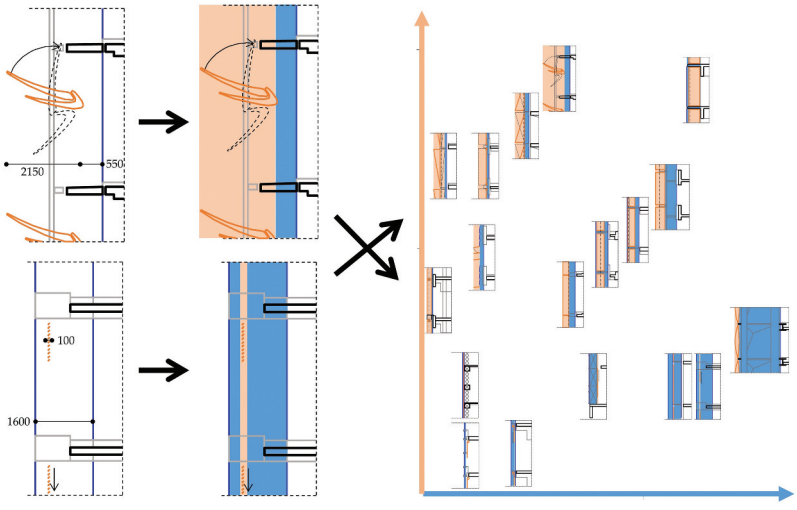
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Cogent Arts & Humanities (2021), 8: 1960699

Brzezicki, *Cogent Arts & Humanities* (2021), 8: 1960699
https://doi.org/10.1080/23311983.2021.1960699

cogent arts & humanities

VISUAL & PERFORMING ARTS | RESEARCH ARTICLE

A typology of adaptive façades. An empirical study based on the morphology of glazed facades

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Received: 10 March 2021
Accepted: 22 July 2021

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Reviewing editor:
Nomusa Makhubu, University of Cape Town, Cape Town, South Africa

Additional information is available at the end of the article

Abstract: A building's façade is its main interface with the external environment. Adaptive façade, one recent invention in the façade industry, has the capability to change its behaviour in real-time to respond to internal and/or external parameters, by means of materials, components, and systems. Among these, the adaptive shading and the façade glazing are two components that must fit together. This paper focuses on the spatial relationship between these components. It presents the results of the morphological analysis of façades with adaptive shading systems and the spatial relation between the adaptive shading system and the building's glass envelope. To characterise this relation, we formulated two measures: depth and distance. The results revealed four types of such relations: (i) the shading elements are located outside the building's glass envelope, (ii) they are covered by the glass envelope, (iii) they are located between the layers of the glazing façade, and (iv) they represent thin coatings that are flush with the surface of the glass. These results provide important insights into the emergence of new aesthetical trends in architecture, especially given the most recent technologies adopted in façades. In conclusion, we bring empirical evidence that the location of the shading system in relation to the glass envelope of a building is the key morphological



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ABOUT THE AUTHOR

Marcin Brzezicki, PhD (1972) is an architect and tutor at the Faculty of Architecture, Wroclaw University of Science and Technology, Poland. After receiving his doctorate in 2001, he became an assistant professor in the Faculty of Architecture at his alma mater. His scientific interest was focused on the perception of transparency in architecture, including his monograph entitled Perception of transparency in contemporary architecture: visual and cognitive aspects. After successful application for tenure in early 2015, his interest was broadened to general issues of façade/architectural envelope morphology and aesthetics. In 2015 he joined COST TU 1403 Adaptive Façade Network.
Marcin Brzezicki participates in international conferences on the subject of transparency and façade morphology, publishes in journals. He is a motivated and ambitious researcher with a strong interest in the optical properties of architectural envelopes. A passionate and enthusiastic academic teacher with a genuine love of his subject and a drive to help students succeed.

PUBLIC INTEREST STATEMENT

Adaptive façade is a new type of façade in architecture, which is – in the contrast with the static façade –actively reacting to the changing environmental triggers: sunshine, wind, temperature. Those adaptive functions are performed by various types of mechanisms, most commonly layered sunshades, blinds or rollers. In just a few minutes they completely change the appearance of the building and how the façade is perceived by observers. Based on the research of 15 case studies of adaptive facades, it turned out, that the dimensional relations of those mechanisms vary a lot, with the conclusion, that the location of the shading system with the relation to the glazing is a fundamental feature that affects the built environment on the aesthetical level.

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feature that determines the extent of spatial transformation of the architectural structure on which such a system is installed.

Subjects: Visual Arts; Design; Philosophy of Art & Aesthetics

Keywords: adaptive façade; kinetic façade; adaptive shading; glass façade



1. Introduction

In recent decades, architects and engineers have worked to create a new generation of buildings: they transitioned from a passive and static system into dynamic and adaptive systems. Adaptive buildings resemble a living organism (Antonini, 2021), whose elements react to the changes in the internal and external environment (Showkatbakhsh & Kaviani, 2021). This was achieved thanks to the presence of smart materials and components, and automated systems. On the one hand, this revolutionized how a building works and how the users' comfort is achieved, and on the other hand, it affects the spatial relation between the elements of the building's façade.

Shading systems, further called shading/regulatory systems (SRS), are particularly important in this respect because they have a significant influence on the architectural form of the building (Baird, 2001). SRS is characterized by optical variability which translates into the potential to significantly alter the building's appearance, particularly the proportions of the façade, its rhythm, directional accents, and even its volume. Precisely, the spatial aspect of the relation between the shading system and the glass envelope is at stake in this paper. In relation to this issue, our first research question is how do the SRS and the façade glazing fit together in an adaptive façade?

Furthermore, the use of adaptive façades, whose most visible element is the SRS, caused a paradigm shift in both the design and the perception of architecture. Nevertheless, up to now, studies have not investigated the consequences of adaptive façades for the architectural form of the building (Böke et al., 2018). Hence, our second research question is what are the consequences of the spatial configurations between the building glazing and SRS on the architectural form of the building?

2. State of the research

2.1. Adaptive façades

The idea of a façade that adapts to the conditions of the external environment appeared in architectural research and practice in the 1960s. Buckminster Fuller's automated sun shades were first used for the US pavilion at Expo 67. In 1969, in a paper titled "A Home is not a House", Rayner Banham identified "three modes of environmental control" in the building envelopes—conservative, selective, and regenerative (Banham, 1969). In 1976, in his paper on "Soft Architecture Machines", Nicolas Negroponte introduced the concept of a responsive environment (Negroponte, 1976). In the 1980s, Michael Davies presented a revolutionary idea of a "polyvalent wall' composed of microscopic layers which performed different functions: regulation, energy harvesting, heat transfer, and signal channelling (Davies, 1981).

It is commonly agreed that the term adaptive façade covers the idea of a "façade system capable to change its function, shape, and behaviour in response to the fluctuating external conditions" (Sandak et al., 2019). Loonen et al. defined the adaptive façade system (also called "responsive" or "dynamic") as capable of controlling insulation, radiant heat exchange, daylighting, solar shading, humidity, ventilation, and energy harvesting (Loonen, 2013). This system is also referred to as a facade "which can react" (Szolomicki & Golasz-Szolomicka, 2019). Façade adaptivity can be "manifested in several manners: by the physical change of the façade shape (so-called kinetic façades), by the active control of the energy flow (e.g., by opening and closing windows, retracting sun-shades, or operating fans), or by energy harvesting (e.g., by solar collectors or photovoltaic panels)" (Sandak et al., 2019). Various components of those façades and subsystems can "change the size, shape, volume, phase, or colour when subjected to various environmental triggers" (Sandak et al., 2019) and "adapt to changes in climatic variables" (Chang et al., 2019).

