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Considering Materiality of Glass as a System with Interactive Layers

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Abstract

In contemporary architecture, glass is being used less as a single piece for the exterior envelope, due to a variety of influences such as increased performance regulations, the market environment and technical developments. An architectural exterior wall today is usually installed as a 'system' wall, not as a single plane glass wall. That brings up the necessity to question the appropriateness of the materiality of an individual piece of glass for the exterior envelope in urban settings. Therefore, in many cases it is appropriate to examine materiality of glass as a system. A new examination of materiality can be carried out by analyzing the interactions between layers that constitute a system. This paper examines the experimental use of glass systems in contemporary architecture, and analyzes them to interpret the relationship between the layers of each system in order to establish the diversified materiality of glass in contemporary architecture.

Keywords : Glass, System, Materiality, Interaction, Technology

1. INTRODUCTION

Architectural glass has been one of the most popular materials throughout the history of the use of architectural skins. In particular, when architecture of the late 19th and early 20th Centuries was refined to accommodate the ideology of modernism and technological developments, glass, with its dominant transparent materiality, expanded its presence in the architectural field and became the most widely used material in architectural design[1] . In contemporary architecture, various factors have influenced the evolution of glass from its traditional materiality. Public awareness of environmental issues has led to stricter environmental performance regulations, which has forced designers and manufacturers to add certain elements to their products in order for them to comply. The changes that have occurred in the media environment and marketplace have also meant that the exterior envelope has become significantly more informative and visually striking. Glass designers and manufacturers have consequently needed to find innovative ways to make their products visually impressive.

The result is that glass is no longer seen as a singular material. In recent architectural projects, glass is assembled into units, coated, film-laminated, and overlaid with other elements or even laminated with multiple layers of glass in order to achieve the required thermal performance value and/or to satisfy safety requirements. In other words, it is fair to say that glass is not simply used as a single component of the exterior envelope. Today, a glass wall is usually a system wall, not a single-plane glass wall[2]. This reality demonstrates that the materiality of individual glass is usually no longer of use in an exterior envelope. The materiality of glass should therefore be examined as a 'system'. In order to establish materiality, we need to focus less on glass as a single element, and focus more on speculating the interactions between layers of glass that constitute a system.

This paper examines the use of glass systems in the experiments of contemporary architecture, and the interpretations of the relationship between layers that comprise each system in order to determine the more diversified materiality.

This study examines contemporary architectural designs that explore new possibilities of glass materiality. First, Dominique Perrault's French National Library project will be considered in terms of a building that represents the background of the change in glass materiality brought about by technical and environmental requirements. The paper will then focus on the diversified glass materiality in the following. A) Identity of glass affected by the surface treatment, such as silk screening or lamination. B) Inherent quality changes with technological development C) Interactions created by new surface fabrication technologies D) Comparison of Farnsworth House with Laminata Glass House to explain the change of paradigm of materiality E) An integral system to consider materiality as a system with

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[1] Although meanings of transparency were expanded in terms of spatial experience of time by Sigfried Giedion, Colin Rowe, György Kepes and other theorists, the focus of this paper is the materiality of a substantial element rather than spatial perceptions.

[2] A simple exterior glass window in contemporary architecture is actually a unit, called an Insulating Glass Unit (IGU). Insulating glass incorporates two or more sheets of glass separated by a hermetically sealed space for thermal insulation and condensation control. The airspace between the sheets of glass can be filled during the manufacturing process with either dry air or a low-conductivity glass. (Bell, V. (2006) Materials for design. New York: Princeton Architectural Press, p.17)

interactive layers. Project examples are limited to relatively flat surfaces in order to focus on the change of materiality, and to avoid possible confusion with other design ideas for projects.

