

Engineering without the engine: An integrated panelized passive shading system for transparent façades

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ABSTRACT: During the latter half of the last century, architects emphasized lightness and transparency in buildings, with trends towards fully glazed building envelopes, including glass façades, atriums and roof structures. However, these glass facades presented challenges such as, the structural design of the envelopes for safety, durability of joints, as well as daylight glare control, thermal insulation and solar heat gain. Today's changing paradigm for design, places an ever-greater emphasis on integrated solutions that are not only aesthetic and experiential, but embrace environmental influences. Environmental imperatives necessitate an agent for change that integrates environmental concerns with the human experience.

Two contradictory factors influence the design of glass envelopes. On the one hand, stylist design overemphasizes the benefits of maximizing transparency (the desire to create 'glass cathedrals'). This infatuation with transparency results in unintended consequences, namely, that glass facades are generally heavy and energy inefficient, resulting in solutions that are more expensive and wasteful of the planets resources. Therefore, there remain significant challenges for resolving the functional aspects in building facade designs. Whereas designs that are driven by pragmatic functional parameters are generally only concerned with the performance of a building, this in turn sacrifices the aesthetic form of a building in the interests of high performance.

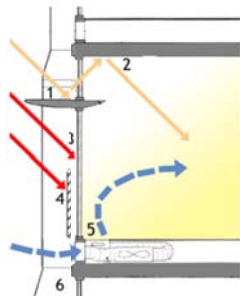
We address this conflicting issue by, considering both stylistic and pragmatic functionality, through an integrated passive solution. We address this by integrating "macro form" through function, related to occupancy and overall massing, with "micro configurations" through functional technology driven parameters. Thereby we adopt an integrative approach, which embraces multiple agents of interconnectivity that address aesthetics, energy, light, structure, materials, transparency, form and function. Our approach is to merge macro scale with micro function thorough what we call a "functionally graded" façade system. The system passively integrates these multiple agents within a single customized solution that uniquely responds to the specifics of building program, site and geographical location.

In this paper, we demonstrate how such a novel façade system may function at the intersections of architectural design - aesthetics - structural - energy performance and human comfort, as a an effective high performance solution for transparent façades, with an exciting range of expressive aesthetics.

KEYWORDS: glass structures, shading system, translucent glass, micro function, functionally graded facade

INTRODUCTION

The function of a façade is to separate a comfortable interior space from the elements of the outside world. There are different functions that a façade serves: it defines the architectural appearance of the building, provides views to the inside and outside, resists wind loads, bears its self-weight, modulates heat transfer between internal and external temperatures and transmits light to the interiors. In addressing these functional parameters, various advanced facades solutions have drastically altered the appearance of the building envelope, and incurred extensive costs in an attempt to maximize light transmission, minimize energy losses and maximize transparency, by adding various components to improve system performance. (CIBSE 1997). (Fig. 1)



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Fig. 1: Façade functions - advanced solutions, (CIBSE 1997)

Windows are a dominant feature in a building's appearance. They can be highly reflective, translucent or completely transparent. The traditional purpose of windows was to provide light, view and fresh air. As completely sealed, mechanically ventilated and electrically lit commercial buildings became the norm, the original primary role of windows were altered, demanding a new paradigm for the building envelope function. One of these paradigms created the concept of "advanced facades" (Fig. 1) (CIBSE 1997) which have significantly altered the building envelope landscape, creating a plethora of accoutrements that are now

attached to facades to enhance envelope performance, to the overall detriment of appearance and human experience. In contrast, windows are still valued entities in the building envelope that contribute to the satisfaction, health and productivity of the building's occupants. (Carmody 2007) However, a disfunctional schism exists between architects who usually pay attention to exterior design features, and the mechanical engineers who focus on selecting windows to control solar heat gain, meet energy codes and downsize mechanical equipment. Advanced facades have attempted to address this challenge, however this has resulted in an additive system of functional components (shading louvers, triple facades, light shelves, glazing films and the like) in an attempt to produce energy efficient, healthy and economic buildings, to minimize environmental impact. (Carmody 2007)

In response to today's changing paradigm, that prioritizes environmentally friendly design, facades are better suited for more integrated concepts to avoid component layering. This provides multifunctional performance characteristics that embody aesthetics, light transmission, experience and structural performance within an all embracing passive strategy. We are proposing a new paradigm that effectively transitions "macro form" with "micro function" at the intersection of architectural design, structural efficiency and energy efficiency.

