一般論文

# Praising of Shades: New façade system with the construction depth for a near future housing

## 陰影礼賛　近未来建築の陰影のあるファサードシステム

● 上原雄史／富山大学芸術文化学部
UEHARA Yushi / Faculty of Art and Design, University of Toyama
● Key Words: Survival cell, faceted facade, Shade, Biomimetics, Circadian rhythm, Daylight, reciprocal frame, design-by-research.

**要旨**

近年、特異な形態の建築が都市を飾るようになった。しかし、そのような建築は、「環境摂理を内包した構造物こそが建築である」と、ロージェが指摘した建築の本質に応えているだろうか。技術革新は、建築物の多様な形態や素材利用を可能にし、BIMなど自動化手法は、設計•建設技術の高度な統合を実用化した。一方、新しい建築形態は環境摂理を内包する論理性に基づいているだろうか。例えば、ヒートアイランド現象への対応は過去20年間指摘されて続けているが、建築意匠学は体系的な答えを生み出していない。本論文は以下の２つの仮説を、デザイン•バイ•リサーチ手法を用いて検証する。１）環境への対応が形態を論理化するということ。２）そのような建築は、「概日リズム」（シルカディアンサイクル）に従った健康な睡眠と持続性のある都市環境を作り出し、健康な生活空間を生み出すこと。これらの仮説を検証することを通じ、本論は新しいファサードを具体的に提案し、次のステップへの明確な方向性を示す。

**Abstract**

Recent architecture possesses diverse shapes that decorates the contemporary cities. Yet do those architecture embody what M.A. Laugier's fundaments: natural and intrinsic? Recent fabrication technology in building construction allows nearly individual couture of its façade, its geometry and materialization. Building Information Model technology coordinate complex projects seamlessly from design to construction. Yet, do architectural design lack reasoning to its unique form? The cause of heat island phenomenon is known for some time, but few design principles were theorized to reduce the heat island phenomenon. This paper applies the Design-by-Research method to this issue. Hypothesis: the first, the building physics is the reason to innovate architectural form; the second such architecture frames space for healthier life by visualizing Circadian rhythm thereby forming healthier sleep and sustainable city. This paper presents a palpable new façade system that features the shades. This paper describes its performance and provides the next steps.

### 1. Introduction

In 2013, the following statements are issued by the International Energy Agency (IEA) to address the member countries. "The rationale for changing our current energy and climate path is compelling. Energy efficient and low-carbon technologies will play a crucial role in the energy revolution needed to make this change happen. The buildings sector is the largest energy-consuming sector, accounting for over one-third of final energy consumption globally and an equally important source of carbon dioxide ($CO_2$) emissions. In certain regions highly dependent on traditional biomass, energy use in buildings represents as much as 80% of total final energyuse."[1].

This frames the philosophical innovation on design as the driving force of economy and outlines the key items on new design.

The citizens are integral part of this as the user of a city, who dictates the energy consumption. Even if IEA defines the architectural design as the crux of the matter[*1], currently, the building physics do not satisfyingly stimulate the developments of new architectural designs. The current building physics do not to stimulate architectural aesthetic, even if it can expose its relevance. The building physics neither actively seeks association with the good healthcare that attracts increasing public interests, nor with tradition to live in an open climate in harmony with nature.

This research targets this innovation on architecture reasoned by building physics. This research is

formulated as the Research by Design method by which the new design put on the test by simulation that only the recent technology made possible. This project is framed to persuade the capacity of architectural design to point the future direction for the technology and the engineering. It does so by composing a set of sound logic on both theory and tectonics.

The research is framed in the perspective that the moral of function prohibits the exploration on the new capacity of design to actively push the borderlines. I promote to innovate the recent PROGRAM method[*2] to define performance of architecture thereby to achieve more substantial effects from the presence of a building. In the current trend of climate change, the quest of an architect is to rid architecture of the aesthetic of modern architecture that it could no longer materialize the expected innovation and in doing so to expose the alternative.

This research pursuit architecture with shades: a new morphology of architectural facade that casts shades on façade itself and there by deliver the performance. This facade controls sunlight thereby stabilizes the interior conditions. It motivates users to live in daylight that helps Circadian sleep cycle for good health care. It demands new design of shields for light to decrease the illumination as according to the individual needs. In doing so the paper aims to found ground for new philosophy on architecture.

These aspects of daylight and health are important for the paradigm of my entire research project, which focuses on the construction of the survival cell in an extreme climate zone.