2. BACKGROUND OF INTERACTIVE LAYERS

Through the history of architectural glass, several monumental technical advances occurred that facilitated the attainment of the architectural requirements of each period. These include the discovery of the glass blowing technique between 27 BC and AD 14, the development of transparent windows in the sixth century AD, and the development of float glass in the 1952.[3] Prominent modernist architects such as Mies van der Rohe, Auguste Perret, Le Corbusier and others maximized the possibility of using advanced types of glass with higher transparency, smoother surfaces and significantly higher structural capacities. In most cases though, these experiments with glass were more related to the meaning and capacity of the single pane of glass.

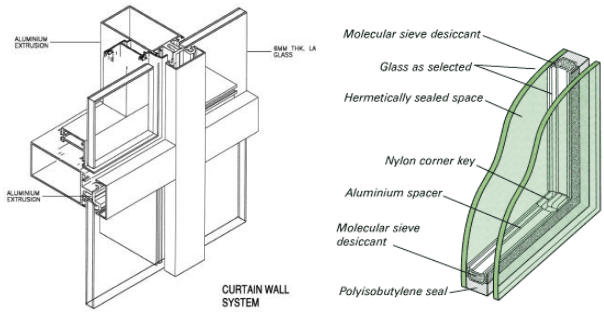


Figure 1. Insulating Glass Unit / Typical Curtainwall assembly

However, as discussed in the introduction, contemporary architectural glass has always been manufactured and detailed as a unit in order to meet performance regulations and other design requirements (Fig.1). Significant changes also occurred in the use of materials other than glass. Brick, stone and other tectonic materials are also now being used not merely as structural elements but also as curtain walls[4]. The development of the manufacturing process has therefore changed the materialistic characteristics of architectural elements: the physical characteristics are now less important than the nature of the substrate. Although conceptually the viewers' perception of the meaning of glass remains, it is not sufficient to determine the materiality of an element by only referring to its imaginary historical characteristics. Ignoring the entire configuration of a system can result in disregarding the existence of a material itself[5]. The analysis should incorporate all elements of a system as well as the interactions between them.

In addition to its evolution into being used as a glass unit, further steps have been taken in the use of architectural glass whereby additional layers of glass are installed in spaces that require subtle environmental controls such as in libraries, research laboratories, museums etc. The exterior envelope of Dominique Perrault's French National Library project (Fig.2) completed in 1995 is an excellent example of an interpretation of 'materiality as a system'. Its exterior envelope consists of two main layers: a glass layer of clear, reflective glass, and a moveable wood panel layer. Although the glass layer and the wood panel layer can be separately analyzed, and each layer has its individual materiality as glass and wood, this paper will examine these two layers as one system to examine its overall materiality.

Figure 2. Interaction between glass layer and wood layer

The French National Library can be considered as a piece of urban art, a minimalist installation[6]. However, since the building is a library that stores books which are very sensitive to thermal and sunlight exposure, a glass layer cannot satisfy functional requirements while accomplishing aesthetic goals. The wood screens were added behind the glass wall in order to control the transfer of sunlight and heat. In its traditional functional concept, glass is a material that is used to express dematerialization. However, due to the adjustable wood screens behind the glass, the inherent materiality of glass, its transparency and ambiguity, is in this case seriously diminished. Here, the role of the wood panels is to achieve an expression of transparency and ambiguity through the adjustable openings. The quality of 'reflectivity', rather than 'transpar-

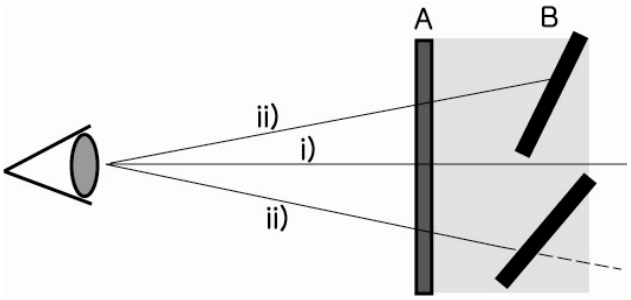
[3] History of glass development is not detailed here. Major development steps described here are selectively extracted from the following: Elliot, C. (1992) Technics and Architecture: The Development of Materials and Systems for Buildings. London: The MIT Press, pp.140-146