1.0. METHODOLOGY

This paper proposes an approach towards redefining facades as an integrated shading panel system, where the shading elements are structurally layered between the two glass panes. The geometrical configuration of the shading elements allows for a geometrical transition to be created within the system, that responds to various interior functions, both locally within a floor plan and generally across the overall façade. In order to evaluate the performance and relative effectiveness in comparison to various façade solutions, we have developed a methodology for determining the efficiency of this system according to a set of metrics that both quantitatively measure environmental and structural performance using computer simulation and experimental testing, and quantitatively measure user experience based on surveys and subjective assessments.

The intention of this paper is to create the argument for the need of a new paradigm based on past experience and lessons learned from precedent case studies; and then to propose a new paradigm that can be fully evaluated through future research, highlighting the essential behaviors of the various façade components and showing the initial results of research carried out by the authors in this area and to propose next steps towards establishing a fully evaluated paradigm.

2.0. PRECEDENT CASE STUDIES

Designing glass envelopes brought transparency and light into buildings on one hand, but caused unintended thermal and structural problems on the other hand. For example, the *Cite de Refuge*, a building with a large glass envelope, designed by Le Corbusier in 1932, was the first documented case of overheating with serious health consequences for the occupants. (Banham 1984) In order to reduce the heat gain through the glass façade, Le Corbusier applied a type of macro scale "brise-soleil", as an external shading system. It was comprised of horizontal shelves and vertical fins distributed over the entire extent of the facade, which appeared like a large external egg-crate. This significantly influenced the external appearance of the building, which diverted from the original intended building appearance. (Fig. 2)



Fig. 2: Le Corbusier's Cite de Refuge: original project (left) and with shades (right), (Banham 1984)

In the Bibliotheque Nationale de France, the library was originally conceived as a complex of ethereal glass buildings filled with light. (Anonymous 1997) After construction, it was necessary to introduce additional interior full floor to ceiling height wooden shutters to avoid direct sunlight and potential damage to the books within, at great additional expense. However, this approach still failed to effectively control solar heat gains within the building, since the wood panels were placed inside the glazed façade, to preserve the original intended external sheer glazed appearance of the building. (Fig. 3)

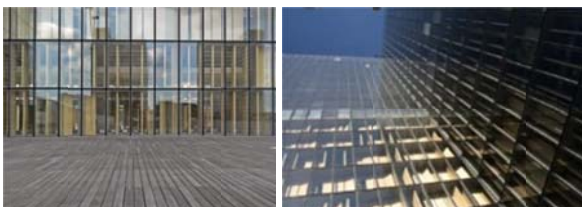


Fig. 3: Bibliotheque Nationale de France and the interior wooden shutters, (author, 2013)

These case studies demonstrate the significant impact of heat and lighting considerations in the design of a glass envelope, together with the consequences of not taking these into account during the design stage and how this can significantly alter the original concept as well as the user experience of the building both internally and externally.

3.0. MULTIFUNCTION APPROACHES TO FAÇADE DESIGN

3.1. Transitional passive shading devices on glass envelopes

The use of passive shading devices (SDs) on glass facades provides benefits in terms of reducing solar heat gain. Fixed SDs can reduce thermal loads during summer daylight, enhance vision experience (transparency) and reduce glare. (Mandalaki 2012) Louvers and blinds may be composed of multiple horizontal or vertical slats, which are used not only for solar shading, but also for redirecting daylight. Fixed or moveable horizontal louvers provide shading similar to an overhang with improved daylight potential. (Lee, et al. 2002) In a study, Mandalaki referred to Brise-Soleil as horizontal and vertical louvers, in a large-scale window. Then he showed that this exterior surrounding shading system, called Brise-Soleil facade, creates the lowest energy demand on heating, cooling and lighting as compared to other systems. (Mandalaki 2012) In another study, Kim demonstrated that external shading devices are much more efficient than any other form of internal devices since the internal devices absorb solar heat, which radiates to the interior. (Kim 2012) Gratia and De Herde suggested that in the case of a double-skin facade, the blinds could be integrated in the cavity. The shading device is thus protected from inclement weather and pollution. (Gratia and De Herde 2007) However, past research has not addressed how the integrated shading devices can have a structural role in glazed facades, in addition to their shading function. In other words, intermediate venetian blind systems will not only have thermal benefits, but also they can potentially provide extra stiffness and strength to a double glazed system that can lead to a reduction in glass thickness, saving on material costs and weight.