## 2. Problem

The Circadian neurology claims that daylight and health are strongly related. Frandsen A.K. discusses that daylight heals the cause of stress, anger, anxiety and further psychological effects on grief, illness[2)]. Foster R. unfolds theory of causal effects between daylight experiences and circadian sleep, which has effects on mental stability of mammal[3)].

Even if the general public sees the profit of good healthcare by allowing daylight in architecture, current mode of economy prefers the lighting fixture above daylight. It evaluates daylight as instable therefore opts to limit it and stabilize it by artificial lighting. The technological shortcomings to control artificial lights were the ground of this approach. This mode of fenestration[*3] performs poorly, the Daylight Factor to be lower than 3 in most parts of building, while the value between 4 and 5 is desired. In terms of floor area, it poorly translates in just about 1m wide strips along the façades that can provide between 320 and 500Lux for deskwork (Figure 1 left). Consequently, the condition of the daylight illumination of area no further than ca. 2 to 3m from the fenestration is drastic, varying its scale of illumination from 1500 Lux to below 200 Lux with problems of glare, overlit and high contrast. Obviously, this condition offers no redemption of the daylight.

Here, I introduce one recent attempt in saving daylight by turning it into the source of indirect lighting system. The method implements the reflection device of daylight; thereby I name this the system-R[*4]. It is the work of the firm Bartenbach[*5] for the German house of Parliament Office for the Member of Parliament Jakob-Kaiser Haus[*6] in the years between 1997 and 2000. The concept is to control the daylight by adding one wing like device in the middle of the fenestration, which cuts penetration of the direct sunlight and reflects it to the ceiling covered by aluminum sheets, thereby emitting "cold" indirect sunlight free from heat-gain. The issues: solutions for rainwater, snow, ice, dusts and birds, which reduce the effects. It intensifies cleaning but the wing raise more issues. Additionally this system-R required the artificial lighting always on for support. Bartenbach's recent development mounts a series of devices outside the façade; a vertical assembly of prism as the daylight reflector, which costs more and the need for maintenance is not less.

I analyze that the cure is to tackle current design trend on architecture. Hypothesis is an alternative aesthetics of an undulating façade geometry, which gives shades and reflection, shall bring in the integral breakthrough: a trend that supersedes the principle of modern architecture.

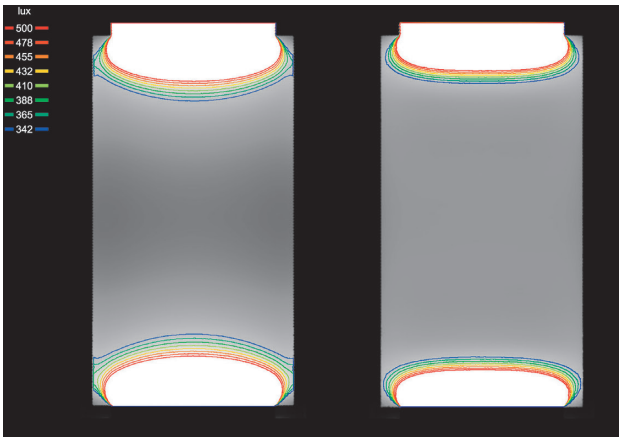


Figure 1: The flux of luminosity between 320 LUX (dark blue line) to 500 LUX (red line) of a standard fenestration (left) and the system-R (right). Standars façade has the zone of about 1m wide while the system-R produce much narrower zone. The measurements are taken in the CIE confirmed overcast sky on 21 March at 12:00 at the location specified by the paradigm of this entier research paradigm.

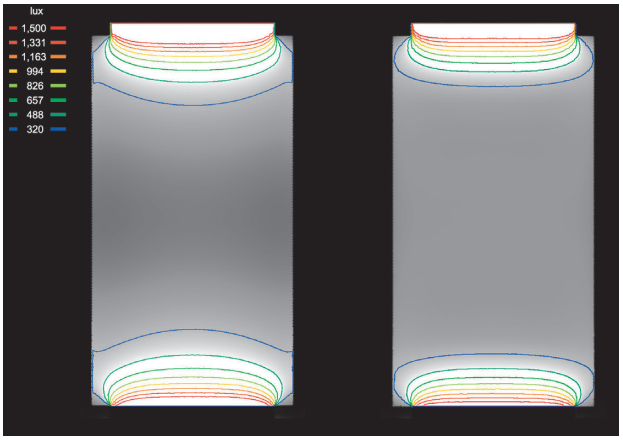


Figure 2: The daylight illumination shown by the graph on the ISO contour between 320 Lux to over 1500Lux. The Red Line shows the threshold of 1500LUX. The center parts are lower than 320 Lux. Both standard (left) and the system-R (right) has the band quite close to the façade. This causes issues such as glare as the contrastsa are high.