[4] Although the meaning of the term curtain wall is any wall that is non-gravity-load-bearing any non-gravity-load-bearing wall, the metal and glass curtain wall is commonly referred as curtail wall. Brock, L. (2005) Designing the Exterior Wall: An Architectural Guide to the Vertical Envelope. Hoboken, New Jersey: John Wiley & Sons, Inc., p.89

[5] Leon Krier even stated that everything in architecture is a fake, referring to losing of tectonic use of architectural materials. (http://doyouwantcoffee.blogspot.com/2006/03/materiality-and-architecture-leon.html)

[6] Though the relationship between minimalism and this project is debatable, an excerpt from the competition text is included to emphasize the interaction between layers in a simple frame. Perrault (1995) Dominique Perrault: Arch en reve centre d'architecture. Basel, Switzerland: Birkhauser, p.63

ency', of the glass is created, claiming a clear boundary of the building's outline.



A: reflective vision glass
B: adjustable wood panels
i) 'B' is open. Visual transmission through 'A' is enabled with reflections on the surface.
ii) 'A' reflects sunlight, boundary materialized. Vision is interrupted by 'B'

Figure 3. Diagram of French National Library

Consequently, the overall exterior envelope has a clear boundary, is sometimes transparent and sometimes not, and glistens due to the interactions between sunlight, glass and the ever-changing louver configurations. If the configuration were to be analyzed piece by piece, the analysis would show a confliction with the expected traditional materiality of each element. Here, glass materializes the boundary of a building, while the boundary is immaterialized by the wood panels.

3.INTERACTIVE LAYERS IN CONTEMPORARY ARCHITECTURE

3.1 IDENTITY OF GLASS AFFECTED BY SURFACE TREATMENT

In contemporary architecture, the thermal performance of glass has become a crucial issue mainly due to public awareness of environmental problems. This has resulted in a need for stricter environmental regulation standards, and a higher level of technical capability in order to accommodate these environmental needs. Among many techniques that can enhance thermal performance of glass systems, silk screening and lamination have been used to resolve thermal issues and challenge traditional aesthetics through various experiments.

Silk screen glass has a ceramic frit which is screen printed on the surface of the glass. Silk screening maintains a level of visible transparency while increasing the opacity of the glass in order to block thermal transmission. In terms of architectural aesthetics, silk screening also enables experiments to be conducted in visual expressions. Sometimes, visual design experiments are justified by environmental and architectural needs. Along with silk screen glass, recent technology has enabled architects and designers to experiment with laminating many different materials. Combinations of possible laminations include glass with glass, glass with film, and glass with other solid materials. Within limitations, visual opacity, color variation, and a safe and even blast resistance can be achieved with glass.

Figure 4. Three different surface treatments

In the O-Museum in Japan, completed in 1999, Kazuyo Sejima experimented with silk screen glass. The building is a gallery which requires strict thermal control. Rather than using other materials known for their good heat blocking characteristics, the entire building is clad with transparent, somewhat reflective glass, where white silk screen glass was used to control different functional and aesthetic requirements (Fig 4). Glass with an extremely heavy frit was used for an area exhibiting art collections in order to prevent damage from sunlight. Medium frit glass, expressed with dense vertical lines, was applied to areas that were not sensitive in terms of performance value but required visual control. No frit pattern was applied to the glass for window areas that required transparency. Although the entire wall is made of glass, only this later area can be termed a 'window' in the traditional sense (Fig 5). In this building, glass serves as a frame or a background that supports the various changes of the frit patterns. There is no concept of transparency even though transparent glass is used throughout the entire building. However, this building clearly demonstrates the sensual quality of glass and its wide range of potentials. While this experiment shows an alternative use for glass, it is not particularly high-tech; its audacity to re-interpret the possibility of the all-glass building is noticeable.