2.2. Literature review

The topic of adaptive facades topics generate considerable research interest, but the results are scattered, mainly due to terminological reasons. In the review from 2018 Romano et al. (2018) state, that in the context of building facades the term "adaptive" is "often associated in the literature with a long list of similar terms" including: *active* (Luo et al., 2019), *adaptable; adjustable; biomimetic* (López et al., 2017); *bio-inspired, controllable; kinetic; intelligent* (Böke et al., 2018); *interactive; living; modifying; movable; polyvalent; reactive; reconfigurable; reflexive; resilient; responsive* (Negroponte, 1976); *selective; sensitive; sentient; smart; switchable* (Pflug et al., 2015); *transformable; transient; and passive*. Moreover, there is no consistent definition of façade adaptability, as different authors approach the topic from a different perspective. The papers reporting individual studies of adaptive/responsive/switchable façade are frequent but focus only on those parameters/features that are used by the authors to study the solution being investigated, like the studies by Holstov et al. (2015), Jayathissa et al. (2018), and Tabadkani et al. (2019). Multi-criteria investigations across different fields of adaptive facades are generally uncommon, however, some studies consider general characteristics of adaptive facades. Those studies can be classified based on criteria that are used by the authors to organize the rich set of described features of adaptable facades. In 2012 Ramzy and Fayed (2011) have analysed the adaptive façade using the criteria of *kineticism; control techniques; system configuration; control limit; cost*. In 2013 Loonen et al. (2013) have presented an extensive review of adaptive facades including the new, previously unused criteria of *relevant physics; time-scales; scales of adaptation; control types*. Despite the time of publication, the study by Loonen et al. (2013) continues to be an important and timely contribution to the discussion in the discipline. In 2014 Favoino et al. (2014) have added the criteria strongly associated with building physics and energy efficiency like *window-to-wall ratio; U-value, g-value; visible transmission infiltration rate*. Loonen et al. (2015) and D. Aelenei et al. (2016) refined the criteria previously defined by Lonnen et al in 2013 but included in the discussion the distinction between *component, element* and *material*. Again, in 2017 Loonen et al (2017) have presented the review of current status, requirements and opportunities for building performance simulation of

adaptive façades, including additional criteria of *occupant influence* and *user interface*. An important contribution to the analysis of adaptive façades in a broader perspective was made by Barozzi et al. (2016) who analysed the mechanics of kinetic systems and adopted respective criteria to analyse the features of adaptive facades like *kinematic* and *elastic systems*. In 2018 Attia et al. (2018) have analysed the issues of performance assessment of adaptive façade systems, introducing structural and safety criteria including, among other: *fire resistance, seismic resistance* and *durability*. The closest to the approach presented in the paper was adopted by Hosseini et al. (2019) and by Moloney (2011). In 2019 Hosseini et al. (2019) published a paper that concentrated on morphological analysis of adaptive facades but from the perspective of *parametric design thinking, biomimicry* and *kinetic movement types*. The authors state that "by means of morphological approach" (Hosseini, 2019) geometry and the politics of control might be investigated. Moloney (2011) addressed the kinetic/adaptive façade from the perspective of *architectural form, kineticism* and *compositional systems*, and is numerously cited in the presented paper. Table 1 shows a comparison of the review studies on adaptive facades with the criteria that authors used to describe/define the features of adaptive facades.

2.3. Knowledge gap

Literature review shows, that "adaptive" façade is analysed from a different perspective by the different authors, those authors or author teams consider different aspects of the adaptive facades formulating different criteria to describe the different features of this new, constantly developing technical solution. Visual aspects of facades are frequently analysed in the context of visual comfort, rather than aesthetics (Hosseini, 2019). However, none of the approaches presented above attempted to analyze adaptive facades from the perspective of architectural form, recognizing the nuances and spatial relations of the elements that constitute such a façade—including the feature of the cognitive projection of façade elements from the background creating the morphological depth of the facade. The presented approach allows for consideration of proportion, a manifestation of form, clarity of the message, that is conveyed through the façade. Failure to address this issue so far is seen by the authors as a gap in knowledge that needs to be filled to get the full picture of the phenomenon described, especially because the literature lacks this type of approach. We think that the architectural/sculptural/aesthetical values of adaptive façade have not been sufficiently analysed and researched. Therefore, the aims of this paper are *(i)* to perform a morphological analysis of adaptive façades by comparing the spatial relation between façades glazing and SRS, and *(ii)* to discuss the effects of these spatial configurations on the architectural form of the buildings. To achieve this goal, we analyse fifteen façades of buildings from Europe presenting different types of adaptive shading systems which differ in their spatial relation with the building.

2.4. Adaptive shading and façade glazing

In practice, integrated façade solutions that could fulfil all the requirements of a multifunctional building envelope do not yet exist. Selected functionalities are being implemented individually as pilot sub-systems of larger façade schemes. Historically, daylight regulation and its influence on visual comfort were the first automated sub-system. Adaptive shading—as it was referred to by Adriaenssens et al—"reflects a barrier function against harmful and disturbing solar radiation" (Adriaenssens et al., 2014) which might influence not only the indoor microclimate but also the user's health conditions (Geller et al., 2003), and the perception of glare (Brzezicki, 2012), (Konstantzos & Tzempelikos, 2017), (Perry, 1990).

Mechanically or pneumatically controlled blinds, sunshades, or apertures operate on relatively simple principles involving a photo-sensor that detects the amount of daylight. The control system is extrinsic—meaning "operated remotely" or intrinsic—meaning "self-regulating" (Aelenei, 2016). The extrinsic system can be described as comprising three phases of operation: *(i)* collecting information about the state of the environment (sensing the illumination level, detecting the position of the Sun); *(ii)* processing the collected information according to an algorithm, *(iii)* physically activating the shading elements (e.g., actuating, folding, rotating, and inflating). In

Table 1. Comparison of the review studies on adaptive facades with the criteria that authors used to describe/define adaptive facades

no.	authors	year	analysed criteria
1	**Ramzy & Fayed**	Ramzy & Fayed,	Kineticism; Control techniques; System configuration; Control limit; Cost
2	**Loonen et al**	Loonen et al.,	Sources of inspiration; Relevant physics; Time-scales; Scales of adaptation; Control types
3	**Adriaenssens et al**	Adriaenssens et al.,	Numerical form-finding techniques
4	**Favoino et al**	Favoino et al.,	Window-to-Wall-Ratio; the U-value, g-value; visible transmission Infiltration Rate.
5	**Loonen** et al.	Loonen et al.,	Goal/purpose; Responsive function; Operation Technologies; Response time; Spatial scale; Visibility; Degree of adaptability;
6	**Aelenei et al**	D. Aelenei et al.,	Purpose; Responsive function; Components; Operation (materials and systems); Response time; Spatial scale; Visibility; Degree of adaptability
7	**Loonen et al**	2017	User interface; Solution routines for transient heat conduction through building elements; Control strategies, Occupant influence; Multi-domain integration and physical interactions.
8	**Barozzi et al**	Barozzi et al.,	Kinematic systems (Externally applied, Internally applied Integrated in the façade); Elastic kinetic systems (Externally applied, Internally applied Integrated in the façade);
9	**Attia et al**	Attia et al.,	Fire resistance; Fire propagation; Water tightness; Resistance to dead load; Wind load resistance; Resistance to snow load; Impact resistance; Resistance to horizontal loads; Seismic resistance; Thermal shock resistance; Direct airborne sound insulation; Flanking sound transmission; Thermal transmittance; Air permeability; Water vapour permeability; Radiation properties; Durability
	Hosseini	2019	Movement type; Scale of the kinetic element; Function Indoor environment quality/

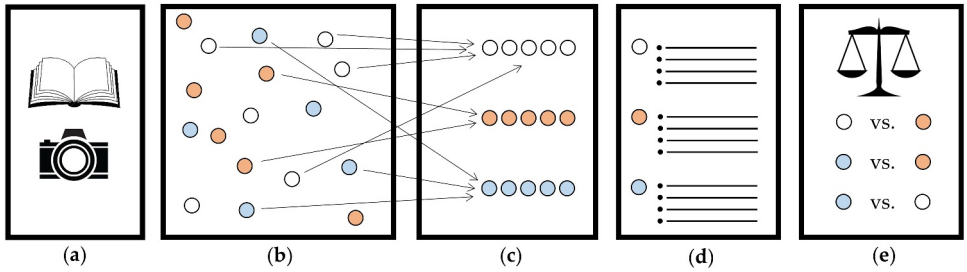


Figure 1. A diagram illustrating the layout of research procedures used in the article: (a) fieldwork and desk study (b) selection of buildings from the database; (c) formulation of trends; (d) description of distinctive features; (e) comparative analysis. Diagram by author based on (Brzezicki, 2021).

practice, if the sensor detects a change in environmental conditions, the algorithm calculates the required actuator displacement and then the actuator rotates the louvres to the proper position. In contrast, an intrinsic control system is self-autonomous. It relies on the inherent properties of the used material/component, for example, shape-changing materials or bimetallic elements. An important drawback of intrinsic control is that the elements cannot be externally regulated. For instance, if the temperature drops, the bimetallic element returns to its original shape regardless of the level of illumination. Therefore, the practical application of intrinsic control in shading systems is limited.