One elegant example of using transitional shading was implemented on a building by, Mehrdad Hadighi from "Studio for Architecture", who designed a wavy "graded" concrete facade for Shantou, China headquarters for the Lafayette 148. This building houses all the functions of the Lafayette 148 clothing label and is organized around the flow of production, literally from conception to shipment of the final product. The real magic occurs on the exterior where a double-skin façade elegantly wraps the east, south and west side of the building. The façade is composed of twisting concrete panels that create a continuously varying or graded pattern on the building exterior. (Fig. 4) Size and shape for the grading not only corresponds to programmatic elements inside, but also addresses environmental concerns. The perforated panels aid in the assembly of the façade, and create different plays of light and shadow on the interior that enhances the user's experience. (Neveu 2012) However in many instances, visible transparency is compromised against prioritizing the external appearance and does not fully address all the necessary parameters that need to be addressed, such as the need for good views out and limiting of high maintenance costs on the external panels

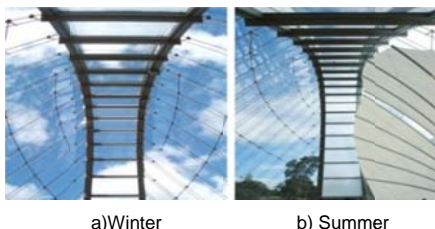


Fig. 4: Mehrdad Hadighi's design for Lafayette 148 in Shantou, China, (Neveu 2012)

However what is demonstrated is that interior and exterior designs can be effectively addressed using vertical or horizontal shading blind systems. This is an effective method for controlling solar heat gain of glass facades as a customized approach related to a building's specific functional requirements.

3.2. Active shading devices for glass envelopes

Active shading devices have been used in various building envelope solutions. One example is the Alpine House, which is an all-glass enclosure in Kew Botanic gardens, which used a system of winches and pulleys with a retractable fabric to provide adjustable shading in order to shield the interior against the morning and afternoon sun. This in turn altered the appearance of the building envelope. (Wilford 2007). The retractable fabric shading operates on the east and west sides of the glasshouse independently, in order to shade against the morning and afternoon sun respectively (Fig. 5).



a) Winter

b) Summer

However, an interior fabric both increases cost and does not address the heat gain issues associated with internal shading, albeit an effective solution for controlling the lighting dynamically. Although this may be an efficient solution for greenhouses, the opposite is true for occupied buildings and as such needs a different approach that integrates building function with energy performance.

3.3. Translucent light emitting facades in glazed buildings

Glass can be transparent or translucent as a device for transmitting or diffusing daylight to different effects. There are instances where transparency is not essential, yet light transmission is, and in some cases, this can be related to programmatic function. As an example, in the Christian Dior building in Tokyo designed by SANAA, glass was deployed in layered vertical planes as a way to obfuscate the slab. (Bell and Kim 2009) SANAA's ideas created a dramatic result that boasts a skin of flat glass panels over acrylic thermo-formed panels that appear like folded fabric. (Philips 2004) These half-transparent curved acrylic screens are located in the interior and make the façade entirely non-transparent but light transmitting. (Fig. 6)



Fig. 6: Dior building in Tokyo designed by SANAA, (Bell and Kim 2009)

Another similar approach was adopted on the Maison Hermes building located in Tokyo. In this case, translucent glass blocks were used as a device to focus the building user experience to the interior, (i.e. the goods on display) by avoiding any transparency to the outdoors yet providing a delightful light emitting experience from within. Inspired by traditional Japanese lanterns, Renzo Piano designed a façade that drastically changes the building's expression from day to night. (Brown 2009) (Fig. 7) This would otherwise not have been possible with a fully transparent façade or one that is heavily shaded.