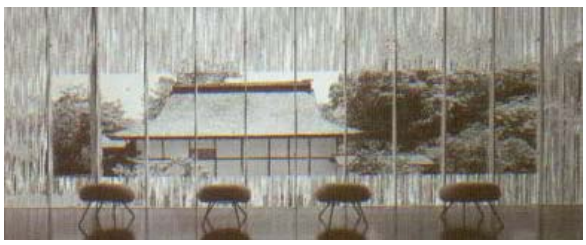
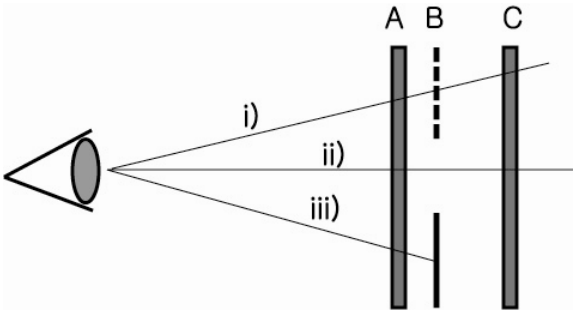


Figure 5. Interior view through frit window



A: Transparent reflective glass
B: Silk screen coating
C: Interior glazing
i) Visual transmission is allowed. 'A' maintains the same reflective quality over different surfaces and ensures homogeneity.
ii) Strips of silk screen create ambiguous interactions with the exterior and the interior spaces. From the distance they are dense opaque patterns that do not reveal what is inside, but the views to the outside from the inside are open with abundant sunlight.
iii) 'A' allows visual transmission but the interior view is completely blocked by the opaque silk screen (B). 'B' functions as a sun blocker to secure sensitive art works.

Figure 6. Diagram of O-Museum

While the O-Museum employs a subtle differentiation between glass surfaces with similar treatments, more recent architectural trends demonstrate a move towards more aggressive directions.

Figure 7. Cottbus library

Figure 8. Utrecht Library

Herzog and De Meuron's Cottbus Library project (Fig 7) and Wiel Arets' University Library of Utrecht project (Fig 8) show an endless repetition of images printed on the surface of the glass, providing a range of different experiences for observers when the surface is exposed to patterns of sunlight. Sunlight creates a bright and vivid boundary, with vibrating and blurring patterns, where it sometimes seems as if the light takes rest on the image[7]. Recent experiments using film coatings and laminations carried out by diverse artists and architects such as James Carpenter manipulate multiple interactions between the viewer, the glass, the coating and the landscape. A new glass system utilizing these interactions will be covered in depth in a later part of this paper. Surface treatments such as coatings or laminations provide more diversified meanings for architectural glass.

3.2 INHERENT QUALITY CHANGES WITH TECHNOLOGICAL DEVELOPMENT

Glass has been a very efficient material in architectural design in terms of visual control. It was also the most dominant material used to express the modernist ideology of transparency. However, when used singularly, it is difficult for glass to qualify as an independent envelope because of its thermal performance limitations. Even if the thermal requirements could be satisfied by applying a range of surface techniques to improve the performance of the glass such as a coating, air/gas filling or laminations, it is considered that glass needs to be protected by other solid sunshade materials.

Figure 9. Bris Soleil of Chandigarh

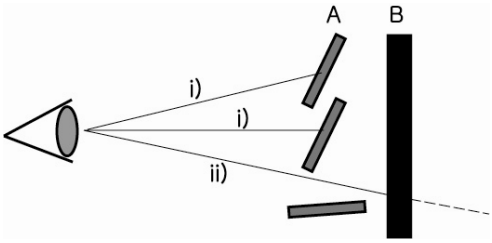
Figure 10. Mechanical louvers

When designers incorporate sun shades to a project, glass becomes passive and the louvers take the place of representing the idea of the design. (Fig 9, 10)

However, recent technical developments have enabled glass to become a much stronger and more protective material. Architectural glass can now be used as a protective skin such as an exterior louver to protect inner walls from sunlight or other environmental damage. The exterior envelope of Torre Agbar, designed by Jean Nouvel (Fig 12) consists of three different layers. The main structure is a load-bearing concrete wall. The concrete wall is clad with multi colored metal panels of more than 20 different colors and gradations. The outermost layer is glass louvers, transparent and translucent. The solid structure is protected by glass louvers. Each louver has a different angle to deflect sunlight. Jean Nouvel states that the surface of the Torre Agbar evokes water: smooth and continuous, but also vibrating and transparent because it manifests itself in colored depths - uncertain, luminous and nuanced[8].