Adaptive shading systems can have various forms: from classic lamellar blinds rotating around their axis, to roller blinds, to geometrically complex multifaceted kinetic systems which—like paper origami toys—fold or unfold in reaction to changes in illuminance, e.g., Al Bahr Towers (arch. Aedas Architects, 2012). Those SRS are, therefore "expressible both externally and internally" (Baird, 2001).

The use of modern technologies and widespread miniaturization helps to significantly reduce the size of the adaptive layer. The most recent solutions could be integrated into only a single IGU (insulating glass unit). Chronologically, the first SRS of this kind was mechanical. Further development and miniaturization brought about a significant size reduction. The reduction in size is particularly true for systems that are based on physical/chemical transformations in the material itself. This applies to microscopic layers of electrochromic coatings and liquid crystals that are deposited on a pane of glass (for a detailed description of these systems, see Brzezicki, 2016).

Other daylight regulation systems that are based on the so-called "thin layers" are visually indistinguishable from a single pane of glass. From the point of view of spatial relationships and the introduction of depth in the façade, those systems are not different from conventional mullion and transom façade. Examples of such solutions include micro-blinds developed at the National Research Council (Canada), electrochromic layers (e.g., Sage intelligent glass) and liquid crystals (e.g., Priva Lite by Saint-Gobain or Eyrise s 350 system by the company Merck (Chasing Transparency, 2019).

In sum, all the different forms of adaptive shading systems can affect the architectural form of the building. In what follows, this influence will be investigated within an empirical study taking into account 15 buildings' façades and analysing different types of spatial relations between the SRS layer and envelope layer (Section 3). As a result of this morphological analysis, four types of façades will be identified and consequences for the architectural form of the building will be discussed (Section 4). Section 5 concludes the paper and future perspectives are proposed. The modus operandi adopted in this paper is frequently used in architectural empirical studies—see Figure 1.

3. Empirical work

Usually, a database of buildings is collected through fieldwork or desk study, as in the work of Pell et al. entitled "The Articulate Surface"(Pell et al., 2010). Buildings that share similar characteristics are grouped and their distinctive features are described—they constitute a formal trend as done for example, by Anne-Catrin Schultz (Schultz, 2015). Routinely, several trends are observed simultaneously and their changes over time and space are determined. The collected database becomes

the subject of a comparative analysis, which in turn serves as the basis for summaries and conclusions as suggested by Ray (Ray, 2016).

3.1. Method and material

For this research, we analysed 15 European building façades selected from an inventory of 382 façades that were collected through fieldwork in the years 2014–2018 within the project entitled "New trends in architecture of transparent facades—formal experiments, technological innovations", ref. no. 2014/15/B/ST8/00191. This research was funded by the National Science Centre, Poland and the objective of the research program was to *(i)* investigate and isolate new trends in façade architecture, *(iii)* identify their geographical range and *(iii)* formulate the trends' models—a group of all the features typical of the trend. The authors of the paper simultaneously participated in the European Program COST TU 1403 titled "Adaptive façade network" which allowed to gain expertise in the field of adaptive facades and allowed following analysis from the perspective of architectural form. One of the important parts of the COST initiative was the establishment of the database addressing different cases of adaptive façade, which was subsequently published in the form of a book (L. Aelenei et al., 2018).

The selection of the case-study buildings was based on the assumption that only the most representative examples are suited the best to present the trends most visibly. Presented buildings have the most profound characteristic features for the illustrated group of trends. Precisely, all presented SRS are environmentally responsive and—roughly speaking—their settings depending on the weather, mainly cloud coverage. The kinetic performance of such systems, or the rate of their response to the environment, varies and depends both on the type of the control system and on the design of its adaptive function. As a result, we expect that the spatial relations between elements of the façade change constantly as a result of the kinetic action that takes place within the façade. In each case, the arrangement of the shading/regulatory layer and the envelope layer is expected to produce a different spatial relation. From an architectural perspective—the presented shading systems are spatially unstable because they depend on factors that the designer cannot control, such as the abovementioned weather. The schematic diagram of the selection procedure is presented in Figure 2.

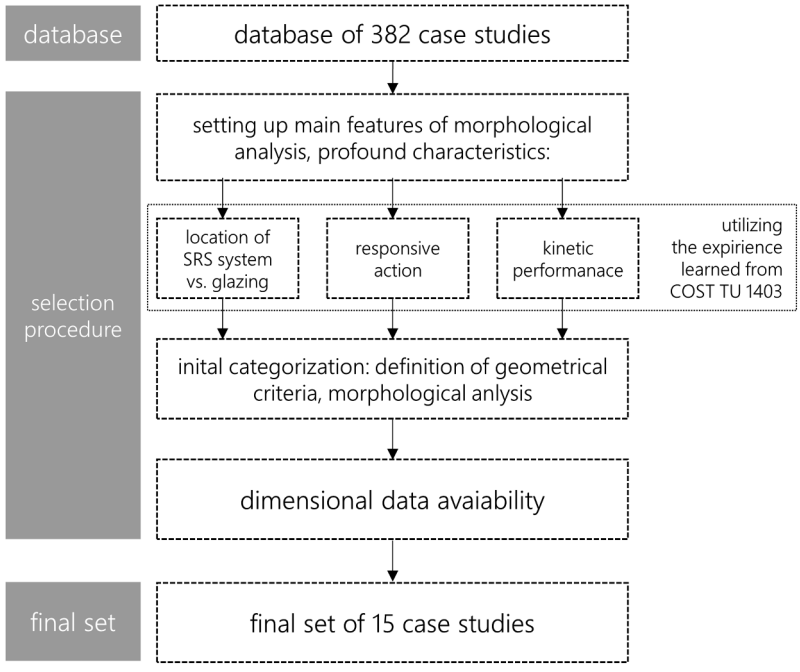


Figure 2. The selection procedure, the explanation of adopted measures.

3.2. Morphological analysis

Morphological analysis in architecture can have at least two meanings. The former—more broadly described in theoretical terms—derives from the medieval works of Ramon Lull and introduces the idea of "pre-concept" (Prokopska, 2001) and "morphological construct" (Thompson & Emmitt, 2013). This second meaning—much closer to the approach adopted in the presented paper—derives from the works of Louis Sullivan and simply means the study of the evolution of form within the built environment. Moloney is even more straightforward and defines the term "morphology" as typically associated with the "outward appearance of (…) a physical structure" (Moloney, 2011), along with Seadman writing, that morphology is a "study of geometric relationships" (Steadman, 1983). The morphological study of the static building describes changes in its formal syntax—while the morphological study in the context of adaptive façade—requires additional measures to describe its specificity. SRS systems are even more unique, as they usually occupy the perimeter of the building, constituting permanent (meaning permanently installed on the facade), but kinetic part of the architecture (meaning changing according to the weather/seasonal conditions).

The main features of the morphological analysis presented here are the location of the SRS system in relation to the glass envelope of a building, the façade's rhythm, directional accents, and —at least as important—the depth in which the building's façade is enriched. The main "source" of a depth is usually the layered arrangement (Davies, 1981) of the elements of the façade with different functions. Depth, on the other hand, is very specific. This feature can easily be perceived by an outside observer (e.g., judging the depth by the play of light and shadow in one-point perspective), but its analysis must happen in the cross-section of the facade, where it is possible to determine the geometric relationships of the individual parts that build-up that depth. Therefore, to analyze the spatial relations within the façade, two measures were formulated: *(i)* depth D_t and *(ii)* distance D_s. Depth D_t, measured in mm, is defined as the boundary of space occupied by the adaptive SRS system in all its possible phases and states. The distance D_s in mm is measured between the elements of the adaptive shading system and the glazed envelope of the building. In the case of double-skin façades, the width of the air-corridor/buffer is also described as D_s. D_s refers to the shading element that is the closest to the envelope. All dimensions are rounded to the nearest 50 mm. The building glazing is marked on the diagrams in blue, while the shading regulatory system is marked in orange.

