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Smart Windows & Intelligent Skin For Optimizing Energy Consumed

(To investigate the potential of diminishing the energy consumed)

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Abstract

The purpose of this work is to investigate the potential of diminishing the energy consumed by typical low thermal mass buildings for heating, cooling and lighting by using smart windows. The windows considered consisted of a double pane glazing unit in which a controllable absorbing layer is added on the interior surface of the exterior glass pane. This absorbing layer allows to change the optical properties of the window, resulting in a direct potential of control of the incident solar heat flux entering the building through the windows.

Keywords

"Smart Windows," "Intelligent Building," "Optimizing energy consumed,"

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Introduction

This research presents an investigation into using intelligent light-deflection techniques to optimize daylighting in buildings. In this chapter, the background of the proposed topic, the research argument, and the objectives of the study are presented, along with insight into the methodology and intended deliverable.

Figure 1

Curtain Walls –The architect's goal was to allow more daylight penetration into the space, as a means of energy-saving[1]

The penetration of daylighting deeply into the space, reducing lighting costs, was the main objective for using curtain wall systems. As time passed, architects started incorporating more glass into their facades, resulting in high levels of illumination inside the spaces. The use of larger amounts of glazing became more common, which made architects worried about their façade performance, and they started looking at the façade as an important filtering layer to the indoor environment. [1]

The word "intelligent" was first used at the beginning of the 1980s to describe buildings, together with the American word "smart". Since then, building façades incorporating intelligent features have come to be known as "intelligent building skin," or "smart windows" where the skin forms the greater part of the intelligent system in the building. Describing a façade or windows as an intelligent element requires the presence of dynamic living capabilities, which enable interaction with diurnal and seasonal changes, and human beings in the surrounding environmental context, in order to achieve a reduction in the energy consumption inside indoor spaces. Intelligence is not an equation of fixed variables; it is a process that is inspired by human intelligence and cognitive capabilities. That being said, the definition of intelligence can be manipulated in different ways according to the designers' intentions and approaches. However, all definitions acknowledge the influence of living organisms in terms of behavior and reasoning. [2]

Bringing daylight into the core of the building is an architectural design challenge that aims for a better visual environment and greater energy efficiency. This can be achieved through the use of advanced dynamic daylight strategies. Today, the increasing notion of scarce resources has demanded better daylight strategies to minimize dependency on electric light. Despite the growing notion of energy conservation, daylight is not often used as a major scheme to exploit renewable sources and reduce energy consumption.[3].

RESEARCH STATEMENT

Energy efficiency in buildings is influenced by the behavior of architectural spaces, part of which can be attributed to daylighting. Daylighting performance is envelope-dominated. For example, designing fully-glazed façades minimizes the efficiency of the envelope, despite allowing huge amounts of daylight into a space. This does not necessarily result in good performance, since illumination levels are not optimized to fall within the acceptable range. The problem is notably experienced in south facing façades, which get the most solar exposure over the course of the day.

Daylighting is a crucial asset for building design, but it is variable. Indoor spaces suffering inadequate daylighting levels during daytime experience illumination levels (quantity) out of the recommended range, and uneven distribution of daylighting (quality). They also suffer the need for electric lighting to compensate for the limitation of daylighting depth into the space. The design profession is currently undergoing technological advancement which will allow for better daylight performance, targeting greater energy savings and reduced electricity consumption. This will happen by bringing daylight deeper into the space, maintaining desired illumination levels (quantity), and achieving even luminous distribution (quality). [6]

The integration of light deflection techniques into an intelligent dynamic panel system allows the enhancement of daylight harvesting, quantity and quality, inside south-facing spaces enclosed by fully-glazed façades – Hypothesis.

This hypothesis combines two different aspects of architecture that correlate: “intelligent skins” and “daylight-deflection technology.” Within the context of this thesis, intelligent skin is the means through which daylight-deflection is enhanced.

panel materials, panel geometry, targeted number of inputs and outputs to and from the system, illumination levels (quantity), and luminous distribution (quality).