[7] Moor, A. translated by Lim, K (2008) Colours of Architecture: Coloured Glass in Contemporary Buildings, Seoul: Spacetime Publishers, p.28

[8] Excerpt from www.arcspace.com/architects/nouvel/agbar/agbar.html



A: Glass louver (adjustable, transparent)
B: Substrate (metal panel, glass or concrete)
i) Varied angles of glass louvers (A) deflect sunlight to create ripple effects that evoke water, protecting the wall behind from solar heat gain and glare
ii) Colored metal panel is viewed directly through gaps between glass louvers

Figure 11. Diagram of Torre Agbar

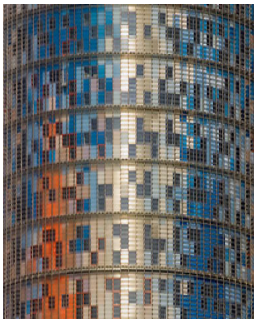


Figure 12. Torre Agbar

Figure13.Boehringer Ingelheim

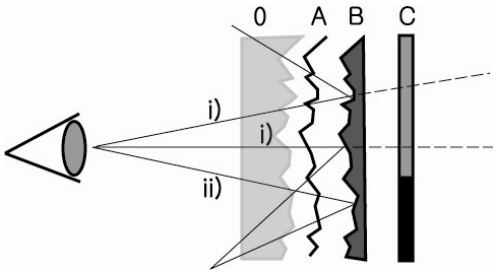
The Boehringer Ingelheim Pharma KG project (Fig 13) in Germany by Sauerbruch and Hutton Architects expresses an overlapping quality with its two glass layers. The outer layer is of colored glass louvers that adjust freely to avoid direct sunlight, while the inner layer is a clear glass envelope. The interaction between the two layers creates an ambiguous image and gives an impression of an uncertain depth, providing a tactile quality to the outer skin.

3.3 NEW SURFACE FABRICATION TECHNOLOGIES CREATE INTERACTIONS

The flatness of glass has been one of the main features exploited in its use, even though sometimes glass is curved or sandblasted to provide a more diverse quality. The term 'free-from' in this paper is not limited to recent glass form-making experiments by architects such as Frank Gehry or Greg Lynn[9]. Netherlands Institute for Sound and Vision, designed by Neutelings Riedijk Architects (Fig 14) employs the effect of multi-colored high reliefs as a new concept for the glass surface. In this project more than 2000 glass panels are actually used as reliefs rather than as flat and reflective planes. Colorful images are burnt onto the surface of each relief, presenting a rapid movement of images. The result is very functional – durable and heat resistant – and also very sensual. The glass skin becomes a tactile surface, attracting the visual attention of observers, inviting them to touch the surface and follow the movement of the skin. The use of CNC[10] enabled this design experiment to become a very logical and practical process.

Figure14. Surface of Netherland Institute of Sound and Vision

A CNC milling machine is used to cut the MDF board to make a form for the cast glass[11]. Glass liquid is then cast into the form to produce a unique high relief surface, and images are then burned into the glass. The materiality of the glass is again diversified due to technological development.



0: MDF Mold carved by CNC milling machine
A: Colorful images representing broadcast burnt into glass
B: High-relief cast glass
C: Transparent glass or opaque substrate
i) and ii) Rough surface with polychromic colors create a tactile surface that attracts views. Observers touch[12] and feel the color and texture of the surface. Shadows and glare created by the irregular deflection of sunlight assists this experience.