Dimensional properties are usually discussed from a strictly technical perspective, e.g., Schultz (Schultz, 2015) compares the dimensions of double-layer façade systems but does not analyse the protrusion of SRS systems. Obviously, from an engineering perspective, D_t and D_s are just technical measures, but their importance outweighs the importance of other adaptive façades' parameters because—from the aesthetical perspective—they constitute the foundation for morphological analysis of architectural forms.

The adopted measures of D_t and D_s were selected because those dimensions are crucial to describe the sculptural features of the façade as a part of its morphology. When the façade is "open", the sum of D_t and D_s describe the maximal protrusion of the SRS system in the relation to the plane of the façade (usually its glazing), that could be also considered as its background (Arnheim, 1974). When an axially rotating SRS system is considered, half of the D_t distance defines the surface of the façade, e.g., when shading elements are closed. Protruding elements greatly affect the depth of the facade in the different modes of operation: in the time scale of minutes, the aesthetical impression of the façade could change dramatically. The protrusion of the façade's elements plays an essential role in constructing the depth that is perceived by the viewer. As Lee et al address this as follows: "façade that has significant depth is optically reduced to a flat surface when seen from a distance" (Lee & Nezar, 2011), but when observed in proximity the "potential to create the (…) depth" (Duygu, 2012) could be observed.

The analysis of each façade resulted in a diagram of the façade, a brief technical description of the façade and the description of the spatial relation between the adaptive shading system and the glazing of the building, as presented in the next section. The sections of the facades in the same scale, the dimensional information, external photograph and bibliographic information are presented in Table 1.

3.3. Data

1. Oval Offices in Cologne (arch. Sauerbruch Hutton Architects, 2010) feature external vertical shutters. The shutter panels in Cologne Oval Offices are made of lacquered glass. The panels pivot about the vertical axis and use a mechanical system to rotate each panel, that is hinged on one side (side-hung). The mechanism that pivots the panels is installed at the slab level on the façade—see Table 1, row 1, and covered by the cladding. When opened, the panels rotate so that they are perpendicular to the plane of the façade. Open shutters are susceptible to a higher drag force, which has to be taken into the account in the design stage. The position of the shutters is controlled centrally. The depth D_t = 900 mm, the distance D_s = 200 mm

2. Fünf Höfe shopping mall in Munich (arch. Herzog and de Meuron, 2001) features external perforated metal bi-fold vertical shutters. Shutters are folded with the use of pantograph systems. The difference between the shutters in Cologne Oval Offices and Fünf Höfe is that in the latter case the shutters are mechanized using a much simpler system (see Table 1, row 2). The distance D_s between the shutters and the glazing is approx. 600 mm and features a service walkway for façade maintenance, while, when opened, the system projects outwards at a depth of D_t = 600 mm.

3. The university building in Denmark named SDU Campus Kolding (arch. Henning Larsen, 2014) features external vertical shutters. Those type of shutters differs geometrically from folding shutters in that the whole segment is rigid and hinged on one side (side-hung), or in the central axis (centrally-pivoted). In the case of SDU Campus Kolding—due to the diagonal grid of the façade—the shutters are triangular in shape—see Table 1, row 3. They pivot about the vertical axis, which causes the corner of the triangle to project outward. The distance between the shutters and the glazing D_s is approx. 450 mm, while the open system projects outwards at a depth of approx. D_t = 950 mm.

4. INES—French National Solar Energy Institute (arch. Atelier Michel Rémon + Agence Frédéric Nicolas, 2013) in Chambery in France features external centrally-pivoted vertical shutters. Shutters are hung on a separate structure that runs parallel to the glazed west façade of the building. They are in groups of four and can be mechanized and individually controlled. When closed, they form a single surface along the west façade. When opened, they allow daylight into the building, reducing heat load. The distance between the shutters and the glazing D_s is relatively large and is approx. 1200 mm, the depth of the shutter itself is approx. D_t = 900 mm, which makes this adaptive shading system one of the deepest in this paper in terms of outward projection—see Table 1, row 4.

5. Equinor Offices in Fornebu in Oslo (arch. A-Lab Architects, 2012) feature a standardized external system manufactured by Colt. Due to their smaller size resulting in lower drag force, individual shutters are easy to operate and are usually operated by a prefabricated/typical mechanical system that is a part of the system solution—see Table 1, row 5. The distance D_s between the shutters and the glazing is approx. 150 mm, while the depth of the system is approx. D_t = 450 mm.

6. Thyssen Krups HQ in Essen (arch. Chaix & Morel et Associés, JSWD Architekten, 2010) features a system which was developed by the Fraunhofer Institute for Solar Energy Systems in Freiburg. This system takes the form of a "movable sunscreen" composed of external vertical fins—see Table 1, row 6. These fins are made of horizontal cantilevered slats that are connected to a central

stud, resembling "vertebrae in a spine" (Sola, 2019). The fins rotate in the horizontal plane to "achieve an adjustable position between 0° (parallel to the facade: total direct radiation blocking) and 90° (perpendicular to the facade: maximum daylight penetration)" (Solla, 2010). Each fin is triangular in shape—the slats interlock to create moiré patterns. The size of each vertical fin is approx. 600 mm, the distance D_s between the fin and the glazing is approx. 150 mm. The depth D_t is equal to 900 mm.

7. The police station in Berlin (arch. Sauerbruch Hutton, 1999) features a system of external glass "scales" that serve as the cladding of the building and cover the entire western façade. Some of them—those in front of windows—perform the additional function of external horizontal glass louvres. When these louvres are opened, they reveal the location of windows that illuminate the rooms—see Table 1, row 7. The distance D_s between the louvres and the glazing is approx. 250 mm, but in this case, the glazing has the form of classic windows in load-bearing concrete walls rather than of a glazed envelope. The open system projects outwards at a depth of approx. D_t = 650 mm.

8. ZVK office building in Wiesbaden (arch. Thomas Herzog, 2003), features an external system of large-scale external horizontal foldable light-shelves—see Fig. 9. By folding in half, these hinged elements can either let daylight into the room or entirely block direct insolation. An average daylight factor of 16,63% is achieved (D'Alençon, 2009). The distance D_s between the louvres and the glazing is approx. 550 mm. In its open state, the system has the largest depth D_t among all of the analyzed facades, which equals 2150 mm, see Table 1, row 8.

9. Media-TIC office building in Barcelona (arch. Enric Ruiz Geli, 2010) uses pneumatics. The entire south façade of the building is covered with double-chamber air cushions arranged on a hexagonal grid. Changes in air pressure cause the inner membrane to move toward the outer or inner wall of the cushion. Because the patterns applied to the outer wall of the cushion and the inner membrane are inverted, they can effectively block the sunlight when the two fabrics are overlaid—see Table 1, row 9. Since the system operates based on the pneumatic principle, it could be classified as either horizontal or vertical or both. The distance D_s between the pneumatic cushions and the glazing is approx. 3950 mm, making it the deepest among all the other systems analysed in this paper. The open/closed system projects outwards at a depth of approx. D_t = 400 mm.

10. Stadtor Düsseldorf (arch. Petzinka Pink and Partner, 1998) features a classic double skin single-story-high corridor façade with properly shaped openings that channel outside air through the façade. External air is allowed into the rooms in preferable weather conditions. In this type of façade, the daylight regulatory system is installed between two layers of glass in the form of horizontal Venetian blinds that are centrally controlled or adjusted by employees. The distance D_s between the external layer of glass and the internal layer of glass is 1600 mm—see Table 1, row 10. The Venetian blinds have a depth of only D_t = 100 mm. The open system does not project outwards as it is covered by the external layer of glass.

11. GSW house in Berlin (arch. Sauerbruch Hutton, 1999) features "a west-facing, double-skin façade that acts as a thermal flue; air in the façade cavity rises due to buoyancy" (Oldfield et al., 2009) across its entire height, as opposed to the single-story ventilated façade in the previous case. An airfoil at the top of the building "uses prevailing winds to generate wind movements across the top of the double-wall cavity and draw additional air upwards through the cavity" (Yu, 2013). In this case, a system of 700 mm-deep (D_t) vertical louvres is placed between two layers of glass in the ventilated façade corridor that has a width of D_s = 1200 mm, in order the regulate the influx of solar energy into the South-facing rooms—see Table 1, row 11. Vertical louvres were chosen as they decrease the resistance of the air that moves upwards in the ventilated space. The open system does not project outwards as it is covered by the external layer of glass.