Fig.7: Maison Hermes in Tokyo designed by Renzo Piano, (Brown 2009)

Another approach that transitions between clear and translucent glazing to different effect, related to function, where, for example, translucent areas are created across the building structural, services and utility parapet areas. Transparent areas are only located in the vision band, whereby a gradual density of translucency is created between the solid and transparent zones. Christian de Portzamparc created a five-story hotel named Arc de Triomphe, using undulating glass ribbons that form a large interwoven glazed plait. Transitional transparency is created using a ceramic frit that grades the translucency density between the lower part of the glazing, to prevent users from experiencing vertigo and the upper part which is fully transparent. (Fig. 8) (Kristal 2011)



Fig.8: Arc de Triomphe hotel, the lines of fritted glass gradually change from bottom to top, (Kristal 2011)

Translucent facades provide a high quality of diffused light into a building. However, by functional consideration, it obscures the view to the outside and may increase direct glare from the facade, consequently reducing user comfort.

Therefore, an appropriate solution may be one that combines functional components to control light, visibility, solar transmission and energy gains within associated zones that seamlessly enhance performance within an integrated solution that is multi-functionally passive.

4.0. A LAYERED FUNCTIONALLY GRADED FAÇADE SYSTEM

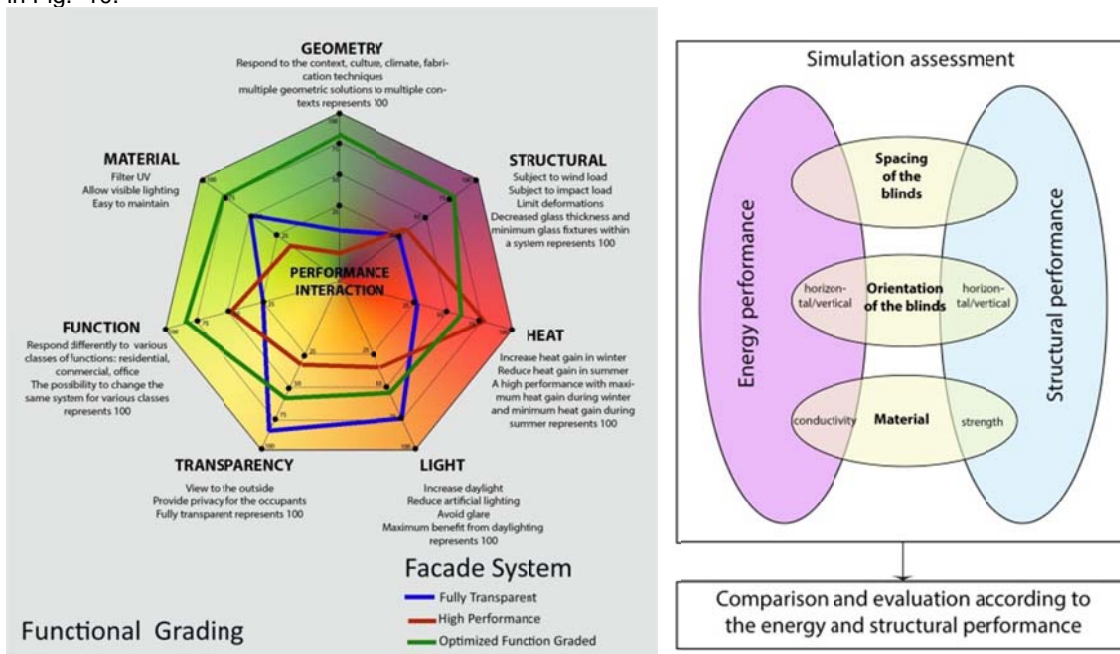
4.1. Functionally graded programmatic parameters

Window design is not just glazing selection, but requires architectural elements to inform the space itself. “Any discussion of windows without considering the means to temper and control light in an integrated manner is incomplete.” (Carmody 2007)

We have demonstrated a number of approaches to solving a façade’s functional requirements, that have failed and others that have been opportunistic towards a particular goal. However fully integrated systems that are cost effective and optimally solve all the complex functional issues, remain elusive. The authors’ proposed approach is for solar controls to be considered not only as one-dimensional elements for energy control, but can also provide a more dynamic multi dimensional response to both internal function and external appearance, by integrating them within the glass layering. This offers further structural efficiency and provides a new aesthetic that represents a multifunctional solution. This in turn offers a wide variety of aesthetic opportunities and reflects the customized nature of a building’s function and performance requirements. The functional parameters that a façade needs to respond to, are demonstrated in the following diagram (Fig. 9). If a façade solution was able to address all these functions simultaneously, we could create the optimal façade solution. Despite many historical attempts to optimize façade system performance, there are always compromises that result in an “either/or” solution. We are attempting to minimize these compromises by proposing an optimized functionally graded façade system that continuously varies across its elevation in response to changing performance, functions, programmatic and appearance requirements. Fig. 9, qualitatively demonstrates an optimization strategy that weights a selection of façade solution performance metrics according to a range of objective and subjective criteria. The largest areas covered in all categories, represent an optimal solution compared to conventional fully glazed and existing advanced façade systems that have less coverage and are skewed in one direction or the other, compromising important performance requirements. These could be better balanced by achieving similar and higher performance in all categories.

