, for the different system categories: this observing the accomplished evolution and rationalization of the construction techniques, which involve the use of load-bearing sections and priority joints according to established and repeated geometries, dimensions and connections.

In this scenario, the “system proposals” observe the conditions of integrated design, whereby the systemic formulation of façades acquires the loads towards the morpho-typological evolution as a consequence of the outcomes related to the products developed for complex works, whereby *component design* correlates with customized production as an expression of the value of the architectural intervention. On this basis, the technical design and the “style” of the façade components derive from the contribution of different needs and skills, which support the definition of the system with respect to the experimental and innovative result: this as the outcome of the combination of the incidence of the design concept, the technical-scientific contribution of the engineering structures and the contribution of the evolved type of window and door frames (often with forms of “technological craftsmanship”). The main system micro-sectors exposing evaluations, innovative proposals and possible mutations with respect to the basic formulation consist of:

- the interface between the elevation framework, vertical and horizontal, and the frame profiles connecting to the vertical enclosures, proposing variations aimed at increasing the thermo-hygrometric and acoustic performance and defining accentuations or reductions in the exposure of the retaining elements;
- the interfaces between the main frames, the frame profiles and the vertical enclosures, manifesting the “minimal” nature of the sections in view, projecting the application of the glazed surfaces with the objective of exposing the maximum transparent surface;
- the connection interface between “combined” profiles, where the joints, vertical and horizontal, allow the extension of profile elements capable of enhancing the “modular” perception of the curtains (Fig. 1.7).

The enclosure systems, within the contemporary scenario, are examined with respect to the orientations and perspectives of current design, production, functional and executive research, on the basis of the widespread technical openness of “components”. The context characterized by flexibility in the manipulation and combination of semi-finished products and elements towards “calibrated” performance, linguistic codes assumed through the individual construction, and relational and aggregative potential is outlined [17].

The configuration of the systems under examination observes, principally, the possibilities of defining the morphological “rules of warping” and constructive

Fig. 1.7 Massimiliano and Doriana Fuksas, *Regione Piemonte* headquarters, Turin. Interfaces between the elevation framework, vertical and horizontal, and the frame profiles connecting to the perimeter enclosures, according to connections directed to accentuate the exposure of the supporting elements towards the outside. © Courtesy of Schüco

"hybridization": this in respect of the "disciplinary" specificity of the sector and of the technical-scientific knowledge to be engaged, making explicit the "orders" and "codes" of architecture in conformity with the criteria of adaptability and connective modulation of frames, "frameworks" and "textures" (Fig. 1.8).

Then, the configuration of these systems, in the "dynamic interaction" with the external environmental stresses, considers the control procedures of thermal, luminous, acoustic and convective transmission, with respect to the ergonomic requirements of the places relative above all to office, productive and commercial buildings. Therefore, the envelope, understood as an active tool in providing for the transformation of external resources into energy sources for the microclimate of built spaces, becomes a technological subsystem with "sensitive" surfaces, "equipped" with protection and reflection devices, heat accumulation or limitation, also capable of conveying air flows for natural ventilation. And, increasingly, in the combined meaning of systems, emphasizing the *techno-organic* qualities of part of the architecture aimed at assimilating external climatic conditions into the overall functioning of the building. The façade systems are therefore studied and assumed:

- as an apparatus of "reaction" towards external loads, observing their "sensitive" nature, their physical and material consistency, which is progressively determined towards "integrated" layers and performances that act, with "adaptive"

Fig. 1.8 Lissoni Associati, *Matteograssi* headquarters, Giussano (Milan). Combination of envelope components according to multiple combinations of architectural textures and vertical enclosure elements. © Courtesy of Oskar Da Riz

Fig. 1.9 Studio Bonetti, *Mangiarotti* headquarters, Sedegliano (Udine). Aggregation of functional apparatuses exposed beyond the curtain of the envelope, aimed at calibrating natural light radiation with the aid of sun-shading foils supported by the steel frame. © Courtesy of Simeon

and "control" capacity, according to the needs of well-being and reduction of energy consumption;

- as a "programmable mechanism", capable of "interpreting" the functions and needs of users in the form of selective and polyvalent "filters", with respect to climatic conditions and ergonomic comfort requirements (Fig. 1.9).

Furthermore, the study on the processes of the "environmental interaction" of the envelope is specified in the systemic and functional fine-tuning of technical solutions that "hybridize" the serial types of the range. For example, through the fine-tuning of joining or connecting devices (especially thermal insulation) by means of the aggregation of elements aimed at increasing the interruption of thermal transmission and interposing additional chamber sections beyond those of the profiles. The paradigm of the "integration" becomes the correlation apparatus between multiple devices and "sub-components", such as the ventilation sections, the sunscreens and the openings (for projecting windows and with parallel movement, operated by means of a concealed electric motor), affirming the analysis and experimental investigation of the "multifunctional façade" type: this consists of the alternating arrangement of glazed sections and opaque enclosing sections, balancing the need for visibility and the reduction of loads due to solar radiation. The enclosure elements are investigated with respect to their character of "changed physicality", which experimental

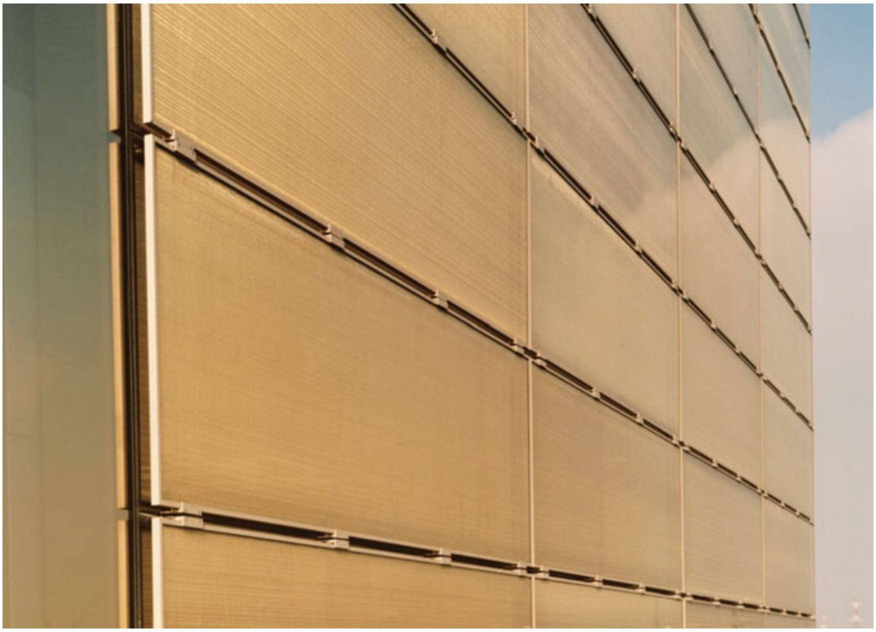

Fig. 1.10 5 + 1AA with Jean-Baptiste Pietri Architectes, *Fiera Milano* office building, Rho (Milan). Processes of "environmental interaction" of the envelope by means of technical solutions that "hybridize" serial typologies, through the aggregation of elements aimed at increasing the interruption of thermal transmission and interposing additional chamber sections. © Courtesy of Caviola

research tends to transform into "dense" and "intelligent systems" interface: in this case, the application of the envelope materials, in the form of "designable entities", is examined with respect to the outcomes of solutions in which the functions tend to become "complex" and combined with each other, realizing multiple performances through different layers (Fig. 1.10).

1.3 The Advanced Technologies and the Traditional Façade Stylemes

The contemporary experimental production observes the determination of an applicative sphere aimed at detecting the foundational, archetypal (in structure and material composition) and tectonic (as an expression of the physical reality) properties of the envelope systems and their supporting and joining tools. In general, the context under examination is proposed through the elaboration of external enclosures defined by the use of products belonging to the constructive "tradition", however inserted in the strategies (working, executive and compositional) belonging to evolved technologies, and by the hybridization of consolidated façade typologies through the use of profiles and frames of different material, mechanical and connective invoice. Again, this area addresses the visualization of "alternative" typologies for façade systems and is part of the progressive and linear developments in the construction sector and functional deepening: this with respect to a situation that sees the use of "adaptable" products and materials, the marketing and diffusion of simple, finished and small-sized elements, within an industrial logic characterized by a high degree of flexibility and capable of understanding and combining different solutions. The alternative typologies for façade systems are arranged in relation to the tendency towards rationalization and "reinvention" of the components and the canonical application and interface methods, in an integrated manner to the multiplicity and variety of expressive possibilities [16] (Fig. 1.11).

The experimental production around alternative façades takes on the conception of systems realized by elements that evoke "fabrility" by the use of "common" and *low-tech* materials, through which envelope forms celebrating substantial consistency and "natural construction" are developed: and the intrinsic essence of the materials, devoid of added meanings, is revealed through such typologies, making the homogeneous totality of the *facies* outer limit "resonate" and "shine" and creating the prerequisites for rooting the architectures to the places and contextual landmarks. The research on alternative typologies includes the hybridization of traditional materials to legitimize the maintenance of the "solid", "massive" presence within the

Fig. 1.11 Renzo Piano Building Workshop, *EMI Records* headquarters, Paris. Archetypical morpho-typological solution of the façade succession, in the recall of the pitched cusps and the press connections through the external framework. © by the Authors

growing "virtuality" and ephemeral, dynamic and "metamorphic" configuration of the envelope.

The development, morphological and functional, that is outlined appears to be directed towards affirming the stable character of a unitary and complete composition, towards the expressive balance of the enclosing 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 [8] (Figs. 1.12, 1.13).

The development of hybrid façades considers, therefore, the proposals of elements capable of "enveloping" the constructions, both in the enclosures and in the supporting and connecting apparatuses, grafting themselves between the current processes of technical complexity and productive and linguistic articulation, often

Fig. 1.12 Nicholas Grimshaw and Partners, *Gresham Street Office Building*, London. Use of transparent, osmotic enclosures, equipped with "hybridized" components and brought up to date with respect to the building tradition, within a modular grid: adoption of components and parts for the façades capable of bringing together the archetypal stylistic features of material culture and the canons of technical-productive innovation. © by the Authors

Fig. 1.13 Nicholas Grimshaw and Partners, *Gresham Street Office Building*, London. Physical and expressive hybridization between "natural" materials and prefabricated construction: envelope system determined by the cladding comprising the panels made from Broughton Moor's green, flame-treated Cambrian slate stone slabs (Burlington production); the slabs are stacked according to horizontal development and are supported by the linear frame with point joints. © by the Authors

leading to the loss of the homogeneity and material congruity of the envelope: this is to the point of searching for more balanced integrations between the distinct materials, semi-finished products and construction elements. The research in question inclines towards the recomposition of the "authentic" peculiarities and values of the envelope, however, according to a work of assimilation of industrial production (within a more pragmatic expressive and constructive culture) and as a necessary condition to initiate a valorization, on a dialogical basis, of "old" and "new" materials. Hybrid façades converge towards the overcoming of 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 grafts characterized by the complementarity between consolidated and evolved construction materials and procedures.

Within this scenario is exposed, as an emblematic development context, the elaboration of envelope systems defined by enclosures or structural elements in the recall to the primigenial paradigms enunciated by the tectonic culture, this design and technical-constructive expression assumed by the craftsmanship of *tekton* and in the poetic action proper to the "art of connection". This context is specified in the realization and use of semi-finished elements and traditional finished components, now belonging to the current "light" industrialization, characterized by flexible and versatile manufacturing processes to design specificities (even for reduced series) and market requirements, combined with the provision of services (Fig. 1.14).

The use of traditional materials for façades manifests itself as an "ecological" proposal, capable of sustaining the harmony and archetypal suggestions of the material in an integrated manner with the possible combination of valuable characteristics obtainable from the varieties of colour and shine: this through the nuances of the natural corporeity of traditional materials and their transformations, maintaining the

Fig. 1.14 Complementarity between consolidated and evolved materials and construction processes: interaction between semi-finished elements and traditional finished components according to flexible and versatile manufacturing processes to project specificities and market requirements. © Courtesy of Reynaers

mechanical characteristics even after appropriate treatments. The experiment around the integration of traditional materials focuses on structural and cladding systems, both aimed at adapting the "traditional" material to advanced production and execution technologies and proposed through the "semantic allusion" of archetypal techniques. The applications manifest the handcrafted constructive intent through flat modulations and linear frameworks, composed of profiles and sections connected by joints and metal adjustment devices (Fig. 1.15).

In this context, the rediscovery of traditional materials is determined and legitimized, with references to the physicality of their surfaces, treatments, gradations and vibrations on the envelope and within the individual components, according to procedures of morphological and constructive hybridization: this evocative procedure emphasizes the "virtuosity" of the façades through the use of material in its true

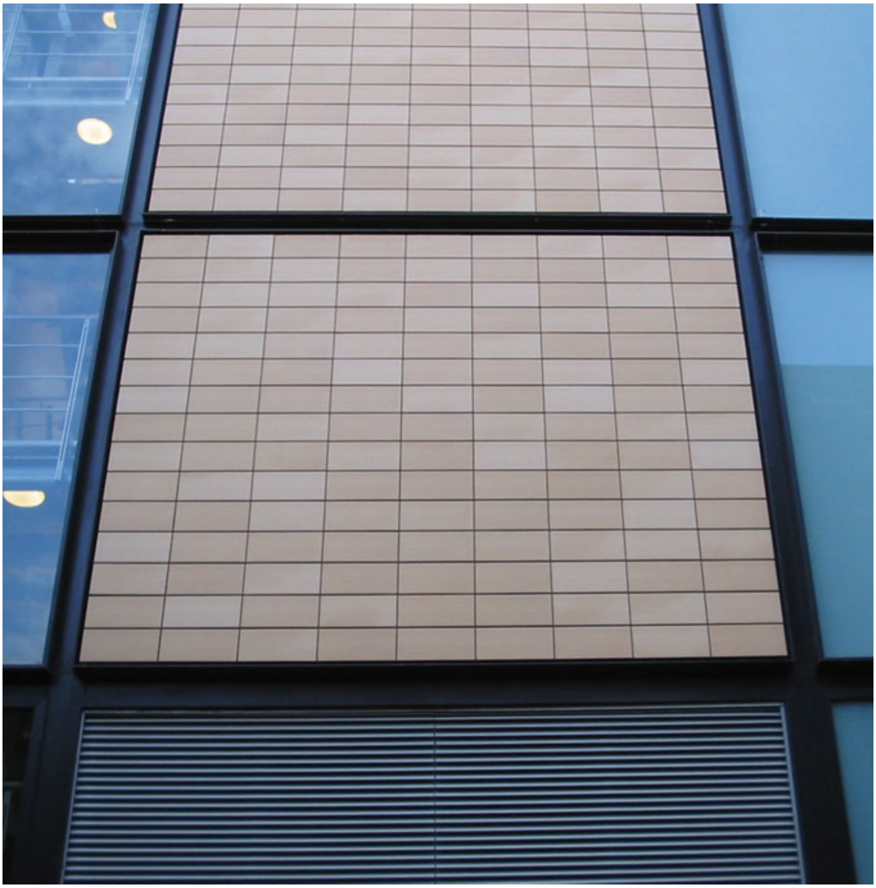

Fig. 1.15 Nicholas Grimshaw and Partners, *University College London's New Engineering Building*, London. Archetypal suggestions of traditional materials in the façade: perimeter texture in aluminium profiles supporting brick and double-glazed modules and bands. © by the Authors

and faithful substantial meaning, also understood as an extroversion of “artefactual naturalness” arising from the environmental context [4].

The arrangement of the vertical enclosures takes on the values of stylistic features and references to material determination, within serial and modular articulations, supporting the combination of the unified and coordinated characteristics of evolved technologies and the natural expression of the components: the alternative façade typologies concern the adoption, “recomposed” and hybrid, warped in elements and shapes regularized in geometries and connections, of stone, brick, terracotta and steel. These materials are executed according to logics directed at revealing their essential properties, rough and free from surface treatments, and aimed at expressing their tectonic, phenomenic and “tactile” reality (Fig. 1.16).

The expressive configuration of the envelope systems proceeds in the aggregation of sections, projections and cladding apparatuses in combination with the horizontal frames of the transoms or to seal the “massive” texture in the vertical expression of the mullions: this with the aid of joints and frame extensions aimed at supporting the cladding elements, for example of stone, brick or wood base, observing the fulfilment

Fig. 1.16 Integration between the envelopment in terracotta elements, the transparent surfaces and the “ephemeral” projection of the upper grid of the *Piterak* system: expressive consolidation of morphological and material connections in the systemic articulation between structures of different tectonic invoice. © Courtesy of Terreal

towards articulation with further materials of the building tradition, such as ceramics. At the same time, the mature development of such expressions of "organic design" combined with façade surfaces (which follow and consolidate the stylistic features started by a peculiar sphere of *high-technology style*) considers the proliferation of screens, projections and textures beyond the perpendicular plane of glazing. This is an evolutionary line in the design of envelope components that concerns the exposure, at reduced distances or such as to allow space for maintenance work, of textures aimed at limiting the direct vision of glass modules: in other words, as an expression of the will to mediate with respect to urban morpho-typological characters, to be observed, in the current outcomes, as a further evolutionary field of the "envelope-machines" rather than as an "obscuring" of the homogeneity feared with the proliferation of the *International Style*. Again, the results from the *mechanical design* of the load-bearing frame sections allow for the attachment and extension towards bracket-like support devices as well as "branching" and complex profile segments often oriented to sanction the ethereal and "dematerialized" character of the supports beyond the curtain surfaces (Figs. 1.17, 1.18).

The *component design* strategies within the advanced formulation of curtain walling include the combined study of profile types, the inclusion of functional fittings (or, applied for compositional purposes only) and possible treatments on

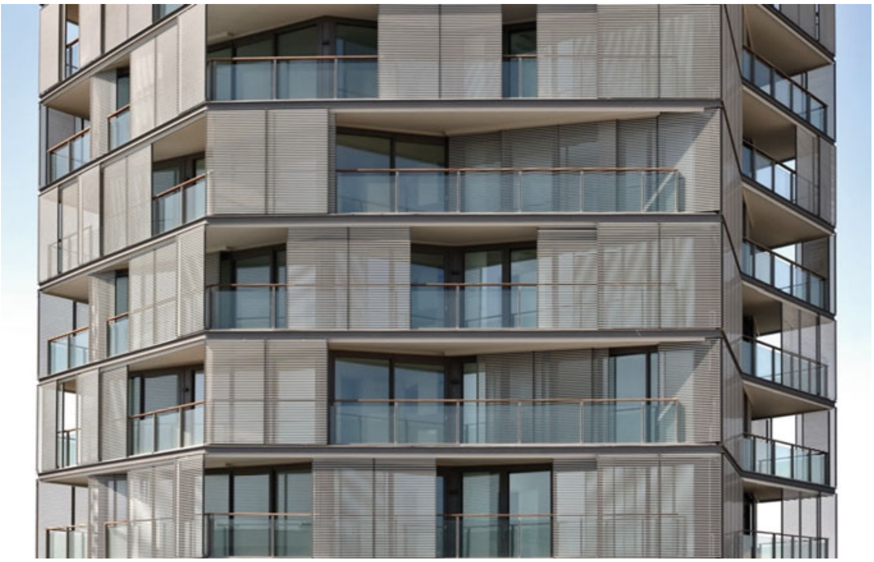

Fig. 1.17 Carlos Ferrater, *Aquileia Tower*, Jesolo. Interweaving the "intermediate spaces" beyond the curtain walls by suspending the façade structure from the roof: the surfaces are made up of a system of intersecting and sliding "sails", capable of screening and defining the osmotic perception between inside and outside. © Courtesy of Schüco

Fig. 1.18 Carlos Ferrater, *Aquileia Tower*, Jesolo. Diaphragmatic conception of the envelope according to the technical hybridization between transparent enclosures and external sunshade curtain textures. © Courtesy of Schüco

glass enclosures: this through the potential offered by current colouring and calibration procedures of both the compounds and the layers of the glass sheets, as well as the evolved techniques of silk-screen printing and the use of films.

The possibilities made available by contemporary windows and doors allow for the composite constitution of façade modules as a direct expression of the design concept, also on the basis of the interaction between the elements and the potential already practicable through the range series. In this regard, the *concept design* of the façade systems derives from the "physical formation" of the heuristic patchwork devised at the design level, allowing for the miscellaneous combination of sections and profile chrome plating, applications that can be aggregated to frames or directly on the enclosures, and graphics that are combined or placed on the surfaces. Beyond the principles of tectonic regularity and environmental functionality, the envelope is elaborated, according to the results of the contemporary experimentation, through reticular geometries, or through "communicative devices" that transcend their physical nature to evoke the dynamic and ephemeral perception of architecture (often an "installation" rather than a building intervention). In this sense, the façades are proposed in a "media" guise (for the proposal of *written façades*), linking themselves to the current (and real) fruition criteria of space [15] (Figs. 1.19, 1.20).

Within this scenario, the transparent enclosures also observe the detection of material properties, according to the aim of making body density visible and accentuating the many possible natural nuances. The alternative experimental production

Fig. 1.19 Giancarlo Marzorati, *Colour Building*, Milan. Architectural organism proposed in the form of a "radiating macro-object", as an interactive urban choreographic tool, affirming the use of polychromy to become a building material. © Courtesy of Giancarlo Marzorati Architetto

Fig. 1.20 Giancarlo Marzorati, *Colour Building*, Milan. Construction procedure of the unit components as cladding for the opaque sections, equipped with profiles in the lenticular sunshade type to maintain the dynamic character of the façade. © Courtesy of Giancarlo Marzorati Architetto

Fig. 1.21 Beniamino Cristofani and Salvatore Re, *San Ranieri* Hotel, Pisa. Ethereal character of the envelope, designed according to iridescent colour gradients and combined with its function as a climate controller. © Courtesy of Schüco

considers the constitution and use of the enclosures defined by light, *soft* and organic membranes: these, in the form of "invisible structures", determine, according to the principle of the *universal floor*, the fluid continuity between the luminous interior space and the external environment (Fig. 1.21). The expressive, typological and functional articulation of the façade systems is concentrated on the offer derived from the production of steel, where the design of the curtains and, specifically, of the frames allows wide ranges of stylistic freedom and performance increase.

The adoption of steel components opens up to the scenario of the advanced envelope the opportunity to perform stereometric or variable curvature compositions, transverse and longitudinal dimension differences, where the aesthetic expression and construction technique simultaneously continue the archetypal tradition of 19th century urban galleries and railway stations. The design of the steel frames and enclosing devices allows the experience of transparent curtains to be projected towards "infrastructural" dimensions and towards the combinations proper to the *megastructures*. Therefore, the mechanical capabilities tend towards the conception of surfaces of such dimensions as to make possible the construction of diaphragmatic simulacra, of extensions and interface systems often related to the geometric-structural steel building (Figs. 1.22, 1.23).

The structural and connective arrangement of the joining elements takes on the physical, applicative and relational values proper to the functional expression of the parts and the assembly methods: the support, interface and, in some cases, movement systems of the enclosures are manifested according to the simplicity and

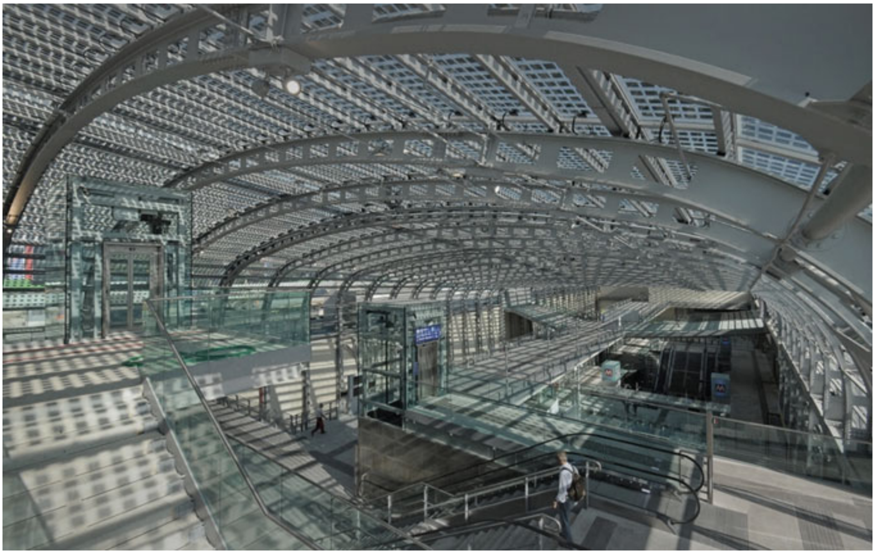

Fig. 1.22 AREP, Silvio D'Ascia, *Porta Susa* Station, Turin. Structural steel frame with curved arches on which the secondary texture of the frames supports both the photovoltaic cell enclosures and the staggered-panel windows and doors. © Courtesy of Mathieu Vigneau

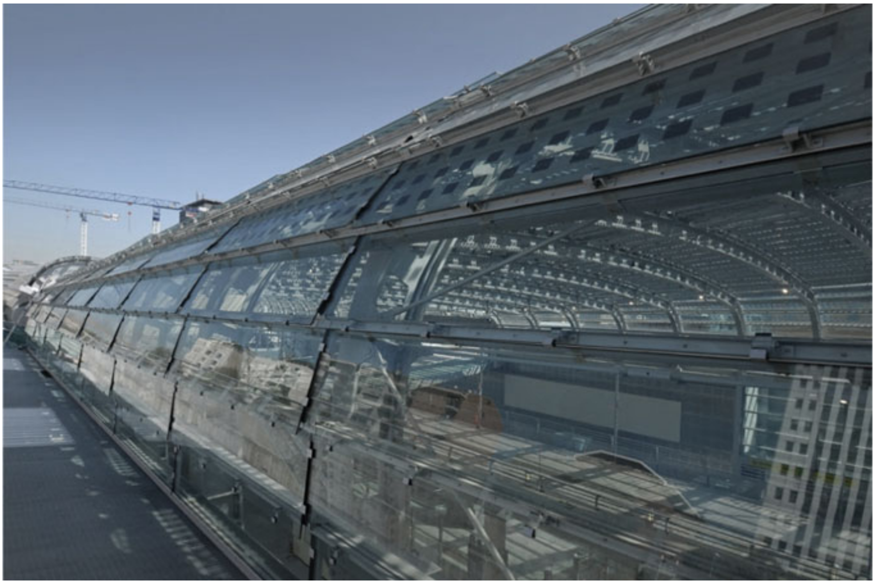

Fig. 1.23 AREP, Silvio D'Ascia, *Porta Susa* Station, Turin. Offset succession of steel frames, overlapping connections for the application of glass panes with pointed joints. © Courtesy of Mathieu Vigneau

rigour of their performance, proposing themselves in the form of devices and objects of *minimal design*. Their development moves away from the exemplary "micro-architectures" defined by mechanical organs and joints composed of artifices in both the functions and the *styling* of the pieces, in order to affirm the homogeneity of the material, the adherence to static and executive principles [13].

The closing elements, through these types of joints and suspensions, are adopted without particular and in-depth processing, or cutting and drilling, matching the supports and framing of the envelope according to linear or point-like poses, without joints or reinforcing treatments. The supporting and joining elements are conceived as "part of a whole" within the façade system and also make explicit the degrees and criteria of combination with the other parts: this, regularizing the serial production and, in any case, providing for different structural and typological possibilities, by means of joints, rods and ropes of multiple articulation [7].

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Chapter 2
The Structural Procedures of the Advanced Envelope Systems

Abstract The study examines the constitution of the components and devices for the mechanical, functional and executive composition of the envelope systems, starting from the configuration of the frames, profiles and connection methods (in the priority forms defined by vertical mullions and horizontal transoms connected to the main load-bearing apparatuses). The construction concept is based on the transmission of the loads from the façade system to the main load-bearing structures of the architectural organism. The frame profiles, consisting of mullions (vertical) and transoms (horizontal), which act according to constraints that allow for the phenomena of expansion, are elaborated with respect to the requirements of "thermal break" and the functions of protection with chemical treatments or coatings of metallic materials. The façade frames provide support for the vertical actions (such as their own weight, the weight of the closing elements and the weights of additional functional elements or devices), the horizontal actions generated by the closing elements and the bending actions. The study focuses on planning and coordination practices for application towards elevation structures, with the examination of geometric and adjustment check criteria. In this regard, the analysis considers the methodologies for anchoring the frames: the elaboration of the stirrup joints observes the types of action with respect to the façade plane, noting the connection modes related to the constraints with the structures. The examination continues with the development of the procedures and operational sequences for the assembly of the frames, highlighting the geometric and executive control methods. Then, the technical interface criteria between the framing, the horizontal elevation structures, the roof and storey sections are determined.

2.1 The Typological and Structural Design of Envelope Frames

The design, production and execution of façade systems involves the examination of structural apparatuses (or frames), realized according to a multiplicity of formal configurations and mechanical solutions, as well as according to the application and coordination needs (performance, dimensional and material) of the enclosing

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elements, fastening elements (with the function of transmitting loads) and joints (with the function of tight correlation). The façade systems are executed through the application of frame structures, consisting of neutral vertical beams (mullions) and/or horizontal beams (transoms), with respect to different mechanical and constructional requirements. The frame structures are generally composed of mullion profiles (vertical) that transmit the loads of the façade system to the main load-bearing structure of the architectural organism. The mullions (fixed to the horizontal elevation structures, undergoing mainly tensile stresses), with a cross-section calibrated to resist static and dynamic loads, are joined together by means of telescopic joints: these allow the vertical movements, the sliding surfaces of which are made of materials with a low friction coefficient, such as teflon or nylon (Fig. 2.1). The mullions are stressed under different possible load conditions, in the form of:

- the beam on three supports, with the central support fixed and the supports at the ends sliding;
- the beam on two supports, with a sliding support at the upper or lower level;
- the continuous beam on *n* supports, i.e. with the interposition of a skid at each span, which allows reciprocal movements between the mullions (Fig. 2.2).

The restraints are considered as simple supports or sliders, with the need to allow for downward expansion to avoid the phenomena of flexural buckling due to the peak load. Following the determination of the static scheme, we proceed to:

- the sizing of the mullions, once the admissible stresses are known;
- the check of the available mullions, once the geometric characteristics are known.

On the basis of the diagrams of the limits of use characteristic of the specific reference production, the setting of the centre distances is determined (Fig. 2.3).

The transoms profiles connect the mullions horizontally, with which they cooperate both in the containment of the enclosing elements (by providing the location for the glazing beads) and in the collection and drainage of infiltration water. The transoms absorb thermal expansion and resist the static loads of their own weight (by means of a telescopic joint provided for each module), of the enclosing elements and of the horizontal loads (Fig. 2.4). The frame profiles, generally made of aluminium, but also of steel (stainless or galvanized), are produced with a tubular and rectangular cross-section (which can also be produced with an "I" and "T" cross-section, according to mechanical, morphological and construction requirements). The profiles, endowed with high thermal conduction, require applications aimed at:

- the mitigation of thermal losses (with the consequent lowering of the surface temperature) and the forming of condense;
- the external insulation of the profiles by means of insulating materials;
- the interruption of thermal bridges, by means of "thermal cutting" procedures performed with the insertion of insulating bars (short or long, in plastic material, polyurethane or reinforced polyamide resins): these are mechanically connected and are aimed at separating the material continuity between the external and internal parts of the frame (Fig. 2.5).

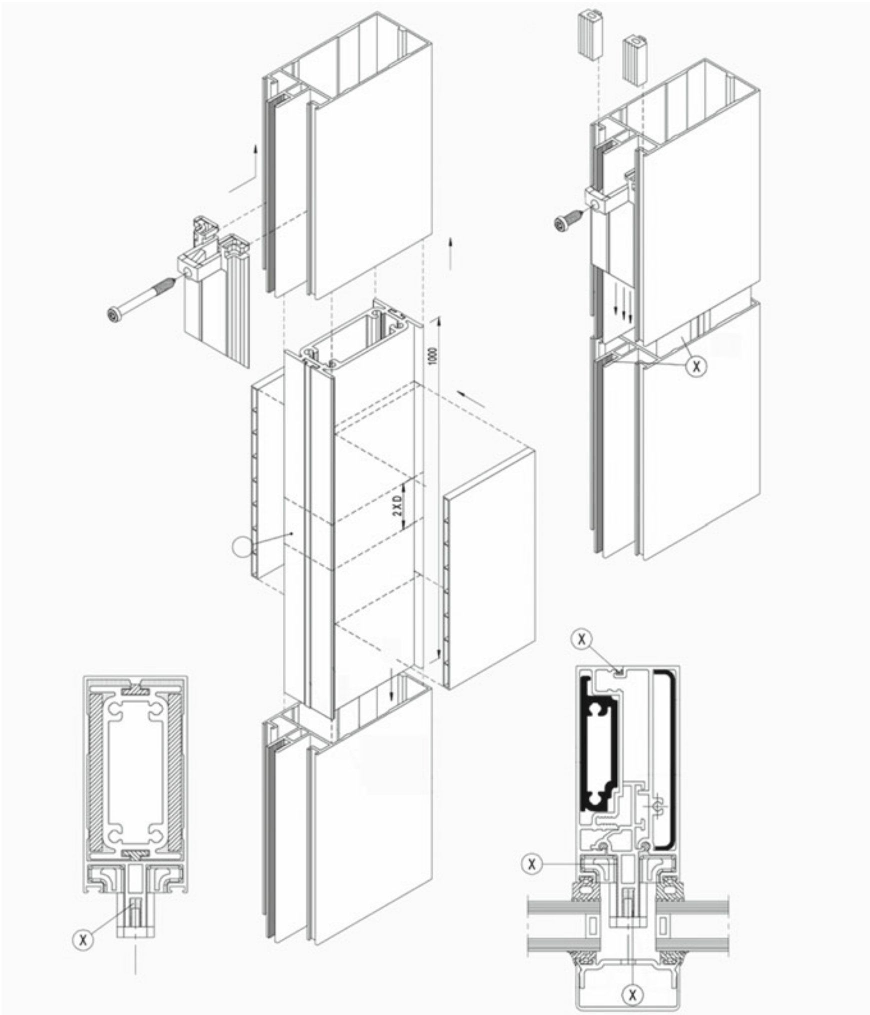

Fig. 2.1 Frame structures composed of the vertical mullion profiles, which transmit the loads of the façade system to the main load-bearing structure of the building. The mullions are made up of: • the calibrated section to resist static and dynamic loads; • the connection by means of telescopic joints, noting the definition of vertical movements and the constitution of sliding surfaces in materials with a low coefficient of friction; • the attachment to the horizontal structures, undergoing mainly tensile stresses. © Courtesy of Reynaers

The production of frame structures requires the use of profiles capable of resisting the aggressive action of atmospheric agents, the connection with materials of high electrochemical potential and abrasion. This entails the application, in façade

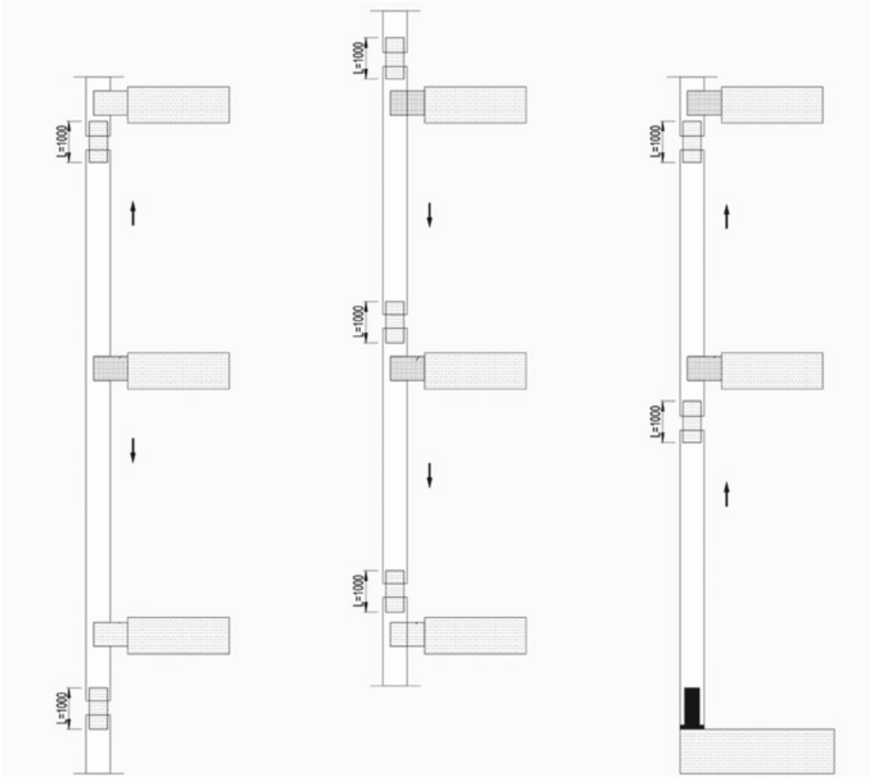

Fig. 2.2 Mullions of the façade system stressed under different load conditions, in the form of the beam on three supports, defined by the central fixed-type joint and the extreme sliding-type joints, the beam on two supports, defined by the upper or lower sliding joint and the continuous beam on *n* supports, defined by the interposition of a skid at each span. © Courtesy of Reynaers

systems, of aluminium profiles treated by means of anodic oxidation (through chemical processes that generate an oxide film on the surface) and painting (by means of organic polyvinylfloride or polyester powder coatings) (Fig. 2.6).

In addition, the production of frame structures is delineated according to the development of stainless steel profiles or those subjected to the galvanizing process, with a hollow "T" section, which carry out the fastening procedures with a press-fit joint, noting the possibility of use with different structural elements.

The application of façade systems requires that the load-bearing frame possesses the mechanical requirements to withstand vertical loads, such as its own weight, the weight of the enclosing elements and the weights of the additional functional devices (exerted, for example, by the sun screens).