12. The Oskar von Miller Forum in Munich (arch. Herzog + Partner, 2000) features one-story-high vertical timber elements, which seem more like pieces of furniture rather than standard facade material, see Table 1, row 12. The sliding wooden screens are installed in the space between two layers of glass, i.e. between a flat internal IGU and the serrated glazed external envelope. The depth D_t of the shading system is equal to 100 mm, but the distance D_s between the internal glazing and the external serrated façade directly behind it is equal to 1350 mm. The open system does not project outwards as it is covered by the external serrated layer of glass.

13. Bibliothèque Nationale de France in Paris (arch. Dominique Perrault Architecture, 1995) features full-height internal vertical shutters made out of wood. Shutters are side-hung/hinged. The system is externally protected from the influence of climate and weather by a glazed mullion and transom facade. The depth D_t of the single shutter is approx. 1000 m. When the shutters are open, they are perpendicular to the façade, in the closed position the shutters are almost coplanar with the façade. In this case, the D_s was determined for the open shitter position and equals 1400 mm. The open system does not project outwards as it is covered by the external layer of glass—see Table 1, row 13.

14. Photonic Zentrum in Berlin (arch. Sauerbruch Hutton, 1999) features a full-height double-skin façade that runs around the entire perimeter of the building. However, in lobby areas, the façade is a conventional curtain wall with serrated geometry in the plan—see Table 1, row 14. A system of centrally-controlled horizontal Venetian blinds is located behind the glazed envelope at a distance of D_s = 800 mm. The depth of the Venetian blinds system D_t is approx. 100 mm—

15. Institut du Monde Arabe in Paris (arch. Jean Nouvel, 1989) features a system of adjustable apertures (mechanical diaphragms) that are installed within the elements of a double-glazed façade. These diaphragms are similar to those used in a camera lens. This extremely complex and expensive system comprised a surprising number of 240 individual facade elements and was based on the principle of traditional mashrabiya. Each façade element comprises 56 apertures of different sizes. They regulate the influx of daylight into the building—see Table 1, row 15. The whole system is embedded in the basic façade element of approx. $D_s = D_t$ = 100 mm and is practically sandwiched between two relatively thin layers of glass.

3.4. Results

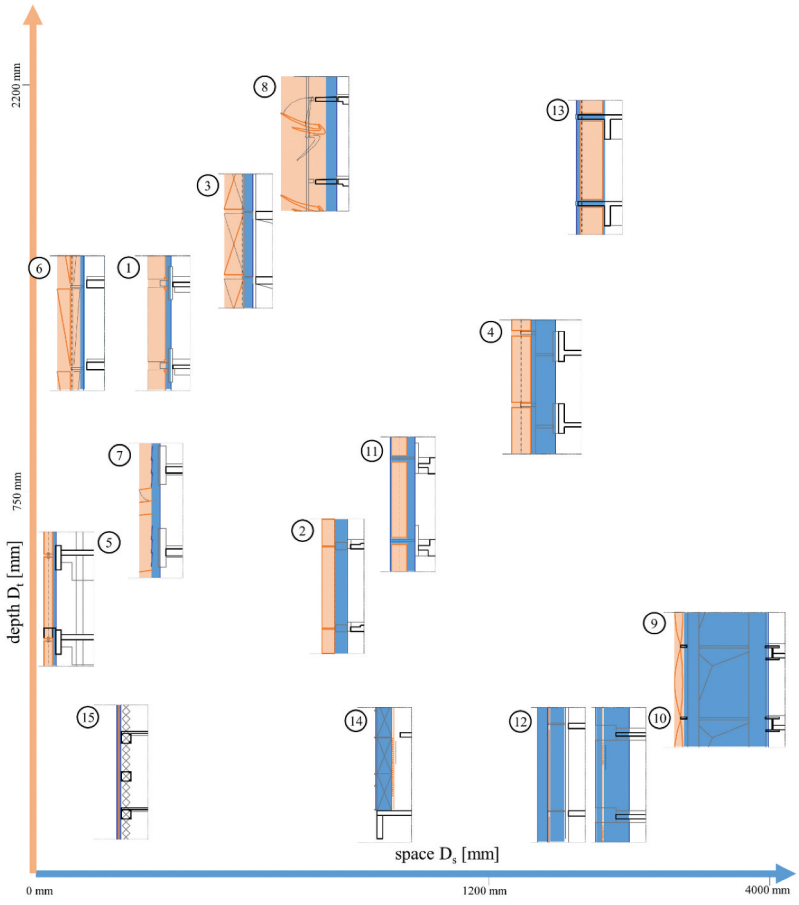
The analysis of the 15 façades showed *(i)* that it is possible to carry out the morphological analysis and to establish basic relationships between the characteristic features of facades in question and *(ii)* that the extraction of those features is possible based on the data that was gathered.

The feature of depth D_t in which the building's façade is enriched was extracted based on the dimensions of the SRS system. The study showed that there is a noticeable similarity in size between cases with external and vertical SRS. The depth of the system in cases 1, 2, 3, 4, 6, and 7 ranges between 600 mm-900 mm. It might be speculated that this similarity is the result of similar technological requirements, permissible spans and maximum dimensions of components. As anticipated, we found that, for each façade analysis, the arrangement of the shading/regulatory layer and the envelope layer is expected to produce a completely different spatial relation, which is reflected in different values and ratios of both D_t and D_s.

Nevertheless, based on the diagram in Figure 3 it is possible to identify features that are case-specific, meaning that they pertain to one particular case or are shared by a group of similar cases. Those features were extracted based on the analysis of façade's photographs, diagrams, façade drawings and information concerning the local climate.

First, systems that are external to the glazed envelope are susceptible to the influence of external conditions, such as the wind which is the main cause of the so-called drag force. Flaps/louvres/

Figure 3. Spatial comparison of all the presented facades in the diagrammatic section. Diagram by author.



shutters of a shading system frequently rotate by 90° or more relative to the plane of the façade, which is why a shading system occasionally protrudes out of the envelope of the building thereby increasing the drag force, as in case 1, 4, 6, 3 and particularly case 8. The size of these individual shading elements determines the depth of the shading system, which, in extreme solutions, is as large as D_t = 2150 mm, as in case 8.

Second, the orientation of shading elements is crucial. In 4 of the 15 studied cases, the system is horizontal. Of those four, only two are external, i.e. case 8 and case 7. It might be speculated that the decision to choose horizontal orientation was based on the climate zone (e.g., the problem of snow accumulation), the prevailing direction of the wind, or on maintenance issues (dirt accumulation).

Third, some external shading systems are structurally integrated with the building envelope and cantilevered as in cases 2 and 5, while others require independent free-standing support structures as in case 4. A system of free-standing support structures requires more space and, if the building plot is small, might reduce the usable floor plan of the building.

Fourth, double glazing creates a thermal buffer that can be climate-activated by properly placing ventilation openings as in cases 11, 12, and 13. Some buffers are used to house the shading system only and do not perform ventilation functions, as in case 14. Additionally, the external glass envelope protects the system from the influence of the environment, e.g., wind, high-temperature differences, and—to some extent—UV radiation.

From a typological perspective and in accordance with the idea originally proposed by M. Davies (Davies, 1981) all types of sustainable facades can be considered systems of functional layers. Each layer performs a different function, e.g., load-bearing or separating layers, or, in the case of adaptive facades, layers that transmit signals, produce energy or regulate energy flow. As far as adaptive shading is concerned, there are two crucial layers: a sealed envelope layer, which is usually made of glass, and a shading/regulatory layer (SRS), which regulates the flow of solar energy from the outside to the inside of the building. The arrangement of these two layers determines their spatial relation: the distance between the SRS layer and the envelope layer and the depth of the system itself.

The schematic drawing below presents all of the analysed facades at the same scale and side by side to illustrate the spatial relation between the façade elements. D_s—the distance between SRS and the glazed envelope is marked in pale blue, while the D_t—the depth of the SRS layer is marked in pale orange—see Figure 3 and Table 2.