This study specifically investigates independent tilt angles and panel geometry, and their impact on optimizing the quantity and quality of daylighting inside office spaces. Independent tilt angles are an approach proposed in which every other louver has the same tilt angle, either in shading or harvesting position. [6]

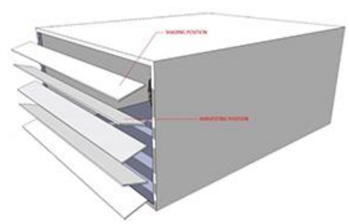


Figure 2

Independent tilt angles – the shading and harvesting configurations of different panels actuate independently in a secondary skin system. [6]

ANALYSIS AND MODELLING
Smart Windows

Most of the people are familiar with the benefits and drawbacks of using large amounts of glass in a residential building or office construction. The natural light and warmth of the sun makes any space more useable and pleasant. Numerous studies suggest that adding natural light to a workspace can improve workers’ productivity and reduce absenteeism. Unfortunately, windows can dramatically increase energy consumption by letting in too much heat during the day, and letting it leak out again at night. In an era of increasing environmental awareness corporations and individuals are seeking ways to make their buildings and offices more energy efficient. Windows are a great place to start. [5]

DAYLIGHT REWARDS (HUMAN HEALTH AND PRODUCTIVITY)

Despite the excessive use of artificial light in architecture, people still appreciate the natural gift of daylight, acknowledging its advantages. Natural lighting has always been an important design feature in the building design field. Besides providing a connection to the outdoor environment, it is as vital an element for maintaining human physical health as it is to plant life. Natural light can bring happiness to a space and make people escalate the value of their presence. It also results in an environment with dynamic light conditions, unlike one lit artificially.

Daylight strategies are crucial for sustaining human health, work productivity and a pleasing work environment [3].

INDIVIDUAL OUTCOMES

In 1996, Veitch and Newsham proposed that lighting quality can be defined as the degree to which the luminous environment supports the following requirements of the people who use the space (Figure 3):

- Visual performance;
- Post-visual performance (task performance and behavioral effects other than vision);
- Social interaction and communication;
- Mood state (happiness, alertness, satisfaction, preference);
- Health and safety;
- Aesthetic judgments (assessments of the appearance of the space or the lighting).

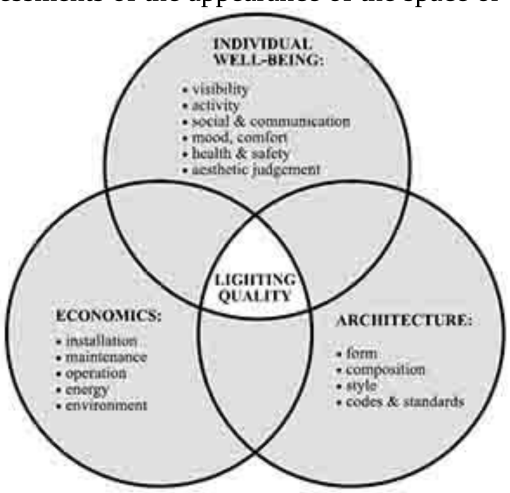


Figure 3

Qualities of lighting – Veitch's proposal determines the quality of lighting in any given installation through determining the balance of the (sometimes conflicting) dimensions shown in the diagram. [4]

They also added that the qualities mentioned above do not allow direct measurement of daylighting, but express an emergent state that is created between the occupant in the environment and the light. According to their report, good lighting quality exists when a lighting system creates good conditions for seeing, supports task performance or setting-appropriate behaviors, fosters desirable interaction and communication, contributes to appropriate mood, provides good conditions for health and avoids ill effects, and contributes to the aesthetic appreciation of the space. [4]

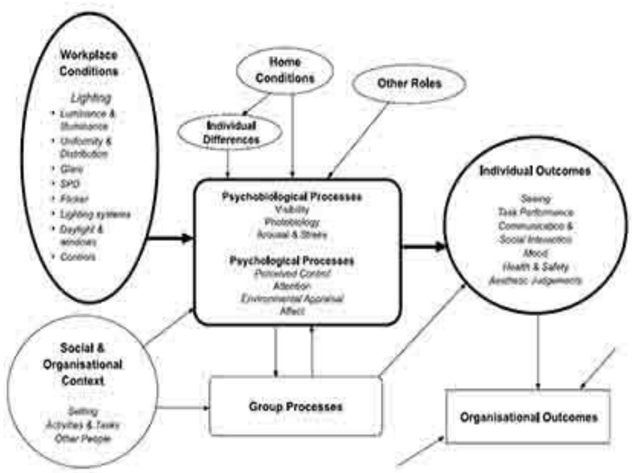


Figure 4

Individual Outcome – the influence of various factors, including lighting conditions, on the individual outcome. [4]

Smart glass

Smart glass is the next evolution in solar control glass. The term applies to any type of glass that can manually or automatically increase and decrease the amount of light that passes through it. This type of solar control glass helps maximize energy savings in all seasons by reflecting the sun's energy outside on hot days, and allowing it into the building when temperatures are cool. Existing types of smart glass need electricity to transition from their transparent to darkened or reflective states.