The frame structures support the forces exerted by the enclosure elements (understood in the form of self-supporting "construction units", which transfer horizontal loads perpendicular to their own plane) which, in turn, are stressed by:

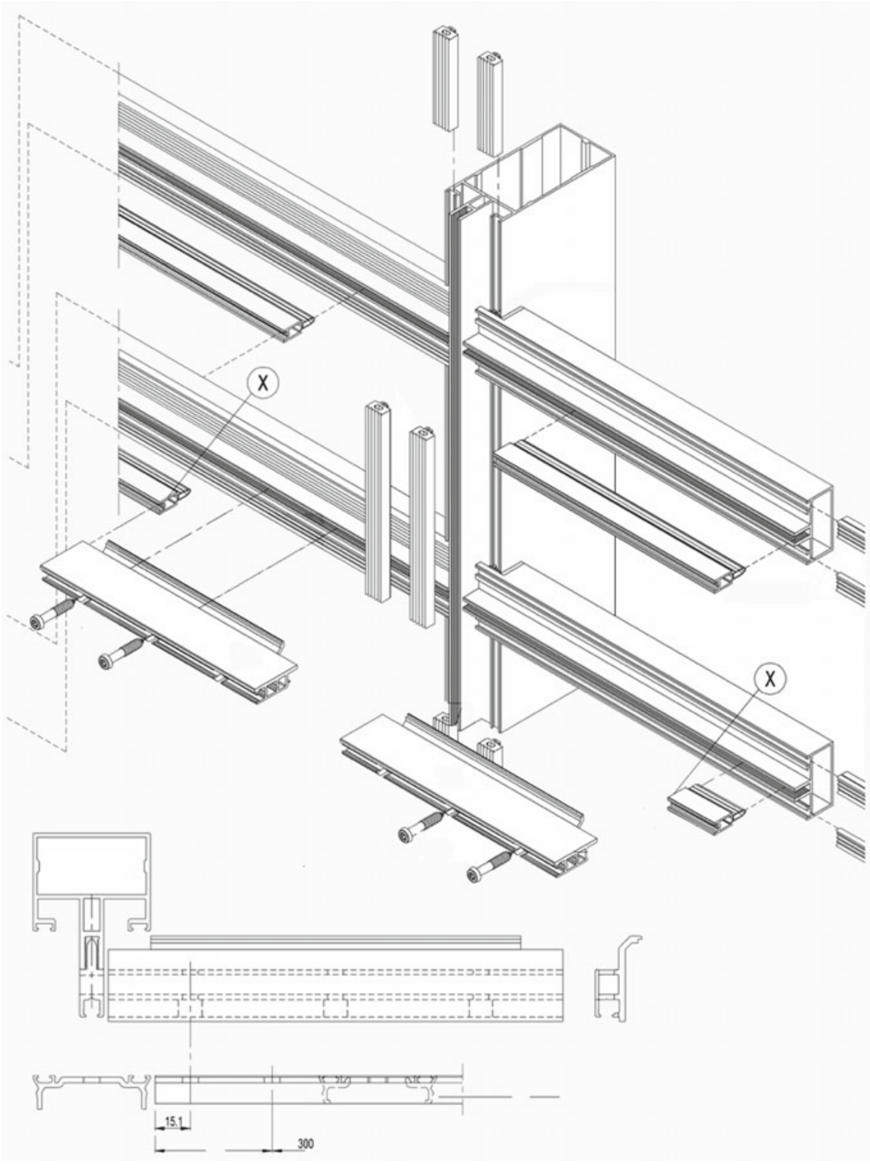

Fig. 2.3 Construction of façade frames observing the setting up of constraints in the form of simple supports or sliders in order to the need to allow downward expansion, the need to avoid flexural buckling phenomena due to peak loading and the check and dimensioning of the mullions. © Courtesy of Reynaers

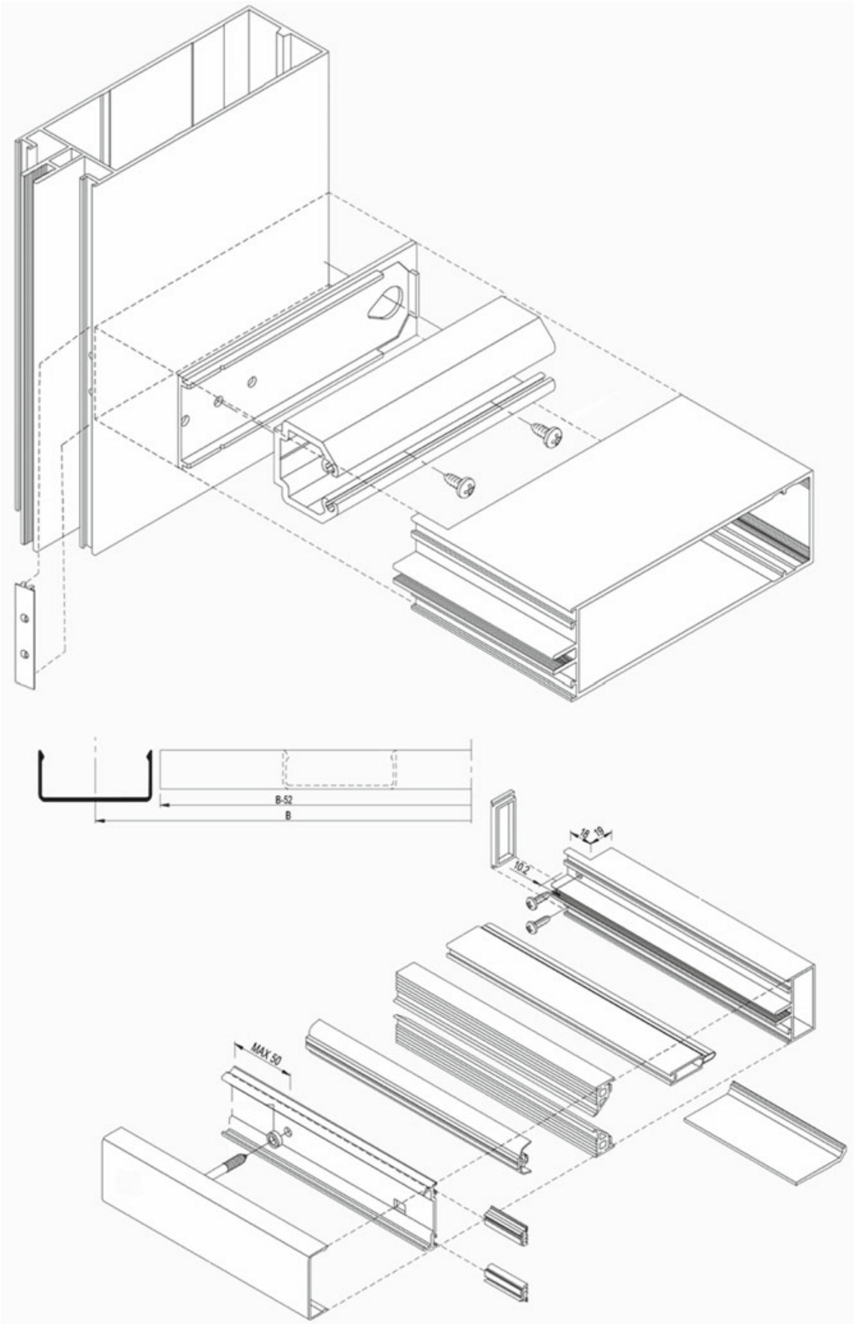

Fig. 2.4 Frame structures composed, in the horizontal direction, of the stringers that act with respect to the containment of the enclosing elements, the articulation of the locations for the glazing beads, the collection and discharge of infiltration water and the absorption of thermal expansion. © Courtesy of Reynaers

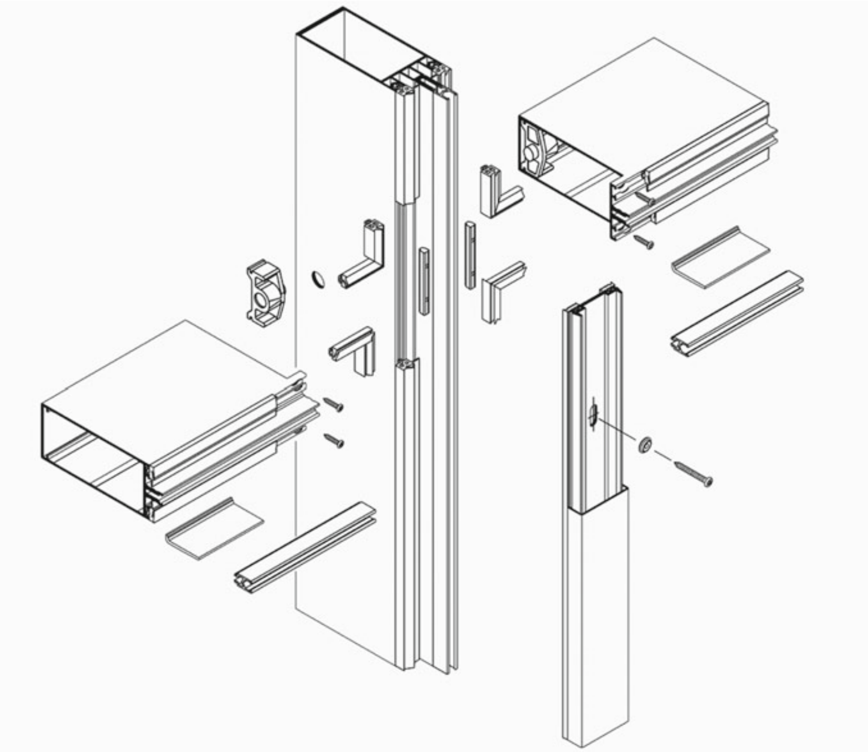

Fig. 2.5 Frame profiles, with a tubular section, require applications aimed at the reduction of heat loss, resulting in a lowering of the surface temperature, the reduction of condense formation, the external insulation of the profiles by means of insulating inserts and the interruption of thermal bridges, through "thermal cutting" procedures performed with the insertion of polyamide insulating bars. © Courtesy of AluK

- the vertical actions (which can be transmitted horizontally to the lateral components) and horizontal actions (normal to their plane, by tension and/or compression), with the possible overlapping of bending moments and normal forces;
- the bending actions (in the direction perpendicular to the plane).

The analysis consider, for the diagram relating to the calculation of own weight:

- the weight of the glass (P, in kN);
- the equivalent thickness of the glass (s, in mm);
- the mullion centre distance dimension (ML, in m);
- the spacing dimension of the transoms (HM, in m).

The evaluation thus leads to the typological identification of the transoms profiles to be adopted according to the evaluation of the moment of inertia.

The structural design assumes mechanical performance with respect to:

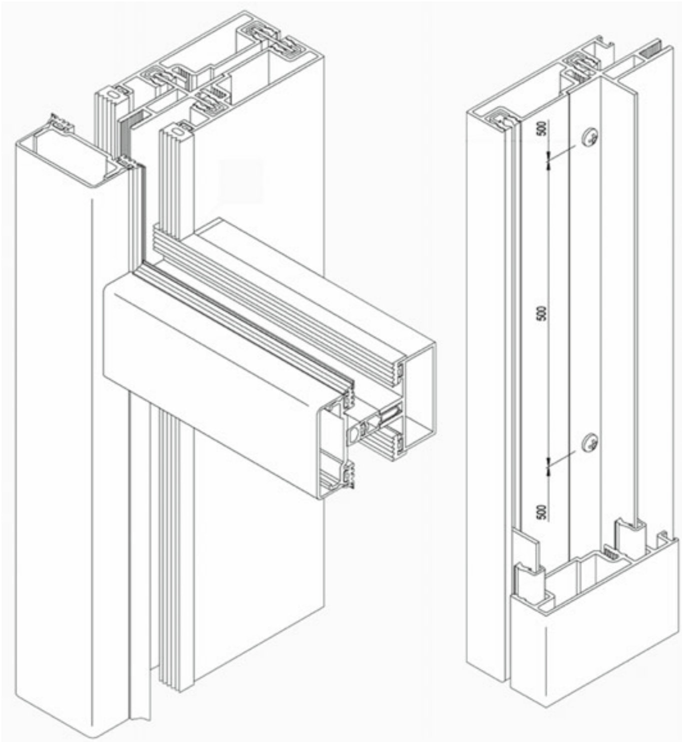

Fig. 2.6 Production of aluminium frame structures for façade systems is outlined according to the use of the profiles characterized by: • the resistance to the aggressive action of atmospheric agents; • the resistance to connection with materials of high electrochemical potential and to abrasion; the treatment with anodic oxidation (through the generation of a surface oxide film); • the treatment with polyvinylfloride or polyester powder coating. © Courtesy of Reynaers

- the resistance to wind loads, implying that the maximum permissible elastic deformations of the mullions and transoms are less than 1/200 ÷ 1/500 of the span measured between two successive attachment points, depending on the type of enclosure and the performance required;
- the resistance to horizontal service loads and to seismic stress.

The analysis consider, for the static diagram relating to the wind pressure:

- the system diagram, the horizontal structural centre distance dimension (H, in mm) and the mullion centre distance dimension (M, in mm);
- the general formula for calculating the moment of inertia (J_X, in mm^4), including the values inherent in the total load (Q, in Newtons), the kinetic pressure of the wind (w, in Pascals), the modulus of elasticity (E, in N/mm^2), the static deflection (f_{cd}, in mm, established for a maximum value equal to the dimension of the horizontal structural centre distance $H/200 = 15$ mm).

2.2 The Anchoring Procedures for the Façade Systems

The procedures for the connection and installation of the envelope systems with respect to the main structural apparatus concern the fine-tuning of joining devices, sequences and interfaces, both organizational and technical, and the criteria for the correct application of the technical elements and the specific working practices. The constructive operation involves examining and planning the ways of tracking starting from the cornerstones fixed by the plan dimensions (on the vertical structures) or the reference lines (on the horizontal elevation structures), with the check of the structural tolerances (in order to assess that they do not exceed the adjustment possibilities of the attachments and that they do not impede the assembly operations).

The construction of the façade systems, with respect to the main load-bearing structures of the building organism, is based on the control of the verticality relative to the anchoring methods (which must not present deviations of more than 20 mm, for buildings of less than 25 m in height), and on the executive coordination of the interfaces established by the dimensional tolerances (for the association of different executive techniques), which entail:

- the inter-storey tolerance of ± 20 mm (not cumulative for more than three storeys);
- the tolerance on the edge of the horizontal elevation structures equal to ± 20 mm between floors and equal to ± 25 mm for all floors;
- the tolerance on the laying of inserts equal to ± 10 mm in each direction.

The anchoring procedures of the envelope systems contemplate the design and the installation of the brackets, aimed at transmitting the loads to the main elevation structures with the objective of preventing the vertical movements of the mullion profiles and according to the aid of an anchoring element for each length unit. The application considers the use of the sealing connections facing the top and the base of the mullions to resist wind loads, considering the intervention of intermediate joints in the case of multi-storey development of the vertical frame profiles. The design and the execution elaboration include:

- the arrangement of the anchorage guides made by the "C" transversal configuration profiles, in general, carried out during the casting phases of the reinforced concrete structures and embedded in the horizontal structural sections, following the laying of the main steel load-bearing frame (with connection by welding or by dowelling to the reinforced concrete structure);
- the arrangement of the engagement sequences of the brackets intended to connect the mullion profiles and the main elevation structures;
- the prediction of the loads acting on the anchorage device composed of the own weight of the façade components (as a vertical load condition), of the wind and seismic stresses (as a horizontal load condition), of the moment produced by the distance generated between the centre of gravity of the mullion profile and the point of constraint relative to the horizontal elevation structure.

The “C”-shaped transversal configuration profiles are produced to standard dimensions and directly for the installation, without any further processing, emphasizing the arrangement of the element identification code on the back and inside of the rails themselves, while the lateral arrangement follows the production of the profiles with the foam filling. However, when cutting is required, the operating procedures involve:

- the realization of the cut perpendicular to the geometric development of the guide;
- the arrangement of the free space between the first and the last anchorage and the ends (with a dimension of 25 ÷ 30 mm);
- the arrangement of the maximum and minimum projections at the end of the rail (size 35 ÷ 175/225 mm);
- the application of (at least) two anchors per rail.

The design and application of the bracket joints assumes the possibility of movement defined by:

- the vertical actions with respect to the facade plane, due to the phenomena of thermal expansion and contraction of the mullion profiles;
- the horizontal actions with respect to the façade plane, allowed by the sliding exercised by the bracket head inside the “C” anchoring profile, arranged during the laying sequences in order to proceed with the vertical axial alignment (as a “plumb” practice);
- the orthogonal actions with respect to the façade plane, arranged during the laying sequences in order to proceed with the planarity check as geometric and dimensional coordination of both the assembly tolerances referred to the metal structure and the tolerances referred to the main elevation structure.

The design and application of the anchorage brackets reveal, with respect to the main elevation structures, the assembly procedures according to:

- the frontal section, related to the concentration of the constraint on the head of the perimeter truss. This solution observes how an overhang band is determined between the façade edge and the frontal section so that the anchoring devices are subject to shear actions;
- the extrados section, related to the execution of the envelope components with respect to the flush of the floor observing the concentration of loads towards the horizontal elevation structure while the anchoring devices are not subject to shear actions. However, the solution contemplates the production of operational interferences between the envelope components and the interior finishes;
- the intrados section, related to the execution that subjects the anchoring devices to tensile actions and avoids the operational interference between the envelope components and the horizontal elevation structure.

The execution planning observes how the fixing of the metal rails (provided with anchoring elements or spacer plates to ensure connection to the formwork or to the corrugated sheets) provides for direct connection to the extrados surfaces of the wooden formwork by means of:

- the stainless steel nailing joint, through the holes in the back;
- the junction by metal staples;
- the jointing by auxiliary tools, considering the application to the reinforcing irons of the main elevation structure and the care taken to maintain the heights in order to avoid drowning, even partial, during the casting phase of the concrete on site. Specifically, the auxiliary tools (consisting of aluminium rivets, pliers and wire) are provided for the direct connection to the reinforcement stirrups: good practice indicates, in the executive and operational planning tasks, the preparation of steel jigs, according to:
  - the appropriate arrangement of geometric and dimensional indications to govern and coordinate the application on site;
  - the integration of (welded) profiles to establish the correct distance from the perimeter and the extrados of the formwork;
- the joining by means of "clips", through the connection with threaded grub screws pushed into the holes of the guides.

In particular, the activity is subject to the supervision of the concrete pouring phase in order to observe the compaction procedures, to be carried out with a vibrating cylinder to be placed at a distance from the metal guides to avoid the occurrence of air bubbles and to avoid misalignments with respect to the established placement. On the other hand, the application procedures in respect of the metal formwork (generally expected to be made of galvanized steel) observe:

- the use of grooved extrados surfaces, where the grooves (pre-punched by the manufacturer) must respect the geometries and lateral dimensions of the guides;
- the connection by welding, whereby the rails are clamped by means of clamps placed in position above the grooves, welding points being performed along the upper edge (in the case of the rail lengths up to $l = 60$ cm) and on the lower edge of each end.

In the case of the application of the metal rails of the "pre-installed" type (mainly intended for concealed connections) it is verified that the shaped conformation, relative to the perimeter connection box (prepared and supplied according to specific geometries), is connected to the wood or metal formwork before the concrete casting phase (by screwing or bolting).

The operational and procedural knowledge concerns, first of all, the criteria for the storage and protection of the anchoring devices, in order to prevent possible oxidative contamination on the steel "C"-shaped rails. In this regard, the metal elements are separated from each other and placed at a suitable distance, also considering the necessary precautions to avoid surface damage. The care of the devices also implies the need to avoid storage (on site or off site) under the weather, even though the elements may be wrapped in fabric or other materials.

The coordination and supervision procedures consider:

- the removal of the polystyrene "filler" from the rail groove;
- the removal of the foam filler (by manual or with the aid of a screwdriver);

- the practice of engaging the bolts within the grooves of the rails up to the stop point, continuing with the direct rotation to imprison them through the action of the head in the "hammer" type (noting the perpendicular arrangement between the axis of the rail and the bolt shaft after tightening);
- observing the installation criteria according to the maximum distance from the end (equal to $d = 25$ mm);
- the practice of inserting the bracket on the bolt in position;
- the practice of calibrating the necessary tolerance dimensions with respect to the vertical and horizontal directions;
- the practice of tightening the nut on the bracket to hold the anchoring element in place.

The frames are built by anchoring or supporting the mullions to the horizontal elevation structures, so that they are only subjected to the tensile and bending stresses. The mullions are connected to fastening devices, known as brackets, that are adapted to the main rough load-bearing structure and are capable of supporting the profiles in such a way as to avoid the torsional and bending stresses (Fig. 2.7).

In this respect, the elaboration of the stirrup procedures concerns:

- the identification of the brackets and the relative methods of adapting them to the production and laying tolerances (these due to the elastic deformations of the deck structures): the technical-design analysis of the brackets observes the methods of adjustment in the three spatial directions (two in the curtain plane and

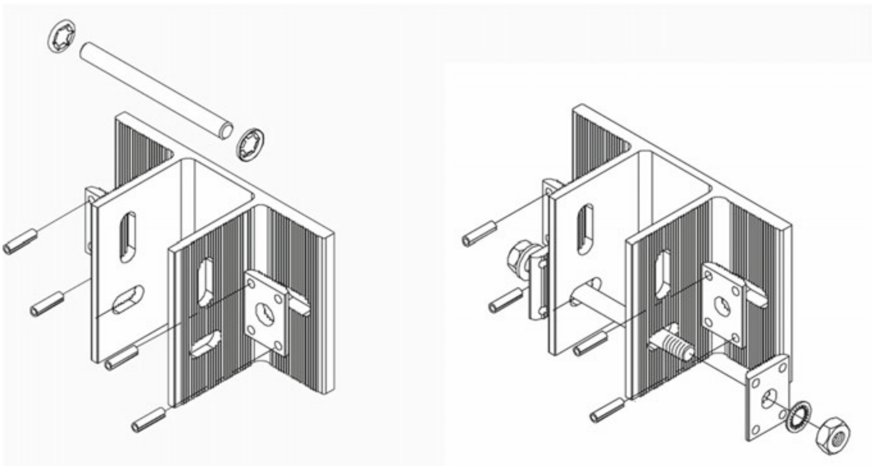

Fig. 2.7 Execution of the frames to the load-bearing deck structures that involves the anchoring of the mullions to the fixing devices, called brackets, by means of: • the constitution in profiles of "π", "C" or "L" geometry, in aluminium or steel sheet (stainless or galvanized); • the inclusion of the slots necessary to absorb construction tolerances; • the connection to the slabs by means of "C" profiles, halfen type or by means of expansion dowels. © Courtesy of Reynaers

one perpendicular to the curtain plane), so as to guarantee the alignment of the façade and to recover the tolerances of the construction work (Fig. 2.8);

- the connection of the frames to the horizontal and vertical structures, through the application of the brackets, with the wings projected perpendicular to the façade plane and provided with slots for the passage of the aluminium spacer tubes. This is according to free or fixed jointing procedures;
- the fixing details and adjustment plates (Fig. 2.9).

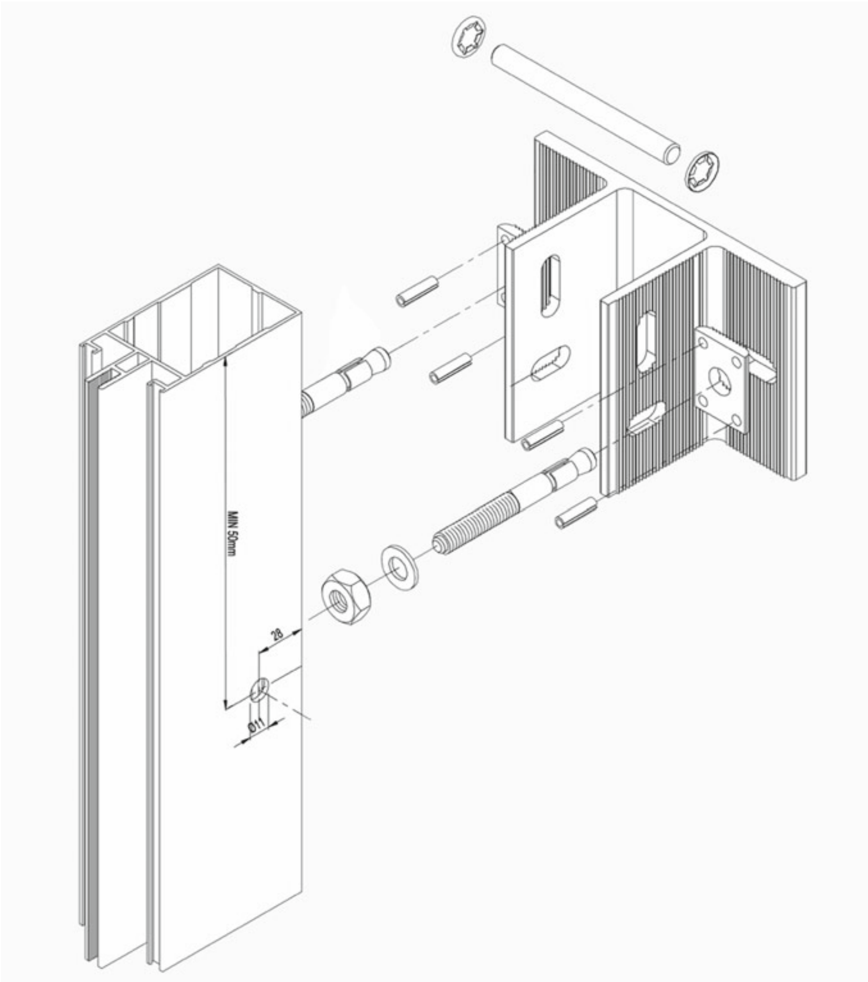

Fig. 2.8 Brackets supporting the load of the façade system and the adjustment to construction tolerances, to ensure the alignment of the frame, assuming: • the adjustment of the frame in the three spatial directions during the assembly; • the adjustment of the mullions in the vertical direction (for movements due to expansion and contraction). © Courtesy of Reynaers

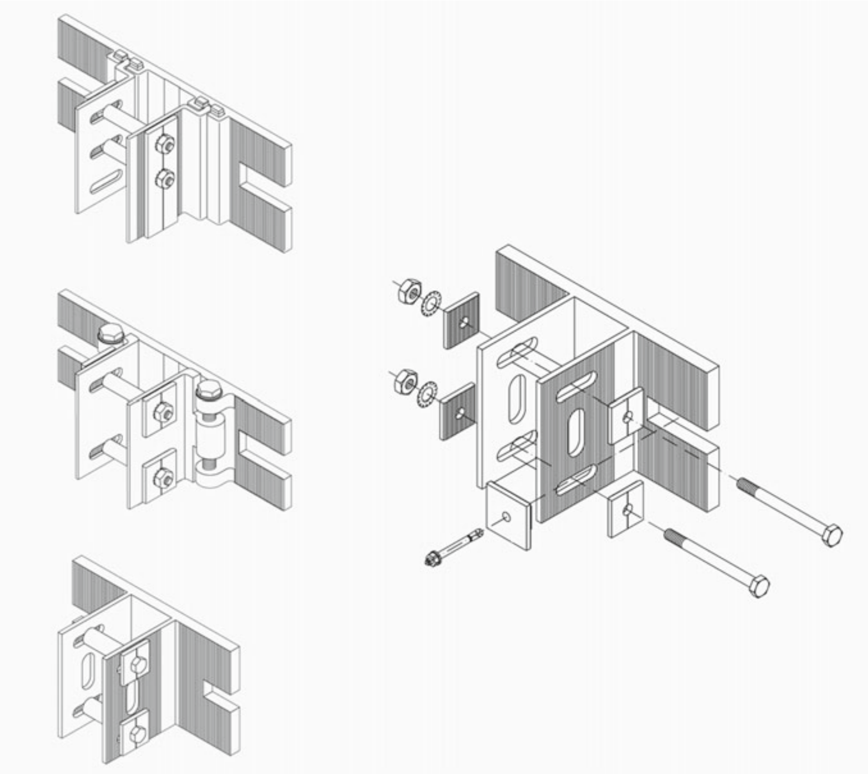

Fig. 2.9 Connection of the frames to the structures by means of planar devices to the façade from which two wings for cross assembly of the mullions develop. © Courtesy of Schüco

The application of the brackets observes the aims aimed at:

- the movement of the individual elements of the façade system as a result of thermal expansion and the applied loads, so as to ensure that they can adapt to structural movements;
- the resistance, absorption and transfer to the horizontal elevation structures of the façade system's own loads and the stresses it experiences (such as the wind loads, or the accidental loads, and the thermal expansion) (Fig. 2.10).

The elaboration of the clamping procedures assumes the examination of anchoring modes through:

- a frontal attachment, on the perimeter surface of the horizontal structures or of the perimeter beams, with the execution spaced out from the external wire;
- an upper attachment, above the horizontal structures and flush with the front surface (avoiding the horizontal enclosure works between the frame and the façade), as a solution that provides:

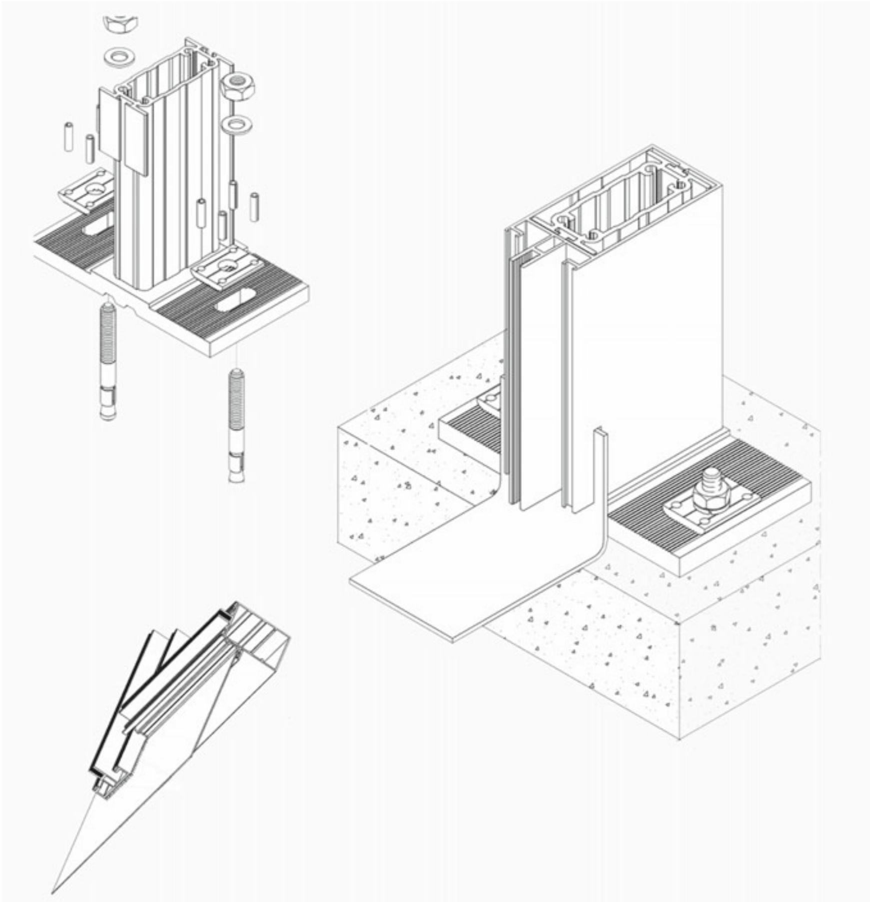

Fig. 2.10 Application of the façade system to the brackets that observes the adaptation of the frame profiles and the enclosure elements with respect to structural movements, thermal expansion and applied loads. © Courtesy of Reynaers

- the transmission of the loads pertaining to the façade system on the horizontal structures, without friction stresses and avoiding shear stresses on the bolted fastenings;
- the conditions of easy accessibility during the installation;

• a lower attachment, below the horizontal structures, that provides for:

- the tensile work of the fasteners;
- the execution at the ceiling and spaced from the edge of the perimeter surface;

• the connection to recesses provided in the deck structures.

The elaboration of the technical interfaces, with respect to the extrados execution, according to the assembly of the plates by means of the double slot, provides for the application study of the geometric configuration profile at "π" (or decomposed into two "L" configuration profiles) adjustable in height, whose wings, provided with holes for the transversal engagement of the crossing bolts, are inserted into the tubular section of the mullions at the lower end. The building of the interface foresees the rear enclosure, in the share included beyond the lower septum relative to the tubular section of the transom, as a containment of the finishing layers of the floor (Fig. 2.11).

The examination of the anchoring procedures assumes:

- the criteria of anchoring by means of a lower attachment, below the horizontal structures, as a solution that provides for the execution at the ceiling and spaced from the edge of the perimeter surface (Fig. 2.12);
- the criteria for assembling the load-bearing framework to the deck works, noting the connection methods using the "bayonet" profiles (provided with the holes and vertical adjustment bolts) connected to the mullions:
  - the application of the "L"-shaped brackets (on halfen profiles, embedded in the reinforced concrete casting), for the construction on the floor level;
  - the application of the aluminium brackets equipped with the insertion projection, for the construction in front of the slab (Fig. 2.13).

The tightening operations, therefore, involve:

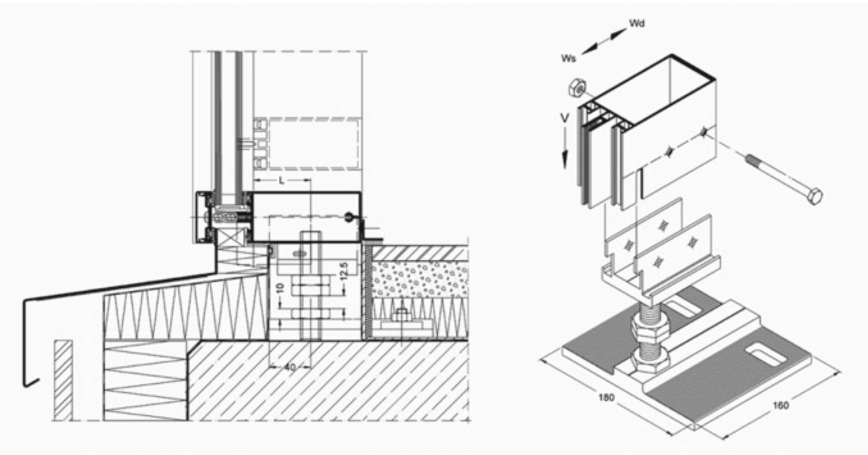

Fig. 2.11 Connection of the frames to the horizontal structures that takes place through the application of the brackets in the geometric configuration of "π", with the wings equipped with slots for the passage of the aluminium spacer tubes, according to the free joint procedures, the fixed joint procedures, the free or fixed jointing procedures and the interposition of the fasteners and adjustment plates. © Courtesy of Schüco

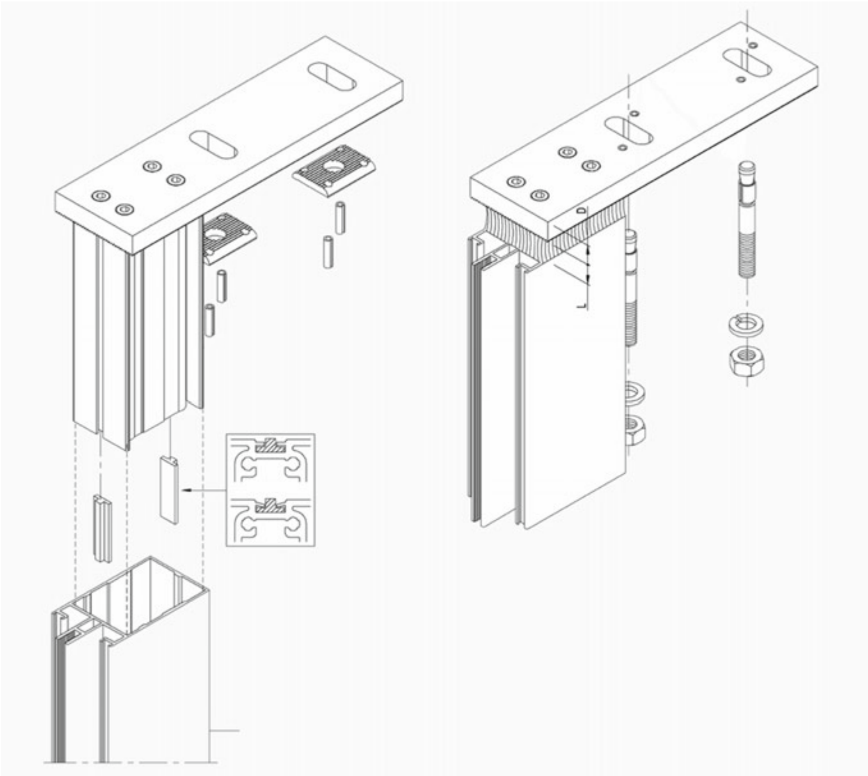

Fig. 2.12 Brackets anchored to the structural ceiling by providing the tensile work of the fasteners and the spacing from the perimeter surface. © Courtesy of Reynaers

- the connection between the metal rail and the bracket according to the insertion of the bolts, after adjustment to the tolerance dimensions;
- the connection between the bracket and the mullion according to the collimation between the mutual slots, proceeding with the application of the nylon discs, respecting the vertical adjustment dimension (equal to $l = 10$ mm) (Fig. 2.14).

The executive coordination procedures, in the construction of the structural façade frame, include the ways of assembling the mullion profiles in accordance with:

- the arrangement starting from the bottom plane, with progressive application upwards, and from the vertical median axis of the construction, in order to distribute any tolerances towards the perspective sides;
- the lifting and the hooking at the top until positioning at the planned height;
- the scheduling of the construction tasks with respect to:
  - the maneuvering practices for hooking to the ground and for the first lifting, accompanied manually;

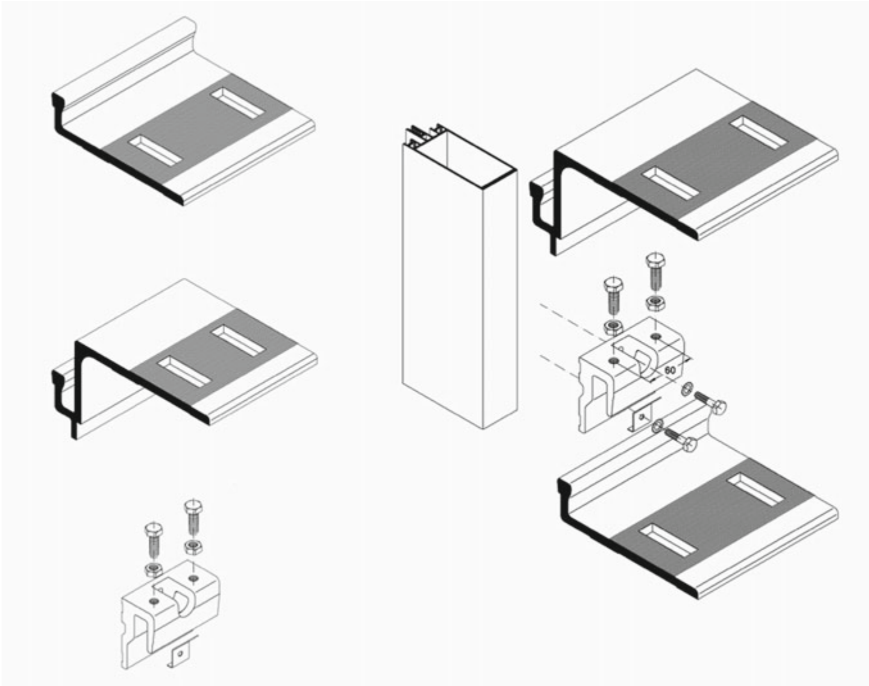

Fig. 2.13 Assembly of the load-bearing framework to the deck structures that notes the connection methods by means of the "bayonet" profiles connected to the mullion, according to the application of the aluminium brackets and to the application of the aluminium brackets equipped with the plug projection, for the construction to the floor slab. © Courtesy of Schüco

  - the maneuvering practices at the arrival level, which note the accompaniment to the junction point, avoiding the impacts against the structures or the façade level, the attachment to the bracket and the subsequent removal of the lifting hook;

- the arrangement towards the holes at the slot height of the bracket;
- the insertion of the crossing bolt for anchoring between the bracket slot and the hole provided in the mullion;
- the attachment to the bracket (by screwing or bolting) in a provisional manner, without carrying out the adjustments;
- the carrying out tolerance adjustments on the brackets, acting on the screwing or bolting to carry out the calibration shifts;
- the practice of final tightening between the guide and the bracket;
- the final tightening practice between the bracket and the mullion.

The coordination and the control work also include the examination of the permissible tolerances with respect to:

- the horizontal axis of the façade plane (understood as positive to the right);

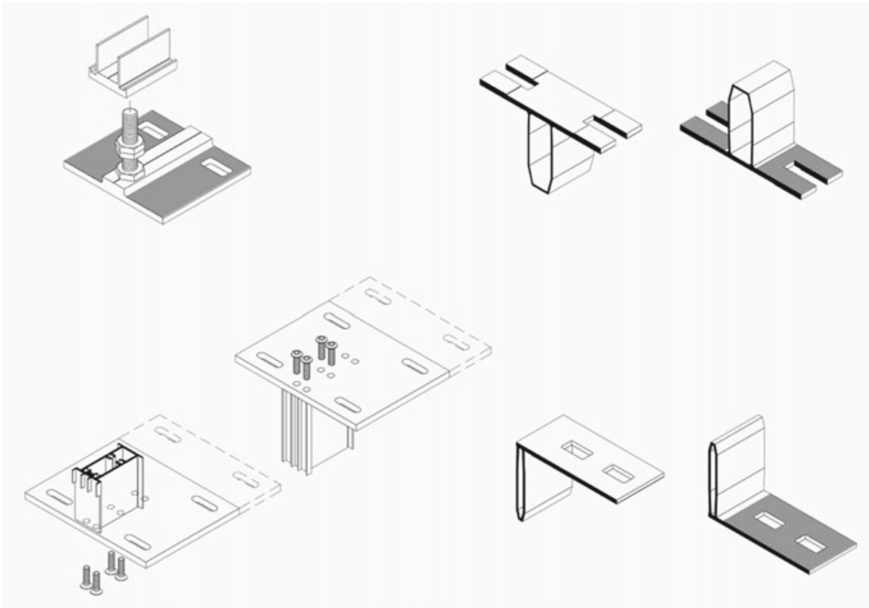

Fig. 2.14 Connection of the frame profiles to the deck structures through the application of extrados and intrados, either according to the lower insertion of the tubular sections of the mullions to the aluminium brackets at "π", or according to the lower insertion of the tubular sections of the mullions to the aluminium box elements. © Courtesy of Schüco

- the vertical axis of the façade plane (understood as positive upwards);
- the horizontal axis in the perpendicular plane of the façade.

The analysis of the tolerances examines the significant points of interaction between the main elevation structure and the components of the envelope, identified as points of attachment, characterized by critical interface aspects such as physical interference or limiting clearance. Therefore, it is indicated:

- the perimeter geometric control of the elevation structure, so that it does not interfere with the sections of the envelope components;
- the control of the structural tolerances, so that they are contained within the limits imposed by the possibility of adjusting the connections (Fig. 2.15).

With regard to the final outcome of the installation of the façade components, the tolerance factors relating to the conditions of verticality and alignment of the vertical and horizontal axes are explained according to:

- the consideration of the "vertical line" if the points do not deviate by ±5 mm from the theoretical vertical axis materialized by the plumb line. This is observing the reduction of ±2 mm between points in the same plane for the height up to $h =$ 3.50 m and ±3 mm between points in the same plane for the height above $h =$ 3.50 m;

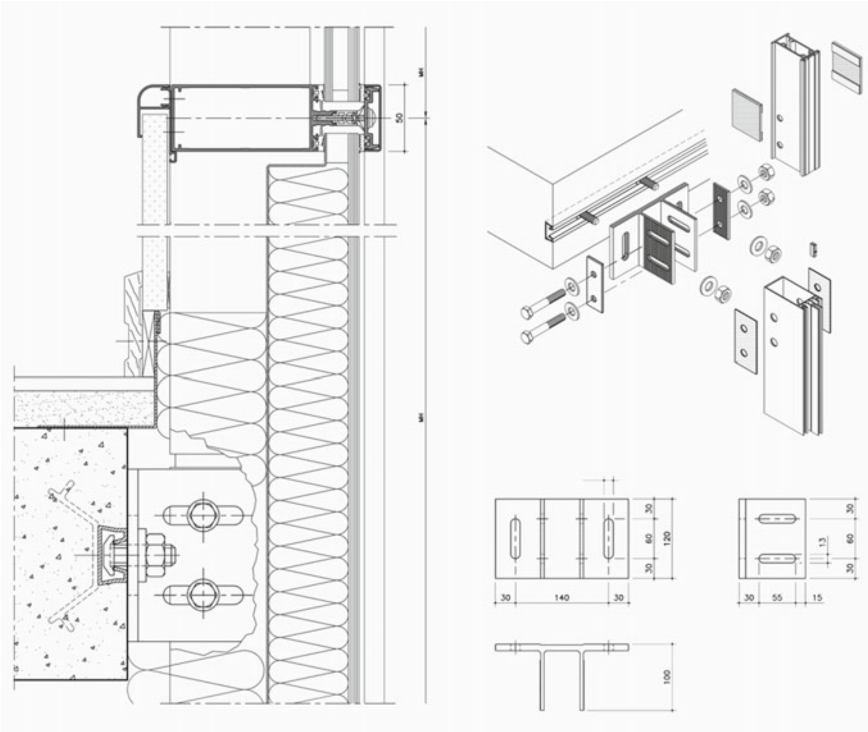

Fig. 2.15 Application of the façade system to the brackets according to the connection to the deck structures, with the transmission of the loads on the horizontal structures. © Courtesy of AluK

- the consideration of the "vertical line" if the points do not deviate by ±10 mm from the theoretical vertical axis if the construction exceeds ten storeys above the ground level;
- the consideration of the "vertical line" if the points do not deviate by ±10 mm if the façade system assembly takes place before the end of the structural construction (manifesting the value increase of ±20 mm if the construction exceeds ten storeys above the ground level).