4.2. Functionally graded technological parameters

In the context of proposing a functionally graded façade system, our technology investigations are exploring heat, light, materials and structural metrics of a double layered glass system, evaluated for various shading configurations, on the environmental performance of a building. This includes a thickness for the glass panes at 3 mm each and the depth of the shading panel system around 100mm. The primary dimensions are based on structural codes governing the glass structures’ design. By integrating the shading panel system within the glass cavity, as the depth of the whole structure increases, the thickness of the glass panes can be kept constant in a particular span, compared to typical glass systems, where the glass thickness increases with increases in spans. The optimization process that relates the two interfacing energy and structural performance parameters with integrated component design considerations, are summarized in Fig. 10.



characteristic:

façade for both parameters,

In the following section, we elaborate further on the proposed configuration imperatives and propose approaches for developing a functionally graded façade system, based on the basic principles developed for an innovative and integrated façade structural system approach (Giles 2008), which monolithically attaches an inner core element in the intermediate air space, to a double glazed sheet, to create a structurally composite facade configuration which is very efficient and lightweight. This approach has the potential to further quantify how the core elements provide a structural role as well as a shading function that also results in overall thermal benefits and reflects internal function. This interactive functionality also enhances the external appearance of a building envelope, by creating a rich and varying textural grain to the entire façade.

4.3 Functionally graded window systems

4.3.1. Partitioned system

A common window system used in many buildings, including churches, castles, residential and commercial buildings, is partitioned. Figure 11a shows this layout that includes punched windows in an opaque wall. This system combines transparency (for light and views) with opacity (for solidity, cost, and thermal efficiency). This approach in window design minimizes the glass surfaces, according to the needs of every interior space. The strategy that considers different functions related to adjacent spaces, is energy efficient, which has a recognizable effect on the appearance of the building. This approach addresses each interior function independently and does not attempt to integrate form with function in a single building envelope. New approaches to materials, construction and energy efficiency have permitted the industry to adopt more contemporary approaches to unified and multifunctional building envelopes, driven by the ‘curtain wall’ construction concept, where the windows are still partitioned or cover entire facades as discussed before.

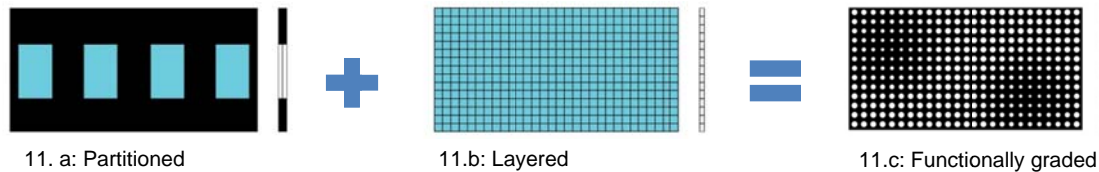


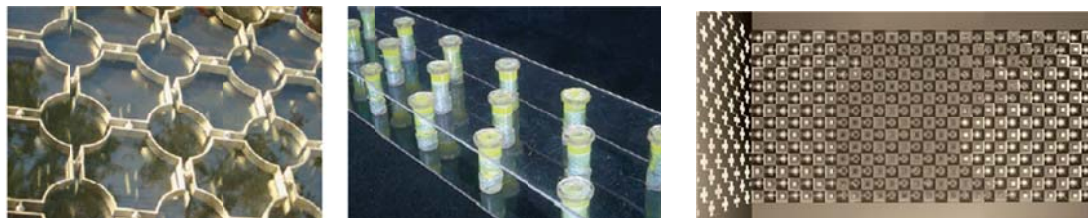
Fig. 11: Deriving a “functionally graded system” by combining a “partitioned” and a “layered” system, (authors 2013)

4.3.2. Layered system

More contemporary approaches have attempted to create envelope systems that are ubiquitous in form, towards larger light emitting facades. The solutions are still somewhat contained within curtain wall assemblies and in some instances, full floor to ceiling clear or transparent facade approaches. This requires the use of excessively thick glass to work structurally, together with addressing the excessive heat gains experienced in such fully glazed systems.