Figure 15. Diagram of Netherland Institute of Sound and Vision

[9] This paper focuses on challenging the materiality of glass. Glass designs by formalists are more a 'tweak' of the existing concept of the glass, and less a new materiality.

[10] CNC stands for Computer Numeric Control.

[11] Cast glass is "made by pouring molten or liquid glass into a mold to form a particular shape before it is cooled and released. The method of casting glass is typically used today mostly by artisans or for ornamental and design-specific purposes", Bell, V. (2006) Materials for design. New York: Princeton Architectural Press, p.17

[12] Gilles Deleuze explains about "touching eye": In Francis Bacon's paintings, spaces have been 'tactile' rather than 'optical', which is a return of Egyptian Art. When one sees Egyptian relief human eyes trace the outline of the reliefs just like touching with hands. Jin J.(2003) Lectures on Contemporary Aesthetics: Duet of the sublimity and simulacre. Paju,Korea: Artbooks, pp.211-212

3.4 RECONSIDERATION OF MATERIALITY: FARNSWORTH HOUSE VERSUS LAMINATA GLASS HOUSE

Contemporary structural glass engineering has also facilitated the shift away from the use of glass in its traditional materiality. Structural glass was initially used for small interior installations such as staircases and curtain wall support. Traditionally, glass needed to be 'supported' by other structural elements, such as frames, beams and walls. It would then be natural to consider fragility as the typical materiality of glass. In 1996, a more advanced use of load-bearing glass was realized through the all-roof canopy designed by Rafael Vinoly for the Yurakucho subway station as part of the Tokyo International forum project. A series of laminated toughened beams with 19mm leaves are joined together by bolted connections[13] (Fig 16, 17).

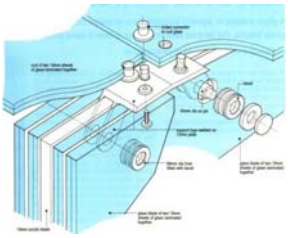


Figure 16. Bolt Connections

Figure 17. Glass Beams

This glass canopy covers the staircase which is approximately 8m X 4.8m. Multiple laminations of glass allow the material to be used as a glass beam, which has enough strength to support the roof above. Glass beams are carefully connected to each other with bolts, successfully transferring forces to the base of the canopy.

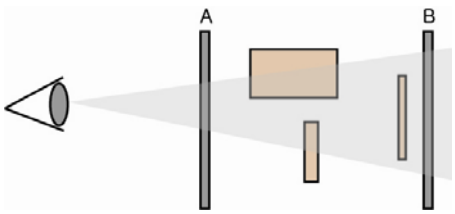
What is special about this project in terms of glass materiality is that glass is treated as a structural material, not as an element supported by other structural members. Here, glass is no longer dematerialized. In many modernist architectural projects, designers used glass to express dematerialization, where metal supports became thinner or were hidden inside other members, creating the optical illusion that the structural supports had disappeared. Conversely, in this canopy project the key concepts are existence, strength and material identity, rather than non-existence, fragility and dematerialization, although a concept of transparency is maintained. This building represents the beginning of a concept change in the use of glass. More recent developments of glass express even more adventurous challenges.

The Laminata Glass house project in Amsterdam, designed by Kruunenberg Van der Erve Architects (Fig 19), demonstrates a radical approach, establishing a new concept for the glass wall. Walls consist of float glass sheets, laminated together with adhesive, creating a very unique 1.7m thick wall system. This remarkable section provides not just an aesthetic freshness, but also the necessary performance values for the building to be qualified as a house. This project focuses on the materiality of the glass itself. The use of glass in terms of its solidity and materiality are the key concepts expressed, rather than the typical modern concept of glass as transparent, dematerialized and dependent. Comparing this project with the Farnthsworth House project designed and constructed by Mies van der Rohe from 1945 to 1950 (Fig 18), it clearly demonstrates the overall paradigm shift of the materiality of glass. This new Laminata Glass house project is a good example of where a new identity for glass is defined. Many other experiments using structural glass have been carried out such as the use of glass beams, glass domes and glass tubes.