Chapter 3
The Building Procedures of the Advanced Envelope Systems

Abstract The study examines how frames are jointed to the anchoring structures and their interfaces to load-bearing structures. The analysis focuses on the engagement procedures of the devices applied to the frame profiles. In addition, the analysis observes the connection criteria of the main types of framing with respect to the brackets and fastening connections to the structures: specifically, the investigation implies the assembly criteria according to the tubular cavities of the framing, with respect to the extrados and intrados sections of the structures. The technical interfaces contemplate the connection and finishing extensions (by means of the profiles and shaped sheets to close the layers and connective passages). The specific roof connection provides for the assembly of the mullion profiles to the structural sections pronounced above, where the last transom realizes the support plane for the completion layers. The study examines the criteria for the assembly between the mullion and transom profiles, according to the telescopic insertion of the trestles within the tubular cavities. In the case of the structural façade system, the frame profiles are assembled with respect to the studs projected beyond the mullions and transoms: the connection procedures also involve the use of locking and latching devices on the centre studs and tubular sections. The study of the façade systems focuses on the methods of collecting and draining rainwater, considering the execution of the sealing and the criteria of vapour pressure compensation and drainage for glass enclosures. The analysis of framing is completed with an explanation of the methods of mechanical and structural fastening of the enclosures, noting the criteria for pressure and structural silicone assembly.

3.1 The Typologies of Connection of the Envelope Frames

The assembly of the envelope system, after the analysis and examination of the tolerance allowances relative to the elevation structures, follows the removal of the provisional shoring works, so that the deformation actions are active. The elaboration of the technical interfaces, with respect to the frontal execution to the elevation structures, by means of the brackets extended beyond the external edge, involves the

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PoliMI SpringerBriefs, https://doi.org/10.1007/978-3-031-49608-0_3

"bayonet" coupling of the devices prefixed to the rear septum of the tubular sections related to the mullions, observing the vertical adjustment modes and the enclosures with respect to both the floor finishes and the floor support (Fig. 3.1).

The application of the brackets may provide for the mullions to be attached above the horizontal structures (avoiding the horizontal enclosure works between the frame and the façade), as a solution that entails:

- the transmission of the loads pertaining to the façade system on the horizontal structures, without the friction stresses and avoiding the shear stresses on the bolted fastenings;
- the conditions of easy accessibility during the installation (Figs. 3.2 and 3.3).

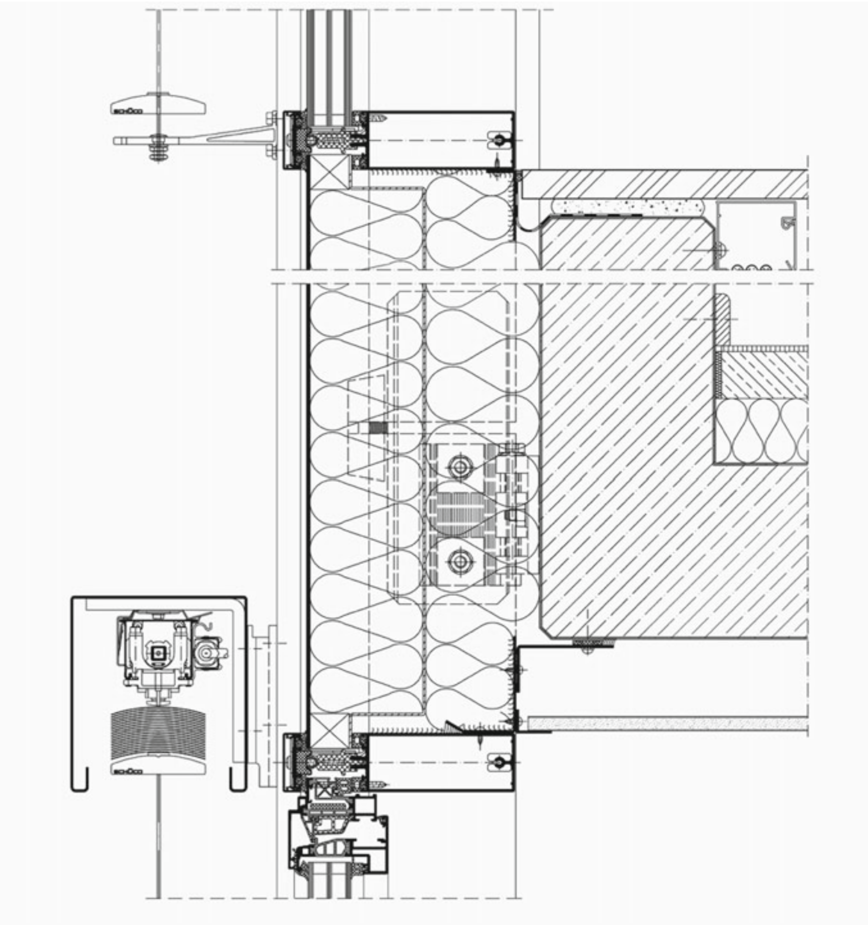

Fig. 3.1 Execution of the envelope system at the horizontal structural interface according to the assembly of the mullion, by connection to the bracket, and application of the stringer panel (*spandrel* type), by means of press-fitting from the intrados transom. © Courtesy of Schüco

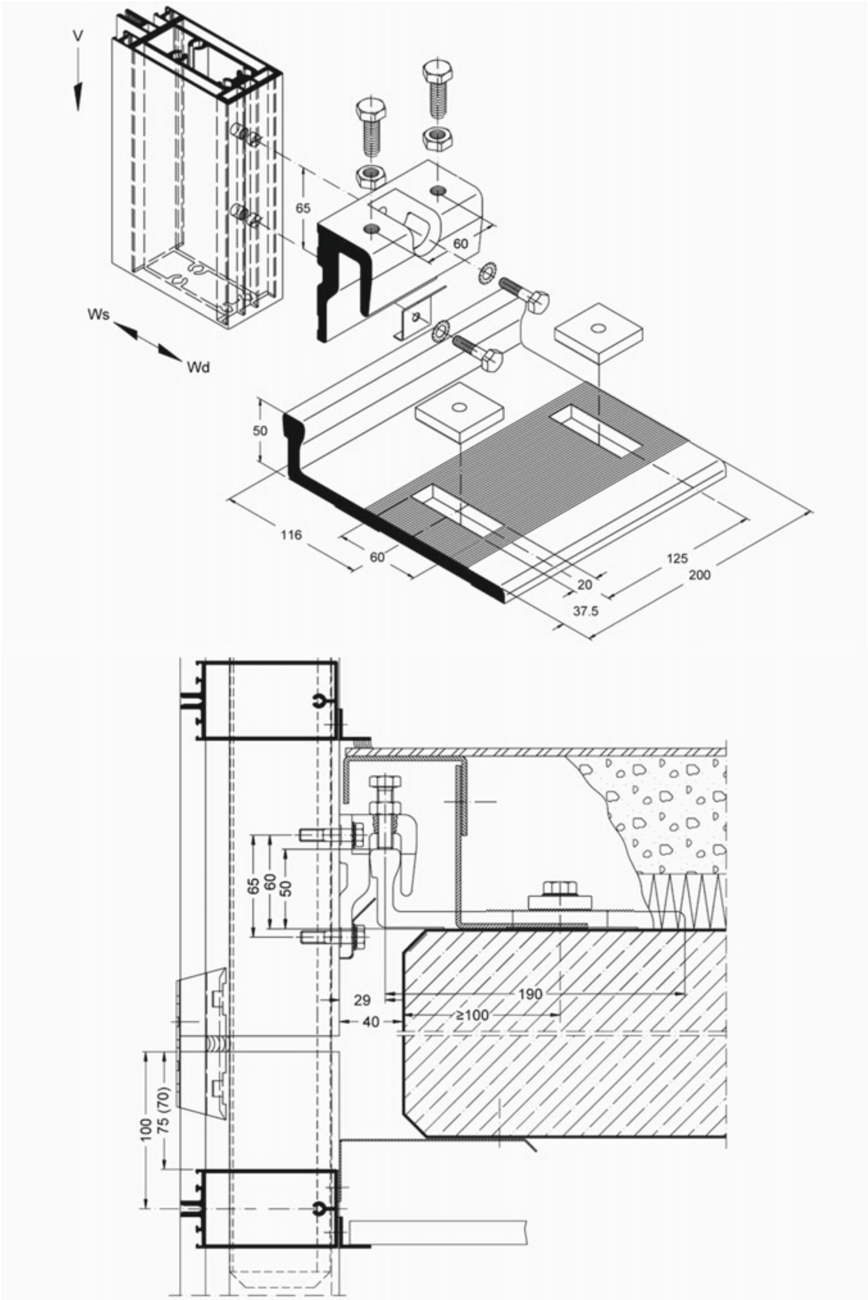

Fig. 3.2 Frontal execution to the horizontal structures, by means of the aluminium "L"-shaped brackets extended beyond the external perimeter that entails the "bayonet" coupling of the devices prefixed to the rear septum of the mullions. © Courtesy of Schüco

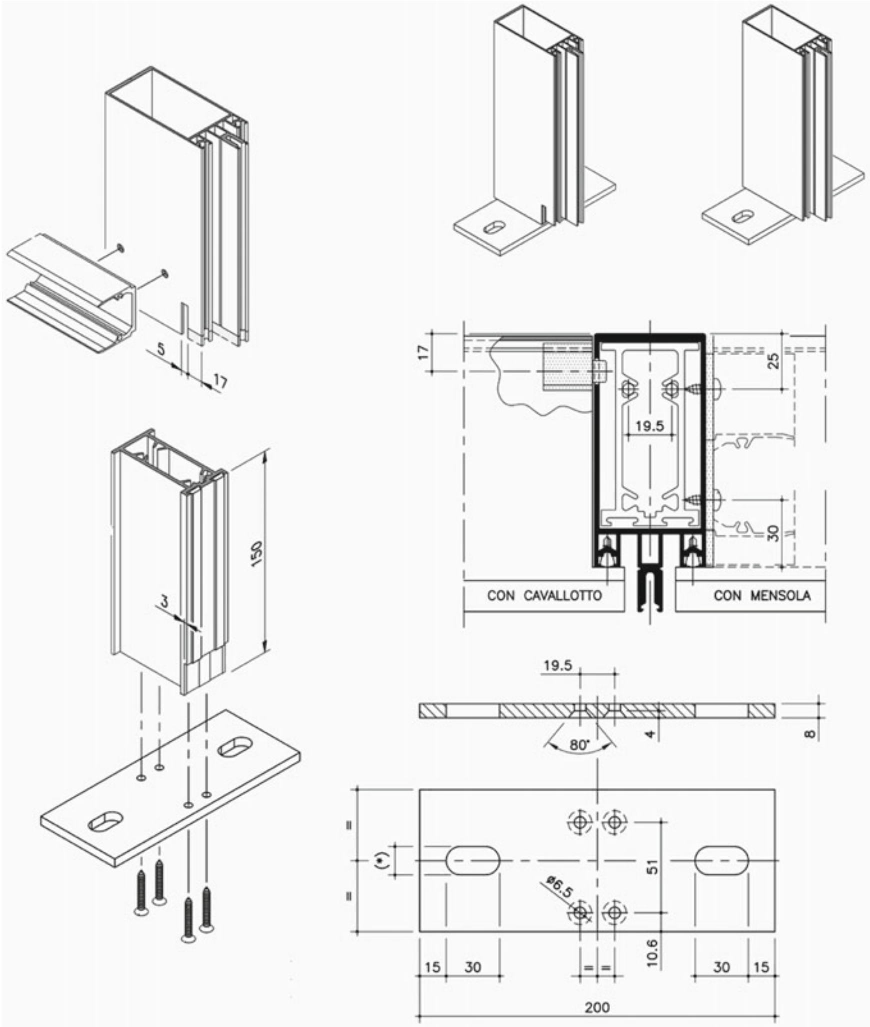

Fig. 3.3 Application of the façade system to the brackets that provides for the upper attachment to the deck structures, according to the transmission of loads on the horizontal structures: • in the absence of friction stresses; • in the absence of bolting shear stresses. © Courtesy of AluK

The elaboration of the technical interfaces, with respect to the execution to the horizontal structures, observes:

- the application modes of the brackets at the extrados, of "π" geometric configuration (on halfen profiles, embedded in the reinforced concrete casting) for the lower insertion inside the tubular sections of the mullions;
- the modes of application of the profiles shaped on the ceiling, for the upper insertion inside the tubular sections of the mullions;

- the methods of application of the steel plates on the extrados (on halfen profiles, embedded in the reinforced concrete casting), equipped with inserts for lower insertion inside the tubular sections of the mullions;
- the methods of application of the shaped profiles at the extrados and intrados, for the lower and upper insertion inside the tubular sections of the mullions of the combined type.

The elaboration of the technical interfaces, with respect to the extrados and intrados execution, considers the methods of assembly of the shaped profiles for the lower and upper insertion within the tubular sections of the mullions, involving the insertion of the crossing bolts and the enclosures at the finishing interfaces, internal and external, by means of the sheet metal fittings. The execution of the extrados and intrados, in the same way, observes the use of the brackets for the application of the combined mullions, according to the assembly of the shaped profiles for the lower and upper insertion within the tubular sections: this involves the insertion of the crossing bolts and the enclosures at the finishing interfaces, internal and external, by means of the sheet metal fittings (Fig. 3.4).

The processing of the technical interfaces, with respect to the execution of the envelope system at the roof connection, involves the assembly of the mullion profiles to the structural sections pronounced above, by means of the connection to the bracket. The last transom realizes the assembly to the press-fit insert and, by means of the upper surface of the tubular profile, the support plane to the cladding sheets and the heat-insulating layers (also intended to envelop the structural building sections), beyond which the support to the sheet metal flashing is arranged. Furthermore, at the interface with the intrados of the slab, the tubular profile of the transom makes the connection with the sheet metal flaps, fixed by screwing and directed to contain the thermal insulating layer inserted between the façade curtain and the structural building surface (Fig. 3.5).

The elaboration of the technical interfaces, with respect to the execution of the envelope system to the horizontal elevation structure, involves the assembly of the mullions profiles, through the connection to the bracket.

The application of the stringer panels (*spandrel* type) is aggregated by means of the press fastening performed by the intrados transom, which makes the connection with the sheet metal flaps, fixed by screwing and aimed at containing the thermal insulating layer inserted between the external cladding of the façade and the structural building surface. The application includes the extrados transom, which makes the connection with the structural section and the finishing works (Fig. 3.6).

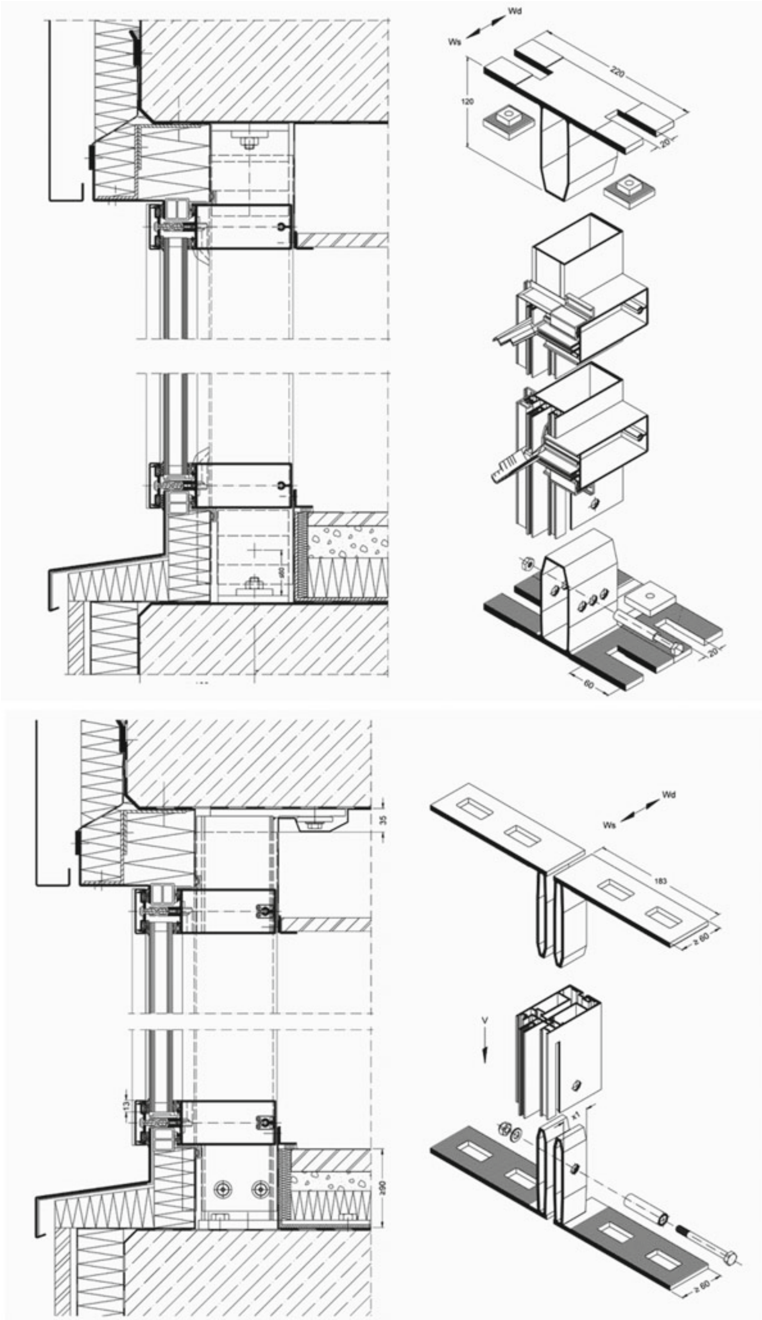

Fig. 3.4 Execution of the extrados and intrados of the shaped profiles, for the lower and upper engagement in the mullion sections, that involves the insertion of the crossing bolts and the application of the aluminium sheet metal fittings at the internal and external finishing interfaces. © Courtesy of Schüco

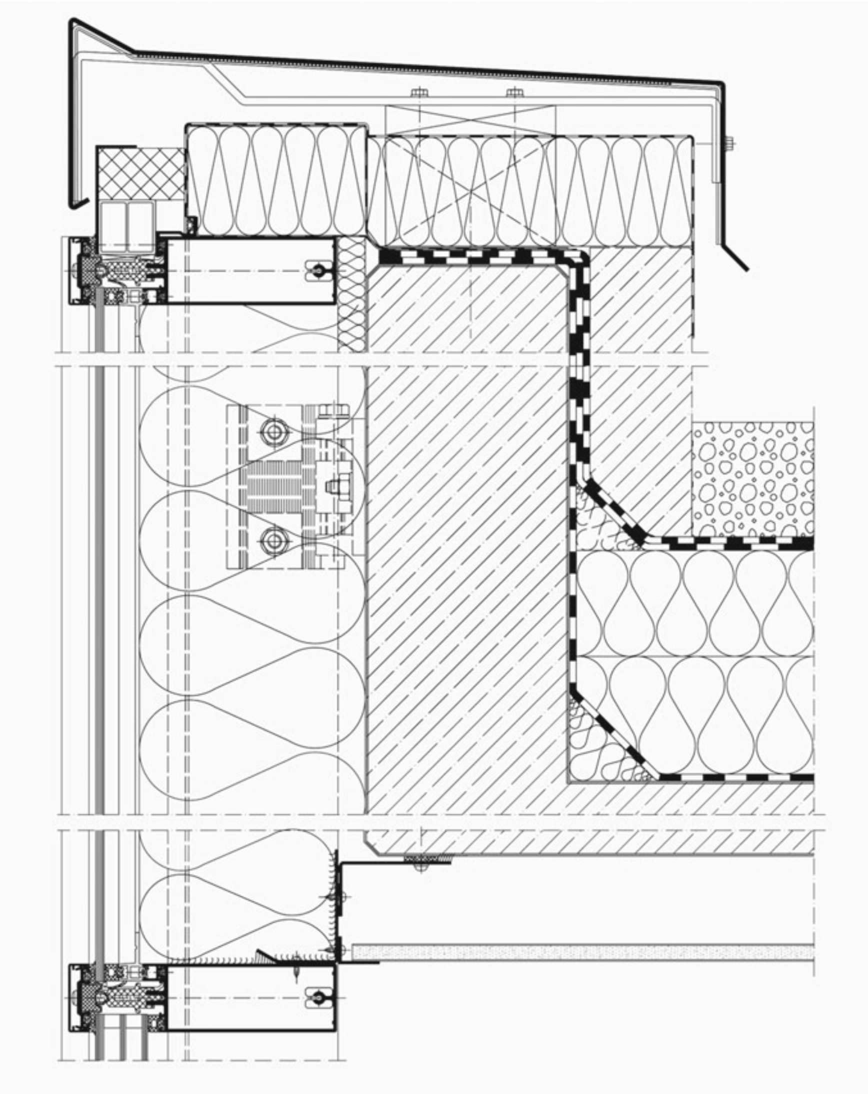

Fig. 3.5 Execution of the envelope system at the roofing interface that involves: • the assembly of the mullions to the upper structural sections, through the connection to the bracket; • the application of the upper cross-piece, aimed at the assembly of the press-fit insert and the support plane to both the thermal insulation layers and the cladding sheet metal; • the application of the support to the sheet metal flashing; • the connection with the sheet metal flashing to the intrados of the slab; • the containment of the thermal insulation layer, inserted between the façade curtain and the structural building surface. © Courtesy of Schüco

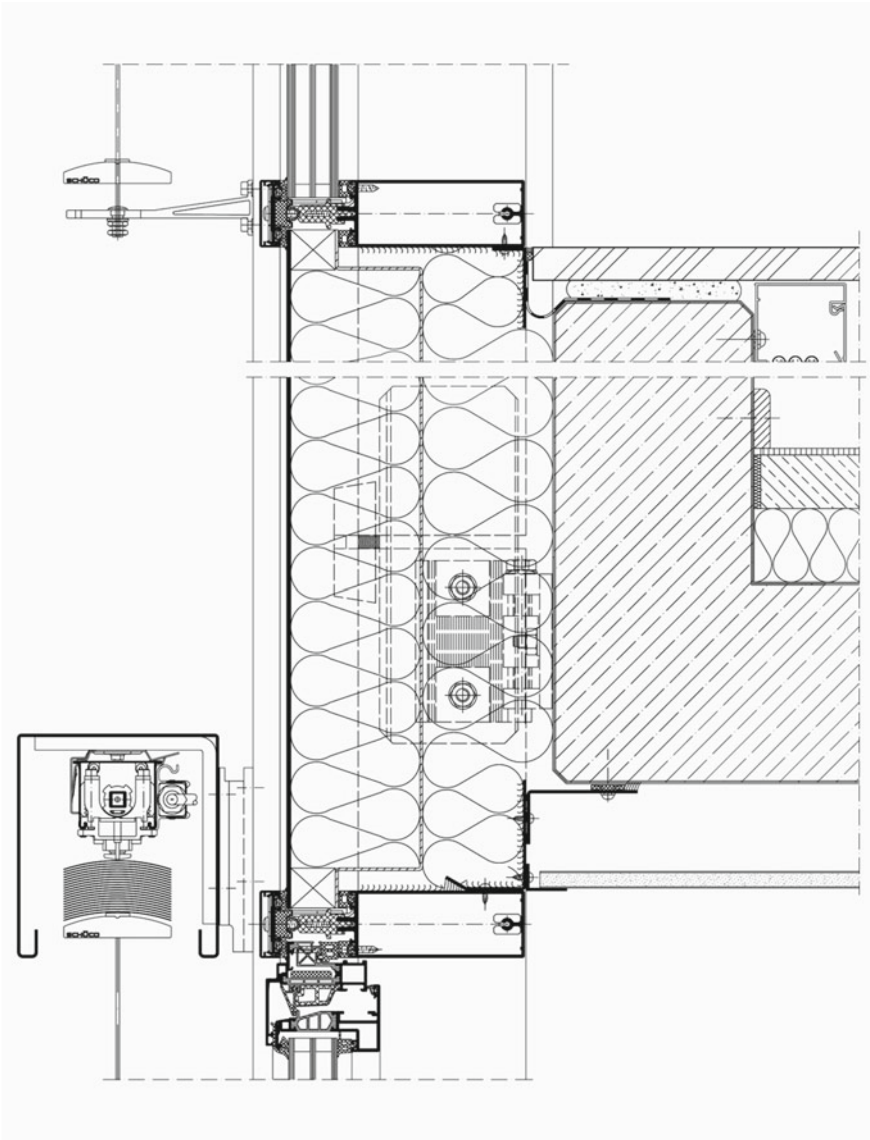

Fig. 3.6 Execution of the envelope system at the horizontal structural interface that involves: • the assembly of the mullions, by connection to the bracket; • the application of the stringer panel (*spandrel* type), by means of press-fitting from the intrados transom, the containment of the thermal insulation layer and the extrados transom. © Courtesy of Schüco

3.2 The Assembly Procedures Between the Framing Profiles

The assembly between the mullions involves the telescopic insertion of the "U"-bolts inside the tubular cavities, implying the frontal application (on the linear pins) of the plastic jointing elements (fixed by screwing). The "U"-bolts, as connection devices in the vertical joints, take on the task of allowing and absorbing the horizontal expansion movements of the transoms (Fig. 3.7). The frame structures have to be able to expand as a result of thermal expansion (e.g. the thermal expansion for aluminium is 1,2 mm/m), according to the application of:

- the expansion joints at each floor, for the mullions, and the expansion joints at each façade module, for the transoms;
- the covering of the joints (made by the aluminium trestles) with materials with a low coefficient of friction (such as teflon or nylon).

Specifically, the assembly between the mullions and the transoms is carried out by means of the "U"-bolts (also equipped with the interface performed by the flanges), as connection devices in the horizontal joints, with the task of providing continuity and structural inertia at the connection points and allowing for the expansion movements of the mullions. The holes on the mullions for the ("T"-shaped) junction of the

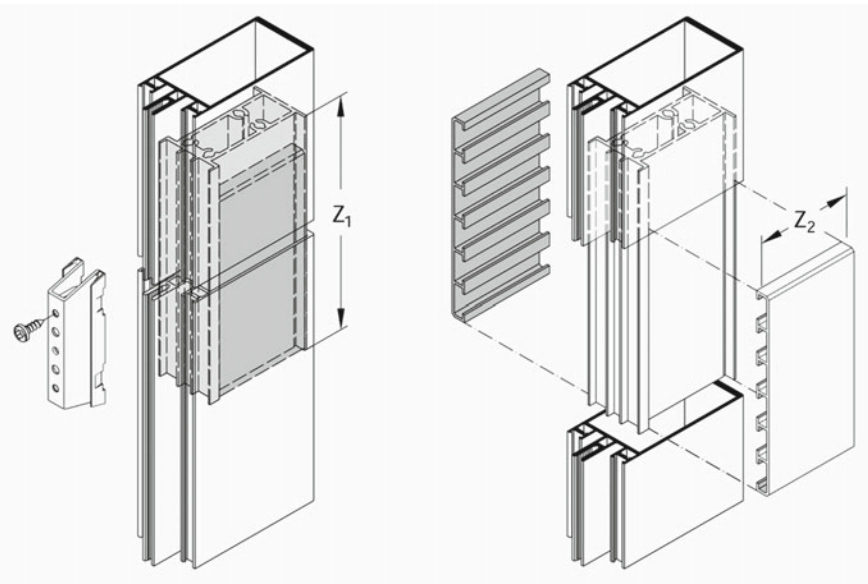

Fig. 3.7 Assembly between the mullions of the façade system that involves: • the telescopic insertion of the "U"-bolts inside the tubular cavities, with the task of absorbing the horizontal expansion movements of the transoms; • the frontal application of the plastic jointing elements. © Courtesy of Schüco

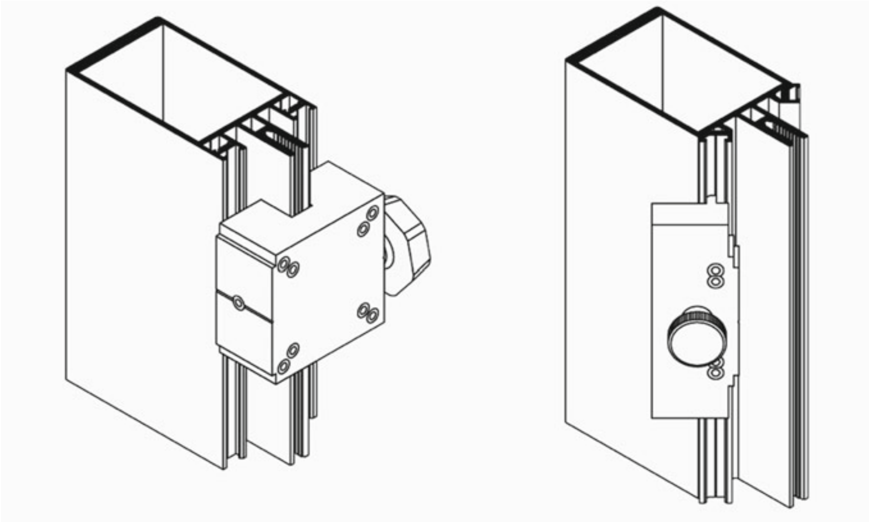

Fig. 3.8 Execution of the holes on the mullion profiles that observes: • the use of the "masking" device for centering the manual milling machine; • the use of "masking" device for the drilling aimed at fastening transoms. © Courtesy of Schüco

transoms with respect to the rails and the lateral partitions of the tubular profile (providing for the fastening of the "U"-bolts) are drilled by means of the "masking" devices, for the drilling aimed at both the fixing of the cross-pieces and the centering of the hand milling machine (Fig. 3.8).

The façade elements can be manufactured either by pre-assembly or by direct assembly on site. The execution procedures involve:

- the method of attaching the transoms to the mullions by means of the coupling of the trestles (with the horizontal crossing screwing passing through the tubular sections of the mullions), providing for the use of the reinforced jointing units for spans exceeding 2.000 mm or for the support of loads up to 7 kN;
- the application of the supports to the glass enclosures by means of crossing vertical screwing through the tubular sections of the transoms (Fig. 3.9).

The connections between the mullions and the transoms may be carried out, depending on the façade structure and the loads, both general and specific, through:

- the execution of the "T"-shaped junction by means of fixing the transoms by screwing them to the cavities for the internal gaskets (Fig. 3.10);
- the execution of the "T"-shaped joint by fixing the transoms to the combined mullions, either by screwing them to the internal gasket cavities, or by screwing the union between the mullion's lateral septa and the linear inserts inside the transoms (Fig. 3.11);
- the execution of the joint by fastening the transoms to the mullion, either by screwing them to the internal gasket seats, or by screwing the union between

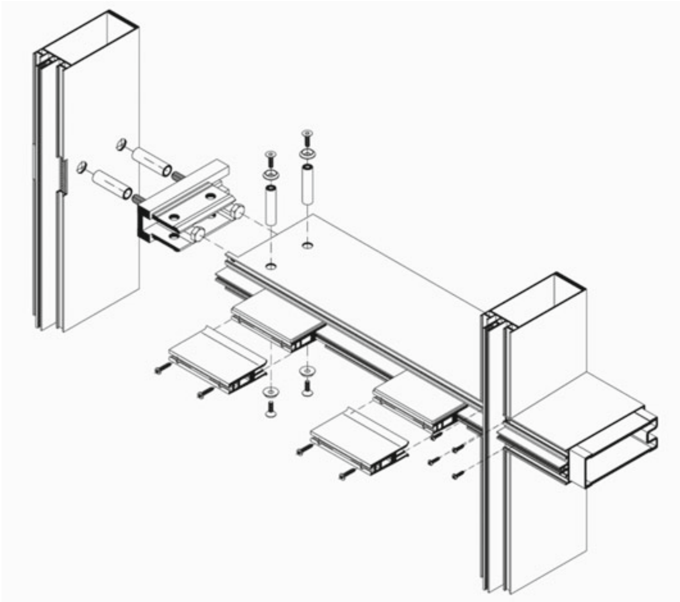

Fig. 3.9 Framing realized by pre-assembly or by direct assembly on site, involving the attachment of the transoms to the mullions, with the through-screwing into the tubular sections of the mullions and the application of the supports to the glass enclosures. © Courtesy of Schüco

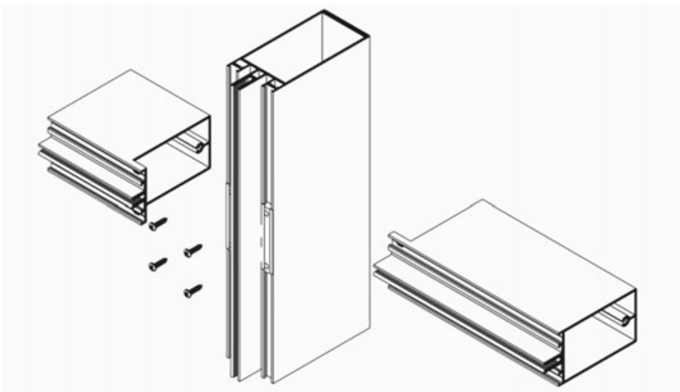

Fig. 3.10 Assembly procedures between mullions and transoms realized through the fixing of the transoms by screwing, with respect to the cavities of the internal gaskets. © Courtesy of Schüco

the mullion's lateral septa and the linear inserts inside the transoms, with the interposition of the "U"-bolts (Fig. 3.12);

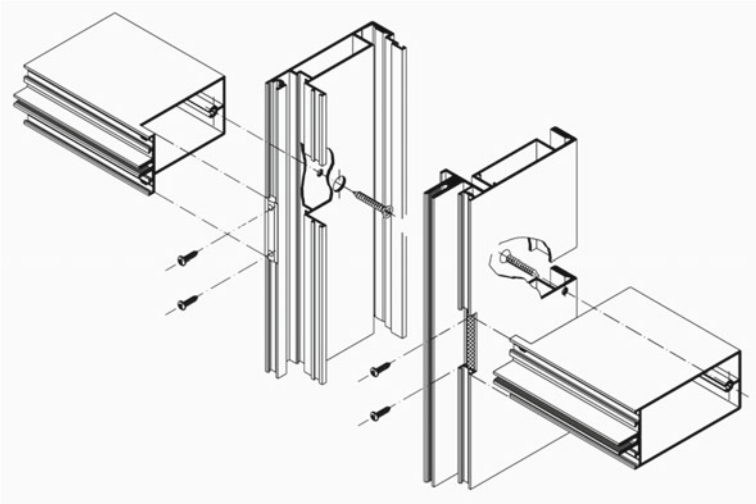

Fig. 3.11 Structural assembly that observes, with respect to the "T"-shaped joint, the attachment of the transoms to the combined mullion: • by screwing with respect to the internal gasket seats; • by screwing between the lateral partitions of the mullions and the inserts inside the transoms. © Courtesy of Schüco

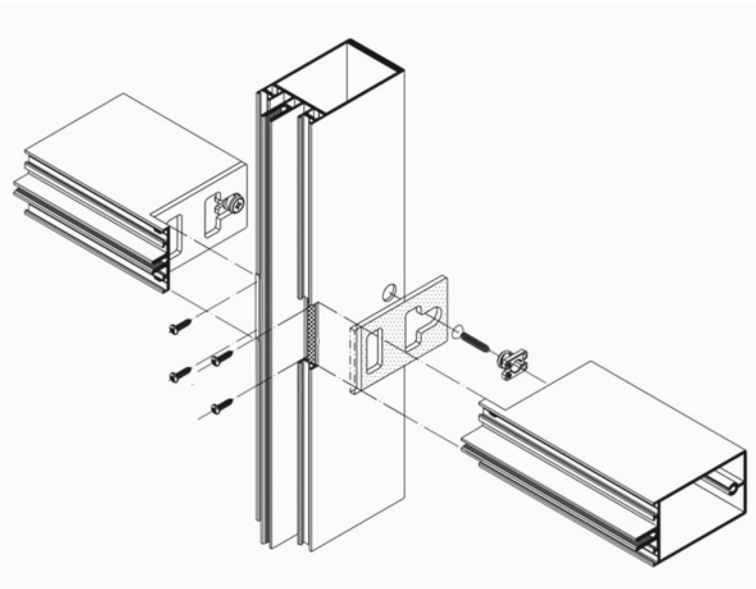

Fig. 3.12 Structural assembly according to the "T"-shaped joint determined by screwing with respect to the internal gasket seats and by screwing between the lateral partitions of the mullion and the inserts inside the transoms. © Courtesy of Schüco

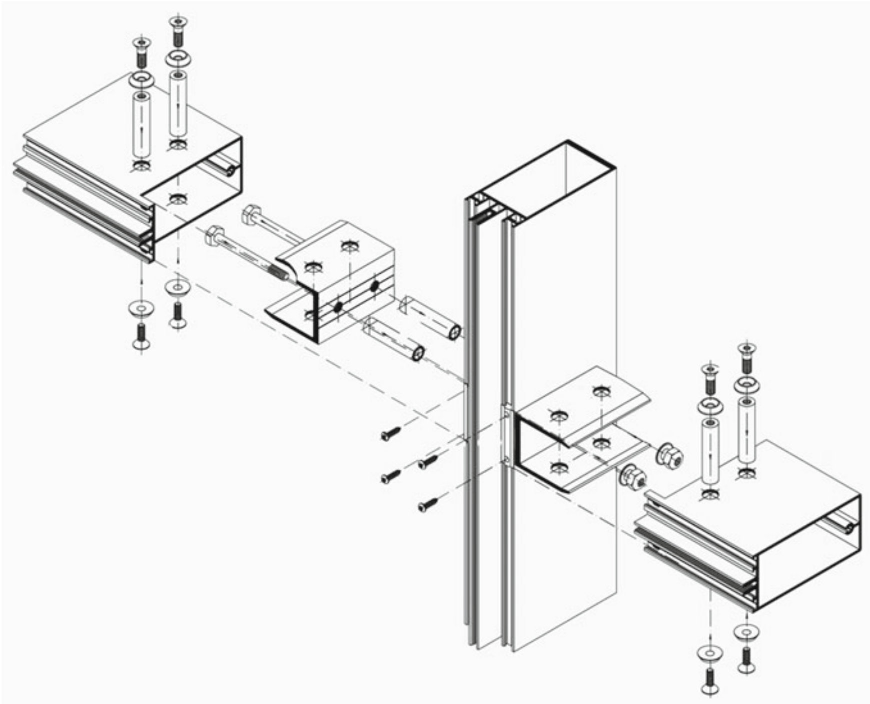

Fig. 3.13 Typology of "T"-shaped junction completed by fixing the transoms to the mullion by screwing to the internal gasket seats and by through-screwing, vertically and horizontally, to the "U"-bolts and transoms. © Courtesy of Schüco

- the execution of the joint by fixing the transoms to the mullion, either by screwing them to the internal gasket seats, or by transverse through-screwing, vertically and horizontally, to join the "U"-bolts and the transoms (Fig. 3.13).

The execution of the structural system provides for the assembly of the frame profiles, including the horizontal and vertical sections to which the double-glazing enclosure is applied: the assembly is delineated with respect to the projected pins, involving the screwing and the interposition of the internal gaskets (Fig. 3.14).

In addition, the connection procedures between the frame elements assume the examination of the structural system in accordance with the use of locking and latching devices (in zinc casting) at the locations defined on the central pivot pins and tubular sections (Fig. 3.15).