Unfortunately, this requirement offsets some of the energy savings created by these windows, and makes them costly and difficult to install.

RavenBrick's filter technology represents a leap ahead of existing smart window systems. RavenWindow is an active-passive, thermoreflective filter; it darkens in response to an increase in the temperature of the window without an electric current or human intervention. This eliminates the need for additional wiring and control systems, and simplifies installation and maintenance. Unlike other smart glass technologies, RavenWindow can be retro-fitted to improve existing windows, including low-e windows. Best of all, RavenWindow costs dramatically less than other smart window systems currently on the market. [5]

CONCEPTUAL IDEA

Intelligence in buildings has always been influenced by human intelligence. But since human intelligence has not been powerfully modeled in simulation tools yet, the integration of all of the above tools into one system – to be used for this study – may enable the simulation of abstracted characteristics of intelligent kinetic features. (Figure 5) shows how these features can be rationalized and abstracted for a simple modeling process using parametric tools.

Grasshopper is responsible for setting the input parameters, according to the desired luminous environment conditions, and passing these to the daylighting simulation tool, DIVA/Radiance, which then processes the data and sends the results back to Grasshopper for evaluation. [6]

Grasshopper compares the results against the pre-defined performance criteria. If the results are acceptable, Grasshopper provides the generated solution as the best possible under the defined simulation conditions.

If the results do not match the criteria, Grasshopper sets another scenario for the skin and triggers the simulation tool to re-run the new scenario and generate an outcome, and so on until an acceptable result is achieved (Figure 5).

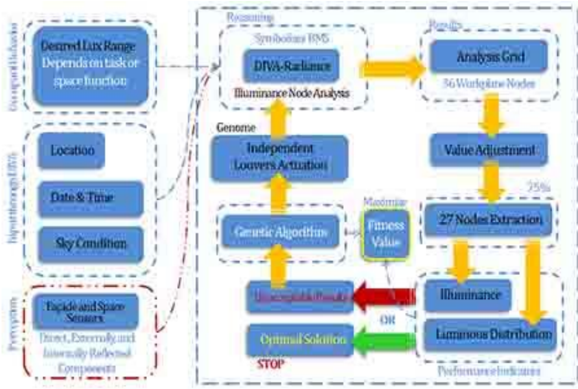


Figure 5

System logic – the path of data exchange between the proposed algorithm and the daylighting simulation tool. [6]

The modeled space in Rhino has dimensions of 6.0m width, 7.5m depth, and fully-glazed height of 3.0m (Figure 6). The interior surfaces have been assigned reflectance of 80% for ceiling, 50% for walls, and 20% for floor. The secondary skin louvers have reflectance of 90%. The opening has been assigned generic doubled-glazed material with 72% visual transmittance. [6]
A place with sunny weather and daylight has been chosen to be the location of the test and this south-facing office space.

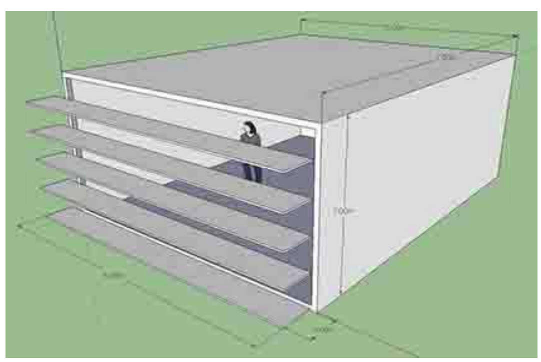


Figure 6

Space dimension - the dimensions of the office space used in the simulation. [6]

Initially, the skin system is divided into 8 louver levels, where each level has two louvers (Figure 7). It is intended to control each of the ten louvers independently with different tilt angles. Though the system simulates daylighting according to the actuation of eight louvers, only five louvers cover the glazing portion of the space. These five louvers have the greatest impact on the luminous quality of the workplane. (Figure 7) shows the algorithm for simulating 10 independent louvers based on five levels. However, for better presentation of the proposed design tool, each two louvers on the same level are treated with the same rotation angle, using another algorithm.(Figure 8). This approach does not eliminate the flexibility of the definition to independently actuate each louver.