The above diagram makes it possible to compare the different proportions of the D_t depth of the system and its distance D_s from the glazed envelope. The depth of an external SRS layer is usually larger than the distance between the system and the glass envelope (cases 1, 3), their ratio ranging from 2:1 to as much as 6:1 as in case 6. The exception is case 4 where the depth D_t is similar to the distance D_s, but this system is built on a separate steel frame. In contrast to external SRS layers, the depth D_t of SRS layers located between glass panes is always smaller than D_s, which is obvious because the size of the kinetic system must fit within the double-glazed envelope. Here too, however, there are cases where the D_t and D_s values are similar, as in cases 11, 14, 15, as well as situations in which the difference between these values is significant, as in cases 10 and 12 where the ratio is as high as 1:16.

4. Current proposal

4.1. A typology of spatial relations between façade glazing and adaptive shading

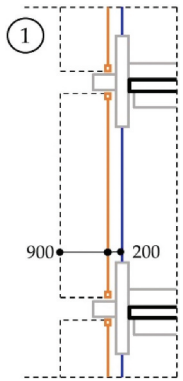
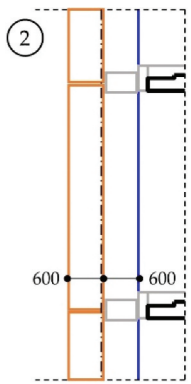
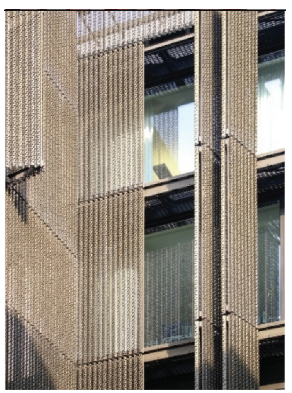
Our analysis revealed that shading/regulatory systems present different spatial relations. The depth of such systems D_t can range from only a few centimetres in the case of rollers, louvres or small slats up to several dozen centimetres, or even more than a meter, in case of elaborate double-skin facades with a climate-active buffer. The depth D_t of the system in the façade depends on the type of kinetic action that occurs within the system. For instance, if the shutter/blind is rotated, slides, or rolls more space is required to accommodate such retracted elements. The distance D_s between the system and the glazed envelope also varies depending mainly on the size of the shading elements and the location of the axis of rotation.

Vertical shutters come in different variations and are more common due to their simpler design and mechanics. Centrally pivoted shutters are easier to construct because the loading is transferred axially in contrast to side-hung shutters where the whole weight of the shutter is cantilevered. On a smaller scale, vertical shutters are commonly used as ready-to-install off-the-shelf systems, for example, by the company Colt as in case 5. Vertical shutters are frequently used because the potential snow load is minimized.

Horizontal shading elements usually take the form of louvres. In terms of protection against direct sunlight, they are more effective than shutters, but also more difficult to keep clean. In the case of double-skin façades, particularly in tall buildings, shading systems in the form of Venetian blinds are typically placed between two layers of glass. The outer layer of glass protects the SRS against the wind, rain and—to some extent—extremely low temperatures in winter.

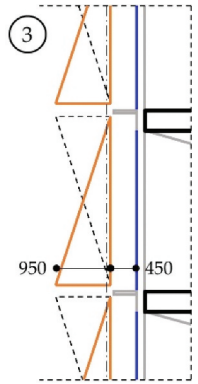
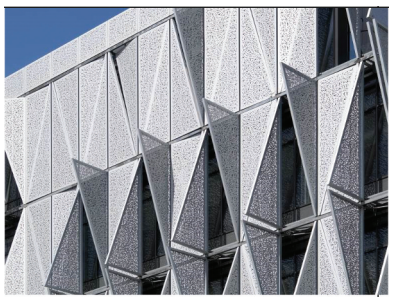
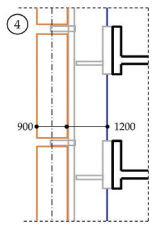
The shading/regulatory layer can also be placed inside the building behind the glazed façade. This decreases the efficiency of shading due to the greenhouse effect and heat build-up but allows daylight to be managed successfully and reduces glare. The advantage of this solution is that the

Table 2. The presentation of the data and measurements of the analysed facades

section diagram	façade view	name	architect
		Oval Offices in Cologne	Sauerbruch Hutton Architects, 2010
		Fünf Höfe shopping mall in Munich	Herzog and de Meuron, 2001

(*Continued*)

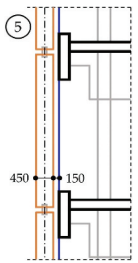
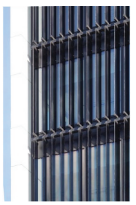
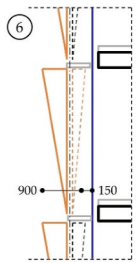
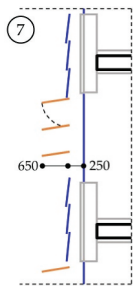
Table2. (*Continued*)

section diagram	façade view	name	architect
		SDU Campus Kolding	Henning Larsen, 2014
		INES—French National Solar Energy Institute	Atelier Michel Rémon + Agence Frédéric Nicolas, 2013

(*Continued*)

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Table2. (*Continued*)

section diagram	façade view	name	architect
		Equinor Offices in Fornebu in Oslo	A-Lab Architects, 2012
		Thyssen Krups HQ in Essen	Chaix & Morel et Associés, JSWD Architekten, 2010
		Police station building in Berlin	Sauerbruch Hutton, 1999

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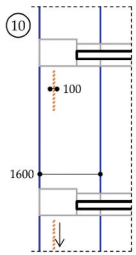
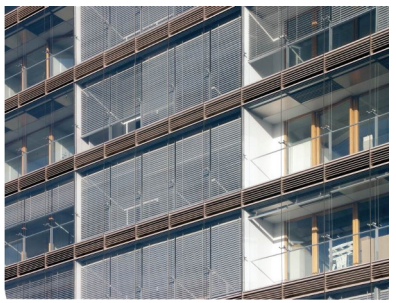
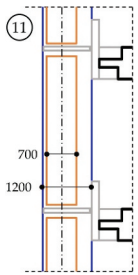
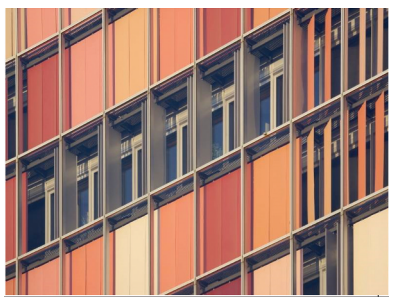
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Table2. (*Continued*)

section diagram	façade view	name	architect
		ZVK office building in Wiesbaden	Thomas Herzog, 2003
		Media-TIC office building façade in Barcelona	Enric Ruiz Geli, 2010

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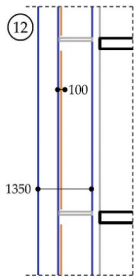
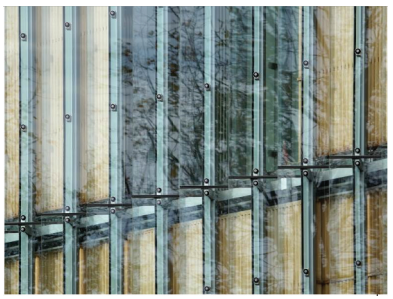
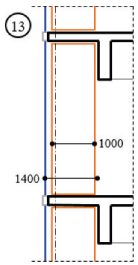
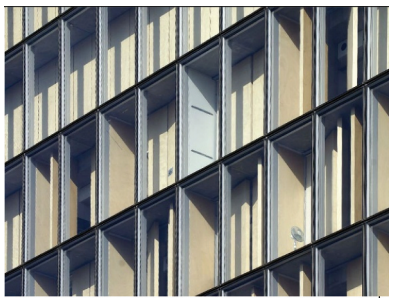
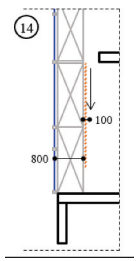
Table2. (*Continued*)

section diagram	façade view	name	architect
		Stadtor Düsseldorf	Petzinka Pink and Partner, 1998
		GSW house in Berlin	Sauerbruch Hutton, 1999

(*Continued*)