In this regard, the executive and operational design analysis for the assembly of the frame profiles includes:

- the locking devices (in general, cast zinc products), with respect to:
  - the connection to the mullions, according to the engagement of angular elements applied to the central pins and tubular sections;

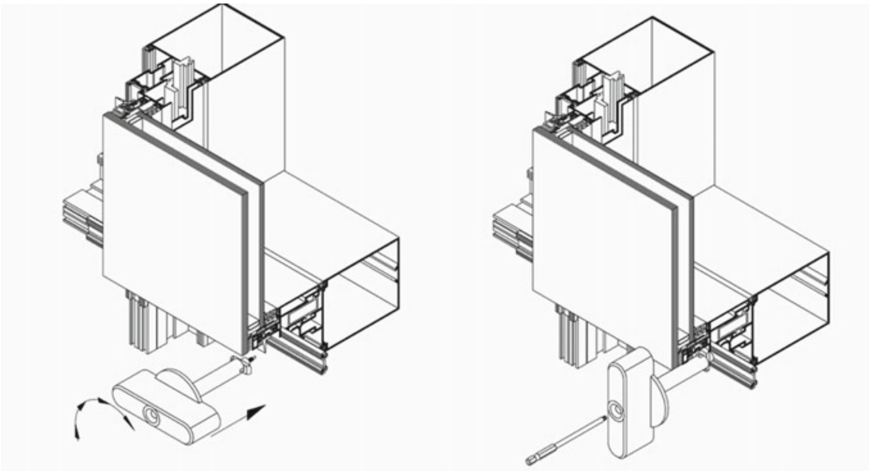

Fig. 3.14 Execution of the structural façade system that involves the assembly of the frame profiles and the connection to the linear pivots, involving the fixing by screwing and the interposition of the internal gaskets. © Courtesy of Schüco

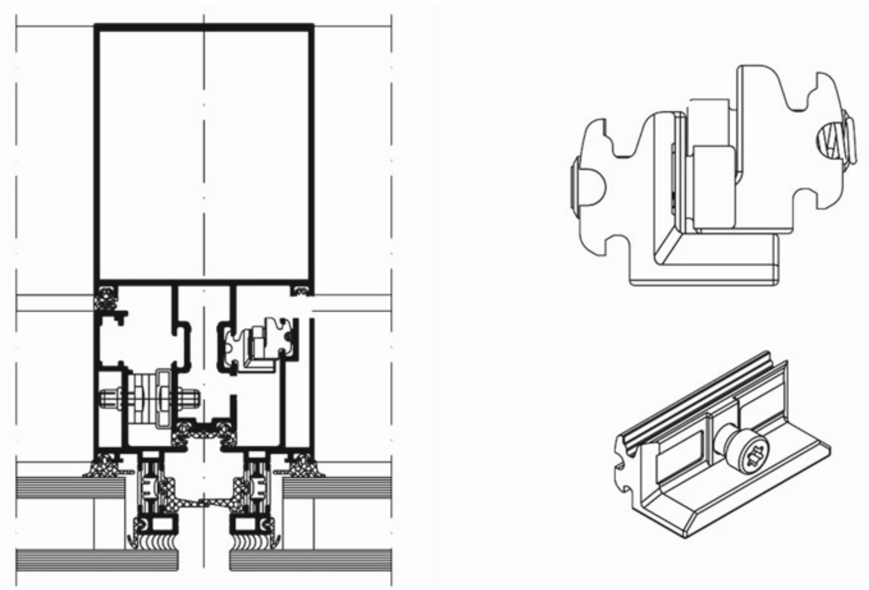

Fig. 3.15 Structural façade system that assumes the assembly of the frame profiles to the mullion through the use of the zinc-cast locking and latching devices and the application on the centre pivots and tubular sections. © Courtesy of Schüco

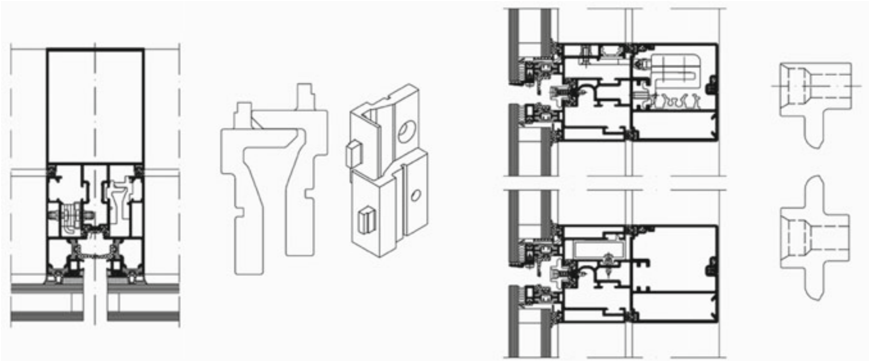

Fig. 3.16 Locking and latching devices for the assembly of the frame profiles made both for the connection to the mullions, according to the engagement of angular elements applied to the central pin septa and on the lateral cavities and for the connection to the transoms. © Courtesy of Schüco

  - the connection to the transoms, according to the engagement of rotating elements (aimed at the insertion of openable parts) jointed to the horizontal septum and to the tubular sections of the transoms themselves (Fig. 3.16);

- the mechanical performances that the frame structures have to possess, with respect to the interface conditions of the load-bearing elements, concerning:
  - the resistance of the joints to the deformations of the main structure;
  - the absorption of the expansion through the differential movement of the joints and the interposition of expansion joints, without inducing tension states on the structural elements (Fig. 3.17);

- the criteria for absorbing the bending moments generated by the vertical loads of the enclosure elements, which determine the tensile and compressive stresses decreasing as the distance from the fixing points increases. At the execution level, the frame structures have to be built and applied in such a way as to coordinate the acceptable tolerances of the different elements of the façade system, providing that:
  - the movements and the thermal expansion are absorbed, without contrast, at the fixing points;
  - the connections are executed in such a way as to remain tight to the fluid diffusion of water and air (Fig. 3.18).

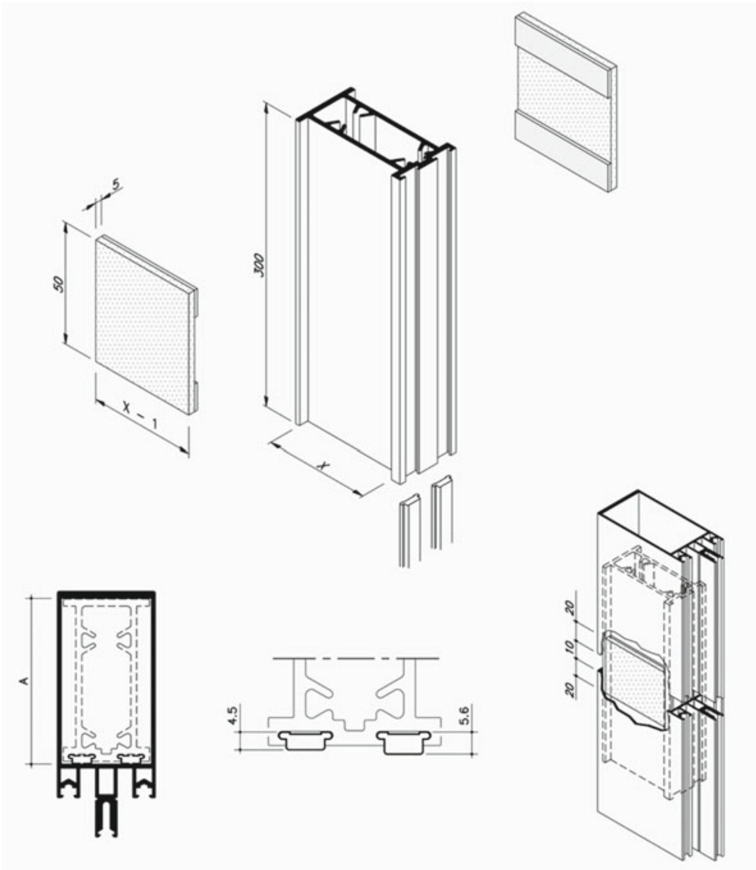

Fig. 3.17 Mechanical performance of the frame structures, with respect to the interface conditions of the load-bearing elements, concerning the resistance of the joints to the deformations of the main structure and the interposition of the expansion joints, to encourage differential movement. © Courtesy of AluK

3.3 The Connections of the Envelope Frames and the Drainage Procedures

The design, production and construction of the façade systems considers, in an integrated manner, the criteria of rainwater runoff, infiltration and condensation (even if coming from other building elements): that is, the functional model of reference is determined with respect to the prediction and conduction of water that is first collected, in the lower transoms of each façade module (fixed or openable), and then drained off in a controlled manner. The specificities related to the examination of the collection and outflow modes observe, in preliminary form:

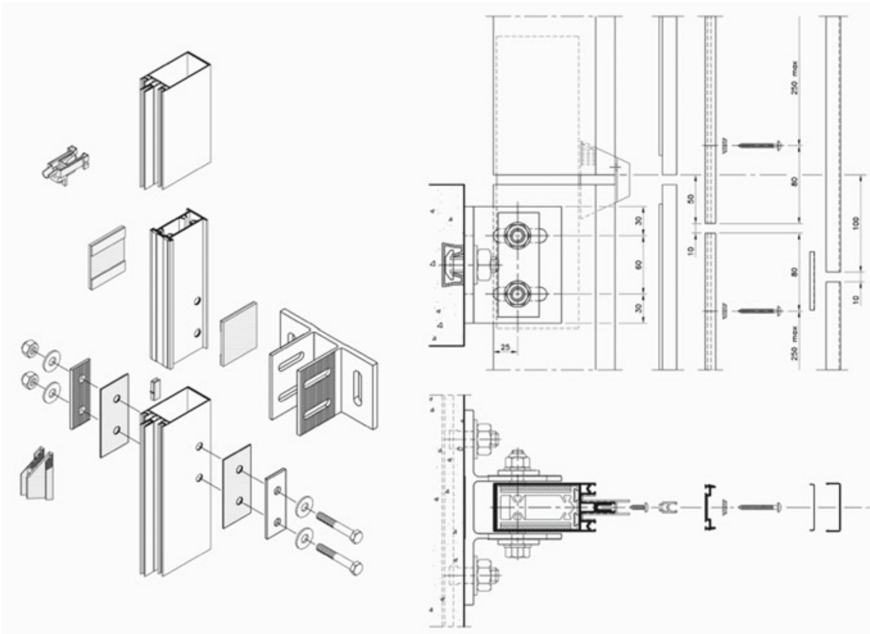

Fig. 3.18 Frame structures elaborated with respect to the resistance to the bending moments, generated by the vertical loads of the fastening elements, and the resistance to tensile and compressive stresses. © Courtesy of AluK

- the execution of sealing against the openings and the junction points in the frame (such as, for example, screw holes and dowels for corner joints), especially in the lower transoms (even when the profile cavities are not used for water runoff);
- in the case of the ventilation and the drainage for individual panels, the vapour pressure compensation criteria at each individual transom: this is achieved by sealing the junction of the bottom of the transom channel with the bottom of the transom channel by means of a sealing element. The vapour pressure compensation takes place at the transom by means of the openings made in the sub-coverage profiles and in the external glazing gaskets; any condensation water is also expelled to the outside through these openings (Fig. 3.19).

The drainage conditions are divided into "levels", corresponding to the water collection planes and, in general, to be carried out from the "first level" (referring to the plane of the transom, with the possible introduction of a further "level" through the insertion of another transom) and the "second level" (referring to the plane of the mullion). In particular, the operation and application procedures detect:

- in the case of the executive design of the mullion and transom façade system:
  - the installation of the drainage accessory at the end transoms and transoms above the expansion joints;

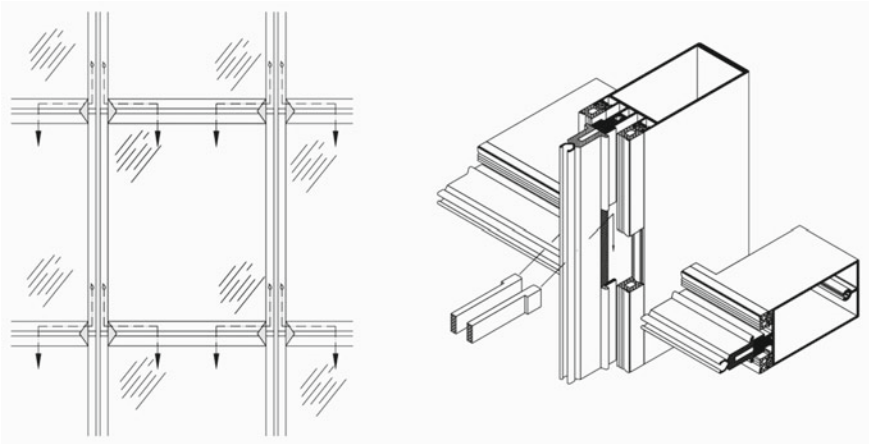

Fig. 3.19 Framings of the façade systems guarantee the drainage of rainwater, infiltration and condensation through: • the collection in the lower transoms of each façade module (fixed or openable); • the sealing of the openings and the frame joints; • the application of the joint plugs between the mullions and the transoms. © Courtesy of Schüco

  - the sealing of the drainage accessory by injecting sealant into the hole in the central part;

- in the case of executive design of the structural façade system:
  - the installation of the drainage plug at the transoms above the expansion joints;
  - the sealing of the drainage plug by injecting the sealant into the three holes located on the front side (Fig. 3.20).

The technical design, execution and application provides for:

- the layout of the mullion and transom profiles on different planes;
- the geometric and connective definition so that any infiltration water is drained from the upper collection plane of the transom to the lower collection plane of the mullion and, from there, conveyed in a controlled manner downwards;
- the configuration and processing of the transom profile in such a way as to be fixed to the seat of the mullion gasket: therefore, the different height of the internal support surface of the glass enclosure that would be created is compensated for by gaskets of a different height;
- the arrangement of the external glazing gasket of the same conformation and size for the mullions and transoms, contemplating the interruption, according to the sealing system, for each module on the left and right (for the portion of 20 mm), in order to ensure ventilation. In the case of module widths *BRa* > 1.500 mm, it is necessary, for each module, to interrupt the glazing gasket in the centre;
- the development of the drainage criteria so that any infiltration water is channelled from the collection plane of the transom to the mullion, from where it is guided outside in a controlled manner: the technical solution emphasizes the location of

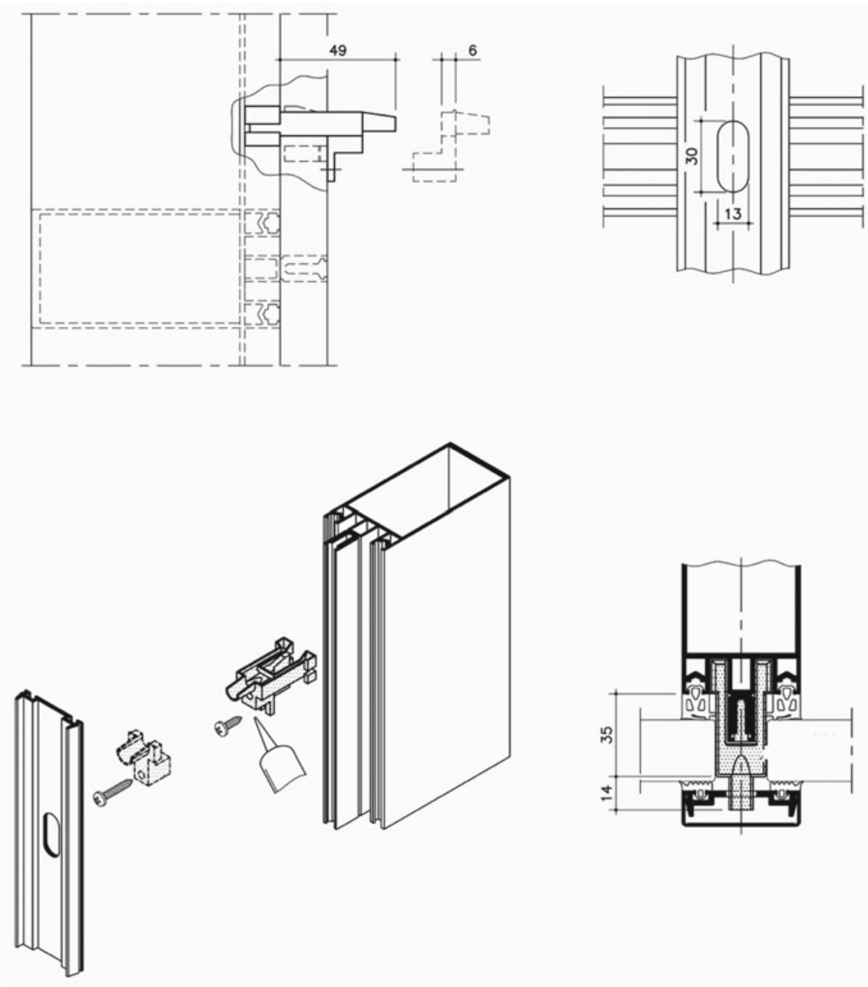

Fig. 3.20 Water drainage procedures in the mullion and transom façade system that include: • the connection of the drainage accessory at the end and top transoms to the expansion joints; • the sealing by the injection into the central hole. © Courtesy of AluK

the enclosure elements on differentiated planes, so that the water is drained from the collection plane of the transom onto the lower plane of the mullion and, from there, directed to the base of the façade. For technical reasons, in the case of wide-base modules, an additional drainage plane should be provided: this additional drainage plane allows for the controlled and safe drainage of any seepage water (Fig. 3.21).

The analysis implies, respect with the enclosure fastening, the separation of the external sealing plane (with the function of limiting or blocking the mixture of air and

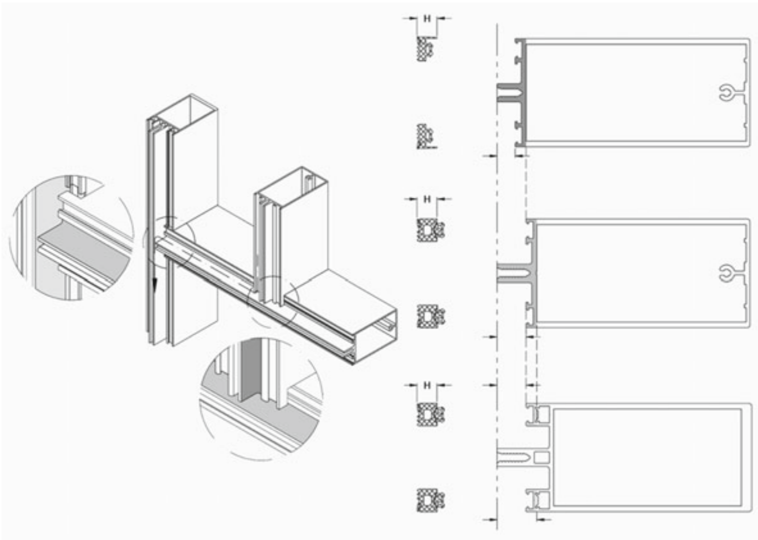

Fig. 3.21 Execution of the façade system that provides for the application of the enclosure elements on differentiated planes and the drainage of water from the collecting plane of the transom towards the lower plane of the mullion. © Courtesy of Schüco

water between the joints) from the internal plane, with the consequent generation of a groove space: this, which does not contain any gaskets, assumes the drainage function aimed at draining water from the joints or from the formation of condensation. The enclosure fixing also involves the connection of the vertical and horizontal joints to a common drainage system, for which, in the horizontal joints, the enclosure elements have to rest on dowels capable of leaving the groove space necessary to conduct the water (Fig. 3.22).

Finally, the analytical and operational examination focuses on:

- the compensation of the vapour pressure present in the glass location of the transoms, which takes place laterally at the connection on the mullion. In this way, each individual module is "ventilated" on all four corners: controlled drainage proceeds by means of devices inserted on the mullion at the upper and lower points of the façade. In the case of a façade composed of more than eight modules, placed one above the other, additional drainage plugs are inserted;
- the realization of the structural façade type, which requires the assembly of the transoms to the mullions by means of the elements of such geometry as to determine the engagement of the central linear pins, with the sealing of the perpendicular silicone joints. This by observing:
  - the fixing of the transom on the gasket seat, which is the same for the mullions and transoms, and interrupted, according to the sealing system, for each module on the left and right (for the dimension of 50 mm), in order to ensure proper ventilation;

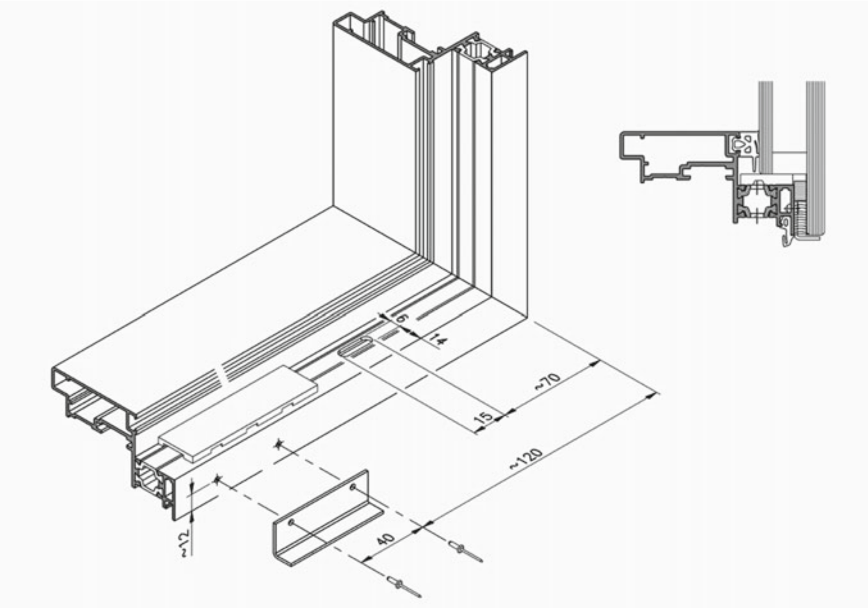

Fig. 3.22 Enclosure fixing that considers the connection of the vertical and horizontal joints to a common drainage system and the application of horizontal dowels to support the enclosure elements in order to determine the groove required for the water conduction. © Courtesy of AluK

– the interruption, in the case of module width *BRa* > 1.500 mm, for each module, of the glazing gasket in the central position.

3.4 The Mechanical and Structural Assembly of the Enclosures to the Envelope Frames

The mechanical assembly of the glass panels to the structural frame by means of the pressure device is carried out through:

- the use of self-tapping screws with a cap head;
- the use of exposed socket-head screws;
- the use of visible cap screws (Fig. 3.23).

The application of the enclosure elements (and, in particular, glass panels) for curtain wall, cellular façade and double skin façade systems (especially for the inner curtain) is determined by means of press-fit glazing beads: the fixing technique involves the joining of two adjoining sealing elements, where the two sealing planes are made of elastic silicone or ethylene-propylene (EPDM) profiles, the configuration of which prevents water penetration. At the application level, this provides for:

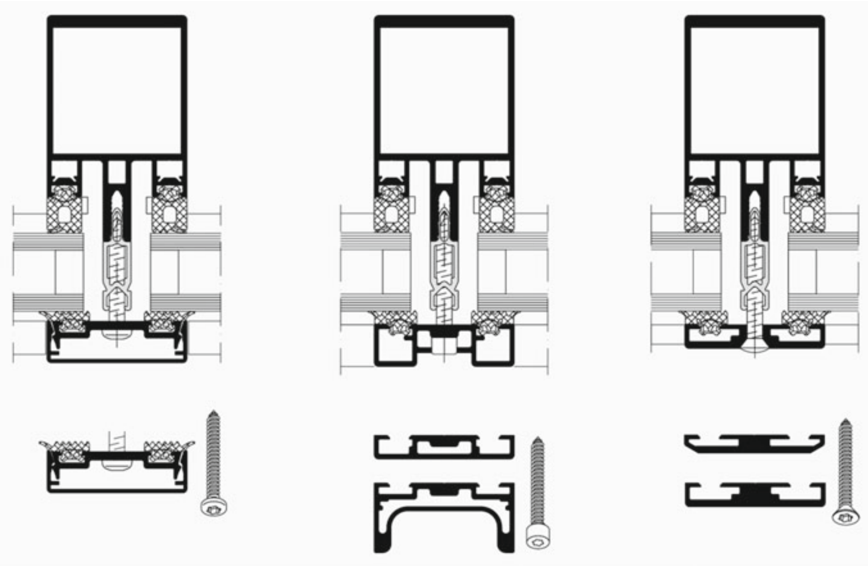

Fig. 3.23 Mechanical assembly of the glass panels to the structural frame by means of the pressure device through the use of self-tapping screws with a cap head, the use of exposed socket-head screws and the use of visible cap screws. © Courtesy of Schüco

- the temporary blocking of the panels with pieces of pressure devices before the definitive fixing is carried out;
- the sealing of the two ends of the transom pressure before laying the cover;
- the tightening of the pressure devices with a screwdriver (Fig. 3.24).

In the façade systems with press-on glazing beads, the outer profiles generate linear pressure on the glazing elements and frame structures: the intermediate profile gaskets provide the sealing and elasticity of the fastening, helping to determine the amount of pressure (Fig. 3.25). The enclosure elements can also be fastened to the frame structures by means of lateral point-fixing, whereby the glazing beads (with press-fit connection by screwing) allow the perimeter to be assembled.

The assembly takes place by points at the edges of the enclosure elements, where:

- the brackets included in the fasteners absorb the stresses parallel to the plane of the enclosure elements (*in-plane*);
- the plates of the fasteners absorb the stresses perpendicular to the plane of the enclosure elements (*out-of-plane*) (Fig. 3.26).

The perimeter fasteners, which realize the façade systems' watertightness, airtightness and insulation, assume the use of seals with silicone adhesive: these determine a sealing correlation without external pressure, on the basis of the adhesion between the parts in connection (also acting for the transmission of forces and under tensile stress). The use of silicone seals for the interface elements, such as wedges,

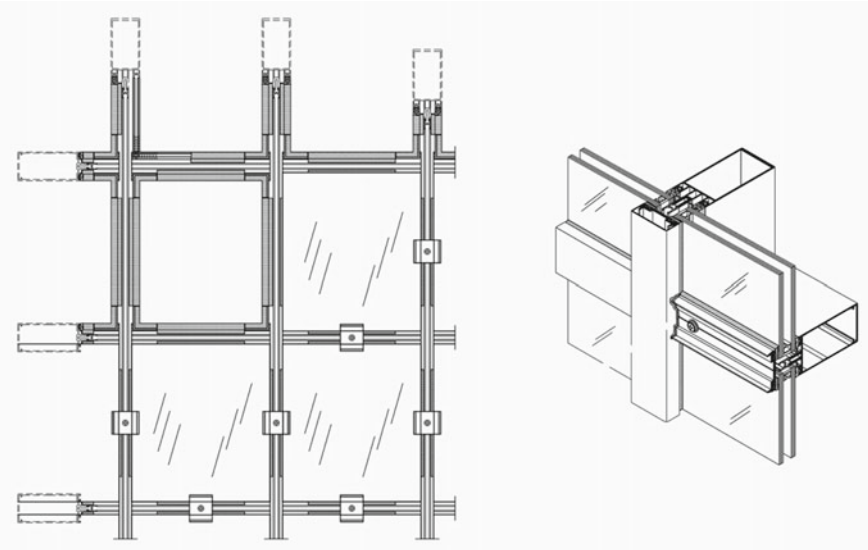

Fig. 3.24 Application of the building enclosures by means of the pressure devices that concerns: • the fastening of two adjoining enclosure elements and the execution of the sealing planes by means of the elastic silicone or EPDM profiles; • the temporary assembly of the panels by means of the locking devices; • the sealing of the two ends of the transom pressure devices; • the tightening of the pressure devices (with an adjustable screwdriver) and the laying of the cover. © Courtesy of AluK

joint-covering profiles and spacers (compatible with the sealants with which they are placed in contact, in order to avoid the phenomena of loss of cohesive capacity), means that movements are absorbed by the elastic expansion of the adhesive, either perpendicular or parallel to the joints.

The application of the enclosure elements for the structural façade system and, in some cases, for the double skin façade system (especially for the external screen), is done through the use of the structural silicone. It has to withstand the action of several combined stresses, such as:

- the self-weight of the enclosure elements;
- the horizontal loads (above all, of a negative type and generated, for example, by wind loads), to be transferred to the load-bearing structure;
- the thermal stresses, which cause expansions in the enclosure elements;
- the stresses due to the ultraviolet component of the solar radiation;
- the stresses due to the deformation of the load-bearing structure under the action of the horizontal and vertical loads (such as the accidental and permanent loads of the horizontal structures, or the vertical components of seismic actions).

The morphological configuration determines a uniform curtain around the perimeter of the building, considering:

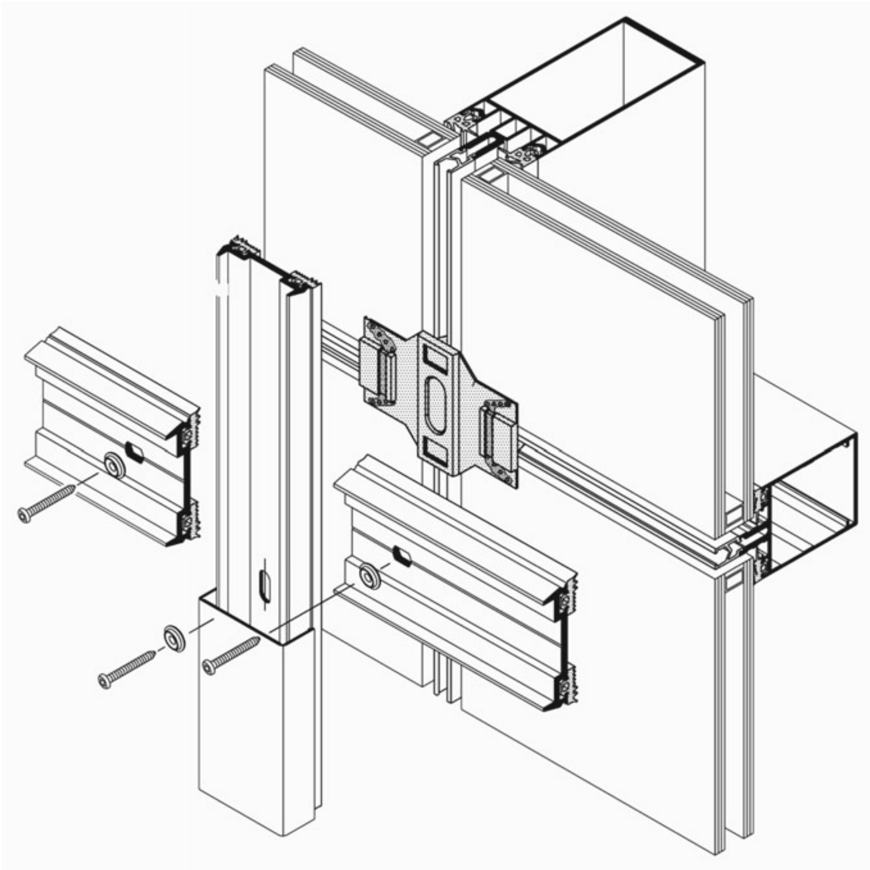

Fig. 3.25 Press-fit façade systems specify the mechanical execution through: • the application of the linear pressure on the enclosure elements and the frame structures; • the installation of the intermediate gaskets, aimed at determining the contribution to linear pressure, tightness (water and air) and connective elasticity. © Courtesy of AluK

- the minimum distance between the enclosure elements (of size $\geq 10 \div 12$ mm, and, in the case of buildings of considerable height with high horizontal torsions and translations, of size at least 20 mm), in order to absorb thermal expansion and deformations of the silicon joints caused by wind stresses;
- the separation distance between the frame and the enclosure elements, so as to avoid the transmission of the stresses (due to the structural movements and thermal loads) acting on the profiles (Fig. 3.27).

The execution of the structural façade system provides for the insertion of the perimeter sealing elements inside the frame (horizontally, in the form of dowels), in order to support the panels in the event of collapse of the fixing glue. The sealing elements are also inserted to mechanically receive the weight of the enclosure

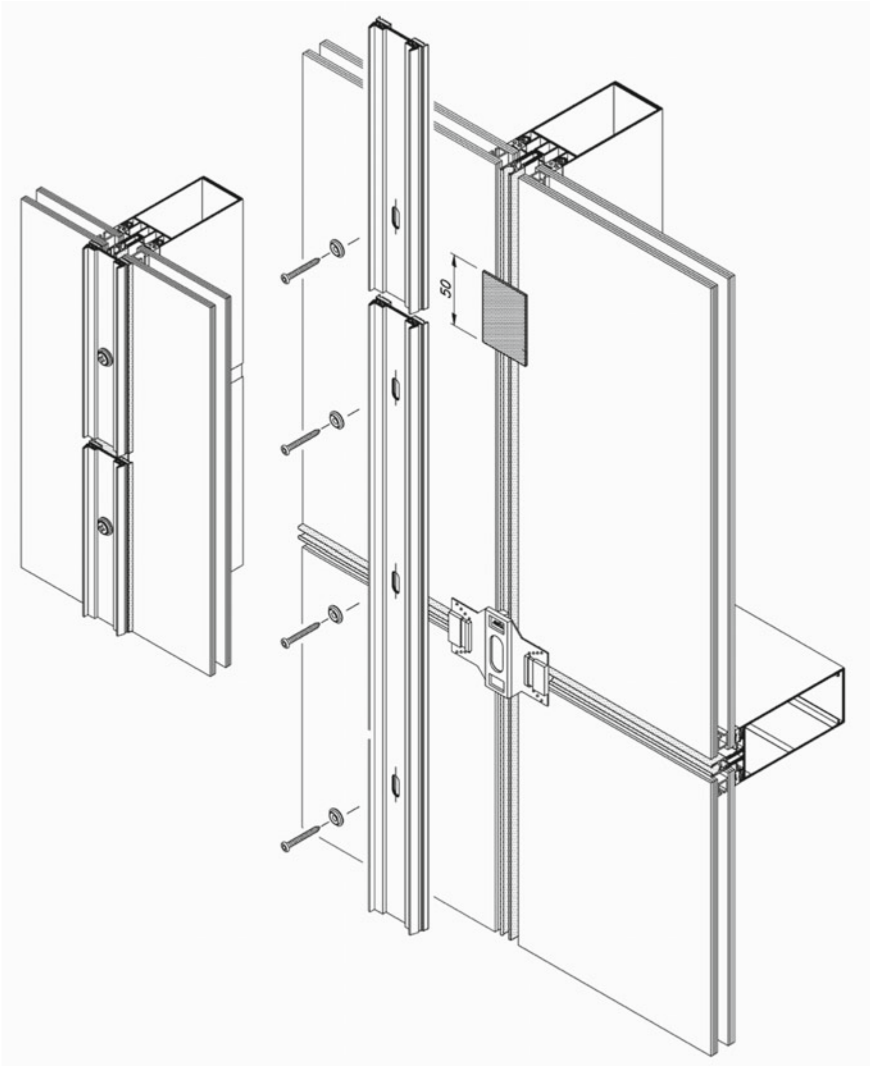

Fig. 3.26 Enclosure elements can be fixed to the frame structures by means of the point-fixing procedure, whereby the pressure devices allow the perimeter assembly, observing the absorption of the stresses parallel to the plane through the brackets and the absorption of the stresses perpendicular to the plane through the pressure plates. © Courtesy of AluK

elements in the event of gravity forces acting on the seals, in order not to constantly shear stress the joints (Fig. 3.28).

Specifically, the structural silicone (which also assumes the function of transferring the dynamic pressure and depressure loads received by the enclosure elements to the frame) has to be characterized by:

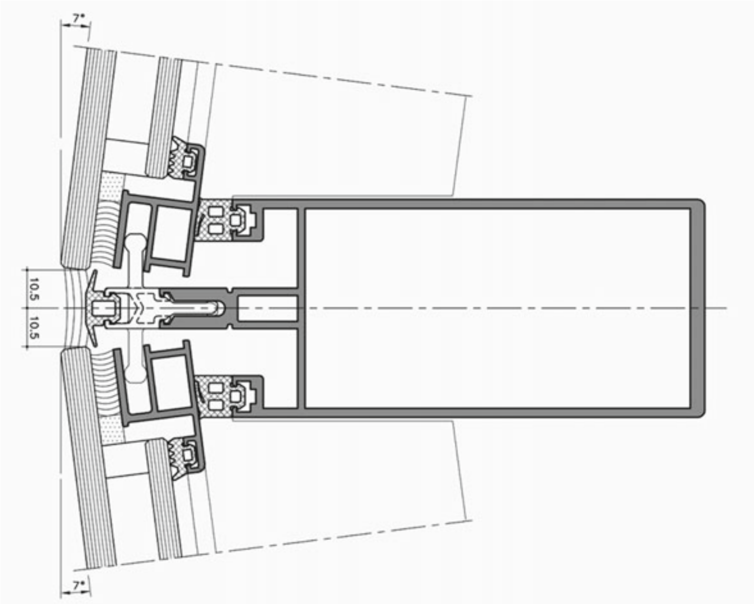

Fig. 3.27 Construction of the structural façade system that examines the absorption of thermal expansion and the absorption of silicone joint deformations, caused by the wind loads, through the minimum distance between the enclosure elements and the separation distance between the enclosure elements and the frame. © Courtesy of AluK

- the neutral, acidic, mono-component formulation (with a long cross-linking time, during which the enclosure elements have to be handled and stored with care, as silicone is sensitive to the thermo-hygrometric conditions) and bi-component (with a short cross-linking time, involving the cleaning of the injectors);
- the absence, during the cross-linking process, both of neutral by-products that may affect the reflective layers of the glass panels, and of aggressive reactions towards the finishing layer (of the anodic type) of the mullions and transoms;
- the resistance to the ageing and atmospheric conditions;
- the plasticity (also permanent) according to conditions of use.

The depth of the silicone joint is determined by the relation:

$$H_1 = \frac{\frac{1}{2} \cdot l \cdot wl}{dfc}$$

where:

H_1 = adhesion length (linear dimension of the silicone sealant along the perimeter of the glass panel, in m);

l = bottom length of the glass panel (in m);

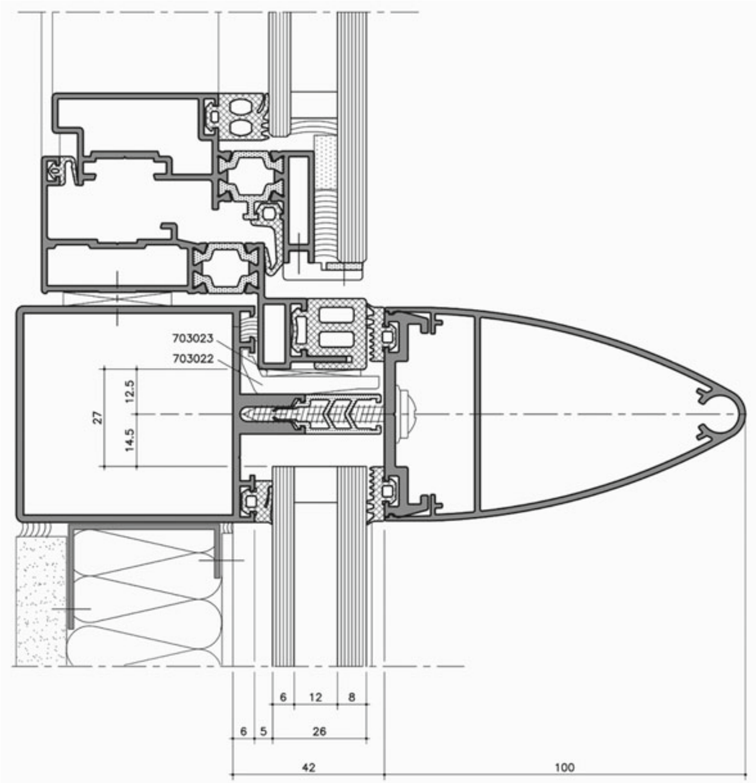

Fig. 3.28 Execution of the structural façade system that involves the insertion of the dowels, aimed at: • the support of the panels in case of collapse of the fixing silicone glue; • the support of the panels in the case of loads acting on the seals, in order to avoid shear stress on the joints. © Courtesy of AluK

wl = wind load (in N/mm^2);

dfc = dynamic strength coefficient of the silicone sealant (equal to 0,14 N/mm^2).

The depth of the silicone sealant joint is determined by the relation:

$$H_2 = \frac{w}{u \cdot sfc}$$

where:

H_2 = adhesion length (linear dimension of the silicone sealant along the perimeter of the glass panel, in m);

w = weight of the glass panel (in kg);

u = perimeter of the glass panel (in m);

sfc = static strength of the sealant (in kg/m^2).

The relation points out that the H_2 value must be compared with the H_1 value and that the higher value must be used. Furthermore, it is noted that the sizing calculation of the silicone joints is commensurate with the shapes, the presence of special stresses, the thermal expansion of the technical elements and the production and execution requirements, reaching a value of $6 \div 7$ mm.

The installation of the enclosures to the frame considers:

- the application on clean (free of grease and dust traces) and dry (free of water or condensation) surfaces;
- the technique of assembling the insulating glass panels according to the "step" type solution, achieved by creating an offset (between the upper and lower panels) and guaranteeing the perimeter protection of the inner panels (even with only the structural bonding of the outer panels to the frame).

Moreover, the installation of the enclosures to the frame involves:

- the use of elements with a very low reflection distortion and the utmost care in cutting and grinding, both edges and corners, avoiding defects such as uneven (cutting) surfaces, chipping or cracking of edges;
- the cross-linking processes of the silicone, which are dependent on the temperature and the air hygrometry.

The structural silicone is dark-coloured and remains visible in the form of a "frame" around the enclosure elements, so in order to conceal the effect, a highly reflective outer panel of glass is often used, even with silk-screening along the edges. The structural façade system requires that the sizing of the bonding joint is carried out according to the shape and adhesion surface of the silicone sealant to the glass panels and the metal of the frame: the contact surface of the joint is determined by the size of the panels, the intensity of the wind loads and the allowable stress of the sealant itself. The dimensional analysis considers the diagonal distribution of the wind load on the glass surfaces, so that the lever arm acting on the joint has a length equal to half of the smallest panel size.

Chapter 4
The Technical Interfaces of the Advanced Envelope Systems

Abstract The study examines the applicative coordination procedures for the main types of façade systems composed by the mullions and transoms framing, the structural sealant glazing façade system, the unit façade system, the suspended façade system and the double skin façade system. The analysis focuses, for each of the main façade types, on the technical interfaces in relation to the connection sections, the way parts of the frame profiles are joined and in relation to the enclosure elements. Moreover, the analysis considers the fastenings for the enclosures (glass or opaque) in relation to the frames, noting how they are applied in order to consolidate the construction against water infiltration (with the aid of waterproofing membranes), air infiltration (with the aid of gaskets) and thermal resistance to external environmental stresses. In this regard, the explanation contemplates the specific sections and connections of the frame profiles, aimed at supporting and including the fastening, heat-insulating and sound-insulating materials, especially with regard to the anchoring parts and the relations to the building structures and cladding systems. The study is confirmed in the form of a technical construction guide through the formulation of the attachment methods of the main façade types with respect to the extra- and intradossal surfaces, lateral and roof surfaces: in this case, the analysis observes the interaction with the additional fastening elements towards other components and technological systems. Based on the contents, frame apparatuses and specificities of the individual façade types, the study explores the assembly sequences and joining phases between the structural, closing and finishing elements.