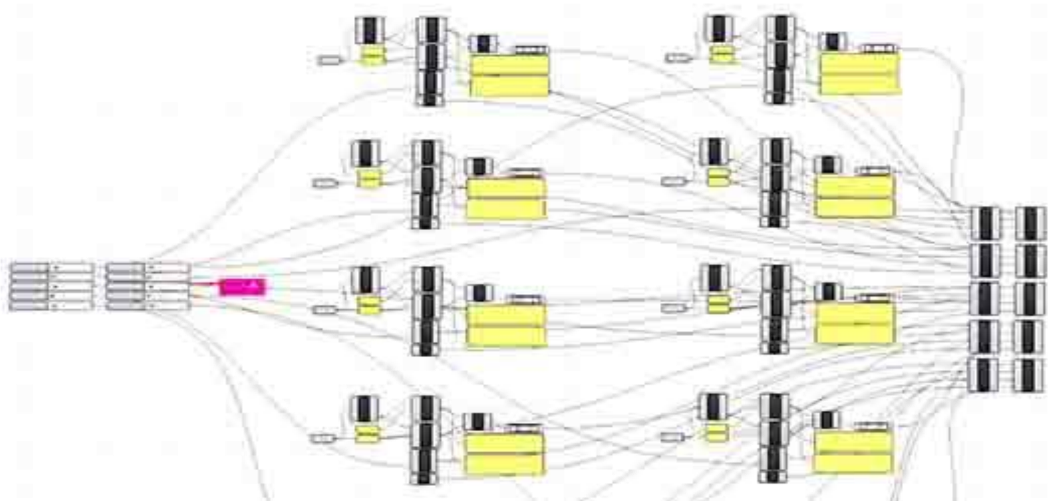


Figure 7

Louvers definition - part of the Grasshopper definition that illustrates the ten louvers with the angle sliders on the left hand side. [6]

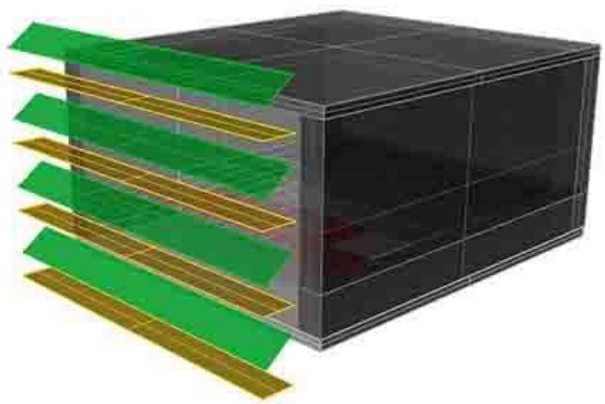


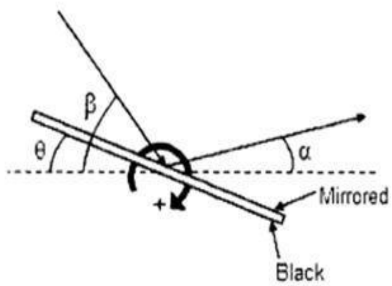
Figure 8

Independent split system - the two independent layers of louvers used in the proposed algorithmic design tool. [6]

SIMULATION METHOD

There are infinite possibilities for the combined skin configuration of the intelligent-kinetic louver system, since the proposed system depends on independent angle control, where each louver may have its own tilt angle. Therefore, the best approach for this study is to use parametric software that automatically generates as many possibilities as the designer desires. But for manual simulation, it is extremely time consuming to adjust each louver to a specific tilt angle. Accordingly, some skin configurations have been defined based on previous research in the field.