The materiality of the glass systems in these projects demonstrates conflicting characteristics. Farnsworth house has a very clear but interesting concept of spatial organization and glass materiality. The following diagram explains this configuration.

Figure 18. Farnsworth House

Figure 19. Laminata Glass House(2002)

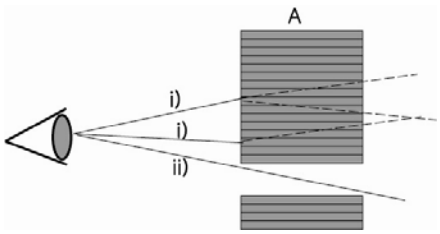


A: Transparent glass
B: Interior elements
i) Perspective View
A: transparency - completely open to visual transmission
B: carefully arranged interior element, contained in a frame formed by top and bottom slabs

Figure 20. Diagram of Farnsworth house

[13] Behling, S. Editor (1998) Glass: Structure and Technology in Architecture: Prestel, p.82

For Mies' project, glass envelopes are pure transparent screens for interior elements such as partition walls, paintings, sofas and other furnishing materials. All these interior elements are carefully proportioned and organized and form an impressive collage of overlapping images. Again, the transparent quality of glass here helps the viewers to perceive the collage uninterrupted. However, the Laminata glass house demonstrates a rather fresh concept for the use of the glass wall. Glass here is not used as a frame or screen to reveal what is inside or behind; instead, it is the object itself. The glass wall is designed to claim its substantial existence. Sunlight from different angles and different viewpoints creates diverse images, allowing a range of perceptions for the glass wall. Stacked cross-cut sections of endless glass planes refuse to be a smooth, transparent and dematerialized element. The diagram below shows this configuration.



A: float glass panes laminated together. Edges are exposed.
i) Refractions are created by multiple laminations of the glass. Cross-cut edges form an irregular rough surface. Cross-cut sections combined with depth do not have transparency, securing privacy of dwellers. However, the wall has a translucency that allows sunlight to light the interior.
ii) View through vision glass: same material, different angle =different quality

Figure 21. Diagram of Laminata Glass house

These projects challenge the typical preconceived notion of the use of glass and instead reveals glass to be flexible, dynamic, rough, tectonic and even structurally durable while satisfying needs for environmental control, through a simple change to the assembly process.

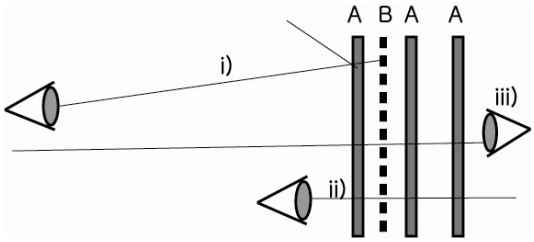
4. AN INTEGRAL SYSTEM: CONSIDERING MATERIALITY AS A SYSTEM WITH INTERACTIVE LAYERS

Thus far, this study has examined various interactions of layers of glass as exterior envelopes. All the cases above show combinations of different elements. While the system may look like an integral system, in terms of the manufacturing process it is still made up of separate materials. Recent developments show new systems that integrate diverse elements into one system unit that can be mass produced, and glass products are now being manufactured in this way.

Figure 22. Des Moines Library - Exterior

Figure 23. Des Moines Library - Interior

In the Des Moines Public Library project in Iowa, USA, David Chipperfield uses a newly developed glass-metal panel. A copper mesh is inserted inside a typical insulating unit. The copper mesh screen has dense penetrations, which allows a diverse range of perceptions for viewers.



A: Vision glass
B: Copper mesh screen
i) View from the distance: reflections, ripples
A: reflects sunlight, allows minor visual penetration
B: blocks further visual penetration, generates ripple effects according to viewing angles
ii) Close-up view: inside, mesh screen
A: allows visual transmission
B: perforations allow visual transmission. Copper mesh is substantial
iii) View from inside: open view through metal screen veils
A: allows visual transmission without reflection
B: serves as a copper screen veil.