4.1 The Functional, Constructive and Applicative Coordination Procedures of the Mullions and Transoms Framing

The applicative coordination procedures of the mullions and transoms framing involve the construction of the glazing cavities on different planes: any infiltration water is thus drained from the collection plane of the transoms onto the lower plane of the mullions and, from there, guided in a controlled manner down to the base of the

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PoliMI SpringerBriefs, https://doi.org/10.1007/978-3-031-49608-0_4

façade. This type of connection allows for perimeter ventilation of the double-glazing from the four corners of each individual module, through the mullion profiles. The execution of the vertical enclosures to the mullion and transom load-bearing frame is carried out by pressure tightening of the linear device (called as pressure device), shaped to accommodate (at the lateral ends) the glazing gaskets to the pronounced linear pins beyond the outer front partitions of the mullions and transoms themselves. Tightening is done by through-screwing, on the inside of the insulation profile on the outside of the linear pins.

The execution of the system is also determined with respect to different types of substructures (made of tubular steel or timber profiles), with the mechanical assembly of the geometric sections akin to the front projection parts of the mullions (with fastening pin and couple of seats for cavity the gaskets). The configuration of the system is obtained by the assembly of the profiles with two portions resting on the tubular or "T" shaped steel substructure, projected to contain the cavities for the internal gaskets and extended to the linear pin, within which the press-fixing (provided with the external gaskets) of the double-glazed units is arranged (Fig. 4.1).

The interface conditions between the mullions, transoms and opaque enclosures (in the *spandrel* and stringcourse form) or the connection sections (e.g. to close off the elevation at the extrados of the deck) involve the insertion, in the assembly space between the internal gaskets and the press gaskets, of PVC profiles. At the same time, the interface conditions relating to the execution of the parapets may provide for the insertion of a plastic profile, on the mullions and transoms, in order to apply the monolithic sheets and to create a pressure-compensating air gap between the

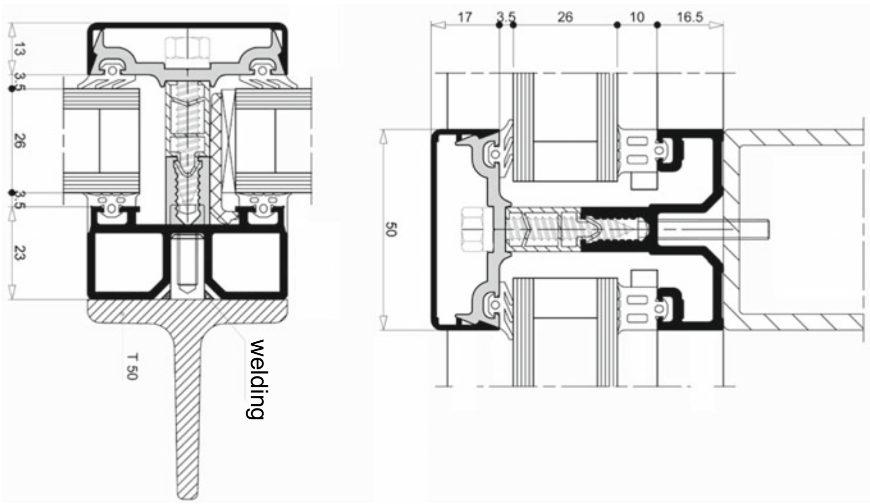

Fig. 4.1 Execution of the system also determined with respect to a substructure (e.g. in tubular or "T" shaped steel profiles), through the assembly of the profiles with two supporting portions, consisting of the cavity for the internal gaskets and the linear pin within which the pressure device for the connection of the double-glazing enclosures is arranged. © Courtesy of Metra

external glass closure and the insulating panel (in the *spandrel* form) (Fig. 4.2). The flatness of the closing surfaces can also be achieved by means of the glass cavity reduction devices, composed of "U"-shaped inserts in continuous or box form (with dimensions between 5 ÷ 45 mm): the profiles are equipped with both the insertion ribs in the slots provided on the front partitions of the mullions and transoms, and the open cavities, towards the outside, for the insertion of the internal gaskets.

The execution of the panels (in the *spandrel* form, with outer glass enclosure, inner aluminium sheet and thermal insulation layer) observes the insertion of the pronounced side sections, in such a thickness as to compensate for the geometric height due to the double-glazing sheets (Fig. 4.3).

The execution of the mullion and transom system to the building works, in the case of the connective interface to the lower support sections, foresees the use of the

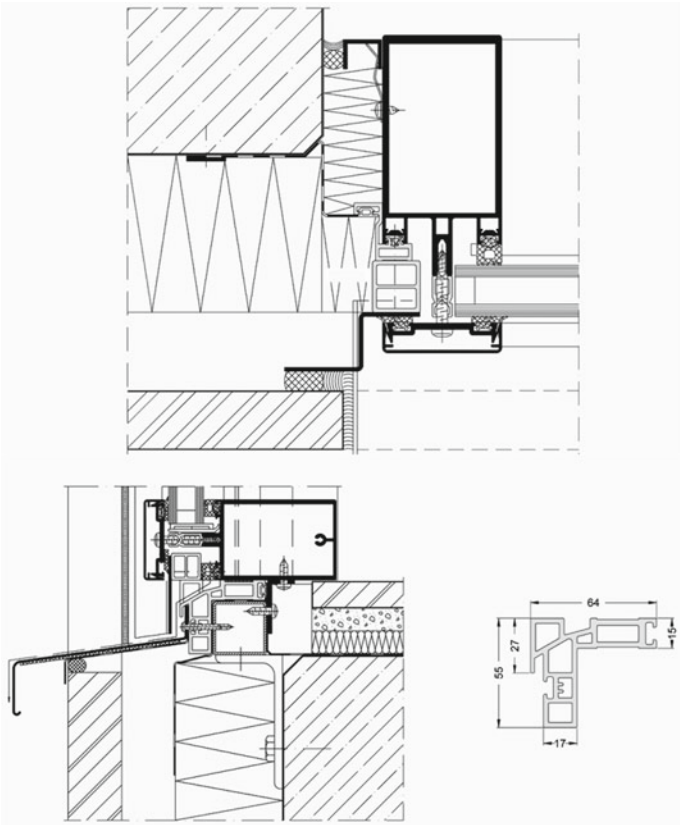

Fig. 4.2 Interface conditions between mullions, transoms and opaque closures (both in the *spandrel* and stringer form, to close the elevation at the extrados of the deck) which involve the insertion of PVC profiles (double chamber with internal stiffening rib) between the internal gaskets and the pressure gaskets and the insertion of plastic profiles, to create the compensating air space between the glass enclosure and the insulating panel. © Courtesy of Schüco

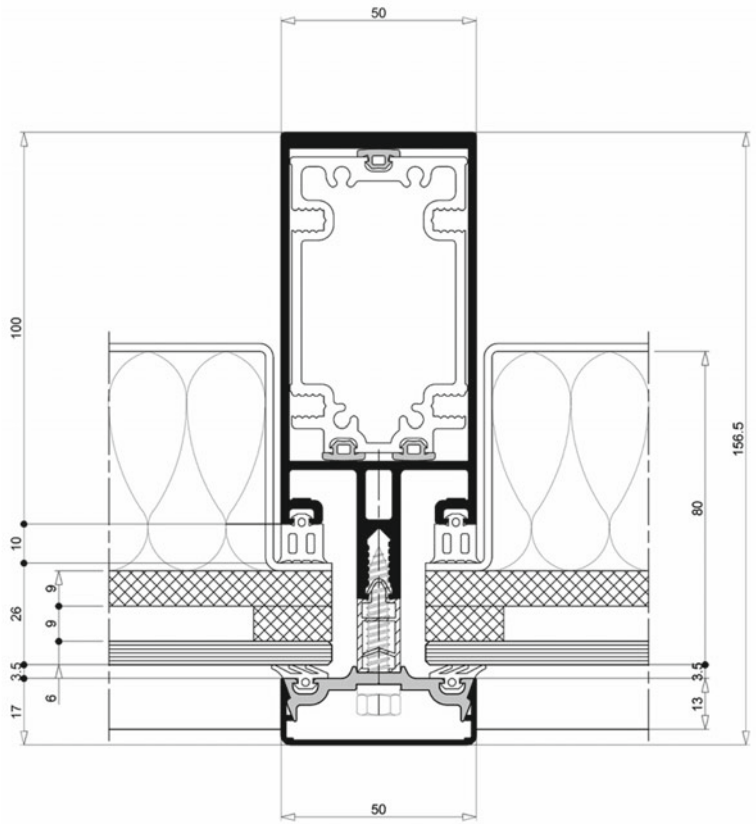

Fig. 4.3 Execution of the panels to the mullion and transom load-bearing frame, in the *spandrel* form, which detects the application of external closing glass panes, the internal aluminium sheet cladding, with interposed thermal insulating layer and the insertion of the side sections to compensate for the geometric height, due to the double-glazed panes. © Courtesy of Metra

aluminium angle profiles for the connection to the horizontal or vertical enclosure sections (as, for example, for the vertical front surface of the elevation, for the finishes and for the thermal insulation panels, at the extrados of the deck, of the false ceiling slabs). The execution related to the lateral section foresees the use of compound elements equipped with an aluminium “L” angle profile, with a double couple of ribs for the passage of two polyamide spacers (aimed at thermal break), stretched up to the linear aluminium profile. These elements are executed according to the insertion of the thickness defined by the two spacers and the profiles into the geometric and dimensional space occupied by the double-glazing sheets, generating, on the outside, the surface correlated to the finishing and sealing, and, towards the inside, the support of the extended wing of the “L” profile on the dowel interposed against the wall surface. The fixing is closed by means of box-shaped elements (to be snapped onto the ribs pronounced by the pressure device), characterized, in the morphological and executive generality of the cross-section, by two lateral wings (varying in size between 10 ÷ 100 mm): these are connected (in the homogeneity of the extrusion) to the front wing of linear geometry, also in the constitution composed of the stiffening due to the external extension of the lateral wings, or convex, ogival, cusp-shaped, also of the "U" and "T" type (Fig. 4.4).

The configuration of the aluminium mullion and transom profiles may also be defined according to the "I" and "T" shape, through the linear structural section provided with an internal cavity, for the insertion of the sleeve in homogeneous form along the box geometry, and through the eventual normal section towards the inside (with lateral dimension equal to 15 mm, for the linear "I" section, and equal to 50 mm, for the transversal section at the internal end, with longitudinal dimension variable between 85 ÷ 250 mm). At the same time, the mullions can be made in combined form, providing for the insertion, guided by the specular couples of ribs, of the two stiffening cantilevers. At the front, the profiles are equipped with both the threaded linear pin (of the "endless" type) for fixing the pressure device, and the parallel couple of seats for cavity the internal gaskets (Fig. 4.5).

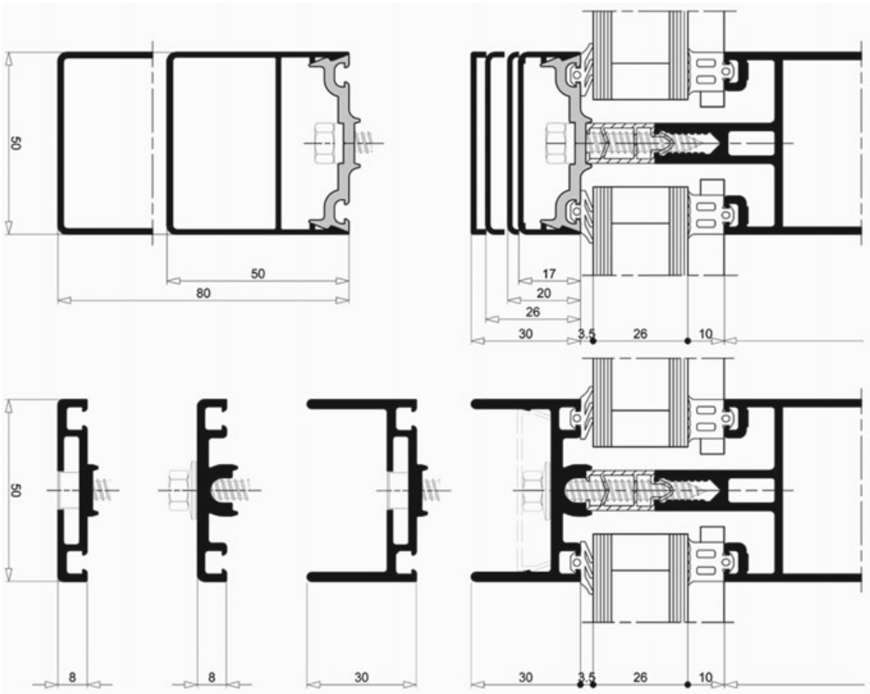

Fig. 4.4 External enclosure of the fastening determined by the assembly of the covers, according to the composition executed by two side wings connected to the front wing of linear geometry, the snap-on application to the ribs pronounced by the pressure device and the constitution executed in box form or by the external extension of the side wings. © Courtesy of Metra

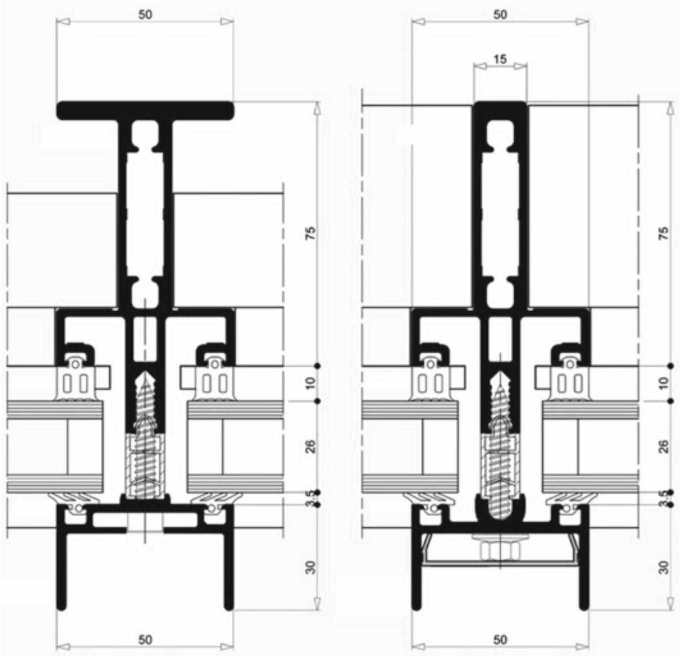

Fig. 4.5 Configuration of the aluminium mullion and transom profiles also defined according to "I" and "T" shaping, by means of the linear structural section, equipped with internal cavity, for the insertion of the sleeve along the box geometry, and the cross-section (with 15 mm dimension for the "I" type, and 50 mm dimension for the "T" type). © Courtesy of Metra

4.2 The Functional, Constructive and Applicative Coordination Procedures of the Structural Sealant Glazing Façade System

The applicative coordination procedures of lateral aggregation of the structural sealant glazing façade system result in the absence of the frame profile at the interface facing the wall, noting (in the same geometric and connective space):

- the inclusion of the waterproofing sheathing, at the cavity of the internal gasket, extended up to the surface related to the vertical enclosure;
- the application of the tubular profile, replacing the glazing profile, equipped with the cavity necessary for the insertion (with the head gasket included) of the turn-up sheet to the thermal insulation layer and such as to define the support to the gasket in rebate on the external cladding (Fig. 4.6).

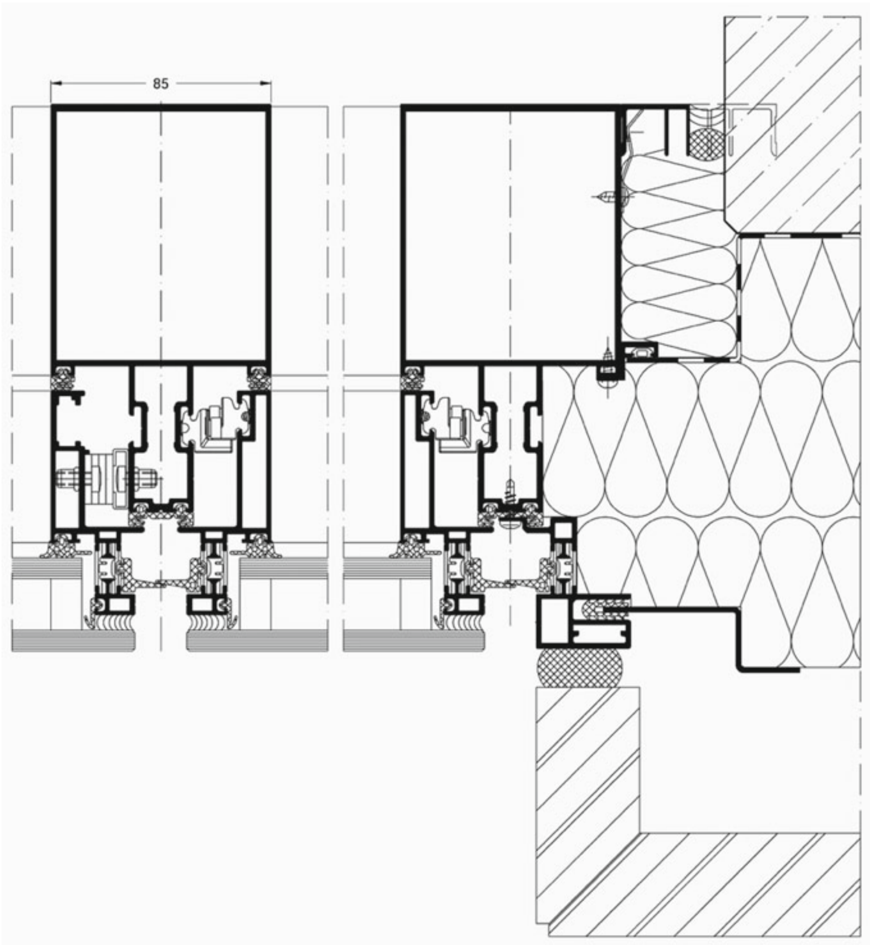

Fig. 4.6 Lateral aggregation of the mullions that entails the absence of the frame profile at the interface facing the wall, detecting the extension of the waterproofing sheathing, from the cavity of the internal gasket to the wall surface, the application of the tubular profile, equipped with the insertion cavity (with head gasket) for the sealing sheet on the thermal insulation layer, and the application of the rebated gasket on the external cladding. © Courtesy of Schüco

The lateral connection of the mullions, in the case of the external projection of the central double ribs profile, entails the absence of the frame profile towards the wall, noting (in the same geometric and connective space):

- the inclusion of the waterproofing sheathing to the cavity of the internal gasket, extended up to the surface related to the vertical enclosure and closed by the angle profile associated with the profile fixed to the tubular section;
- the application of the wing profile (by screwing) extended from the segment equipped with the ribs for the couple of polyamide bars directed to the tubular

device (of the same glazing bead geometry): this extended by means of two wing baffles for the insertion of the corner enclosure profile (Fig. 4.7).

The application of the mullions, through the assembly performed by means of the brackets and sleeves aggregated to the structural surfaces of the extrados, involves the interface to the transoms, consisting of the tubular section without the connection to the lower frame profile. The rear rib of the transom performs the assembly surface (by screwing) to the sheet metal flap placed as a closure against the upper horizontal finishing layers of the horizontal structure. In addition, the transom realizes

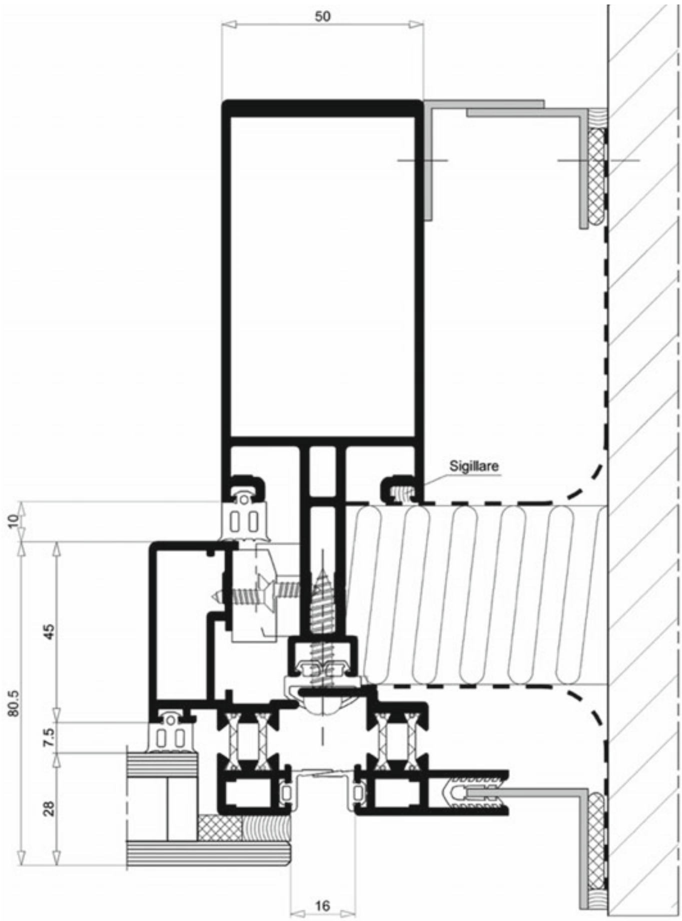

Fig. 4.7 Lateral aggregation of the mullions, without the frame profile towards the wall, that provides for the insertion of the internal waterproofing sheathing, according to the fastening to the cavity housing the internal seal and the fastening to the wall surface (via angle profile), and the insertion of the external waterproofing sheathing, according to the fastening to the wall surface via angle profile, aggregated to the cavity extended beyond the laying profile. © Courtesy of Metra

the connection to the tubular profile, replacing the glazing profile, with the cavity necessary for the insertion of the sheet metal (with the head gasket included) both as a flap to the heat-insulating layer, and as a support to the rebate gasket on the external cladding (Fig. 4.8).

At the extrados interface, the construction of the transom includes:

- in the upper part of the central profile, the assembly of the frame to support both the panelling and the glazing bead, according to the connection defined by the couple of perforated polyamide bars for the drainage of any rainwater (infiltrating the internal section of the glass pane);

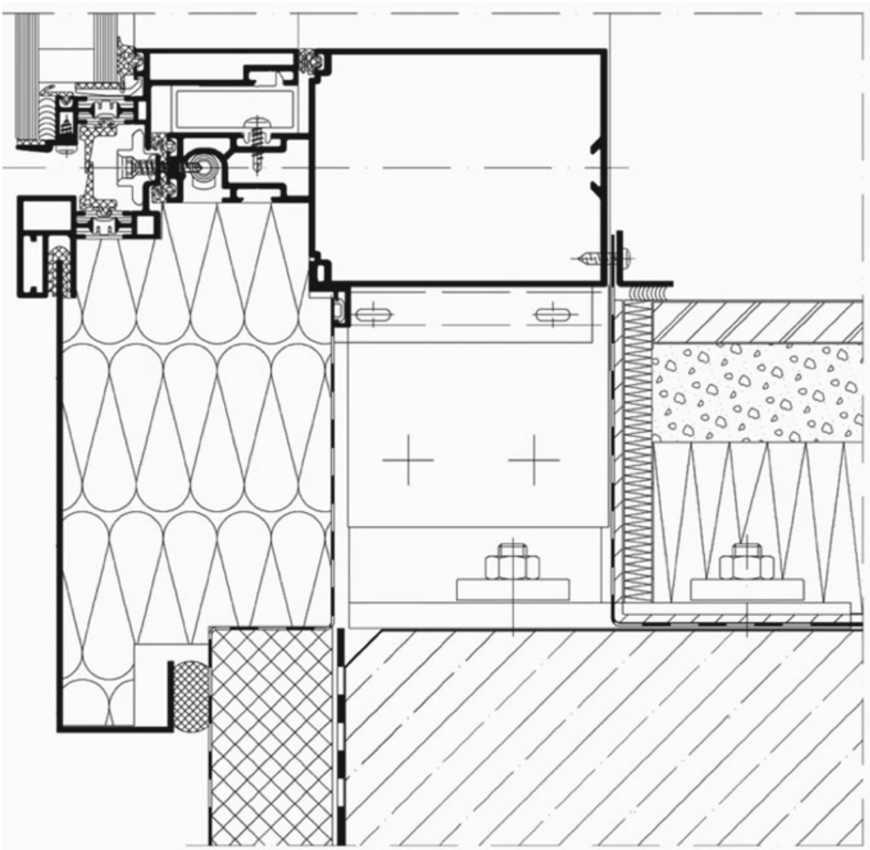

Fig. 4.8 Assembly to the horizontal elevation structures that provides for the connection by means of the brackets, aggregated to the extrados surfaces, the application of the lower transom without the frame profile, the connection of the sheet metal flap to close the horizontal finishing layers and the connection to the tubular profile, replacing the glazing profile, equipped with the cavity necessary for the insertion of the sheet metal. © Courtesy of Schüco

- in the lower part of the central profile, the projection of the vertical segment (assembled, by screwing, to the profile itself) flowing into the ribbed part supporting the couple of polyamide bars projecting towards the compensation profile (in the geometry and dimension of the glazing bead): this equipped with the perforated intermediate rib (for the outflow of any rainwater) and the double open vertical wings, aimed at containing the insert of the angle profile, with interposed gasket, to close on the extrados by means of the gasket, the waterproofing sheathing and the silicone seal (Figs. 4.9 and 4.10).

The mullions, executed by means of the "π" brackets to the roofing structures, support the transoms defined by:

- in the lower part, the connection to the *spandrel* panel (with internal cladding sheet and interposed thermal insulating layer) according to the attachment of the external panel to the laying profile (with structural silicone);

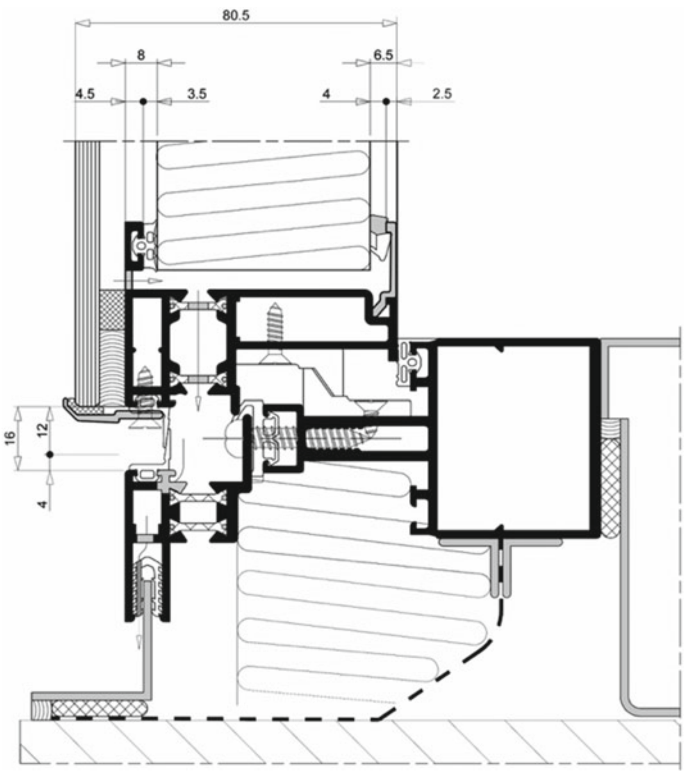

Fig. 4.9 Construction of the transom at the extrados interface that involves the assembly of the rear connection plate towards the deck structure, with silicone gasket and sealing, the application of the internal waterproofing sheathing (by grafting two corner profiles onto the lower surface of the tubular section), the assembly of the front connection plate. © Courtesy of Metra

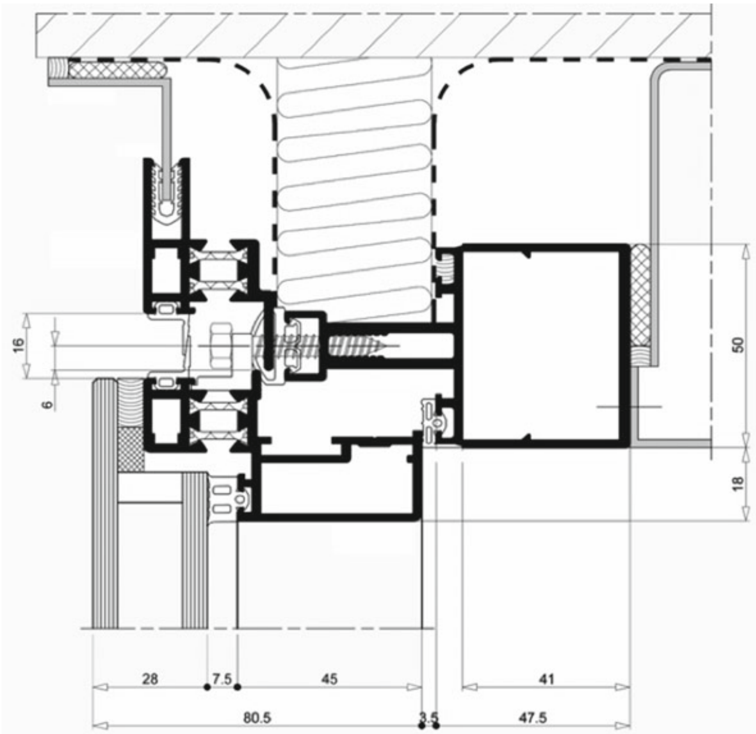

Fig. 4.10 Construction of the transom at the intrados interface that involves the assembly of the rear connection plate towards the deck structure (with silicone gasket and sealing), the application of the internal waterproofing sheathing (defined above the central pin), the assembly of the front connection plate. © Courtesy of Metra

- in the upper part, without the frame profile, the support surface (by means of the longitudinal rib, the central stud rib and the connection bar) in relation to the thermal insulation layers, the waterproofing sheathing and the flashing sheet;
- the connection to the tubular profile, replacing the glazing profile.

In addition, the transoms realize the connection to the tubular profile, which replaces the glazing profile, for the connection of the retaining sheet to the heat-insulating layers and to the flap of the waterproofing membrane (Fig. 4.11).

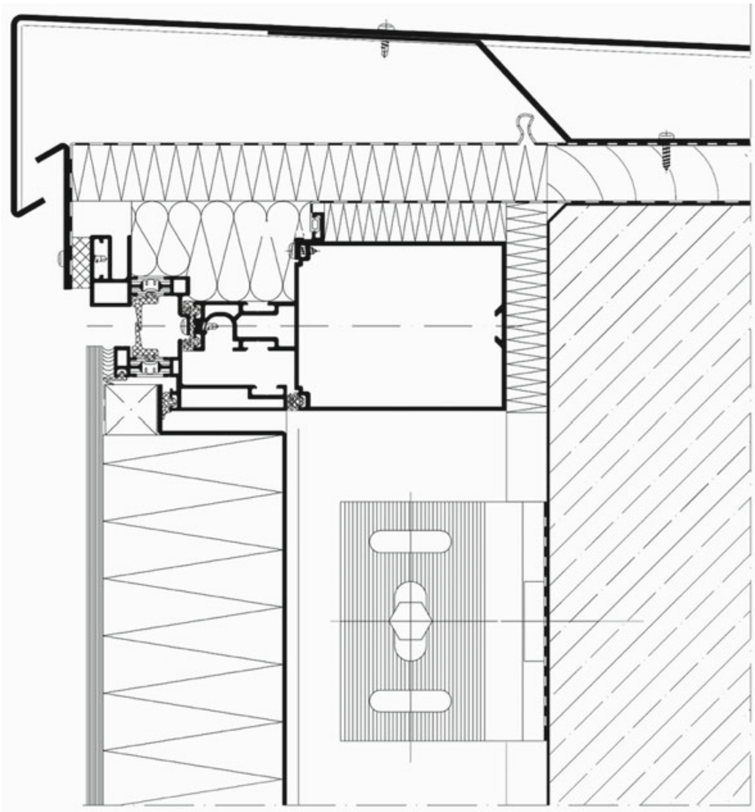

Fig. 4.11 Assembly of the structural façade system to the roofing structures that involves the connection by means of the "π" brackets (aggregated to the perimeter surfaces), the application of the spandrel panel (with cladding sheet and heat-insulating layer) to the upper transom according to the attachment of the outer sheet to the laying profile. © Courtesy of Schüco

4.3 The Functional, Constructive and Applicative Coordination Procedures of the Unit Façade System

The applicative coordination procedures of the unit façade system, with respect to the interface portions contiguous to the main horizontal load-bearing structures, involve the connection to the *spandrel* panelling (with external tempered glass cladding, multilayer with aluminium sheet metal cladding and interposed insulating layer). The assembly of the cellular components involves:

- at the rear, the joining (by screwing) of the cladding to the internal cavity section of the mullion;

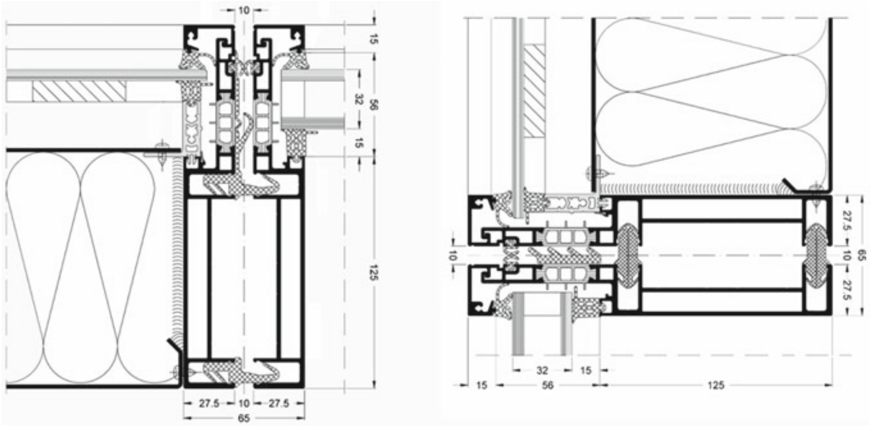

Fig. 4.12 Unit system that provides for the assembly of the *spandrel* panels (with toughened glass cladding, internal aluminium sheet and thermal insulation layer) through the rear joint to the internal cavity of the mullion and the front joint to the PVC connecting insert: this is characterized by the insertion of the internal gasket, which is gripped onto the closing panels. © Courtesy of Schüco

- in the front part, the junction (by screwing) of the cladding to the laminar projection (planar to the façade) carried out by the thermal break insulating insert (in polyamide): this is connected to the internal cavity included on the mullion and is extended to contain the gripping gasket on the internal surface of the enclosure panel (Fig. 4.12).

The possible application of the support to the shielding is noted, in external contiguity to the *spandrel* band, according to the interface established by the cavity made by the upper transom: this involves the guiding of the shielding elements retained by the cantilever device connected to the lower frame transom (Fig. 4.13).

The interface of the system with the walls involves the application of the last cell at a distance that allows, beyond the construction tolerances:

- the interposition of the insulating layers (in contiguity with the tubular section and the rear "U"-shaped profile cavity);
- the internal enclosure by means of an angle profile;
- the passage of the waterproofing sheath over the front cavity of the mullion (stopped with an "L"-shaped profile);
- the execution of the external insulating layer (planar to the wall);
- the execution of the turn-up profile (connected to the profile section fixed to the polyamide insulating insert of the mullion), extended (planar to the façade) up to the joint (in silicone) on the cladding sheet, if present (Fig. 4.14).

The lateral connection to the masonry wall involves the use of mullions with a median tubular section, observing the support on the retaining surface of the external insulating layer: this according to the ribs produced by the lateral cavity guides and according to the inclusion of the silicone seal on the external groove. The frame

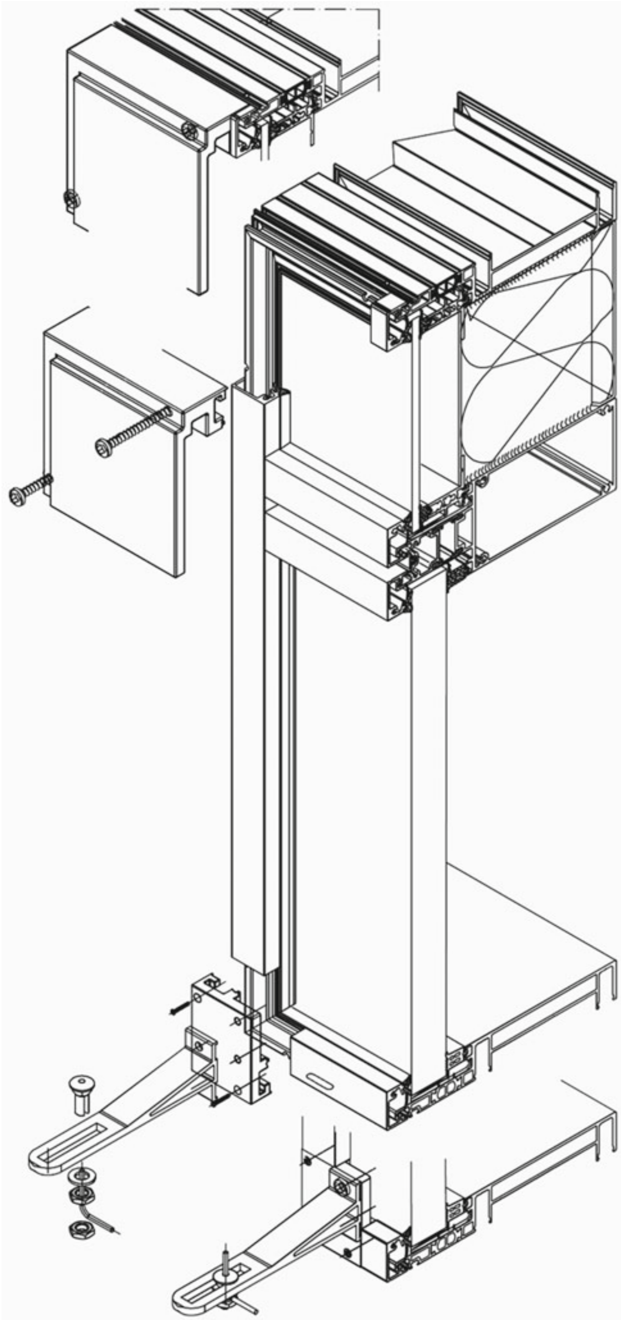

Fig. 4.13 Unit façade system that envisages, in the external contiguity to the *spandrel* strips (in relation to the horizontal structures), the arrangement to accommodate the connective interfaces to the application of the shading by means of the mounting of the support device to the upper transoms and the guide profiles to the lower transoms. © Courtesy of Schüco

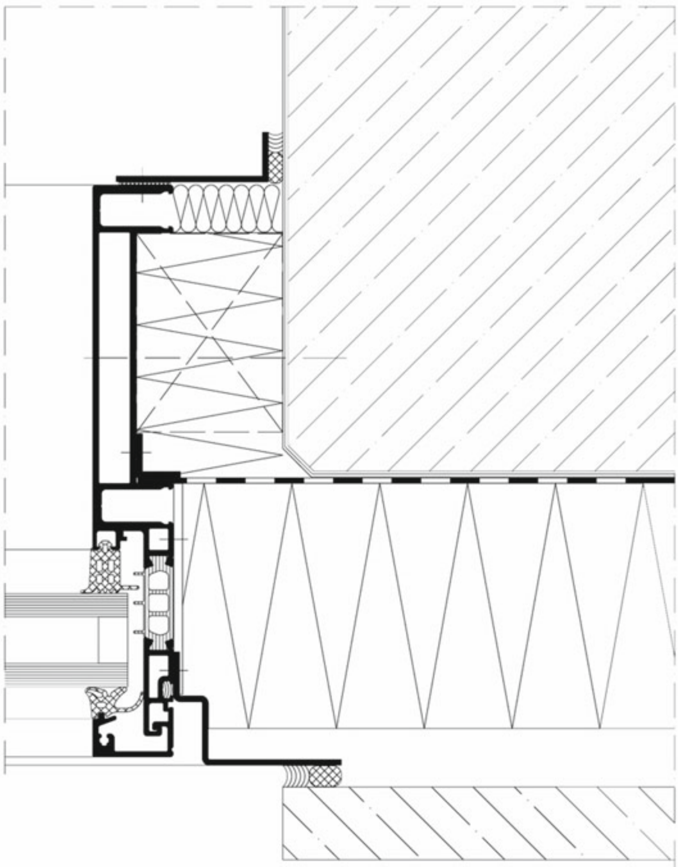

Fig. 4.14 Interface of the system to the walls that provides for the application of the last cell at such a distance that, in addition to the construction tolerances, the thermal insulation layers (in contiguity with the tubular section, the rear cavity and the wall surface) can be interposed: this by noting the installation of the inner end sheet, with silicone gasket and sealing, the application of the outer sealing sheathing, by means of the insertion of the angle profile on the inner surface of the tubular section, and the development of the outer end sheet to the installation profile, with gasket and sealing in rebate on the outer cladding. © Courtesy of Schüco

profiles are composed both with respect to the interface related to the *spandrel* panelling, and with respect to the tubular configuration connected to the linear pin protruding from the mullion and supporting the laminar profile (perpendicular to the façade plane), with a polyamide connector, protruding towards the mechanical retainer and the grip seal on the outer cladding (Fig. 4.15).