Layering of a hybrid sandwich to enhance the structural efficiency of a transparent panel has been researched as shown in Figure 12. This layering can serve to enhance structural efficiency as a composite panel system, with integrated shading elements.

According to Wurm, “The acceptance of sandwich construction to glass architecture depends on how much can be achieved with automated manufacturing processes in terms of economy and quality standards.” (Wurm 2007) The build-up of these sandwiches, selection of materials and the geometry of the layers varies, which opens a wide scope of possibilities for manufacture, function and design. SITUMBRA, which is an innovative structurally monolithic transparent facade system, creates a shading function through various geometric configurations of the connected core elements, as way to integrate structure with shading function in a single façade system. (Giles 2008) (Fig. 13)



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4.3.3 Macro versus Micro grid system

There are three types of grid that can be used to provide floor to floor shading. Firstly, a “macro” system which includes floor to floor ledges and fins; secondly a “medium” system which is based on a 4 or 6 inch deep cavity using spacing of similar dimension; and thirdly, a “micro” system which is based on a 1 inch cavity with an internal venetian type of blind. (Fig. 14) The depth of the louvers in each scenario is

proportional to the dimensions of the grid-shaped glass divisions. Similar to Le Corbusier's solution, horizontal and vertical shading devices can be used in a glass façade system, but scaled down to a medium and micro grid system. In another words, the "large grain" shading louvers can transform to a "medium grain" brise-soleil system that is integrated within the cavity of a double-layered glass system, instead of adding an additional layer external to the facade. This fixed cavity inner structural core, which connects to the inner and outer transparent window material, can meet multiple specifications including enhanced thermal performance of the facade as well as playing a structural role for the whole system. (Fig. 15)



Fig. 14: Three different types of grid: a) Micro, b) Medium, c) Macro (authors 2013)

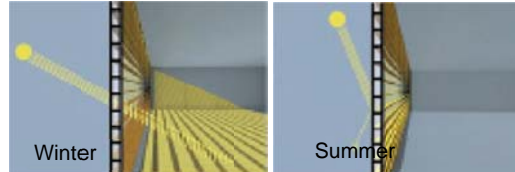


Fig. 15: The shading system functionally integrated between two glass panes. (Giles 2008)

4.3.4. Graded system

It is postulated that a façade system may be configured to combine the primary capabilities of a partitioned and layered system into an integrated system that embraces multi functions (Fig. 9), thus represented as a system that also expresses its functions. For example, a geometric grading (Fig. 11c) may both represent the layout of internal spaces such as the macro scale in the Lafayette 148 building façade represented in Fig. 4), combined with a structural composite configuration such as the SITUMBRA system represented in Fig. 13). This approach also provides the necessary shading, by locating the shading elements by internal function (similar to the transitional grading of the glazed fritting on the Arc de Trimophe hotel façade represented in Fig. 8). Learning from the design solutions for the Dior and Hermes buildings (Fig. 6 and 7), the final solution may be fully or partially translucent, depending on the building program, or graded across various modes of transparency. Therefore, our proposed system effectively morphs a "functionally partitioned systems" and an "integrated layered system", to become a "functionally graded system" (Fig. 11c & 16). In this approach, a core system is still compositely sandwiched between two separate glass panes to achieve excellent structural efficiency. This core system may have a progressively varying geometry, graded by the interior spaces' functions and/or light transmission characteristics. The core plays a role in providing shade, and also stiffens the glass surface to provide a light weight glazing system. The change rate of the geometry is not discrete but occurs through generative parametric modeling. This approach in designing a micro system has the potential to address all the building's requirements parametrically, such as solar angle dependency, orientation and interior function.

4.4. Functionally graded façade geometries

In order to fully embrace the functionally graded components in the design of a glazed façade system, the many parameters, including the building's needs, the core geometry and its variation's, the core's material and the available fabrication techniques are being addressed in a series of geometric and manufacturing studies that optimize on system performance. There is an ongoing exploration on the possibilities of the design and fabrication of the functionally graded core systems. We have started this process by designing a rectangular grid system that may vary by interior function.