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Table2. (*Continued*)

section diagram	façade view	name	architect
		Oskar von Miller Forum in Munich	Herzog + Partner, 2000
		Bibliotheque Nationale de France	Dominique Perrault Architecture, 1995
		Photonic Zentrum in Berlin	Sauerbruch Hutton, 1998

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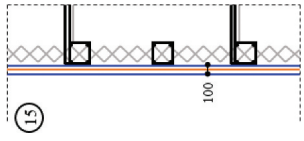
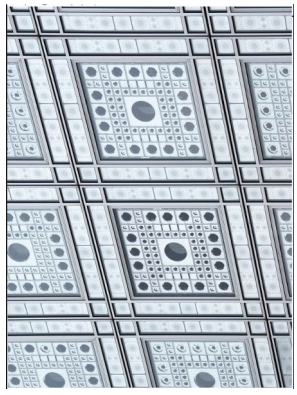
section diagram	façade view	name	architect
		Institute du Monde Arabe in Paris	Jean Nouvel, 1989

Table 3. Case-specific features for different variants of SRS (shading/regulatory system)

no.		building name		D_t	D_s	ratio
		orientation	1	Cologne Oval Offices		900
200	4:1	V				
2	Fünf Höfe shopping mall in Munich			600	600	1:1	V
3	SDU Campus Kolding			950	450	2:1	V
4	INES—French National Solar Energy Institute			900	1200	3:4	V
5	Equinor Offices in Fornebu			450	150	3:1	V
6	Thyssen Krups HQ in Essen			900	150	6:1	V
7	Police station building in Berlin			650	250	5:2	H
8	ZVK office building in Wiesbaden			2150	550	4:1	H
9	Media-TIC office building in Barcelona			400	3950	1:9	V/H
10	Stadtor Düsseldorf			100	1600	1:16	H
11	GSW house in Berlin			700	1200	3:5	V
12	The Oskar von Miller Forum in Munich			100	1350	1:13	V
13	Bibliothèque Nationale de France in Paris			1000	1400	5:7	V
14	Photonic Zentrum			100	800	1:8	H
15	Institut du Monde Arabe in Paris			100	1	1:1	V/H

shading/regulatory system does not have to be protected against the weather and can use weather-sensitive materials such as wood, paper, and fabric.

Based on the results of our morphological analysis, the studied façades and buildings can be divided into four types, depending on the relations between the SRS layer and envelope layer. The proposed typology is shown by the schematic diagram illustrating different spatial relations between the shading regulatory layer and the façade glazing—see Figure 4 below.

The possible arrangements of the aforementioned layers are as follows (the layers are listed from the outermost in relation to the interior of the room):

- Type 1. The shading/regulatory layer is placed outside a thermo-insulating glazed building envelope. This envelope is screened from the outside by the regulatory layer. The load-bearing and signal transmission system of the shading layer is either located entirely outside the

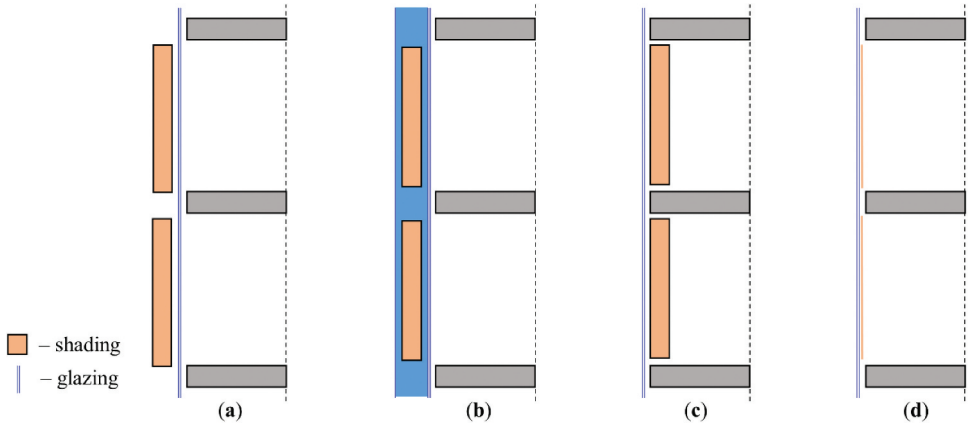


Figure 4. A diagram illustrating vertical sections of four general types of arrangements of the SRS and building envelope layers (a) external SRS; (b) SRS between two layers of glass; (c) internal SRS; (d) SRS co-planar with the glazed envelope. Diagram by author.

envelope or goes through it. From a technical point of view, this type of shading/regulatory system is exposed to the external environment and susceptible to e.g., wind or weather loads.

- Type 2. The shading/regulatory layer is placed between two layers of glass, as in the case of a double skin façade. The inner layer of glass functions as the thermo-insulating envelope of the building, while the outer glazing acts as a shielding/protecting layer against wind gusts. SRS layer that performs load-bearing and signals transmission functions are located between the two layers of glazing. Technically, these systems are protected by the outer layer of glass from wind and rain but are still susceptible to external temperature.
- Type 3. The shading layer is placed inside the building, for instance, in the form of internal roller blinds or Venetian blinds. From a technical point of view, such a solution guarantees that the SRS will always operate in the same microclimate of the room (usually +20°C and approx. 50% of humidity).
- Type 4. The shading layer is co-planar with the glazed envelope of the building. This arrangement is only possible in the case of SRS that is thin enough to be flush with the façade glazing. This usually applies to thin layers of coating that are deposited on glass, liquid crystals or micromechanical systems that can be inserted between two panes of an insulated glazing unit (IGU) in a space of approx. 15–25 mm, except for cases described later in the article.

4.2. Consequences for the architectural form

As discussed in section 2, adaptive façades are a composition of layers that perform different tasks (Aelenei L, 2018). In Davies' original concept, the elements of the SRS were so small that they were unnoticeable concerning the scale of the entire building. In practice, transforming Davies' concept into reality involved the construction of many functional layers at the macro-scale—like the above described SRS layers. Such action entails far-reaching consequences for the architectural form. In theory, "a layer is a two-dimensional entity that does not have the potential to generate space on its own" (Duygu, 2012). In fact, it is the operation of layering (i.e. overlapping layers) that has the potential to do to generate space of its own. Indeed, the functional layers of adaptive façade do have a third dimension, and—in many cases—this third dimension defines the formal depth of the façade. Formal depth—approximately expressed in the presented analyses as D_t—should be understood as space in-between the layers occupying the perimeter around the building, constituting an interface between the inside and the outside. The most important consequence of this layered arrangement is that SRS systems, which are located outmost externally in the relation to the transparent climate-shell of building, dominate its external appearance in an obvious way. The phase of an SRS system—either it is closed, open or in any other intermediate position—creates a specific kind of temporary kinetic composition. Most of these SRS systems are based on elements that rotate in different planes, which is why a SRS system occasionally protrudes on the outside, and thus it visually changes the volume of the building. The abovementioned apparent volumetric change frequently goes hand in hand with a change in the rhythm of the façade, for instance, when the flaps/louvres/shutters of a shading system rotate by 90 degrees and are at an angle as opposed to being flat. The size of a single shutter or louvre and the spatial grid determine the proportions of the façade.

4.2.1. The size and the orientation of the SRS system

The size of the boundary of the SRS system has profound consequences for the architectural form. The SRS's influence on the condition from the internal rooms is the essential condition of its existence—there is no reason to design such an SRS system if it were to be ineffective—this is why designers deliberately plan the change that affects architectural form, especially in the case of oversized elements.

The design of the adaptive façade must take into consideration the fact that, in terms of aesthetics, an adaptive façade can undermine the principles of architectural design, such as proportion, rhythms and hierarchy of elements. As Moloney writes: "the idea of formal composition

in the traditional design sense appears redundant" (Moloney, 2011) in the case of adaptive/kinetic façades. The change is the only constant, with regard to how the adaptive façade looks and works.

Moloney also sees two possibilities for integrating the SRS system into the façade: *(i)* either to embed a shading/regulatory system within the composition of the façade or *(ii)* to articulate them (Moloney, 2011). The bigger the D_t, the more visible and the more aesthetically significant and formally articulated the system is. Frequently movable elements "are exaggerated and ornamented to produce new narratives or expressions" (Moloney, 2011), manifesting the departure of the form far from the modernistic simplicity. It is also noticed, that at a general level, "contemporary kinetic façades are driven toward a rather hedonistic set of performances" (Koolhaas, 2018), despite the strictly utilitarian function, that was at their source.