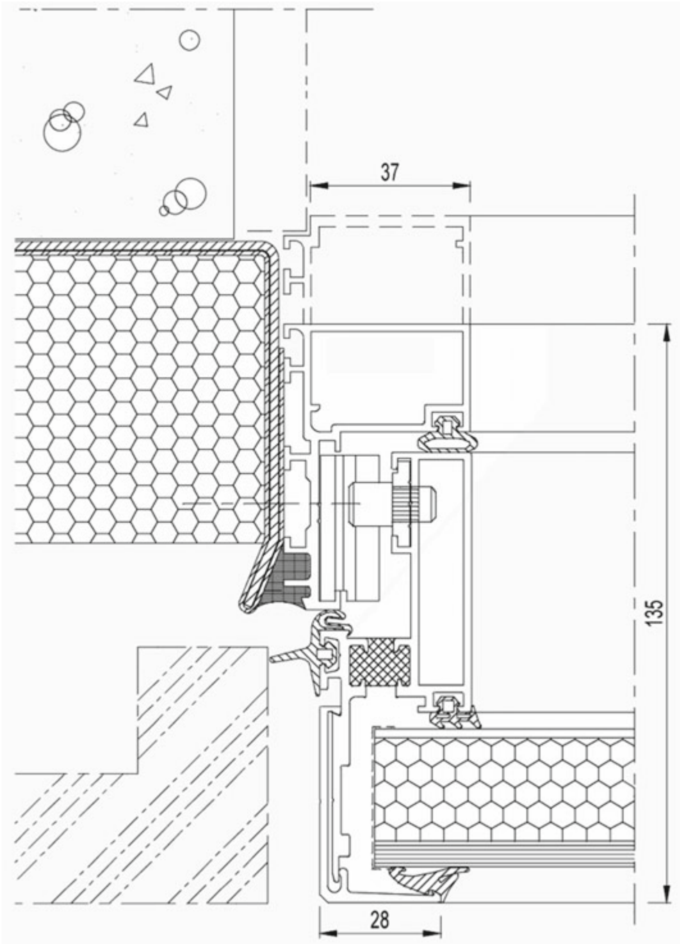

Fig. 4.15 Lateral connection to the masonry wall that involves the application of the mullions contiguously to the retaining plate of the thermal insulation layer, the silicone sealing on the external groove and the rebate sealing of the central seal on the cladding. © Courtesy of Reynaers

The interface of the system with respect to the extrados of the main structural apparatus considers the execution of a transom above a tubular or shaped stainless steel profile (resting on the upper surface of the horizontal structure): this takes over the upper passage of the waterproofing sheathing, extended up to the vertical surface of the horizontal structure itself, and the insertion of a lower dowel. This transom, which performs the connective interface with the lower transom related to the frame of the cell in upper assembly, provides for:

- at the rear level, the connection with an angle profile (in sheet steel) containing the horizontal finishing layers, with the interposition of the gaskets and silicone sealing;
- at the front level, the plastic insert (in the geometric and dimensional space occupied by the double-glazed unit) between the inner gasket and the outer gasket extending beyond the mechanical retainer, on which the flashing is made to turn back beyond the wall.

The covering interface detects the application of the *spandrel* enclosures beyond the surfaces, vertical and horizontal, of the main horizontal structure, involving the lifting with the use of “ring screws” to be removed after assembly to the brackets. The component involves the insertion of the intermediate transoms and the use of a transom to close the top of the cell, in order to create the supporting surface to:

- the waterproofing sheathing carried above the external thermal insulation layer;
- the sloping profile (resting frontally on the aluminium sheet profile, extended beyond the plastic dowel included in the transom between the seals) to support the flashing (Fig. 4.16).

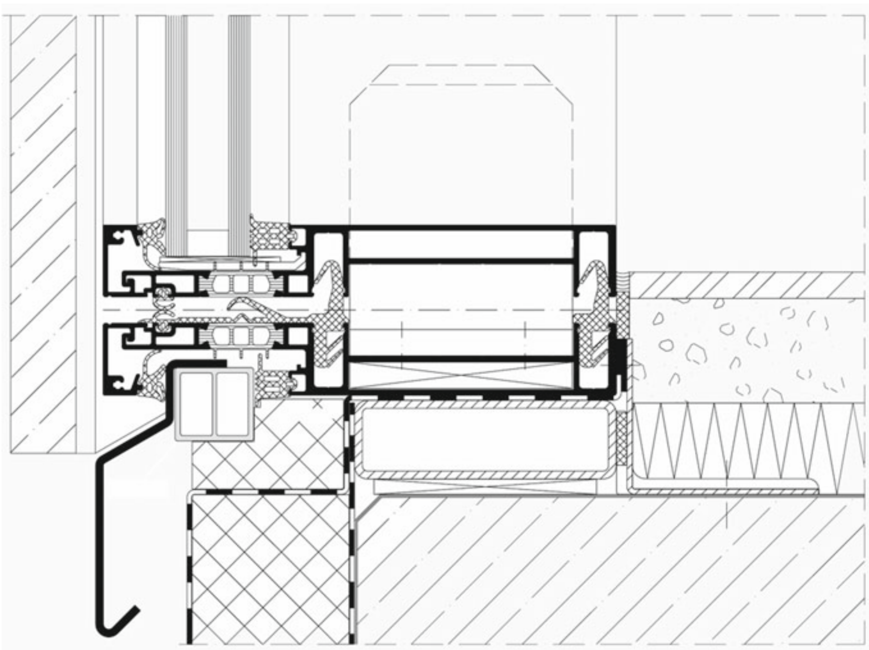

Fig. 4.16 Unit system interface with respect to the extrados of the main load-bearing apparatus that considers the execution of the stainless steel tubular profile for the attachment of the external waterproofing membranes. © Courtesy of Schüco

The construction of the system foresees the assembly of the cells according to the coupling of the "bayonet" device (connected to the upper end of the mullions) inside the slots marked within the brackets (in aluminium or stainless steel): these are made at the extrados of the main horizontal structures, by means of connection to the profiles (*halfen* type) anchored to the reinforcement and embedded in the slab casting. The cells are lifted in place by means of the two through the "ring screws" within the tubular sections of the mullions, connected by bolting: these ribs culminate in the perforated portion and realize the connection to the upper cell, by means of the lateral insertion contained within the vertical grooves (Fig. 4.17).

4.4 The Functional, Constructive and Applicative Coordination Procedures of the Suspended Façade System

The applicative coordination procedures of the suspended façade system focused on the development of the device aimed at point support and the inclusion of the spherical joint, including a support and an external aluminium pressure device. The connection is made through the spherical joint, in order to allow both the transmission of the stresses induced on the panes by external actions and the deformations of the panes themselves: this is achieved by incorporating in the joint appropriate spherical caps in plastic material with a low friction coefficient.

The formulation of the fixing devices examines the physical behaviour of the glass modules which, due to their rigidity, do not allow the stresses generated within them (caused by the action exerted by the devices themselves) to distribute themselves uniformly (as much as to localize at the points of contact) (Fig. 4.18). The modulation of the structural glass façade is defined in accordance with the coordinated positioning of the main structural axes, according to geometries and elevations capable of directing and governing the succession by unified enclosures. The vertical arrangement is between the two sets of transverse steel trusses, base and roof, between which the pattern of modules is articulated by means of the base elevation, the intermediate module elevations and the upper elevation.

The design of the evolved structural glass system is concretized by the positioning of the lower main load-bearing apparatus, composed of the steelwork sections with the holes facing to accommodate (by bolting):

- the arrangement of the pairs of brackets for the attachment, via the holes in the vertical plates, of the series of pins passing through the top of the ropes;
- the arrangement of the central brackets for the attachment, via the holes in the vertical plates, of the individual through-pins to the top of the ropes;
- the arrangement of the cross brackets between the profiles placed in contiguity.

The perimeter arrangement of the steel profile beams, located in transverse succession, involves the application of the brackets (between beams in contiguity) in support a)

b)

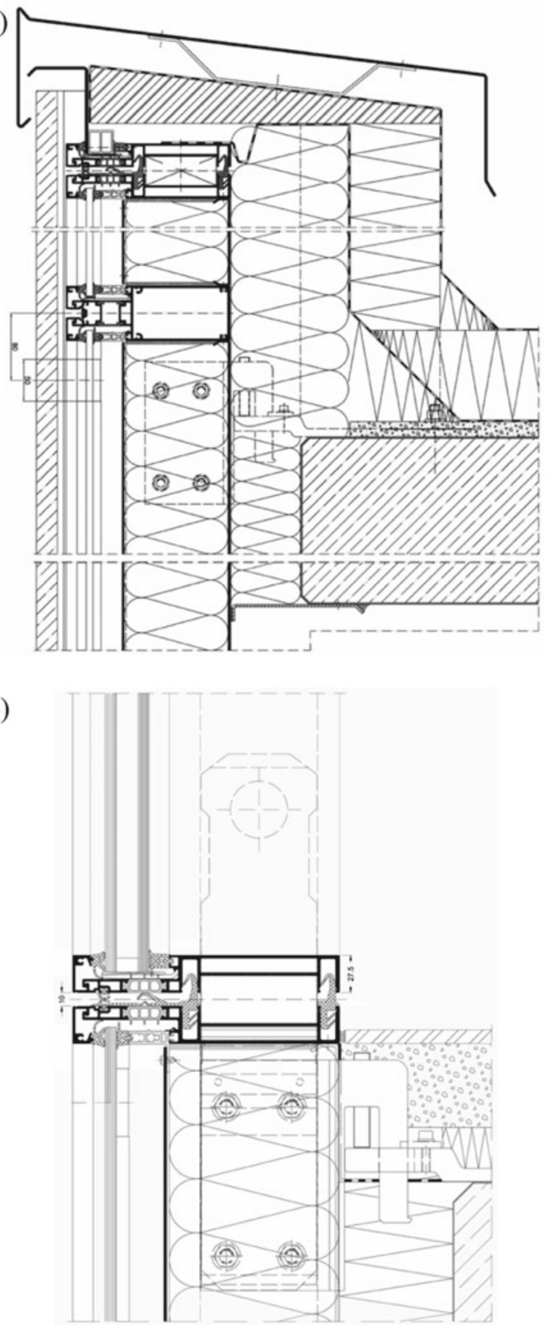

Fig. 4.17 Interface of the system to the roof that detects the application of the *spandrel* panels beyond the main structure, the interposition of the thermal insulating layer and the fixing of the external waterproofing sheathing (**a**). Construction of the system that provides for the assembly of the cells to the main load-bearing structures, by means of the brackets, through the *halfen* profiles anchored to the reinforcement and embedded in the slab casting (**b**). © Courtesy of Schüco

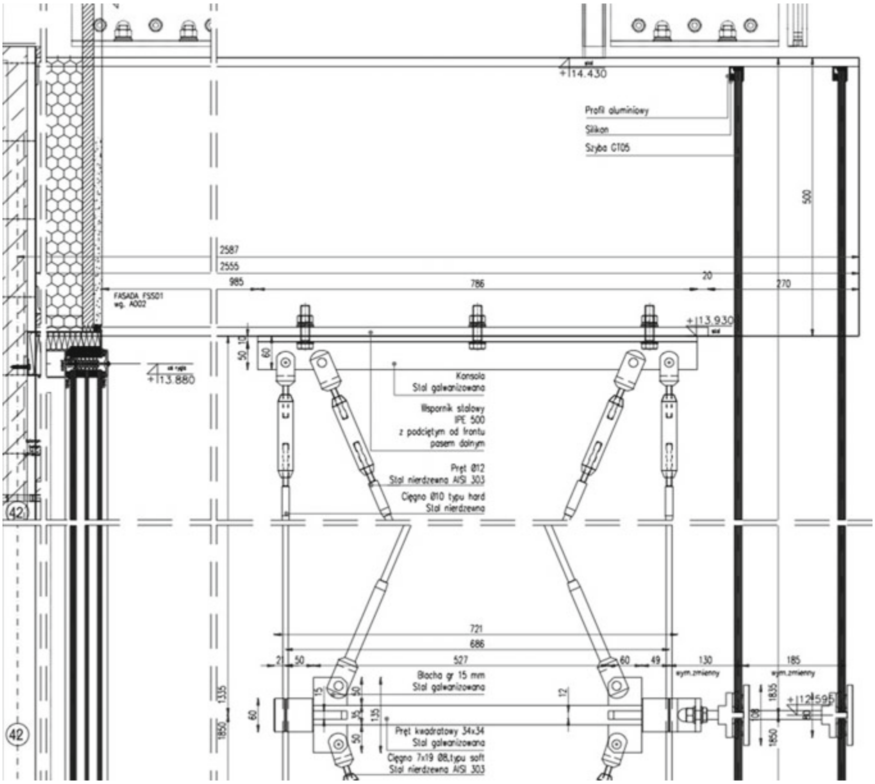

Fig. 4.18 Stelmach & Partners, *CSK*, *Centrum Spotkania Kultur* ("Centre for Encountering Cultures"), Lublin. Connection of the reticular structure to steel brackets for attaching cable end pins. © Courtesy of Lilli Systems

of the linear arrangements. The series of steel plate brackets, connected to the upper wings of the beams, involves the procedures for fastening the end pins for both the linear ropes (in the outer portions) and the diagonal ropes for the forceps combination (in the intermediate sector). The pins result in the engagement of the threaded sleeves for the adjustment of the interface dimensions, while at the extrados of the beam sections, the lower glass modules are supported (with the insertion within the aluminium profiles and silicone sealing) (Fig. 4.19).

The development of the ropes, from the end pins connected to the steel brackets, observes the operation according to:

- the extension with respect to the outer and inner alignments, both passing through the guiding devices;
- the extension with respect to the diagonal geometries, characterized by:
  - the engagement towards the flanges extended by the horizontal brackets, according to the engagement (by bolting) through the holes by the end pins;

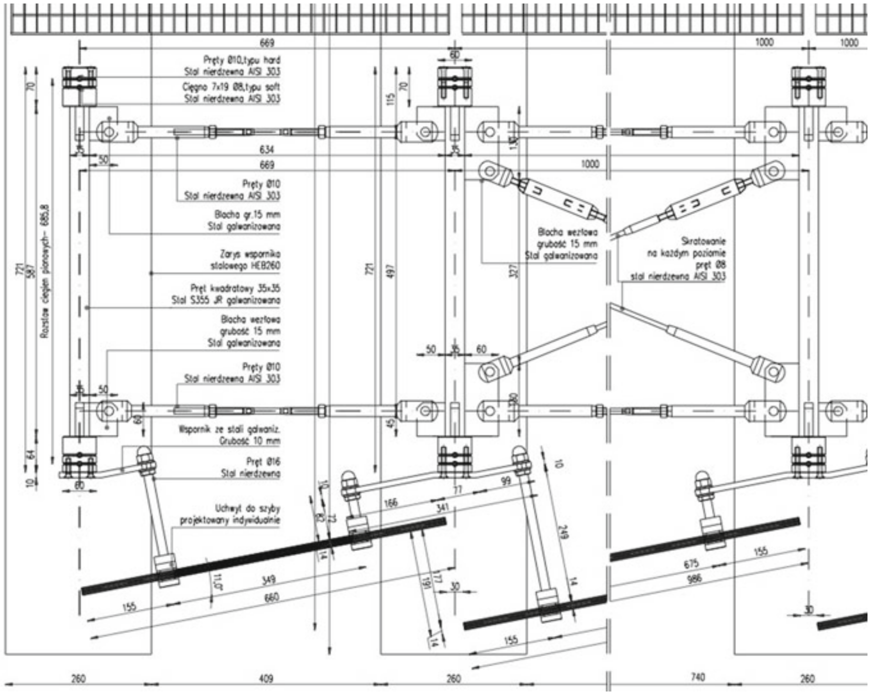

Fig. 4.19 Stelmach & Partners, *CSK*, *Centrum Spotkania Kultur* ("Centre for Encountering Cultures"), Lublin. Composition of the bracing sections according to the fixing procedures of the end pins, hooked to the flanges extended by the brackets, which are directed up to the elements including the cable passages: these sustain the spacers supporting the point jointing devices in accordance with the variation of the geometric dimensions of the glass panes. © Courtesy of Lilli Systems

– the passage within the guiding devices that match the development of the linear beams.

The execution phase emphasizes the construction coordination methods governed by the assembly of the brackets above the base beams, from which the tensors for the engagement of the linear and diagonal beams depart. The warping proceeds with the interposition of the horizontal brackets relative to the bracing sections, from which the support surfaces for the projection of the spacers unfold (Fig. 4.20).

The lower wings of the steel truss provide the fixing surface (by means of the through holes) to the series of steel brackets for the attachment of the end pins; in particular, the extension of the trusses reaches the outermost façade edge (according to the height reached by the "flake" composition of the glass panes), resulting in the cutting of the lower wings. Then, as in the case of the basic solution, the sheets are cut through the aluminium channels and silicon sealed. The upper wings of the transverse truss profiles make up the support plane for the glass framing to create the load-bearing outline for the upper crowning box enclosure, clad in glass panes. Here

Fig. 4.20 Stelmach & Partners, *CSK*, *Centrum Spotkania Kultur* ("Centre for Encountering Cultures"), Lublin. Constitution of the section occupied by the tensile structure, within the space between the curtain walling and the structural glass modules. © Courtesy of Lilli Systems

again, the continuation of the structural framework is outlined with the contribution of the mechanical combination procedures by means of the squares and bolted joints.

The weaving of the transverse booms, for the warping of the bracing sections, is realized through the aggregation of the end pins, provided with the adjustable coupling: these are hooked onto the flanges extended by the booms, which in turn are spaced according to coordinated and variable dimensions. In the case of the passage also due to diagonal beams, the dimensions of the flanges are larger in order to accommodate double drilling and bolting. The brackets extend up to the elements including the cable passages, which in turn serve to make the connection plane for the articulated steel segments supporting the spacers.

In the case of the arrangement of the bracing frame against the main structural axes, the execution foresees the splitting of the brackets, in order to comply with the mechanical requirements of the construction: each of the two brackets in contiguity is provided with the guiding devices and connections aimed at supporting, in an autonomous manner, the segments from which the spacers are unfolded. This not only involves the aggregation of flanges of a size to accommodate the end devices for the diagonal cables.

Within the sequential development of the spans afferent to the bracing structure are the stiffening sections, composed of the combination of the diagonals connected to the flanges extended by the solid profile brackets. The external projection of the brackets, which support the templates supporting the spacers, delineates the load-bearing base for two glass enclosures in contiguity. Specifically, two inclined spacers, one tapered in size and the other extended in size to reach the outward-facing flap, depart from each template.

4.5 The Functional, Constructive and Applicative Coordination Procedures of the Double Skin Façade System

The applicative coordination procedures of the double envelope façade system are defined, principally, through the use of prefabricated cellular façade components, equipped with adjustable operating modes according to the external micro-climatic conditions and the heating or cooling requirements of the internal spaces. The system foresees that the ventilated cavity (wide = 20 ÷ 120 cm) performs various integrated functions (for the definition of complex mechanisms of dynamic interaction with the external climatic conditions), both permanent (for example, for the increase of thermal inertia and acoustic insulation relative to the internal curtain), and temporary (for example, for the disposal of water vapour accumulated in the internal spaces during periods of reduced environmental temperature or for the cooling of the same spaces during periods of high environmental temperature).

Specifically, the double skin façade system is composed of:

- the frame and connective apparatuses with the main load-bearing structures;
- the internal curtain wall system consisting, in general, of double-glazed sheets (with low-emissivity film insertion), in order to avoid the phenomena of both surface condensation of water vapour (on the internal sheet, since, in this situation, the temperature is in any case higher than the external temperature), and overheating (especially during the summer). In this case, it is not possible to foresee direct openings towards the ventilated cavity (also for the placement of the shielding devices), foreseeing the use of sliding or vasistas type openings;
- the cavity interposed between the two closing walls, aimed at the accumulation of thermal energy related to solar radiation and/or aimed at determining the upward motion of the air flow (which also performs the function of an insulating layer), according to the operation referred to:
  - the periods of reduced environmental temperature, for which the air contained in the cavity creates a *buffer zone* (functioning by "greenhouse effect", providing for the enclosure of the ventilation slots) characterized by the intermediate temperature between the external and internal climatic conditions;
  - the periods of high environmental temperature, whereby the air contained in the cavity is set in upward motion (by the "chimney effect") through the absorption of solar radiation by the glass walls, by the shading devices and by the additional connective elements, usually metallic (which re-radiate the radiation itself): in

Fig. 4.21 Maurizio Varratta, *iGuzzini Lab*, Recanati. Building of the internal curtain wall system, consisting of double-glazed sheets, in order to avoid the phenomena of both surface condensation of water vapour and overheating. © Courtesy of Pichler Projects

this way, the flow transports and evacuates the accumulated heat towards the outside (for an amount equal to 25% of the heat resulting from the radiation directed into the cavity) (Figs. 4.21 and 4.22);

- the air flow regulation devices and the ventilation louvers, located near the deck sections that are connected to both the external screen (for the entry and exit of air flows from the environment to the cavity), and to the internal curtain (for the entry and exit of air flows from the cavity to the internal spaces): these louvers can be constantly open (for the realization of a passive system) or they can be controlled by means of a centralized management system (for the realization of an active system) with the aim of also regulating the temperature and air speed;
- transversal baffles, placed horizontally or vertically to the façade plane, which typologically and functionally delimit the contiguous components of the system, necessary for:
  - the aerodynamic control for the inflow, conduction and outflow of air flows;
  - the separation between component units, in order to prevent the outflow of air from one unit being reintroduced into the ventilation duct of the contiguous unit, guaranteeing the inflow of air from the outside without the risk of it being affected by the air expelled from the interior spaces.

Fig. 4.22 Maurizio Varratta, *iGuzzini Lab*, Recanati. Application of the external skin to the main curtain wall, reducing wind pressure and allowing the opening of windows relative to the internal section (even at high levels of the building). © Courtesy of Pichler Projects

Chapter 5
The Connections Between the Framing Profiles and the Glazing Envelopes

Abstract The study examines the functional and application procedures of the gaskets with respect to the façade systems in order to prevent the transmission of air and water loads. In this regard, the analysis focuses on the connections between the framing and the enclosure elements of the envelope, in accordance with the compensation of height differences in order to guarantee impermeability, airtightness and insulation. The technical execution of the gaskets considers the production criteria at the level of cutting, connection and bending as well as the positioning and the installation methods. The study observes and investigates the types of framing elements in which the gaskets are inserted, emphasizing the specific function with respect to the connection interfaces. In particular, the assembly between the mullions and the transoms results from the insertion of the gaskets into the cavities, projected frontally, in the form of the crawler gaskets. With regard to the contact parts, for which only compressive actions perpendicular to the surfaces can be transmitted, the need for dimensioning in such a way as to reduce stresses in the load transmission zones is detected. Next, the study explores the assembly procedures of glass enclosures with respect to façade frames, highlighting the construction sequences and the devices for on-site construction.

5.1 The Framing Connection and Assembly Procedures by Means of Gaskets

The design, production and construction scenario assumes the modalities and the procedures directed towards the examination and application of both the gaskets and the criteria for the performance of the glazing phases with respect to the façade systems. The definition of gasketing elements includes, in general, the types aimed at preventing the transmission and passage of air and water loads, consequent to rainwater and condensation, allowing related movements between the frame apparatuses, the distribution and absorption of both loads and tolerance levels. The knowledge

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PoliMI SpringerBriefs, https://doi.org/10.1007/978-3-031-49608-0_5

and application criteria inherent in gasket materials consider the ability to maintain composition and geometric form in operation, in accordance with resistance to climatic variations and dynamic stresses.

On this basis, the applied knowledge and operation, both design and construction, for the development and control of gaskets contemplates the overall analysis of the joints between the frame elements and the enclosures, as the compression to which they are subjected generates loads acting on the contact surfaces: this by observing, during the study and selection phase, the subsequent geometric and dimensional variations in operation as the forces exerted in compression decrease due to the effects of advancement and relaxation of stresses.

The determination, analytical and selective, of the gaskets, in reference to the production modes of injection moulding or extrusion, is carried out starting from the examination around the compensations of the differences in height between the plane of the enclosures (such as, for example, the glazing plane), the mullions and the transoms. The perimeter fixing joints, which must determine the watertightness, airtightness and insulation of the façade systems and the window frames, require the application of the gaskets to the pronounced cavity locations beyond the frame apparatuses: this emphasizes special types for the connection angles and the engagement by means of a certain pressure in the joints so that, expanding, they adhere to the interface surfaces (Fig. 5.1).

The sealing of the gaskets, whereby contact is made on the linear slats (which must maintain their elasticity by absorbing the deformations of the enclosure elements), is based on the crossing geometric configuration in the form of profiles (or strips) of fully vulcanized elastomeric material: in general, the gaskets are made in a "dovetail" or "wedge" shape, according to a wide range of dimensions, specifying types for the mullions, transoms, sealing plugs and vulcanized corners (Fig. 5.2).

The gaskets must possess sealing and thermal transmission-stopping capabilities, while maintaining their elastic properties (including springback capability), over the temperature range expected for use. The gaskets must also oppose thermal transmission between outside and inside, and resist hardening, abrasion, natural ageing, ultraviolet radiation and polluting atmospheric agents (in any case providing for the possibility of their replacement) (Fig. 5.3). In particular, the seals of the openable closing elements must be arranged outside the area exposed to the weather and must develop, without interruption, on the same plane (Figs. 5.4 and 5.5).

The technical-execution processing of the gaskets involves:

- the procedures for cutting, connecting (in particular, at the angular interfaces) and bending (only in the cases where the geometric and dimensional cavity allows distortions in the cross-section to be avoided);
- the adoption of the extrusions cut to size and glued, or welded and vulcanized;
- the adoption of the shaped and bonded types to the extrusions; according to the purpose of composing the element in continuity within the joint between the frame and the vertical enclosure apparatus.

The applied knowledge and criteria for both planning and control in the execution of the gaskets are based on:

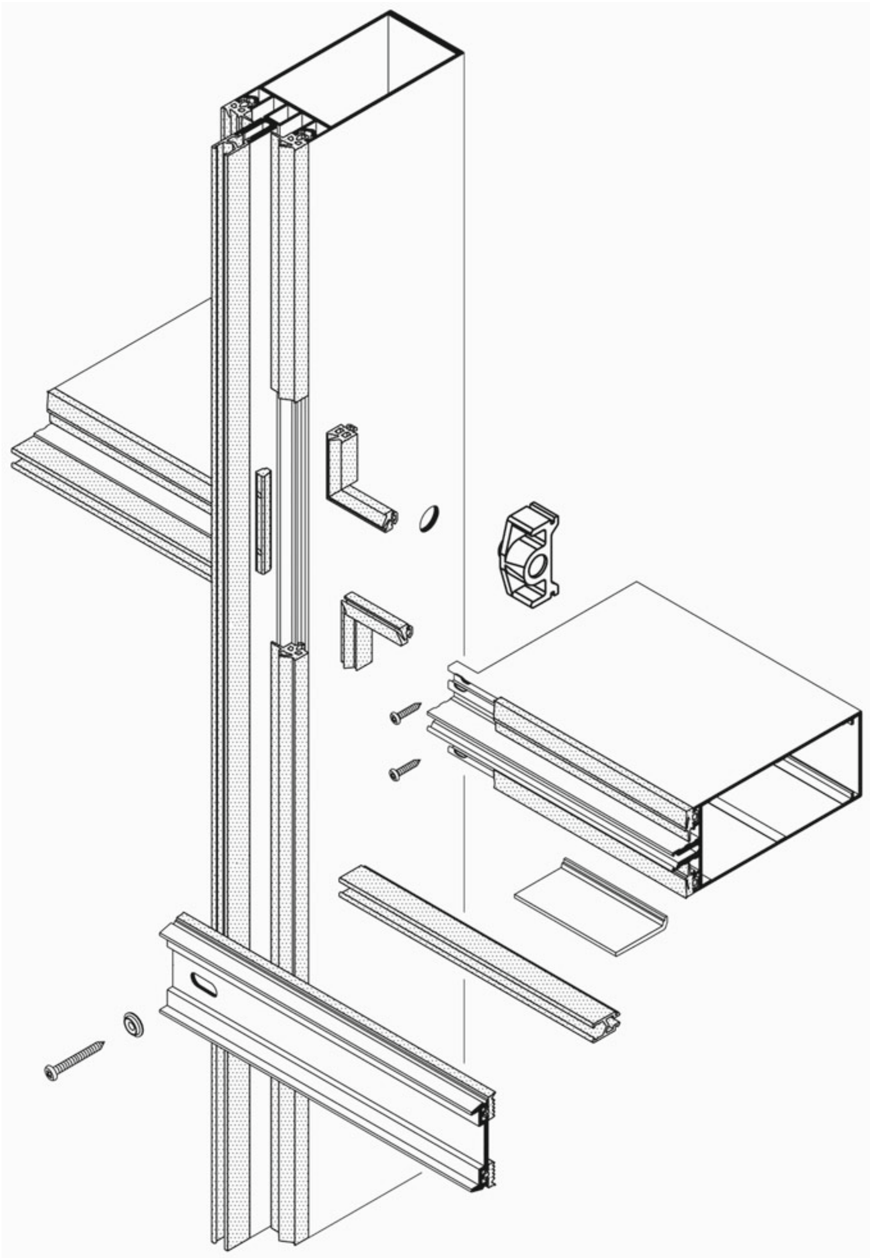

Fig. 5.1 Perimeter joints of the façade enclosures which determine the waterproofing, airtightness and insulation through the application of the gaskets to the cavities, pronounced beyond the mullions, the transoms and the pressure devices, using special gaskets to the connection corners. © Courtesy of AluK

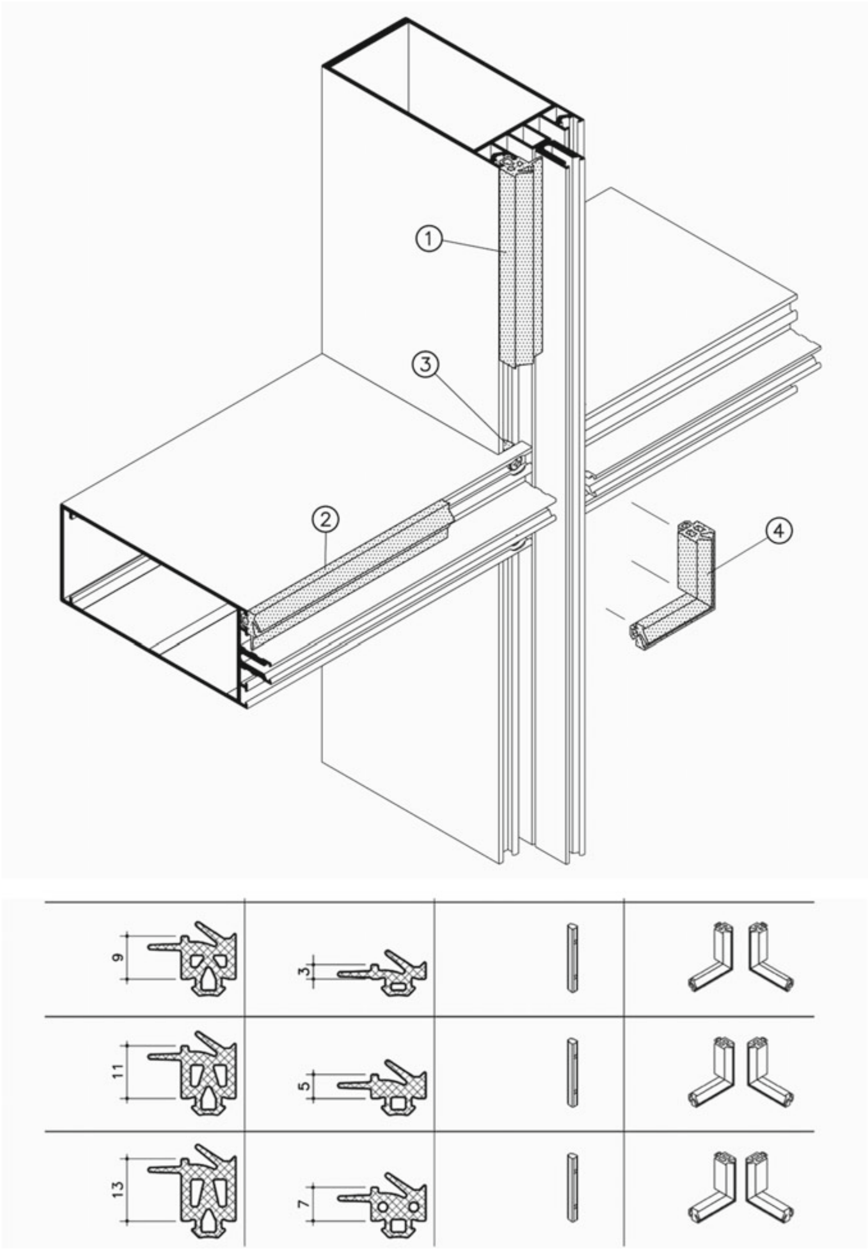

Fig. 5.2 Sealing of the gaskets that requires the contact on the linear flaps, which must maintain their elasticity by absorbing deformations of the sealing elements, through the crossing geometric configuration in the form of vulcanized elastomer profiles (or strips), the connective typology for both the mullions and the transoms, the connective type for sealing plugs and the connective type for vulcanized corners. © Courtesy of AluK

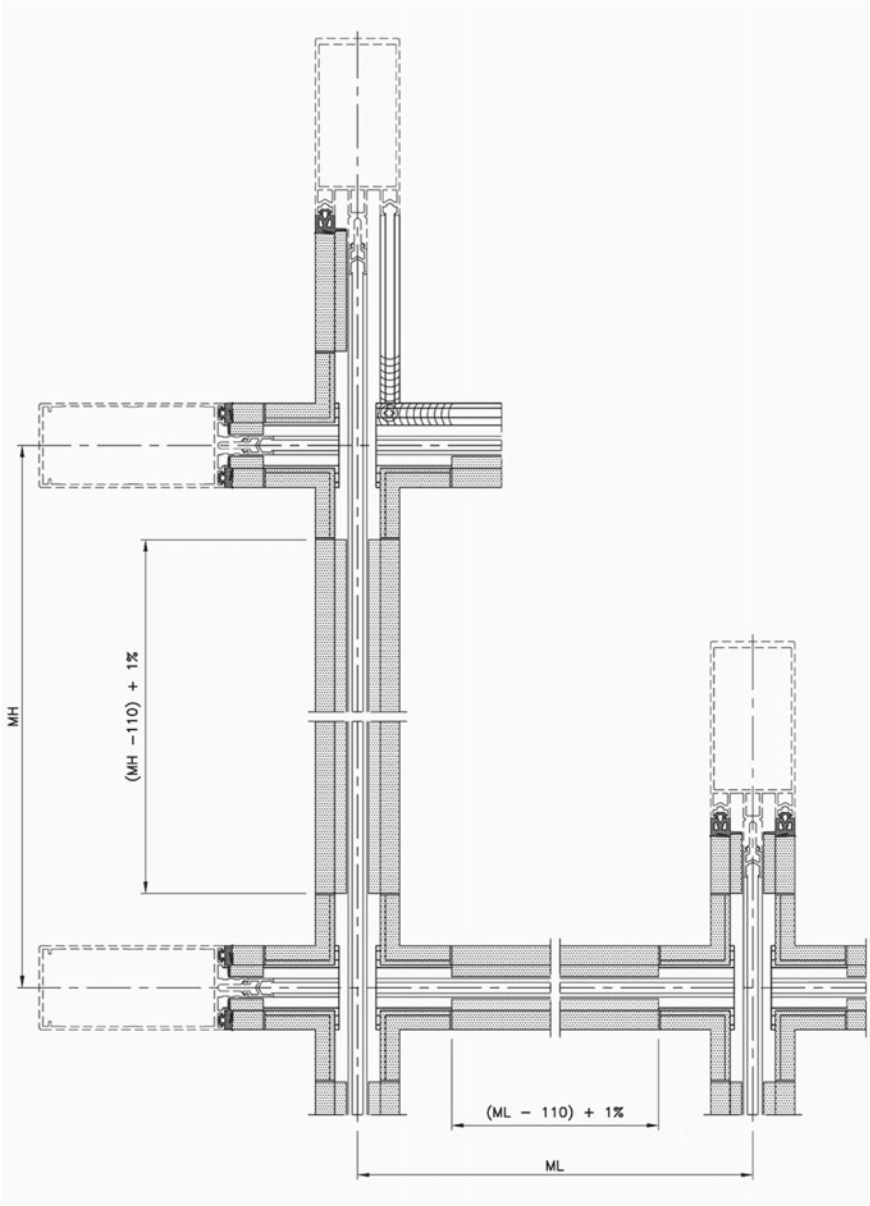

Fig. 5.3 Gaskets must possess the ability to seal and stop the thermal transmission, maintaining elastic properties over the expected temperature range, detecting: • the resistance to the phenomena of hardening, abrasion and natural ageing; • the resistance to ultraviolet radiation and atmospheric pollutants; • the replacement procedures. © Courtesy of AluK

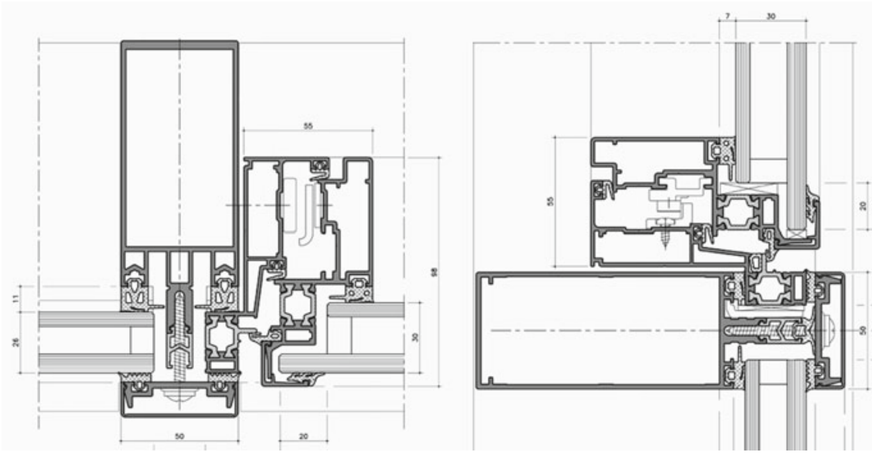

Fig. 5.4 Gaskets of the opening enclosure elements provide for: • the installation beyond the area exposed to the weather; • the development on the same plane, without interruption. © Courtesy of AluK

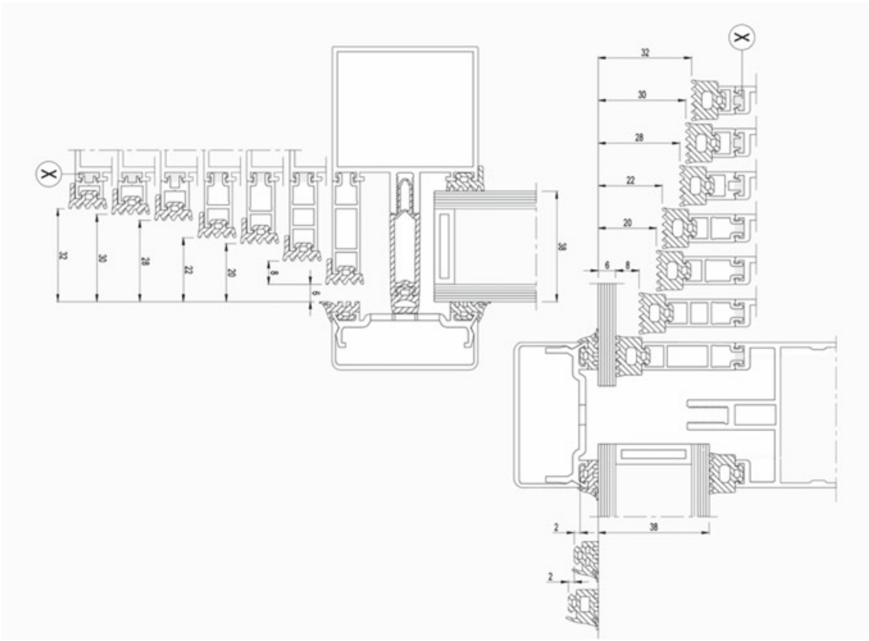

Fig. 5.5 Construction of the glass enclosures to the frame structures, which provides for: • the compensation of the height differences between the plane of the enclosures (such as the glazing plane), the mullions and the transoms; • the insertion of the internal gaskets of different thicknesses. © Courtesy of Reynaers

- the planning and the configuration of the laying steps with respect to the cleanliness of the joint surfaces, with the removal of residues;
- the arrangement of the gaskets within the locations characterized by the average environmental temperatures, absolutely not low, so as to allow the relaxation and the recovery of the original shape prior to the installation;
- the check of the environmental conditions of the installation, since the temperature can affect the flexibility and width of the joint: this points out the need to avoid the application at the temperature $T < 5$ °C, since even at this thermal level the expansion of the joint can be observed due to the contraction of the elements with the risk of excessive compression of the gasket at higher temperatures.

Specifically, the installation procedures are outlined according to:

- the *push-in* positioning methodology, defined for the installation within the groove into the surfaces before the formation of the joint;
- the *drive-in* positioning methodology, defined for the installation within the slot between the surface of the assembly element and the contact surface: this envisages the possibility of tensile removal from the joint, however entailing the critical issues due to the case of production for rigid strips;
- the *slide-in* positioning methodology, defined for the sliding installation within the groove on the assembly surface and the contact surface: this envisaging the possibility of removal by sliding from the end of the groove.

Furthermore, the applied knowledge and criteria for both planning and control in the execution of the gaskets assume:

- the realization of the assembly from the ends and the development towards the centre of the façade component;
- the need to avoid the insertion of the undersized and easy-to-install types, as they are not compressed and do not provide an adequate seal for the extension of the vertical enclosure;
- the need to avoid the insertion of the undersized and constrained types in position as they can crush the edge of the completion material;
- the need to avoid forced insertion as, after assembly, the types resume their original length leaving the gaps between the joints;
- the need to cut slightly the oversized elements and to proceed with longitudinal compression during assembly.