Another design approach uses a circular pattern that varies depending on its distance from an attraction point. Several geometric patterns based on fractal variations are also possible, using a rectangular layout (Fig. 16). Further studies that transition the actual interconnecting cells between glass layers are being carried out to create an interspersed micro to macro grid configuration, such as those demonstrated in Figure 17 below.

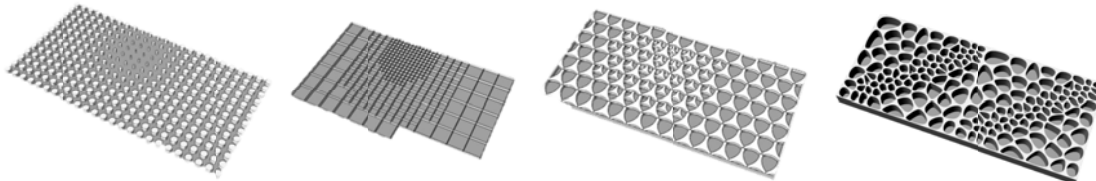


Fig.16: Creating a functionally graded shading system, based on generative component geometries, (authors 2013)

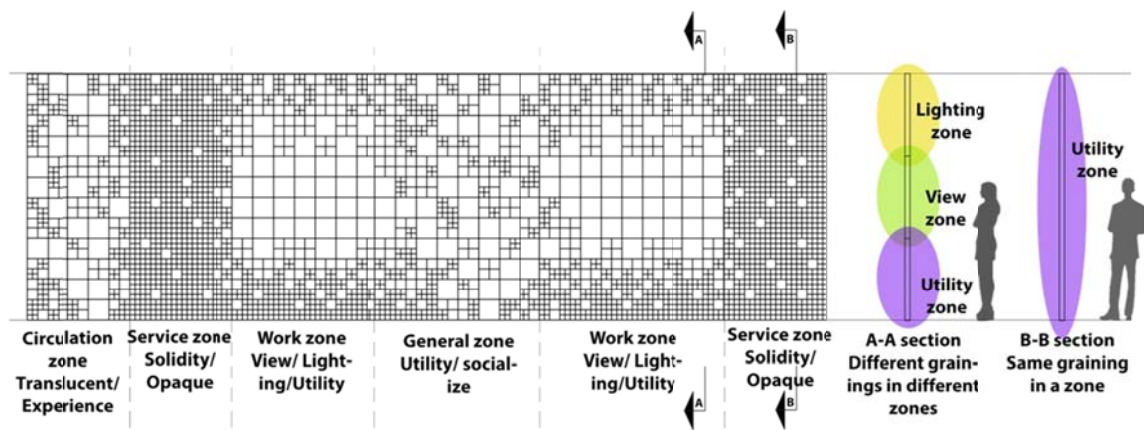


Fig. 17: System wide graded façade concept applied to functional zones across part of building elevation, (authors 2013)

5.0. CONCLUSION

A façade's configuration can be an explicit representation of its functions. There are multiple functions within a building and sometimes a dominant function imposes a configuration that dominates all the other functions. In contrast, we propose a functionally graded façade system that creates a smooth geometric transition in response to different programmatic building functions, by grading the façade's geometry in response to these functions. These transitions are also meant to represent a system that follows a number of functional rules, categorized by space and technical performance, which vary gradually in their geometrical form.

In addition, a layered glazing system that integrates a shading system in the cavity of two glass panes can enhance the role of the blinds from "one-dimensional functioned element" to "multi-functional element" which not only increases the energy efficiency of the system, but also plays a role in the structural efficiency.

The concept of a "functionally graded layered glass system" pushes this boundary even more and adds other functional aspects to the system including a wide variety of aesthetic, more dynamic, multi dimensional responses to internal function and external appearance that proposes a richly varying customized appearance that reflects a buildings function and performance requirements. The enhanced performance of this system has been validated through computer simulation and also lab measurements. In addition, a unique fabrication technique has been developed which is capable of manufacturing structurally integrated cell system. This research will further explore various geometries and associated fabrication techniques for those geometries, in an attempt to refine and optimize the multifunctional capabilities of the proposed functionally graded façade system.

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