In 2005, Molly McGuire explored the independent blind angle control for Using a physical modeling approach, she venetian blinds, and its impact on ceiling illuminance. was able to establish conclusions for light-reflection on the upper surface of venetian blinds. In her research, she presented three equations for three variables: incident angle, reflected angle, and blind tilt-angle. These equations are useful in determining the reflected angle, which consequently gives hints about where the light is going into the space (Figures 9 and 10). The first equation in Figure 5-6 gives the redirected (exit) angle as a function of the depth of the space and the height of the window. The second equation in the same figure expresses the redirected angle as a function of incident solar angle and louver tilt angle.



$$\alpha = 90° - \arctan(\frac{d}{h})$$

$$\alpha = \beta + 2\theta$$

β Incident Solar Angle
θ Louver Angle
α Redirected Angle
d Room Depth
h Window Height

Figure 9

Redirected angle for single configuration - the equations by Molly McGuire for redirected angle calculation for systems with either harvesting or shading setting. [6]

For example, if daylighting is necessary at a depth of 10.00m in a space which has a window opening of height 3.20m, using the first equation in (Figure 9), the desired redirected angle “α” of the rays is 17.70:. By substituting this value in the second equation, assuming the incident solar angle is 62: in June at 10:00am, the louver tilt angle should be -22.15: This angle is measured from the horizontal reference guide counterclockwise (from the right hand side), and this explains the negative sign that refers to the shading position.

$$\cos(\alpha) = \frac{1}{2}[\sin(|\theta_s - \beta|) + \sin(|\theta_R - \beta|)]$$

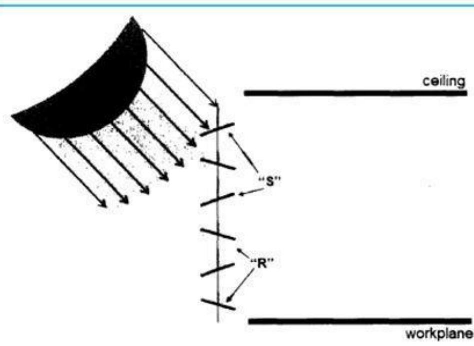


Figure 10

Redirected angle for combined configuration - the equations by Molly McGuire for redirected angle calculation for systems with harvesting and shading settings. [6]

For the purposes of this thesis, the value of "Ɵ" was revised, as shown in Figure 5-8, to measure the angle from the indoor side of the horizontal plane to the tilted louver counterclockwise. This makes it easier to differentiate between shading and harvesting positions, where shading position angles range from 0: to 90:, and harvesting position angles range from 90: to 180: (Figure 11).

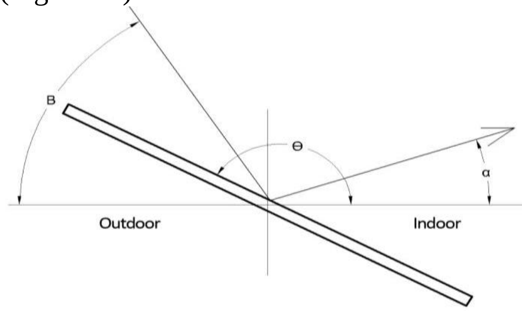


Figure 11

Revised angles diagram - the revised value of "Θ" which is used in this study.

SPACE DIMENSIONS

A space 6.00m wide, 7.50m deep, and 3.00m high was modeled for this study (Figure 12). The louvers are 0.60m deep, 6.00m wide, and set 1.00m from the glazing, to allow for a catwalk. The distance between the louvers was set to 1.30m, which allows partial overlapping in nearly closed shading/harvesting conditions. The depth of the space goes beyond the traditional distance of twice the window height, which is one of the performance criteria, as previously (Figure 13).

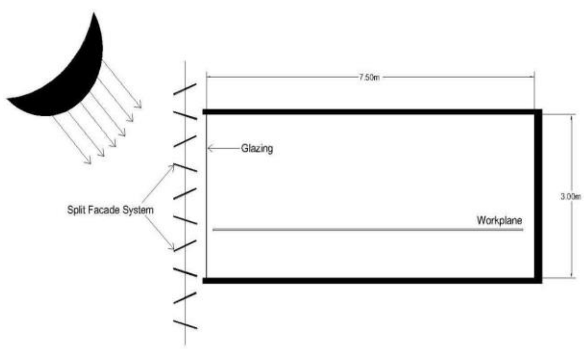


Figure 12

Modeled Space - conceptual image of the space and its dimensions. [6]

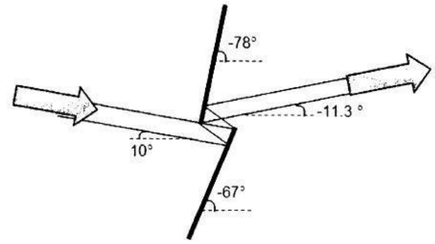


Figure 13

Semi-closed condition - partial overlapping in semi-closed condition. [6]

SKIN SYSTEM

This section of the definition has two similar parts, each of which operates one layer of louvers.