In the case of the façade systems, the assembly between the mullions and the transoms requires the application of the preformed typology (constituted in two pieces), considering:

- the continuous arrangement of the gasket "foot";
- the notch of the gasket, with the appropriate cutting tool and with the extraction of the part to be removed (by means of a clamp) (Fig. 5.6).

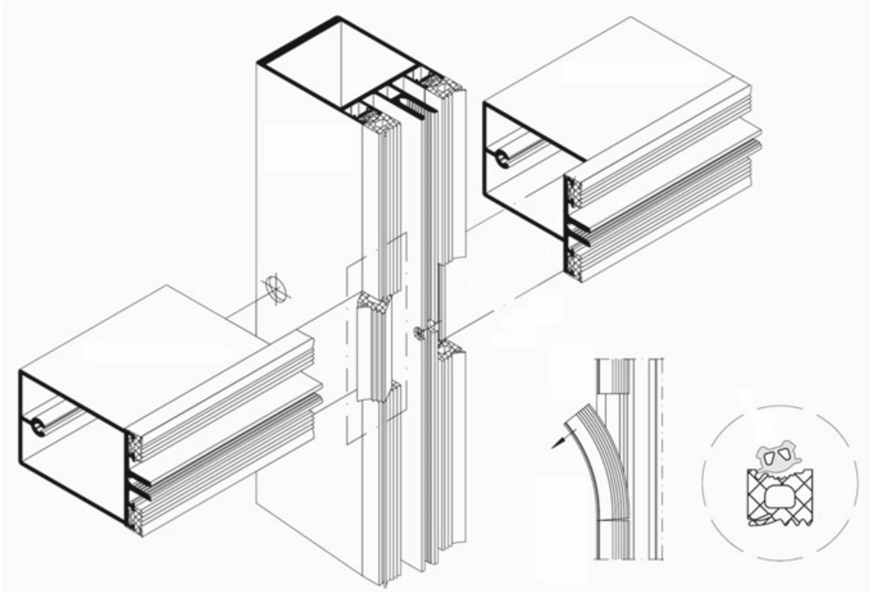

Fig. 5.6 Assembly between the frame profiles that involves the application of the EPDM preformed gasket for the mullion, considering the continuous arrangement of the gasket "foot" and the notch of the pre-cut seal. © Courtesy of Schüco

The assembly between the mullions and the transoms requires the application at vulcanized angles, with sealing details, according to the variant for gaskets of the same height and the variant for gaskets of different heights (Fig. 5.7).

The assembly between the mullions and the transoms also detects the execution of the angles and the vulcanized frames for the combination of gaskets X_1 and X_2, considering the need to express the geometric dimensions between the mullion (PF_Z) and the transom (RI_Z).

The gasket components shall be sealed by:

- the gasket without the vulcanized corners, of the preformed sealing type, involving the sealing under the gaskets of the transom and the mullion at the cavity (such as "step 2");
- the gasket with the vulcanized angles, which involves sealing the corner area before glazing (such as "step 3") (Fig. 5.8).

5.2 The Assembly Procedures for the Glazing Envelopes

The assembly between the mullions and the transoms includes the application of the "cross" sealing details, performed at the perpendicular interface between the profiles and composed of gasket geometries capable of adapting internally to the cavities,

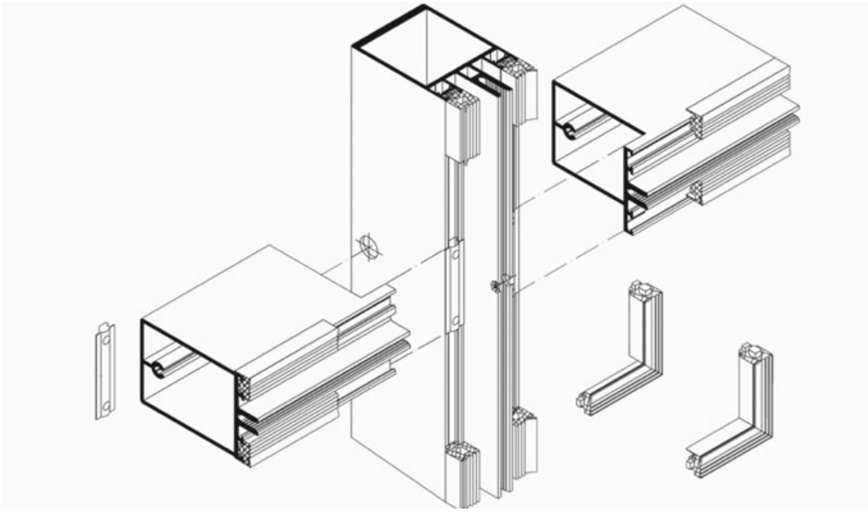

Fig. 5.7 Assembly between the mullions and the transoms that requires the application of the EPDM seal at vulcanized angles according to the type for gaskets of the same height in view and the type for gaskets of different height in view. © Courtesy of Schüco

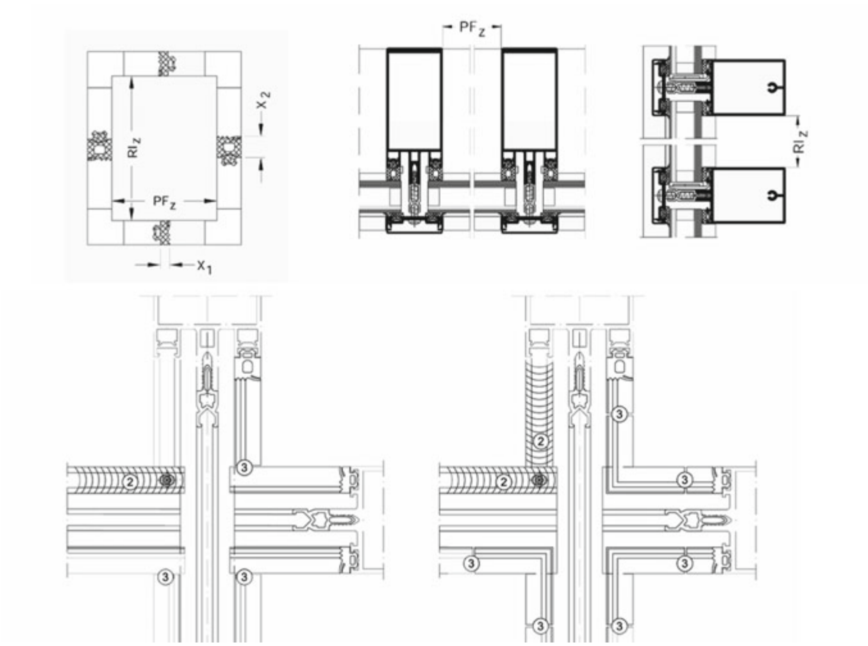

Fig. 5.8 Assembly between the mullions and the transoms that detects the execution of the corners and the vulcanized frames, with a special EPDM seal. © Courtesy of Schüco

and externally, to the aggregation of the pressure devices (Fig. 5.9). The transverse geometry of the internal crawler gaskets detects the composition according to the engagement part in the cavities, projected frontally from the mullions and transoms profiles, the linear continuous cell interposed and the external part equipped with the gripping elements (Fig. 5.10).

The transverse geometry of the external track gaskets detects the composition according to the engagement part in the cavities, included in the pressure profile for the mechanical fastening, and the internal part equipped with the gripping elements towards the surface of the glass enclosures (Fig. 5.11). The transversal geometry of the glass cover seals detects the composition according to:

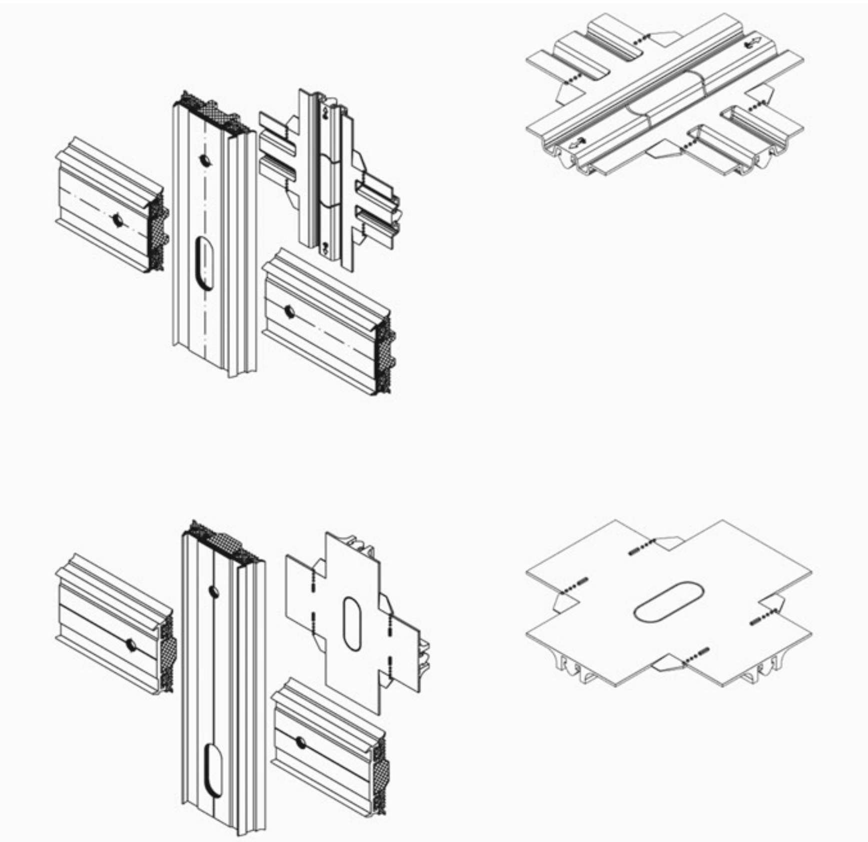

Fig. 5.9 Assembly between the mullions and the transoms that includes the application of the "cross" sealing details in EPDM, observing: • the execution at the perpendicular interface between the profiles; • the composition according to the gasket geometries aimed at adaptability to the cavities, towards the inside, and to the aggregation of the pressure devices, towards the outside. © Courtesy of Schüco

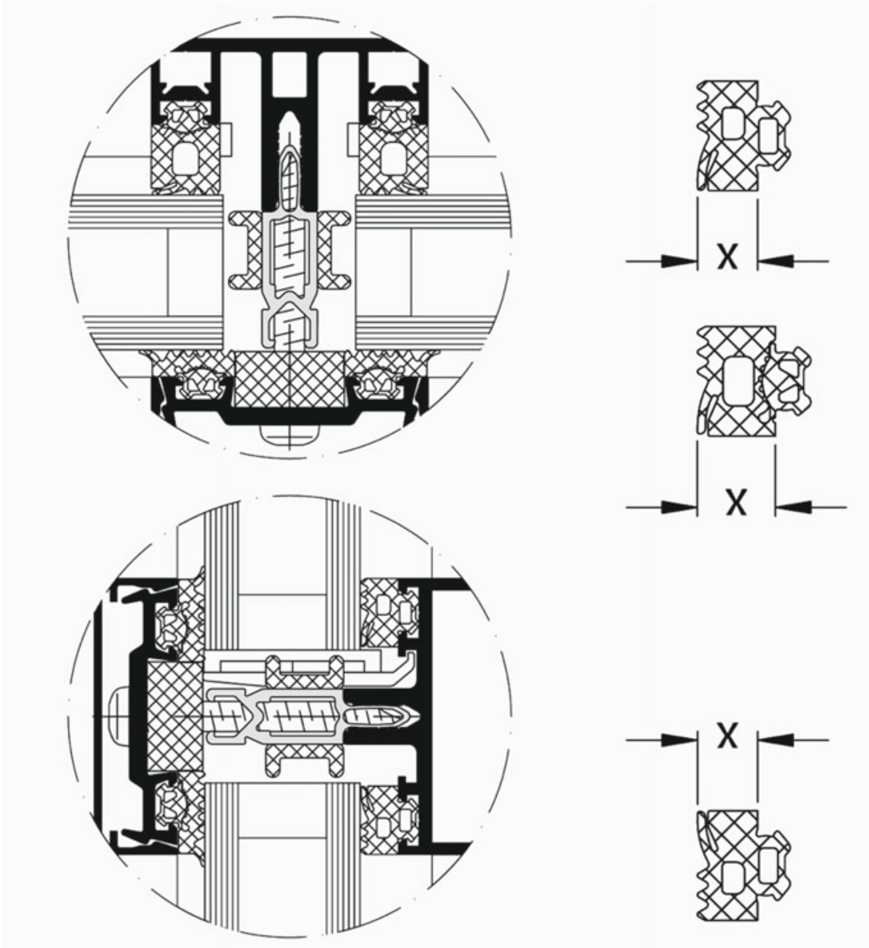

Fig. 5.10 Transverse geometry of the internal crawler gaskets that detects: • the composition according to the grafting part in the cavities; •the frontal projection from the mullions and the transoms; • the interposed linear continuous cell; • the external part fitted with the gripping elements towards the inner surface of the enclosures. © Courtesy of Schüco

- the coupling part in the cavities, projected frontally from the mullions and transoms profiles and included in the pressure profile for mechanical fixing;
- the part equipped with the central and the lateral gripping elements, to accommodate the calibration of the glass enclosures.

Outside, along the fixing section, the butyl rubber aluminized sealing tape is applied to the glass surfaces (Fig. 5.12).

The application of thermally insulated frames considers:

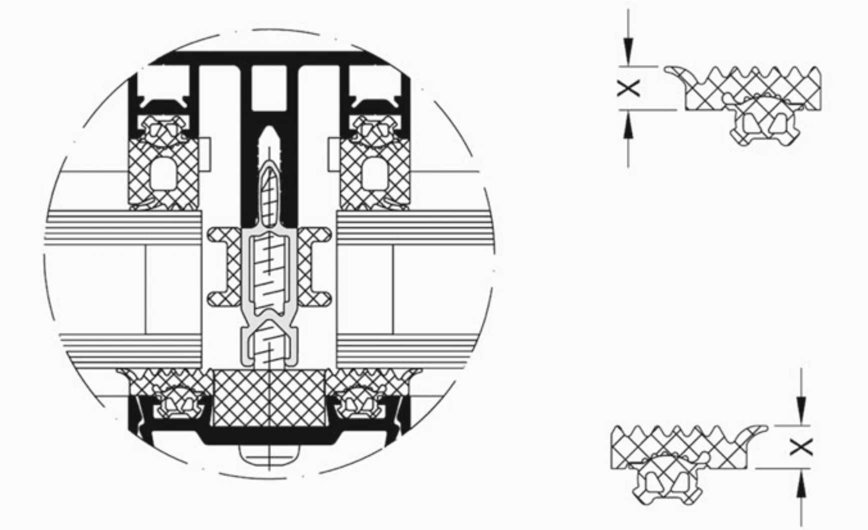

Fig. 5.11 Transverse geometry of the external crawler seals that detects: • the composition according to the insertion part in the cavities, included in the pressure profile; • the inner part equipped with the gripping elements, towards the outer surface of the enclosures. © Courtesy of Schüco

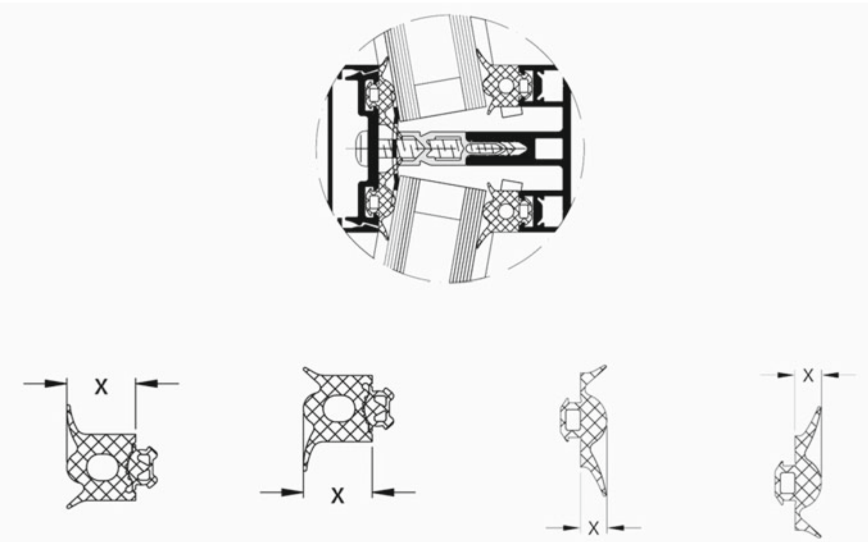

Fig. 5.12 Cross-sectional geometry of the glass cover seals that detects: • the composition according to the engagement part in the cavities, included in the mullions, transoms and pressure profile; • the front part equipped with the central and lateral gripping elements, for the calibration of the enclosures. © Courtesy of Schüco

- the use of the inserts applied to the central linear pin of the mullion, characterized by the internal projections of coupling, the inner cell, the direct wings to the perimeter of the glazing and the stop ends;
- the use of the thermal insulation tape, generally in synthetic foam, shaped to accommodate the stop ends of the inserts and to support the pressure profile;
- the use of the central device to keep the inserts in the right position (Fig. 5.13).

In the case of the structural façade system, the application of the double stop seals is outlined with respect to the external sections of the central pins, projected from the mullions and from the transoms, observing the composition of the "cross" type, of the "T" type and of the angular connection (Fig. 5.14).

The structural façade system determines the use of the central closing gaskets connected to the polyamide rod fittings, placed towards the side and composed, in general, from the flap wings with the possible wrapping extension on the perimeter edges of the glass panels (Fig. 5.15). The structural façade system then manifests a series of interface seals against the glass enclosures such as:

- the gaskets on the vertical perimeter of the panels;
- the gaskets of the glass grip on the inner surface of the panels, in the case of assembly with the grooved glazing ("step" type);
- the gaskets of the grip belt on the inner surface of the panels, in the case of assembly with the planar glazing (Fig. 5.16).

The connection of the glass panels to the frame involves the insertion of the external screen gaskets, connected to the edge of the mechanical retaining (assembled to the laying profiles). In addition, the structural façade system, in the case of combined mullions, involves the use of continuous vertical connection seals, inserted in the cavities projected beyond the tubular sections.

The application of the enclosure elements (and, in particular, of the glass panels) to the frame structures is carried out by means of tales (made of treated wood or elastomer, such as polyamide, chloroprene, EPDM or silicone whose inalterability due to constant compressive stress and tolerability must be noted): these allow the own weight of the locking elements to be discharged through the anchoring points or nodes of the fixed frame. For example, in the case of monolithic or insulating glass panels, the tiles are made of:

- the application to a flat support or through adapters, if the groove profile is interrupted;
- the arrangement beyond the panels (at a distance of at least 20 mm) so that they can rest throughout their length (Fig. 5.17).

The contact parts (where only the compressive actions can be transmitted, which insist in a perpendicular form to the surfaces of the enclosure elements) have to be dimensioned so as to keep to a minimum the stresses appearing in the areas of force transmission. The devices applied to the transoms, as support to the glass enclosures, are carried out according to:

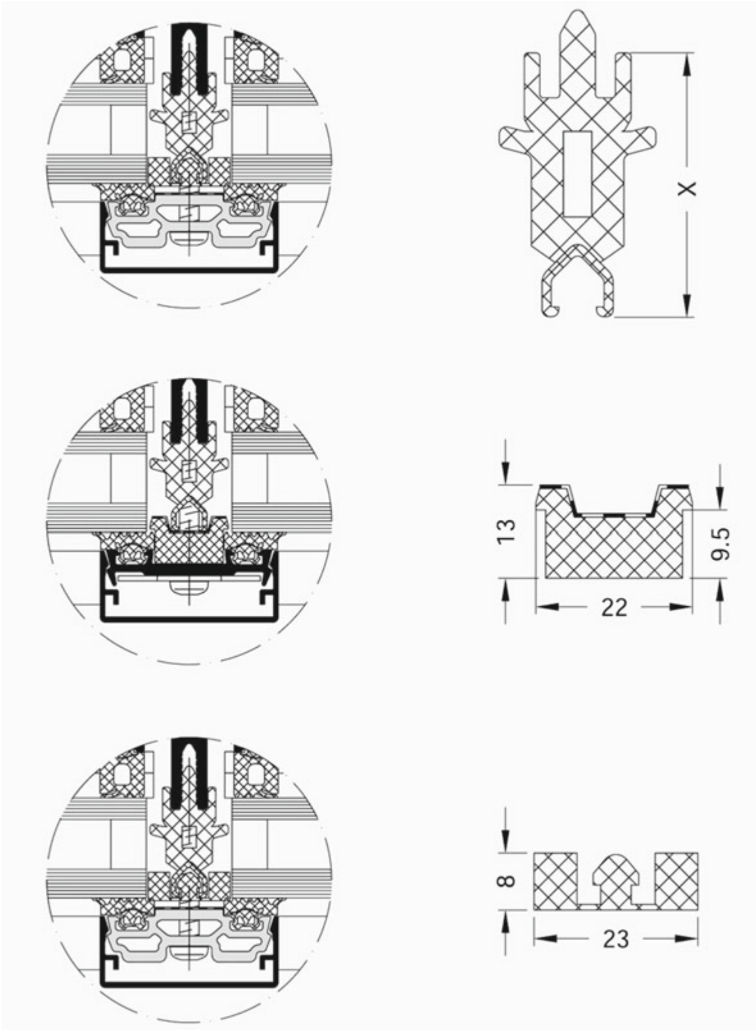

Fig. 5.13 Construction of thermally insulated frames that detects: • the use of the inserts applied to the linear pivot of the mullion, consisting of the internal projections of coupling, the interposed cell, the direct wings to the perimeter of the glazing and the stop ends; • the use of the synthetic foam tape for the thermal insulation; • the use of the EPDM centering device to keep the inserts in position. © Courtesy of Schüco

- the "standard" type, to be attached on site, for a maximum panels weight of 185 kg and for thicknesses between 6 $\div$ 64 mm;
- the type for the increased loads, to be fixed by the manufacturer, for a maximum panels weight of 445 kg and for thicknesses between 24 $\div$ 64 mm;
- the "cross" type, to be attached on site, for a maximum weight of the panels of 700 kg and for thicknesses between 42 $\div$ 64 mm.

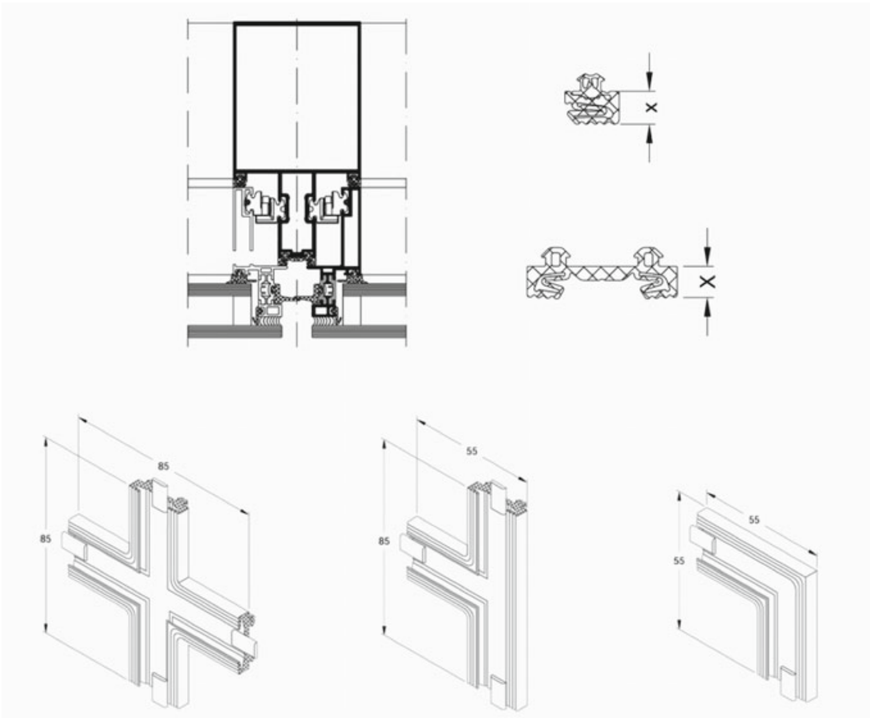

Fig. 5.14 Structural façade system that explains: • the application of the double-stop central closing gaskets, protected by the linear pin sections; • the composition of the "cross" elements, the "T" elements and of the angular connecting sections. © Courtesy of Schüco

The fixing solutions are provided with elastic intermediate layers:

- in the case of rigid laying surfaces (in the contact between glass and metal), by means of snap-on glass-stoppers or by means of the fixing plate between two enclosure elements, or by means of glass-stoppers for points or glass-stoppers and spacers;
- where the movements and structural or geometric imperfections are to be absorbed (Figs. 5.18 and 5.19).

The transmission of the loads by the friction, with the mechanical interlocking between the micro-scabrosity of the two contact surfaces, requires the application of the intermediate layers with elasticity and long-term rigidity: these are made of soft metals, such as pure aluminium, reinforced plastics or even processed natural materials, such as cork, leather or cellulose.

The friction correlations may fail due to:

- the slipping of contact surfaces due to the changes in the same friction properties (for example, in the case of the penetration of moisture into contact surfaces);
- the sliding of the contact surfaces to loosen the clamping forces;

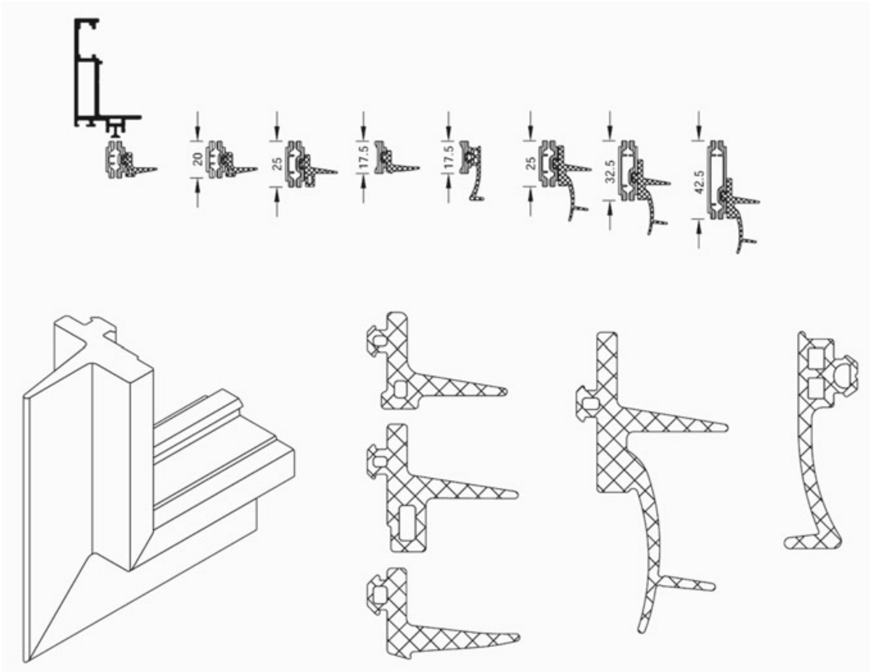

Fig. 5.15 Structural façade system that includes: • the use of the central closing gaskets, connected to the polyamide rod fittings; • the composition of the gaskets, according to the wings for the stop and the extension towards the perimeter of the glass enclosures. © Courtesy of Schüco

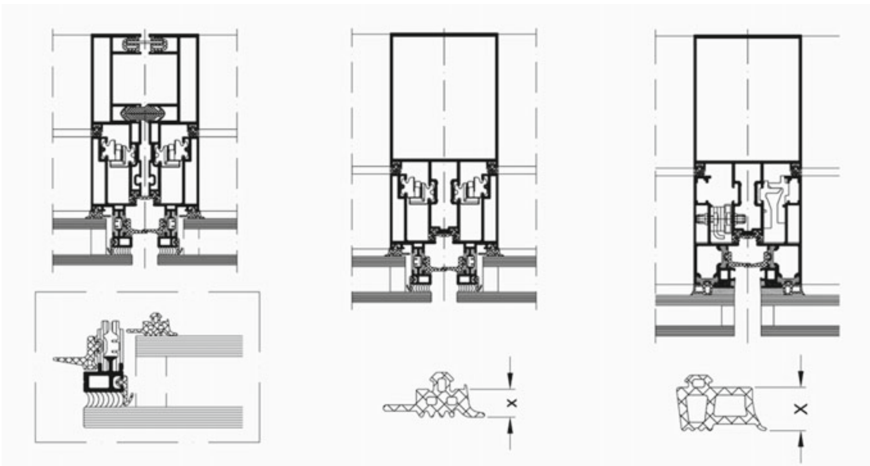

Fig. 5.16 Structural façade system that considers the seals of interface towards the glass enclosures, such as: • the gaskets on the vertical perimeter of the panels; • the gaskets on the inner surface of the panels, in the case of grooved glazing ("step" type); • the gaskets on the inner surface of the planar panels. © Courtesy of Schüco

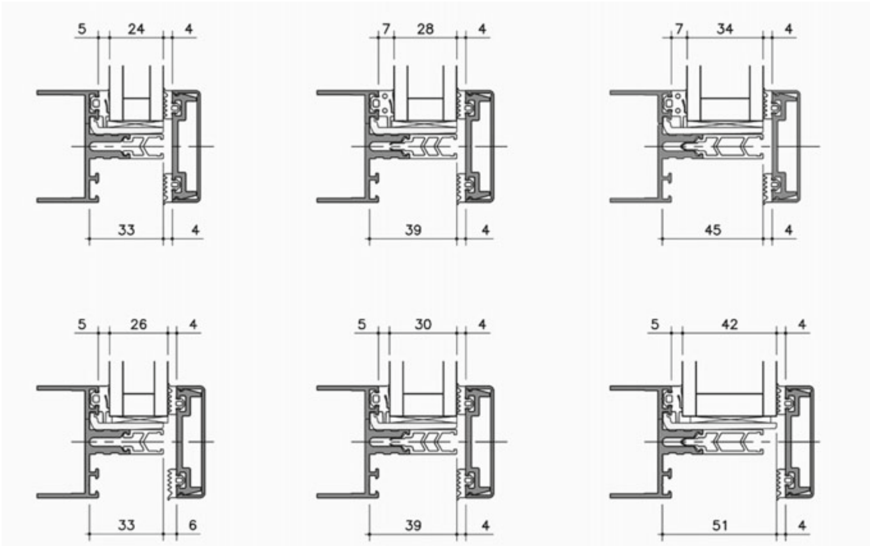

Fig. 5.17 Execution of the glass elements that involves the assembly of the tales, according to: • the transmission of the loads through the anchorage points or nodes of the fixed frame; • the application on flat support or through adapters; • the arrangement beyond the panels, to ensure total support; • the types of treated wood and elastomer (polyammide, chloroprene, EPDM). © Courtesy of AluK

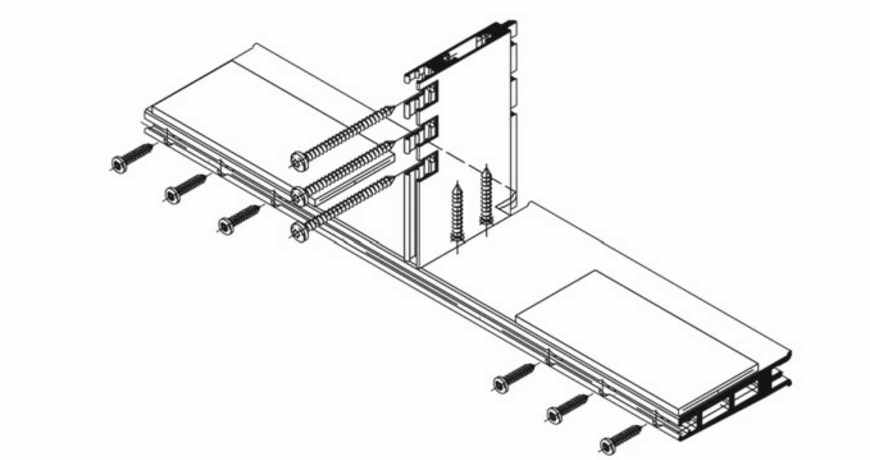

Fig. 5.18 Devices applied to the transoms, as support to the glass enclosures, made according to the "standard" type, the type for the increased loads and the "cross" type. © Courtesy of Schüco

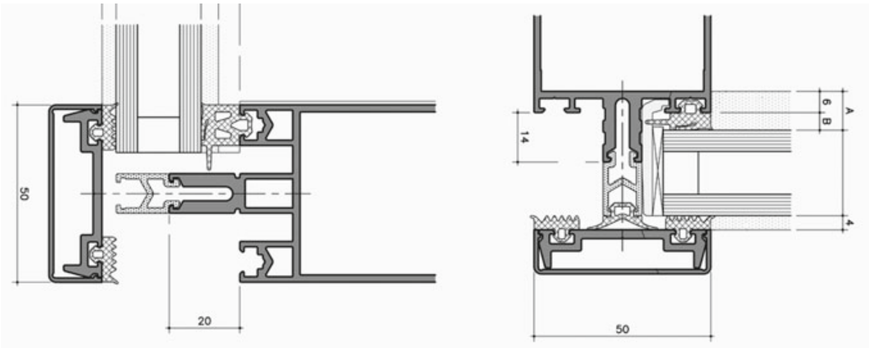

Fig. 5.19 Execution of the glass enclosures to the frame structures that considers the installation of elastic intermediate layers aimed at • the transmission of the compressive action, which is applied to the surfaces of the panels; • the maintenance of the minimum tension levels in the load transmission zones; • the absorption of movements and structural or geometric imperfections. © Courtesy of AluK

- the breakage of the panel for too high tempering of the glass, so combined with the connection with the plates too soft or rigid, or of inadequate geometric shape (Fig. 5.20).

The transmission of the loads by adhesion between the enclosure elements (transmitted perpendicular or parallel to the connecting surfaces, according to the adhesion or cohesion mechanisms) takes place through:

- the brazing, as in the case of the application of metal to glass;
- the sealing, as in the case of the application of silicon elastic sealants (used for laminated safety glass, for insulating glass and for structural façades).

The application of glass sheets to the structural frame involves the use of circular rosettes for safety locking for the purpose of punctual assembly, performed on site by means of self-tapping screws with head cap (Fig. 5.21). The operations of temporary fixing of the glass enclosures to the frame profiles also involve the use of standard profiles (for example, in the form of small pieces of perforated under-cover with gaskets), fixed by screws. However, for the application of butyl tape it is necessary to gradually dismantle the temporary clamps from the transoms, lay the tape and, subsequently, the under-cover profiles. The evolution of this clamping procedure requires the use of "loose" elements on the insulation profile and the subsequent fastening by tightening: according to the reduced height dimension on the glass surface does not hinder the execution of butyl tape, gaskets and undercoat, continuing with the phases of glazing without further processing (Fig. 5.22).

The execution of the glass panels to the frame structures takes place through the contribution of the "clips" for the pre-installation of the under-cover profiles of the transoms: specifically, the "clips" are attached to the sides of the under-cover, then connected to the insulation profile of the crossbar. Afterwards, the profile held by the "clips" can be aligned in the right position and then fixed (Fig. 5.23).

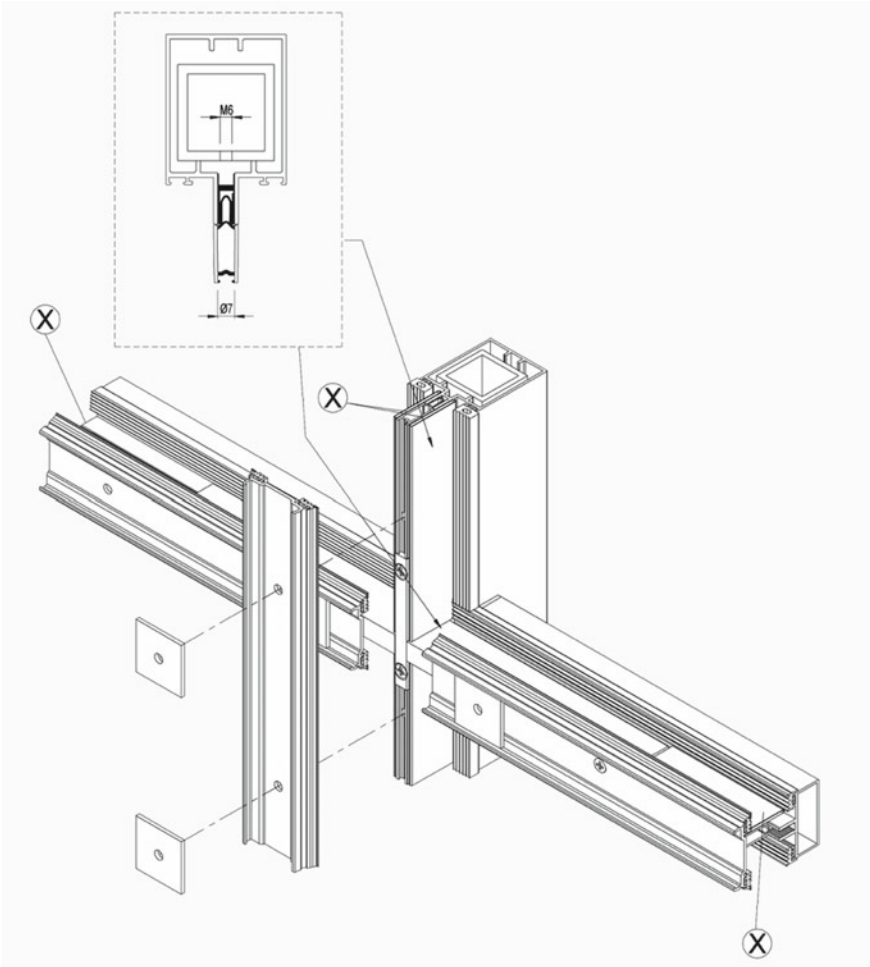

Fig. 5.20 Execution of the glass enclosures to the frame structures, in relation to the transmission of forces by friction, that assumes: • the application of the intermediate layers with elasticity and rigidity (consisting of soft metals, reinforced plastics or processed natural materials, such as cork, leather or cellulose); • the examination of the correlations by friction, which can yield due to the sliding of the contact surfaces for the penetration of moisture or for the loosening of the clamping forces; • the examination of the possibility of breakage of the panels, due to the high tempering of the glass or the connection with glass-stoppers too soft or rigid. © Courtesy of Reynaers

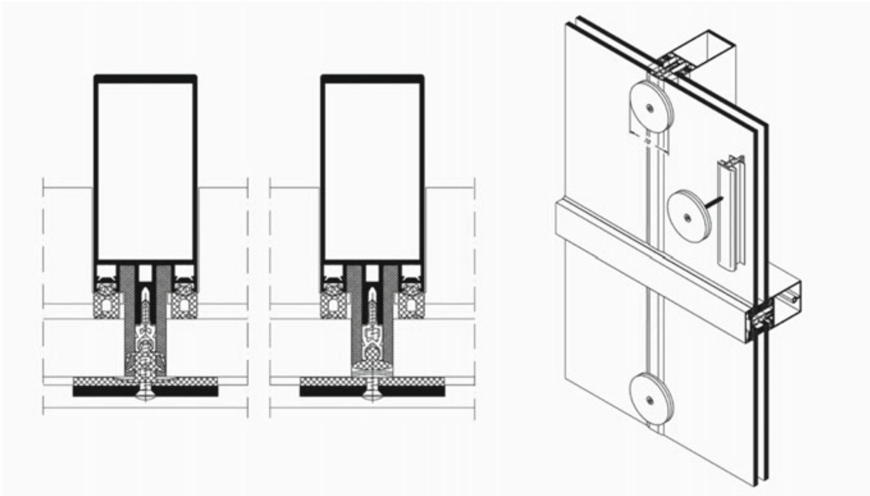

Fig. 5.21 Application of the glass enclosure elements to the structural frame that involves: • the use of circular rosettes for safety locking, for the purpose of punctual assembly; • the execution on site by self-tapping screws with head cap. © Courtesy of Schüco

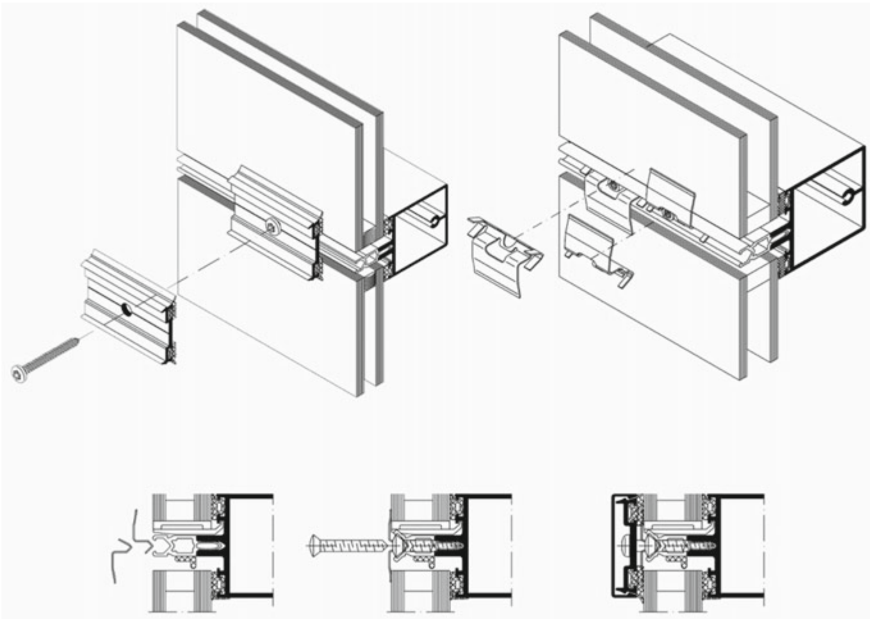

Fig. 5.22 Temporary assembly of the glass enclosures to the frame profiles that involves the use of locking devices, through the configuration in perforated sub-casing profile pieces, according to the equipment of the seals and the fastening procedures for tightening and the application of butyl tape. © Courtesy of Schüco

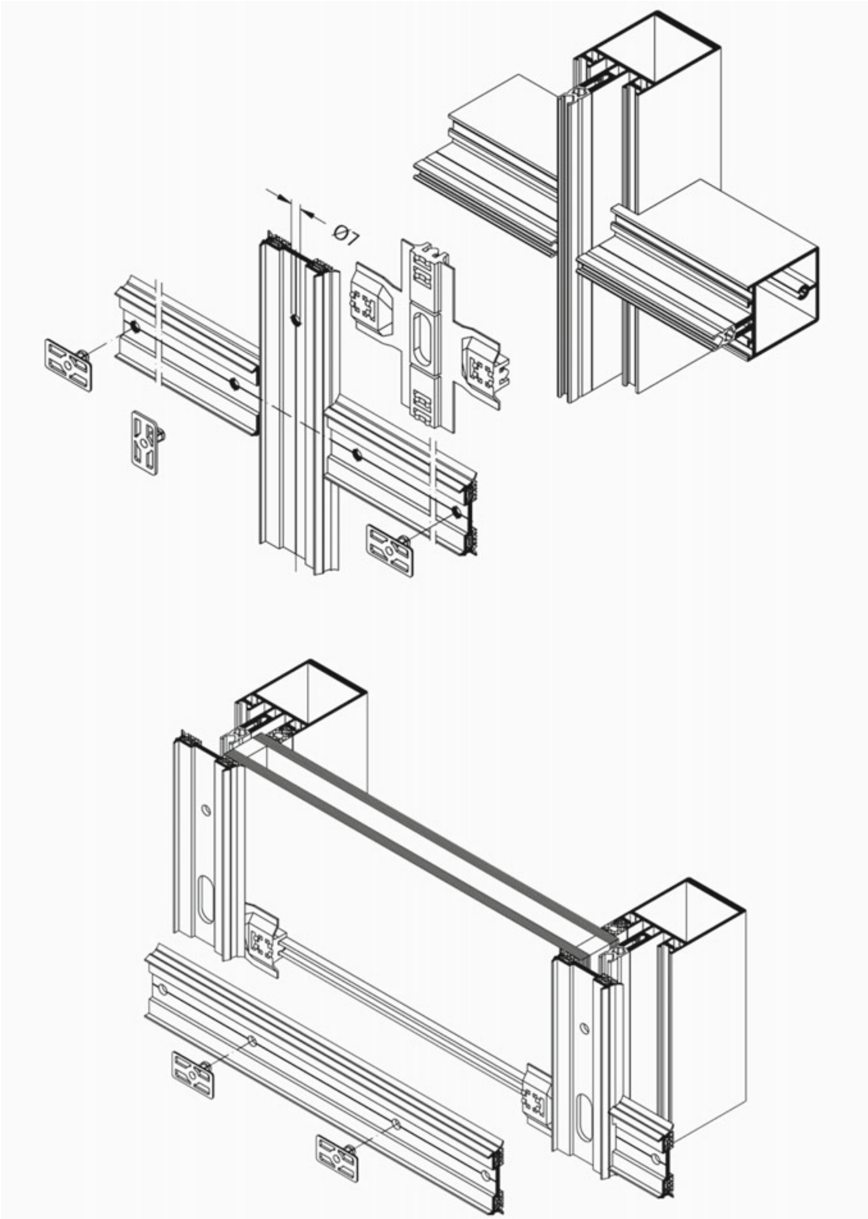

Fig. 5.23 Execution of the glass panels to the frame structures that assumes the contribution of the "clips" for the pre-installation of the pressure device, detecting: • the attachment to the sides of the transom under-cover profile; • the fixing of the pressure device to the transom, for the self-tapping screwing. © Courtesy of Schüco

Chapter 6
The Technical Processing of the Joints in the Façade Systems

Abstract The study examines the assembly and interface conditions between elements of different composition and production within the façade systems. The examination of the technical interfaces involves the development and application of sealants, based on the loads exerted on the jointing devices, in order to fulfil the requirements of sealing and tightness with respect to mechanical, thermal and hygrometric, water, air and wind stresses. The execution of sealants concerns jointing techniques according to the adhesion to the contact surfaces. The sealants are subjected to stresses due to ultraviolet solar radiation, low temperatures and thermo-hygrometric loads. At the same time, the sealants can be subjected to failure procedures, due to the loss of adhesion, recalling the correct dimensional, geometric and connective design methods. The design study of joints recalls the evaluation of the width, the in-situ preparation of the adhesion surfaces and the filling of the thickness between the technical elements. The design study differs from the sealing of glass enclosures and technical elements, according to the different application types. In addition, the execution of the sealing involves the analysis of the surface treatment conditions and the physical state of the substrates, considering the procedures for cleaning, the application of the primer, the application of the "joint filler" and masking on the sub-layer surfaces.