Figure 24. Diagram of interactions of layers

From a distance (view i), the holes in the mesh are small enough for the visual penetrations to be undetectable. Reflections appear on the surface of the outer glass, and a mesh screen behind the outer glass generates endless ripples according to viewing angles. When closer to the wall, (view ii) viewers are able to look inside and the geometry of the copper mesh screen becomes visible. Views from the inside to the outside are completely open, thorough the slight veil of the mesh screen. All these layers constitute a complete system, which is a single product that cannot be disassembled into separate elements. In other words, this complete unit should be regarded as a single material. There is no purpose in analyzing the materiality of a single piece of glass, the metal layer or the inner glass plane. The materiality of this glass/copper unit should be understood as a single system, since it actually performs as a single system.

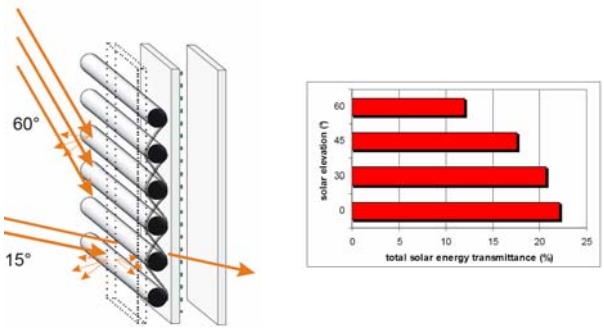


Figure 25. Des Moines Library – Glazing system configuration and energy chart

The copper mesh layer is not only an aesthetic element, but is also a very effective sun shading device (Fig 25). The perforated metal mesh is also an element used to generate small shadows. During the summertime when the sun angle is high, this screen is effective at blocking heat transfer. And during the wintertime it functions to minimize sunlight transmission.[14]

5. CONCLUSION

In contemporary architecture, glass has been used as a system. It therefore becomes difficult to conceive of a single glass plane performing as a valid exterior envelope. This situation provides an argument for the necessity to consider the materiality of glass as a system. A variety of influences such as performance regulations, market environment and technological development contributed to this change, and a significant number of architectural projects incorporate revolutionary surface techniques to glorify their skins.

Therefore, the categories used to classify the materiality of glass should be extended. When used as part of a system, glass can be combined with multiple materials including glass itself. Many combinations of layers can create a variety of systems that can meet technical, aesthetic or even market needs. The materiality of the glass, as a system, can be distinguished from its traditional materiality. These distinctions are noted below:

1. Glass today is less used as a single piece for the exterior envelope due to technological development, strict environmental regulations, public awareness for environment issues, media environment, market and other conditions.
2. It is necessary to consider the materiality of glass as a system.
3. Materiality of a single layer is flexible according to its relationship with adjacent layers.
4. Therefore, an analysis of materiality should focus more on interactions. It is much more important to investigate what glass becomes when it interacts with another layer, than what it is in itself.

As Deleuze explained in his concept of 'becoming'[15], the materiality of a single glass layer is not determined until what comes next is revealed. A glass layer can be extremely transparent, opaque, ambiguous, brittle, durable, and even works as a catalyst to support interactions between layers, depending on the surrounding configurations that form the system. Similarly to other architectural materials, the boundary of what defines the materiality of glass has become blurred, and the focus of further research should explore the possibilities created by the interactions.

[14] Lee, S. Editor(2007) Matters of materials: Glass Concrete Steel, Seoul: Spacetime Publishers, P.126

[15] In Deleuze's concept, one's identity is not limited. It extends its horizon of existence by creative connection with others. (Jin J.(2003) Lectures on Contemporary Aesthetics: Duet of the sublimity and simulacre, Paju: Artbooks, p.200) According to Deleuze, "true becoming does not have an end outside itself…..it means changing and varying in inhuman ways without any sense of pre-given purpose or goal." (Colebrook, C. (2002) Gilles Deleuze, London: Routledge, p.145)

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