The orientation of shading elements is thus a crucial issue regardless of whether they are positioned vertically or horizontally. Vertical systems tend to visually increase the height of the building, while horizontal systems tend to decrease it. This orientation changes the proportions of a building's volume and how it is perceived.

4.2.2. The location of the SRS in relation to glazing

It should be also noted, that the location of the SRS concerning the glass envelope of the building is also crucial as it is the glass that significantly changes the appearance of the façade. This is a result of the optical properties of glazing itself, the way that it is perceived depending on the momentary daylight conditions. Therefore, this might be a key morphological feature that determines the extent of visual and aesthetical transformation of architecture on which such a system is installed.

For the SRS installed behind a layer of glass, this outer layer of glass defines the boundary of the building. In such a case, the abovementioned volumetric variation does not occur and the appearance of the building depends on the balance between light reflection and light transmission through the external glass skin. Thus, two factors determine how a building is perceived: *(i)* the optical performance of glass and *(ii)* the quantity and quality of daylight. As quantity should be understood as the level of illumination, the quality refers to whether the light is diffuse or direct, and to its colour temperature. Because of how light behaves, glass observed from certain angles can reflect light like a mirror. Therefore, the SRS is usually visible only under favourable lighting conditions and at a certain angle. In other cases, SRS systems are not visible at all because they are obscured by reflections that appear on the glass surface. The same principle applies to systems located entirely inside the building. Given the above, the colour of the SRS system seems important for its visual performance too. Darker colours reflect so little light that daylight tends to dominate the reflection thus making these systems invisible at certain angles. On the other hand, lighter or brighter colours tend to reflect enough daylight to make the system visible even if the system is behind an external layer of glass (see the comparison of the two buildings in section 3.2). Colourful vertical shutters in GSW House are much more prominent than dark-coloured Venetian blinds in the Dusseldorf Stadttor's façade.

Since the perception of glass by an observer outside a building depends on the overlay of transmitted and reflected light, there are limitations as to the extent to which a system can change the exterior appearance of a building. The system, where the shading layer is co-planar with the glazed envelope of the building (smart glazing, mechanical systems "embedded" in the width of a pane of glass) are the most resistant to changes in the level and quality of daylight. The reason for this is the fact that smart glass changes its degree of transparency which affects the amount of light it transmits rather than the amount of light it reflects. The visibility results for all the types are grouped in Table 3 and 4.

Table 4. Visibility results for the four types of spatial relations between glazing and SRS. Legend: "↑" high, "→" moderate, "↓"low

	Type 1[1]	Type 2/Type 3	Type 4
visual domination of SRS	↑	→	↓
façade rhythm/ proportion change	↑	→	↓
apparent volumetric change	↑	↓	↓
façade orientation change	↑	→	↓
boundary definition by glass	↓	↑	↑
influence of light reflected	↓	↑	↑
observation angle dependency	→	↑	↑
colour dependency	→	↑	↑

5. Conclusion and discussion

This paper presented a morphological analysis of adaptive façades based on the spatial relations between the external shading systems and the shading systems that are externally protected by a glass envelope. All of the presented systems share some similarities but there are also clear differences between them. The proposed analysis in terms of spatial relations between the SRS (shading regulatory system) and the glazing of a façade helps distinguish between common and case-specific façades features.

The common properties are related to the fact that all the systems respond and adapt to changes in the external environment, thus, the spatial relations between elements of the façade change constantly as a result of kinetic action that takes place within the façade. As a result, the most noticeable utilitarian differences result from the use of a glazed envelope in front of the system, as glass significantly reduces the environmental impact of such systems because its panes screen rain, wind and extreme temperature. This confirms the conclusions reached by Schulz, who sees the "space as being contained in-between physical boundaries, not distinguishing only between interior and exterior, but also articulating different functions and messages" (Schulz, 2015).

As postulated, the location of the shading/regulatory system in relation to the glass envelope of a building is the key morphological feature that determines the extent of spatial transformation of architecture on which such a system is installed. The extraction of the characteristics was possible based on the dimensional analysis performed in the paper. The case-specific façades features pertain to the fact that shading/regulatory systems have different spatial forms that are determined by multiple factors. The depth of such systems D_t can range from only a few centimetres in the case of rollers, louvres or small slats up to several dozen centimetres, or even more than a meter, in case of elaborate double-skin facades with a climate-active buffer. The depth D_t of the system in the façade depends on the type of kinetic action that occurs within the system. For instance, if the shutter/blind is rotated, slides, or rolls more space is required to accommodate such retracted elements. The distance D_s between the system and the glazed envelope also varies depending mainly on the size of the shading elements and the location of the axis of rotation.

The results of the conducted research agree with the results achieved by other researchers who studied facades from the aesthetic point of view, however, the exact same approach has not been taken before. Sauerbruch and Hutton state that "one can manipulate surface and depth to emphasize or

counteract the bas-relief that the layered façade offers", while SRS systems "begin to provide the material to establish their own identity" (Sauerbruch & Hutton, 2011). Sunikka-Blank—in the chapter of the book titled "Aesthetics of Sustainable Architecture"—states that "depth is traditionally expressed by means of layered planes and a flat composition of sliding screens" (Sunikka-Blank, 2011), while Zaera-Polo concludes, that standard façade is replaced by the solutions "in which different layers of performance are played out against each other to produce a wide range of complex effects" (Zaera-Polo, 2009). . Schulz also concludes, that "light and shadows further enhance the notion of depth and complexity expressing superimposition and dynamic forms" (Schulz, 2015).

The presented study also demonstrated the need to observe the façade's dimensional parameters relating to the aesthetical quality alongside the criteria given in the paper. The comparison of the quantitative parameters (measurements) showed a wealth of different spatial relationships, those SRS elements may relate/stay/interact with each other.

The observed tendency is that SRS systems are more prominent if located outside the climate shell of the building, while—when glass-covered—their aesthetical influence depends mainly on the daylighting conditions, regardless of their relationship with the climate shell. However, despite specific differences, common features were noted as well, both for the glass-enveloped SRS system and those located externally in the relation to the climate shell. The author concludes that it is necessary to consider the location of the SRS system in the relation to climate shell to properly estimate the façade's aesthetical impact and significance. This is also important to take the daylight conditions into an account.

In conclusion, the main innovations of the presented study are: *(i)* the recognition of many possible relationships between the SRS and climate shell of the building *(ii)*, the simplified typology of those relationships; *(iii)* discussion of architectural consequences and conclusions drawn based in the discussed, and analysed data.

However, the presented study has some limitations, which should be noted. First, a limited number of case studies were used which is—in general—the result of the relatively low number of realized adaptive facades at the moment that the information was retrieved for use in the presented study. Second, the authors were unable to assess exact dimensional information, because the data (façade sections with measurements) were not available in all case studies, thus the precision was limited to 50 mm. Yet, this aspect is not suspected to distort the results significantly. Third, the selection of the case studies for the presented analysis might be subject to bias, as aesthetical properties were claimed to be the most profound characteristic features that were taken into the account. Aesthetic properties are difficult to measure and their evaluation can vary significantly, limiting the objectivity of the information presented.

In the presented paper, only the dimensional relationships of the SRS façade elements are analysed. In future research, attention should be paid to the reasons for keeping particular distances, dimensions and proportions. More technical analysis of the conditions of adopting particular dimensions is required, concentrated more on technical, than formal issues. It is also important, to elaborate on the consequences that a new trend has for the architectural form. From this perspective, it is also important to analyse the façade thoroughly in terms of both *(i)* two-dimensional relations (e.g., flat composition) and *(ii)* three-dimensional form e.g., by decoding dimensional relations in the sculptural terms, looking at the façade as on bas-relief, Haut-relief etc.

Conflicts of Interest: The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Funding
This work was supported by the National Science Centre, Poland grant entitled: "New trends in architecture of transparent facades – formal experiments, technological innovations ", ref. no. 2014/15/B/ST8/00191.

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Cover Image
Source: Author.

Citation information
Cite this article as: A typology of adaptive façades. An empirical study based on the morphology of glazed facades, Marcin Brzezicki, *Cogent Arts & Humanities* (2021), 8: 1960699.

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