The selected variables for the skin alteration are the rotation angle of the louvers and the distance between them. The rotation angle was set to a range of 0: to 180:, where 0: to 90: allows for a shading configuration of the louvers, and 90 to 180 allows for a harvesting position. The distance between the louvers ranges from 0.50m to 2.00m, where 0.50m allows for 0.12m overlap of two louvers, if required under certain

circumstances, while 2.00m provides more potential for greater light penetration and better view of the outdoor environment, for certain overcast sky conditions.(Figure 15)

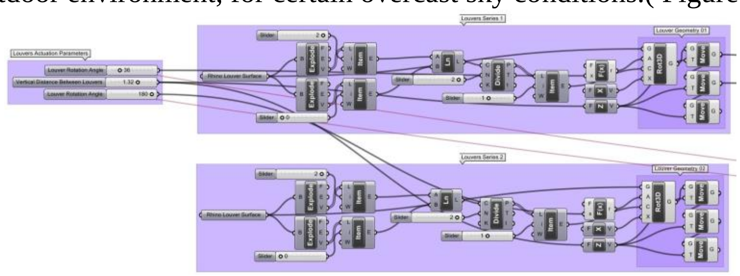


Figure 14

Independent louver actuation - the two independent layers of louvers used in the proposed algorithmic design tool. [6]

Figure 15

Illuminance Scale - the desired illuminance scale based on the color swatch in the definition.[6]

VISUALIZATION OF SIMULATED SCHEMES

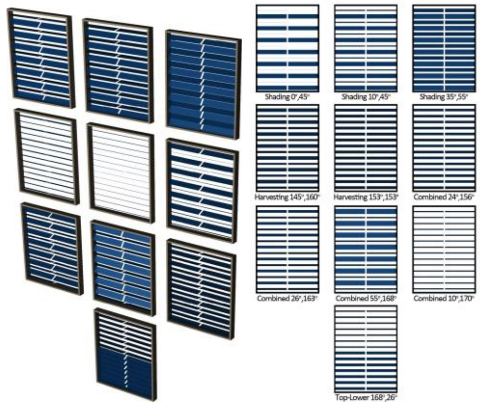


Figure 16

Front & Perspective view of simulated schemes - a visualization of simulated schemes. [6]

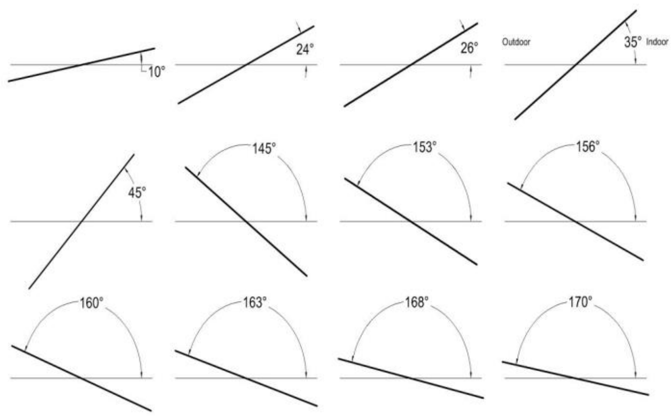


Figure 17

Visual presentation of tilt angles - all tilt angles used in the simulation. [6]

RESULTS AND DISCUSSION

Conclusions

In conclusion, a high integration of design and research flowing between architects, computational designers, and consultants is important to achieve innovation and efficiency. human behavior in the simulation will enhance the performance of an architectural space in terms of energy-consumption.

Moreover, intelligent skins & smart windows are controversial; they may present solutions for better energy-performing architecture, but they cost a lot of money and can be difficult to maintain. If research keeps exploring the performance of these kinds of skins independently without comparing them to feasibility models for cost and development, intelligent skins may not be applicable in the real architecture world. This area requires effort and input from many disciplines other than architecture; among which are business and feasibility, mechanical, electronics, material science, and physics. The integration of inputs from all previous disciplines may result in a system that is cost effective and has a short payback period.

However, the architect should be a dominant element in the design process to support new trends in form geometry such as complex geometry and make sure other disciplines are not changing the architecture to make their lives easier. We need to support changing architecture trends rather than narrowing it down to cube and linear geometry only.

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