6.1 The Procedures and Application of the Sealants Between the Technical Elements

The arrangement of the technical-executive contents related to the application of the façade systems is outlined through the apparatus of knowledge and procedures that find expression during the assembly, according to the conditions determined by the physical, material and functional interfaces due to the connections between elements of different composition and production. In this regard, the technical operation, at the level of planning and management from the project to the maintenance of performance over time, is expressed through the analysis and the correct implementation of the jointing devices by means of the sealants. Specifically, the examination and

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PoliMI SpringerBriefs, https://doi.org/10.1007/978-3-031-49608-0_6

execution procedure of the connective and relational characters of the sealants is outlined on the basis of:

- the stresses exerted on the jointing devices, through which movements are caused by the thermal variations, by the reduction in elasticity of the frame elements, by deformations of overall order (as in the case of structural contractions and expansions) and punctual order, by the incidence of hygrometric loads and by the dimensioning of the structural tolerances;
- the stresses exerted in the forms of extension and compression, through which a permanent action is applied to the sealant.

The movement of the joint L produced by tension and compression is determined according to the relationship:

$$L = \left[\left(\frac{100}{X}\right)(M_t + M_o)\right] + T$$

where:

X = movement capacity of the sealant, according to the expression equal to: ±12.5%, ±25%, ±50%;

M_t = movement caused by the thermal expansion (mm);

M_o = movement caused by the load (mm);

T = structural tolerance dimension (mm).

The execution of the sealants is aimed at the constitution of the sealing enclosures against the loads caused by mechanical, thermal and hygrometric stresses, rainwater, air and wind action, in accordance with the need for flexibility in the connections to allow for the movements of the frame and of the envelope. Furthermore, the execution of the sealants is proposed with respect to:

- the application aimed at covering the joint lines according to the adhesion to the contact surfaces;
- the application aimed at ensuring the movement between the technical elements, based on the relationship between the *coefficient of thermal expansion* and the length of the material.

The objective of governing the operation of joints using the sealant assumes the examination of operating conditions according to:

- the failure procedures due to the physical deterioration produced, in general, by the incidence of ultraviolet solar radiation, reduced temperatures and hygrometric loads. This by noting how the type of sealant consisting of an organic polymer can generate a physical hardening process or can regress to a non-polymerized state: in this regard, during the handling of the joint, the hardened organic sealant can manifest the concentration of adhesive and cohesive cracks up to the delamination of the substrate;
- the breakage procedures due to the loss of adhesion to the substrate, which recalls both the correct design, geometric, dimensional and connective elaboration of

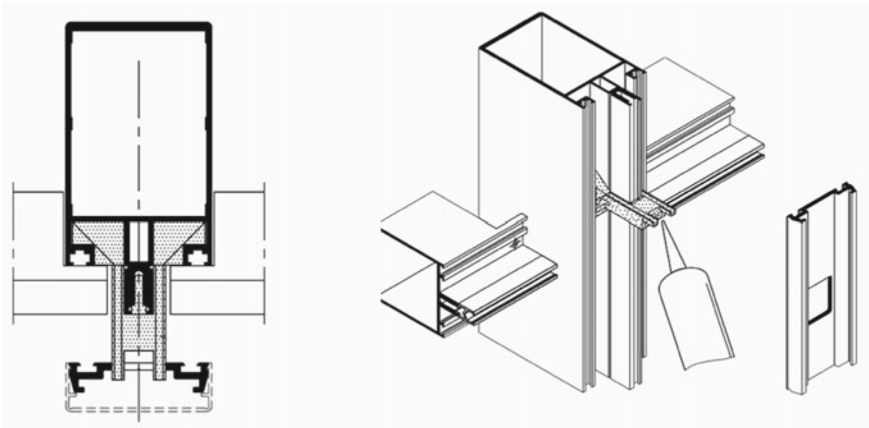

Fig. 6.1 Sealing fixation of the façade system that considers: • the separation between the external sealing plane (with the function of limiting the mixing of air and water between the joints) and the internal sealing plane; • the generation of the groove space, with the drainage function aimed at draining water from the joints or condensation formation. © Courtesy of AluK

the joints, and the correct application during the installation. In particular, the operational examination involves

- the analysis of the contact surface (envisaged at $l > 6$ mm);
- the physical analysis focusing on the sealant's ability to move, to be established in a higher form than the movement of the joint (Figs. 6.1, 6.2).

The movement defined by the applied sealant between the technical elements of the system is realized according to the relationship:

$$\text{dimension of the movement} = CDT \times \Delta T \times L$$

where:

CDT = *coefficient of thermal expansion* (1/°C);

ΔT = temperature variation (°C);

L = material length (mm).

The design elaboration of the joints, with respect to the execution of the sealant, includes:

- the effective calibration associated with the difference between the original width and the width following the load produced by the tangential tension. The dimensional design of the calibrated joint with respect to the application of the sealant considers the relationship:

$$L^2 = (L_1)^2 + (L_t)^2$$

where:

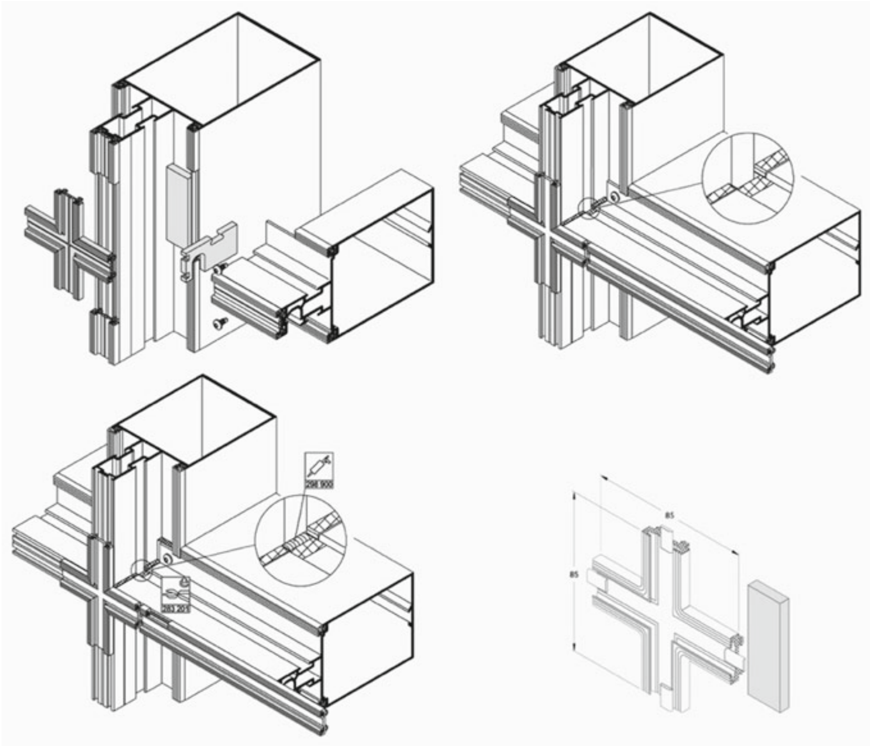

Fig. 6.2 Structural façade system that, in particular, notes: • the fixing of the transoms on the interrupted gasket seat, according to the sealing system, to ensure ventilation; • the sealing of the perpendicular silicone joints. © Courtesy of Schüco

L_1 = original joint width (mm);
L_t = movement of the joint under tangential tension (mm);

- the in-situ preparation of the adhesion surfaces and the filling of the thickness between the technical elements according to:
  - the cleaning of the surfaces using a solvent (soluble in water such as, for example, isopropyl alcohol or methyl ketone) in the phase preceding the application;
  - the checking for the presence of the moisture on the substrate surfaces;
  - the exposure of the one-component sealant, during the curing phase, to the atmospheric hygrometric loads;
  - the application with respect to the ratio of width to depth equal to twice the size;
  - the application in accordance with the absence of adhesion on the "back" of the joint, avoiding the execution on three sides (by means of the "joint-bottom" materials or tapes) and realizing the exclusive connection to the substrates;

- the construction of the expansion joints with respect to the correlation between the width of the joint (for the dimension equal to $l \geq 6$ mm), the thickness of the sealant (above the “joint-bottom” spindle, for the dimension equal to $l = 6 \div 12$ mm) and the contact surface of the sealant (for the dimension equal to $l < 6$ mm);
- the construction of the double joints aimed at resisting atmospheric stresses with respect to the width of the joint (for the dimension equal to $l = 18$ mm, in order to allow for the execution of the internal joint), observing the need to provide spaces for the circulation of air between the seals or to apply an open-cell polyurethane “bottom-joint” mandrel as the internal sealing joint (Figs. 6.3, 6.4 and 6.5).

Then, the design of the joints involves the selection of the sealant through:

- the reference to the contents expressed according to the general distinction between the sealing of glass enclosures and the sealing of the other elements;
- the configuration of the sealant assuming the application possibilities of:
  - the acrylic type, suitable for the porous substrates and resistant to the incidence of ultraviolet radiation, noting a slow cross-linking process and the critical aspects of the actions due to driving or standing rainwater;
  - the polyurethane type, suitable for all the substrates and resistant to atmospheric stress, noting its high elasticity, rapid cross-linking process and critical aspects towards actions due to ultraviolet radiation;

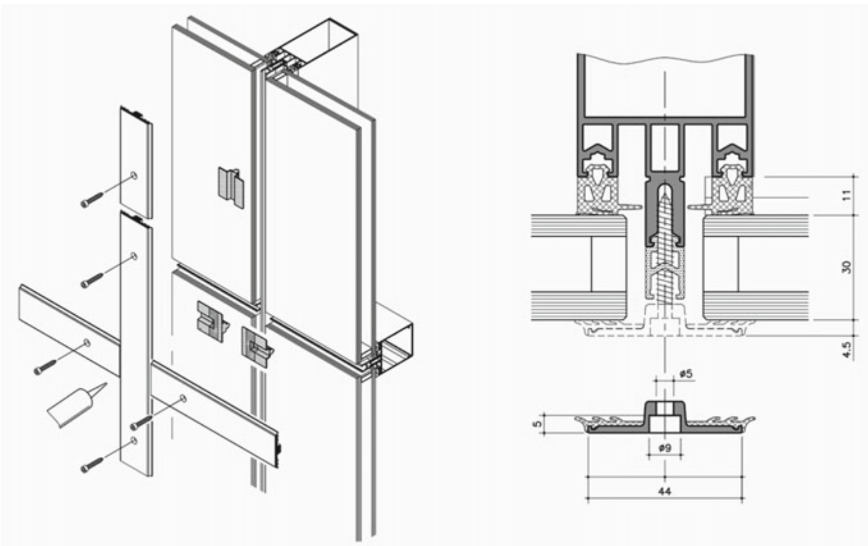

Fig. 6.3 Execution of the perimeter fixing joints, which determine the waterproofing of the façade systems, the sealing (to water and air) and the insulation, that involves: • the application of the gaskets with adhesive silicone; • the correlation of the sealing without the external pressure. © Courtesy of AluK

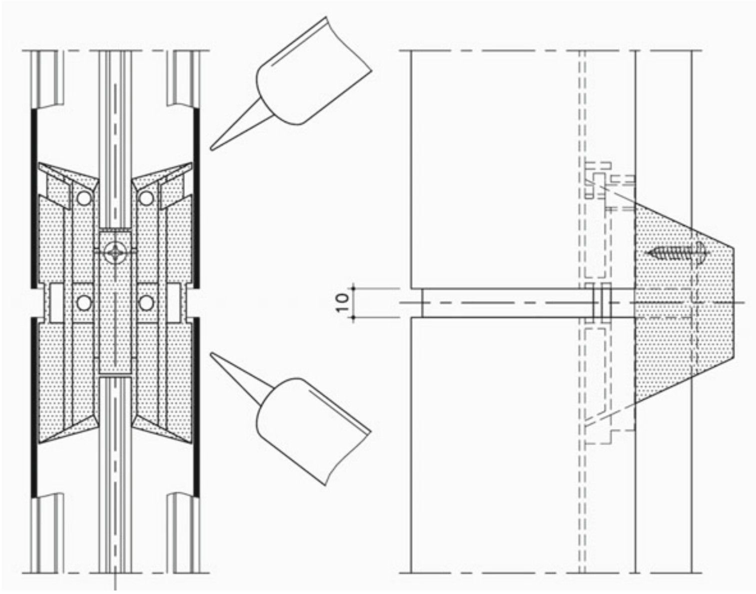

Fig. 6.4 Execution of perimeter fastening joints using silicone adhesive gaskets, determined with respect to the closing interfaces with wedges, joint cover profiles and spacers. © Courtesy of AluK

- the silicone type, suitable for all the substrates and resistant to the effects of ultraviolet radiation, noting its high elasticity, adhesion, maintenance of performance over time and critical aspects towards painting;
- the hybrid type, suitable for all supports, noting the rapid polymerization due to the atmospheric hygrometric action and the maintenance of performance over time;
- the organic type (referring to the polymeric structure of carbon), noting the critical aspects with respect to the incidence of ultraviolet radiation that can cause hardening and loss of movement capacity;

- the identification of the sealant with respect to the specific modulus of elasticity, according to the application purposes in the connections between the frame elements (observing the adoption of high modulus sealants, i.e. with reduced elasticity) and between the frame and the enclosures (observing the adoption of low modulus sealants, i.e. with high elasticity).

6.2 The Application and Control of the Façade Seals

The adoption of the sealants for the façade systems recalls the operation of pre-application checks, such as the “out-of-print” time test, with the aim of examining the complete polymerization and elastomeric properties in order to test the state of

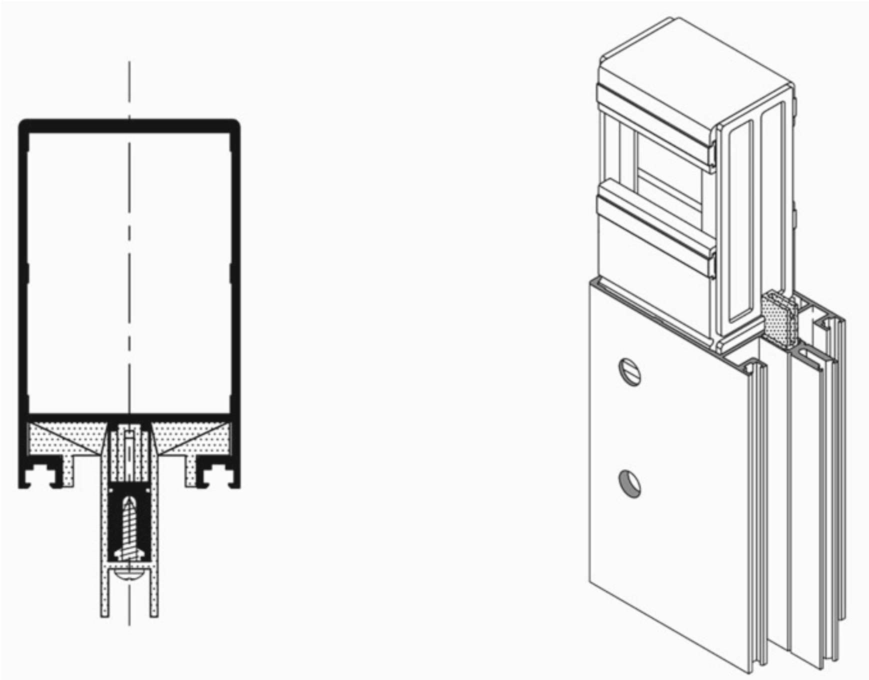

Fig. 6.5 Execution of perimeter fastening joints using silicone adhesive gaskets, determined with respect to the absorption of movements according to the elastic expansion of the adhesive, perpendicular or parallel to the connections. © Courtesy of AluK

preservation of the product. Furthermore, the sealant check includes the execution of the adhesion test by peeling and the field adhesion test (aimed at highlighting the conditions of cleaning, primer realization, joint filling and installation of the "base-joint"). The sealant application tests involve:

- the examination of the objective state of preservation of the product (in accordance with the expiry date shown on the packaging);
- the adoption in the case of low-temperature climatic conditions, considering both the use of the silicone type (flexible and extrudable at low temperatures even without heating the material), and the need to assess the condensation or freezing temperature for which the possibility of condensation and frost on the substrate surfaces may increase. This is in accordance with the operation aimed at low temperature and low moisture conditions. Furthermore, the adoption in the case of low-temperature climatic conditions allows the joint width to increase (due to the thermal contraction of the façade system components), resulting in reduced material stress;

- the adoption in the case of high-temperature climatic conditions, considering the critical aspects connected to the use of the silicone type and the possibility of the generation of air bubbles on the contact surfaces that compromise the adhesion and, consequently, the sealing performance;
- the prevention of the execution during precipitation, the presence of fog and in wet substrate conditions (Fig. 6.6).

The application of the sealants involves the cleaning of the substrate surfaces, considering the different treatment conditions, according to:

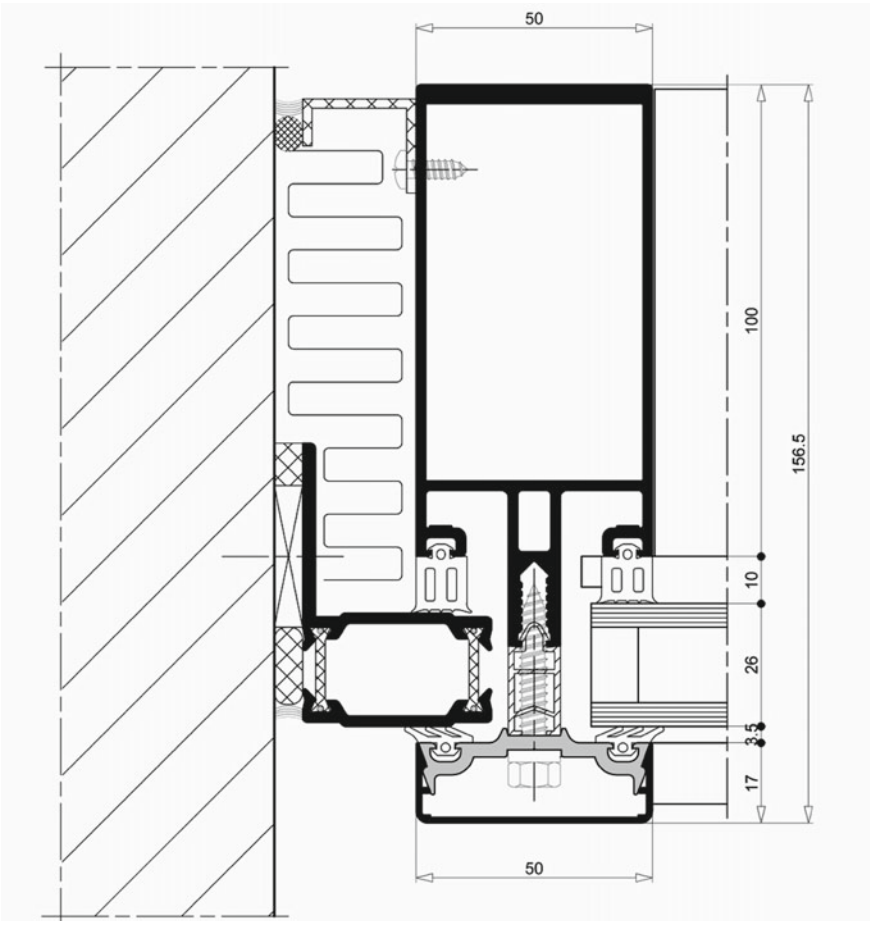

Fig. 6.6 Execution of the mullions and transoms system interface to the building that observes: • the application of the connector with an aluminium "L" angle profile; • the application of the linear aluminium profile; • the adhesion to the building sections by sealing and the interposition of the gasket (on the outside). © Courtesy of Metra

- the execution towards porous substrates, which foresees the use of tools suitable for smooth or rough surfaces, for which the abrasion and subsequent use of a hard bristle squeegee, hoover or compressed air free of oil and moisture is required;
- the execution on non-porous substrates, which requires the use of a double mop.

Therefore, the joint-laying activity considers:

- the cleaning procedure through the detection of:
  - the removal of any debris from the surfaces;
  - the application of the solvent on the first mop (in completely clean conditions) and the treatment of the surfaces;
  - the application of the second mop (in completely clean conditions);
- the procedure for applying the primer, with respect to which it is indicated:
  - the checking of the expiry date of the product and the storing at the temperature envisaged by the product (in general, between $T = 5 \div 25$ °C);
  - the application (within four hours of cleaning) by means of a thin, even layer, with the exclusion of the surfaces that do not involve the sealant. This detects the need to dose the product (as the excessive application causes the generation of a powdery film on the joint surface, which could affect the loss of adhesion to the substrate);
  - the drying of the product until the solvent has completely evaporated;
- the application of the "joint-bottom", according to the correct sizing of the joint (i.e., for the width of more than 25% of the joint in order to guarantee its stability during installation), with the exclusion of the adhesion on three sides;
- the application of the masking (by means of the adhesive tape) on the surfaces of the substrate, in the case of difficulty in removing excess sealant or better finishing of the joint.

The application of the sealant (which must be smoothed to ensure its application, according to the process known as "wetting") requires the joint to be filled and then smoothed with light pressure against the substrate material (i.e. the "joint-bottom").

The polymerization of the sealant requires direct exposure of the joint to atmospheric moisture: the reaction takes place from the connection surfaces, which must be kept stable and in position to avoid deformations in thickness and tightness. In this regard, the coordination and the technical management of the installation involve the width of the joint and movement controls (which, in turn, are a consequence of both thermal variations and the size of the elements, especially in the case of enclosure panels). In order to contain the deformation of the sealant generated by the movements during the curing process it is observed the use of the polyurethane "joint-bottom" with open cells to reduce the reaction time and the sealing of the joint at medium temperature levels to reduce the overall movement.

The technical operability, with respect to sealing content and procedures, also refers to the management of functionality and maintenance of performance, assuming replacement procedures (as in the case of polyurethane and polysulphide products).

In this regard, the technical operation concerns the examination of the procedures related to:

- the cutting of the existing sealant near the edges and the removal of the "bottom-joint";
- the removal of the sealant (by abrasion with a wire brush, grinding and cleaning with solvent);
- the removal of dust and debris using oil-free and moisture-free compressed air.

Chapter 7
The Executive Design of the Technical Interfaces According to Performance Under Fire Loads

Abstract The study of the envelope systems examines the methodologies directed towards fulfilling the requirements with respect to the actions caused by fire loads, considering the contents related to both components and connections and fixing surfaces. The objective is to identify the containment and interruption criteria towards the development and propagation modes of the fire loads: on this basis, the study focuses on the technical interfaces with respect to the fire behaviour. The design study involves the specific sections of separation with respect to the fire compartments: this is to limit the propagation of a fire originating inside the building, the fire of a façade and its propagation, the fall of the façade elements. The attention is focused on non-load-bearing external façade systems, independent of the main elevation structures and, in general, fixed in projection with respect to the perimeter surfaces of the horizontal structures and transversal enclosures: for these systems, the application of a fire resistance strip is indicated in correspondence with each floor and each transversal wall, with a compartmentalization function. In the particular case of non-inspectable double envelope systems, supplemented by mechanical or natural air circulation in the cavity, it is examined the type consisting of the closed external wall and the type consisting of the open external wall. In addition, for the double envelope systems that can be inspected, the type consisting of the closed external wall, with the cavity interrupted by the fire-resistant inter-floor elements, the type consisting of the closed external wall, with the cavity with no horizontal interruptions, and the type consisting of the open external wall, for which the internal wall must have the similar fire resistance requirements to "simple façade" systems, are considered. The analysis implies the applications and interfaces for the main types of enclosures, specified by fire resistance classes, observing compliance through the methods based on tests, calculations and, finally, model solutions.

I. Paoletti and M. Nastri, *Construction of the Façade Systems*,
PoliMI SpringerBriefs, https://doi.org/10.1007/978-3-031-49608-0_7

7.1 The Main Typologies of Façade and Their Evaluation of Fire Protection Solutions

The technical and executive design of the façade systems assumes the procedures, contents and application methods correlated to the performance against actions due to fire loads. In this regard, the study focuses on the profile sections, the material and interface specificities, both at the system level and at the connection level with respect to the structures and fixing surfaces, according to the priority identification and check of the components, elements and materials according to the "reaction" and "resistance" with respect to the fire behaviour. This is in order to determine the criteria of attenuation, containment and interruption towards the onset, development and propagation of the fire loads. At the same time, the design, production and executive composition of the system accommodates the contents aimed at the analytical arrangement of the fire behaviour concentrated on the individual materials and the examination of the interfaces defined by:

- the modes of the fire propagation in the vertical direction, by conduction and convection, within the section between the perimeter surface of the horizontal elevation structures and the façade plane. The interface is demonstrated according to the reduced fire resistance and reduced smoke propagation, in relation to the fasteners of the system towards the horizontal enclosures;
- the modes of fire propagation in the vertical direction, by conduction, through the passage inside the "under-window" portion of the enclosure modules;
- the vertical fire propagation modes, outside the façade plane, in combination with the breakage of the glass enclosures (due to the increase in temperature), whereby the fire rises up the levels outside to re-enter at the distance of one or more inter-floor levels.

The executive design, check and control activities consider the development of specific horizontal and vertical separation strips and sections with respect to the fire compartments in order to:

- limit the likelihood of the propagation of a fire originating inside the building, due to flames or hot fumes escaping from compartments, vertical cavities in the façade, gaps that may be present between the head of the floor slab and the façade or between the head of a fire separation wall and the façade: this with the consequent involvement of other compartments whether they develop horizontally or vertically, inside the building and initially not affected by the fire;
- limit the likelihood of a façade fire and its subsequent propagation, due to a fire having an external origin (such as a fire in an adjacent building or a fire at street level or at the base of the building);
- avoid or limit, in the event of a fire, the falling of façade elements (such as fragments of glass or other broken or ignited parts) that may compromise the safe escape of the building occupants and the safe intervention of the rescue teams.

The fire resistance requirements are not needed in respect of the elements of the façade system which belong to the compartments with a specific fire load value (of $\leq$ 200 MJ/m^2, net of the contribution made by the elements themselves, inserts and insulating materials which may be integrated into the system). Furthermore, the fire resistance requirements are not needed in respect of the elements of the façade system which belong to the compartments within which the specific fire load value is greater than 200 MJ/m^2 if these are equipped with automatically activated fire extinguishing devices.

The technical-execution processing and both check and control activities, in the case of:

- the "simple façade" systems, also composed in multilayer form and including both the types covered by prefabricated elements (fixed with wet or dry binder in adherence to the underlying existing wall, such as "thermal coats") and the brick or block façade types equipped with an air chamber for thermal insulation;
- non-load-bearing external façade systems, independent of the main elevation structures and, in general, fixed in projection with respect to the perimeter surfaces of the horizontal structures and transversal enclosures;

involve, in order to limit the probability of the propagation of a fire originating inside the building, the need to present, in correspondence with each floor slab and each transversal wall, with the function of compartmentalization, a band consisting of one or more construction elements of fire resistance class E60-ef (o $\rightarrow$ i). In addition, in the case of curtain wall type façade systems it is required that the joint element to the floors and transverse walls of the compartments be of fire resistance class EI60 (i $\rightarrow$ o). In this regard, the sections that belong to the interface, which have to meet the fire resistance requirements, may have openings provided that, in the event of fire, the automatic intervention of a fire damper, or an equivalent system, with the same fire resistance requirement as for the parts of the façade.

The technical processing and the activity of both check and control in the case of "non-inspectable ventilated double envelope" systems, integrated with mechanical and/or natural air circulation in the cavity (between 3 $\div$ 60 cm in size), are divided according to:

- the type consisting of the closed external wall, whereby the cavity is provided with non-combustible interrupting elements capable of maintaining its integrity during the exposure to the fire (in correspondence with each window and/or door-window compartment and in correspondence with each ceiling), according to the same functional rules as the "simple façade" systems. In this case, no horizontal break elements are required in correspondence with the floors if only the insulating material classified at least Bs3d0 is present in the cavity, i.e. if the internal wall has a fire resistance rating of EI30 for the complete height and for all floors;
- the open external wall type, whereby the internal wall must have the same fire resistance requirements as the "simple façade" systems if there is only insulation material classified as at least Bs3d0 in the cavity, or if it has, for the entire height

and for all floors, a fire resistance rating of EI30 if there is insulation material with a lower fire classification in the cavity.

The technical processing and both check and control activities in the case of "ventilated double envelope inspectionable systems" are developed according to:

- the type consisting of the closed external envelope, with the cavity interrupted by fire-resistant inter-floor elements. In this respect, if the cavity is interrupted by floors or E60 partition walls for each floor, the external envelope or the internal envelope must offer the same functional rules as the "simple façade" systems. In this case, the openings may be made inside the fire-resistant floors and partitions that interrupt the cavity in order to allow the air circulation within the entire cavity, provided that the continuity of the inter-floor partitioning is maintained through the intervention, in the event of fire, of the automatic closing devices with E60 fire resistance requirements;
- the type consisting of the closed external envelope, with the cavity free of horizontal interruptions. In this regard, the interior envelope must have a fire resistance of EW30 (i $\leftrightarrow$ o) for the entire height and for all storeys. In addition, if the wall belongs to the curtain wall type, it is required that the connection element of the façade to the floors and the transverse walls of the compartments has a fire resistance class EI60;
- the open external envelope typology, whereby the internal wall must have similar fire resistance requirements to the "simple façade" systems.

In particular, in the case of "ventilated double envelope inspectionable systems", it is possible to apply an automatic water extinguishing system, positioned inside the two curtains and sized so as to guarantee a discharge density of not less than 10 l/min m^2 on the internal walls of the entire perimeter delimiting the compartment (for which no specific fire resistance requirements are needed if the internal curtain is made of tempered glass with HST treatment). The capacity of the system, which is to be considered additional to the capacity intended for the other extinguishing systems foreseen for the building, must be such as to guarantee the simultaneous operation, in dispensing, of the nozzles on the floor immediately above the floor affected by the fire, while the discharge duration of the nozzles must be at least 60 min. The system must be controlled by an appropriate fire detection system serving each floor of the building and the dispensing devices, located above each floor, must be oriented towards the internal wall. Furthermore, the intermediate space, or "air corridor", must be provided with a suitable smoke evacuation system, which can be identified by means of a natural ventilation surface, created in both the lower and upper part of the façade, with an area equal to 10% of the horizontal section of the cavity itself.

The technical processing with respect to the ventilated cavity systems is specifically structured with respect to:

- the arrangement of the cavity with no horizontal interruptions, if the external curtain consists, for more than 50% of its surface, of fixed elements that break at temperatures above 100 °C. In this case, the internal curtain must have, for its full height and for all storeys, a fire resistance EW30 (i $\leftrightarrow$ o) to be verified by a test in accordance with Standard EN 1364-1:2019 in the case where the internal curtain rests directly on the floors and in accordance with Standard EN 1364-3:2014 in the case where the internal wall is a curtain wall. For the latter case, it is required that the connection element of the façade to the floors and cross walls of the compartments is of fire resistance class EI60 (i → o);

- the arrangement of the cavity without interruptions, if the external wall is made up, for at least 50% of its surface, of elements with movable ventilation slats that open automatically in the event of fire (with an opening equal to at least 30° with respect to the horizontal) or fixed gratings distributed uniformly or, finally, of panels made of materials that melt at temperatures below 100 °C. For this case, the internal wall must have similar fire resistance requirements to the "simple façade" systems.

7.2 The Standard References, Types of Test and Products for Fire Protection of the Façade Systems

The conformity of the different façade types is to be assessed through:

- the test-based method, by which the portion of the façade for which the fire resistance requirement is envisaged is verified according to the following indications:

  (a) for the "simple façade" type of system resting on floors, Standard EN 1364-1:2019, *Fire resistance tests for non-loadbearing elements. Part 1: Walls*;
  (b) for the type of curtain wall façade system, Standard EN 1364-4: 2014, *Fire resistance tests for non-loadbearing elements. Part 4: Curtain walling. Part configuration*;
  (c) for the type of curtain wall façade system that has to guarantee the fire resistance requirement for the entire development and not limited to the strip facing the floors and partition walls, instead of the Standard indicated in the previous point, Standard EN 1364-3:2014, *Fire resistance tests for non-loadbearing elements. Curtain walling. Full configuration (complete assembly)*;
  (d) for linear joint sealants, Standard EN 1366-4:2021, *Fire resistance tests for service installations. Linear joint sealants.*

  The Classification Standard EN 13501-2:2016, *Fire classification of construction products and building elements. Part 2: Classification using data from fire resistance tests, excluding ventilation services*, provides the procedure for the classification of "simple façade" and curtain wall types according to the criteria E, I with the suffixes "I" (inside) and "o" (outside) linked by an arrow to indicate the direction of fire exposure, as well as the suffix "-ef" in the case where the classification is made with regard to the external fire exposure;

- the method based on calculations and tables, whereby the façade elements made of heavy elements (such as concrete, stone or masonry), i.e. made of materials that are not very deformable at high temperatures, are verified for the fire resistance classification purposes: this is by noting that the EI60 requirement of a wall also guarantees the EI60-ef (o → i) requirement. However, for the façade systems it is not possible to proceed by means of solutions based on calculations or reference to tables;
- the method based on the model solutions, articulated with respect to:

(a) the façade elements made of heavy elements (such as concrete, stone or masonry), i.e. made of materials that are not very deformable at high temperatures, for which the check for the purposes of the E60-ef (o → i) classification can be carried out using the European Standards EN 1992-1-2:2009, *Eurocode 2: Design of concrete structures. Part 1–2: General rules. Structural fire design* and EN 1996-1-2:2005, *Eurocode 2: Design of masonry structures. Part 1–2: General rules. Structural fire design.* In this regard, it should be noted that the EI60 requirement of a wall automatically also guarantees the E60-ef (o → i) requirement. The elements or parts of the façade that must meet the fire resistance requirements must be joined with the remaining parts of the façade, floors and partition walls through sealed joints, using plaster, mortar or rockwool. If the façade elements in concrete, stone or masonry do not rest directly on the slab, the relevant joint can be made through:

   – the continuous rockwool infill (with a minimum height of 80 mm and a density of not less than 80 kg/m^3) covered by a steel support plate (with the thick of 0.6 ÷ 1 mm), fixed on both sides of the joint by metal and mechanical fixings (with a minimum cross-section of 20 mm^2, at least three per meter). The covering of the metal sheet must wrap around the façade elements, floors or partition walls concerned (for a minimum depth of 100 mm, the same dimension must affect the overlap between one sheet and the next);
   – the use of a product certified for fire resistance in accordance with the Standard EN 1366-4:2021 and specifically manufactured for the linear type of infill;

(b) the curtain wall type façade systems and other lightweight façades, in respect of which the parts or the elements at each floor slab and at each transverse wall, with a partition function, including the connected joints with the floors or walls, must be verified exclusively by the test-based method. In the case of the dimensional or technological variations of the anchorage system with respect to the system under test, the procedure allows for specific evaluations to be carried out, in any case, on the basis of the experimental results of the system under test.

With regard to reaction to fire, the cladding panels, fixed decorative elements, thermal coats, thermal insulation, sealing materials, sealants and insulating products contained within the façade systems must be of at least class 1 reaction to fire, i.e. class B-s3-d0 (as established by the European Commission 2000/147/EC of the 8 February 2000). The insulating products, with the exclusion of applications placed close to window and door-window openings (for a band of width equal to 0.60 m and for elements placed at the base of the façade system up to 3.00 m above ground level) may avoid meeting the reaction to fire requirements as long as the installation provides for their protection, even within the eventual cavity, according to:

- the adoption of an insulating product C-s3-d2 if protected with materials of at least class A2;
- the adoption of an insulating product of class no lower than E if protected with materials of at least class A1, characterized by a thickness of no less than 15 mm;
- the adoption of an insulating product D-s3-d2 if protected with materials of at least class A1.

The development of additional protective solutions can be evaluated and adopted as long as they are supported by specific reaction to fire tests on a combination of products (substrates, insulating materials, protective materials) that guarantee a reaction to the fire class of not less than 1, i.e. type B-s3-d0. The reaction to the fire, with respect to other specificities of the façade system, observes:

- in the case of gaskets, sealants and sealing materials, if they occupy a total surface area greater than 10% of the entire surface area of the envelope, the guarantee of the same requirements as indicated for the insulating products;
- in the case of the other components, if they occupy a total area of more than 40% of the entire surface of the enclosure, the guarantee of the same requirements as for the insulating products;
- in the case of glass enclosure elements, the absence of reactive fire performance.

If the façade systems are composed of "brittle" materials or if, in the event of fire, breakage and detachment of non-minimal parts can occur, it must be ensured that the escape route landings, external safe places and rescue areas are protected against falling elements. The design and configuration (dimensional, functional and relational) of the escape system considers:

- the conditions of difficulty of access to the building from the outside, in the event of fire, by rescue teams;
- the prohibition of the use, in double envelope systems, of the cavity by the occupants for evacuation purposes.