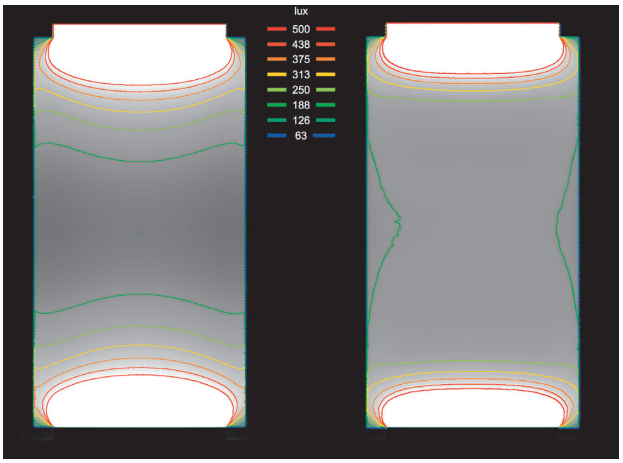


Figure 3: The daylight illumination shown by the graph on the ISO contour lower than 500Lux; compare standard fenestration (left) and the system-R (right). The system-R improved the luminosity of the center part, from 126 Lux to 188 Lux but compressed the area between 250 to 500LUX.

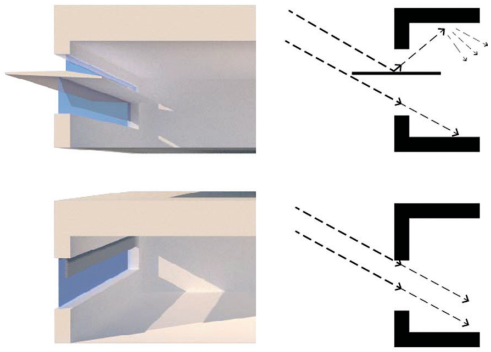

Figure 4: schematic representation of day light penetration through the facades. The system-R (above) aims to alter direct ray of daylight into indirect light.

## 3. Program

This section programs the aim, the goal and the demands on the design, on engineering and on technology. Here, I demand the rudimental effects of the new three-dimensional façade morphology and its performance.

The frame of this research is the architectural design of a survival shelter for researchers in an extreme weather condition to house spaces for their various activities: from detailed machine work, drawing, office works to sleeping.

The prospect is the new daylight distribution that allows *natural* building use: agreement between the notional grades of public/private and the degree of daylight availabilities. The new façade: a) maximize the area with Daylight Factor between 4 to 8 and minimizes the area that are lower than 3; b) creates even illumination; c) realizes smarter distribution of luminosity, the area between 320 Lux to 1000 Lux; d) to create two clearly distinguishable zones, for detailed work between 500 to 1000 Lux and between 500 Lux to 320 Lux for deskwork; e) makes use of simple devices to decrease illumination for comfortable usability; g) cut direct sunlight.

The system will define a new attractive look of a town. The research takes notice on a floor plan that locates its circulation path along the external perimeter, turning façade into a more public zone. This suggests a new concept for a vegetation and landscape design principle that help resolve issues on glare and at the same time raise comfort.

## 4. Projected Site condition

The tested variants are geographically allocated in

E54.54 N24.41 with the idea to equip survival shell by taking advantage on its climate conditions. The frame of the research is programmed to cover other capacities of building physics.

## 5. System

This innovative façade system is to cover a fairly conventional construction bay: 7200mm in the wall to wall width, 12600mm in the façade to façade length and 2700mm in the floor to ceiling height[*7]. The system is framed to achieve the following points. a) Daylight efficient: effectiveness of proposed façade design in mitigating raw effect of sunlight and spreading of indirect diffused illumination into the room. b) Shades: to reduce energy load on glazing and to create upward looking metal paneling that possibly mounts equipment for a renewable energy sources. c) Modular system that increases applicability to other renovation projects, to cover diverse building shapes. d) Systematic approach for possible building shapes: box; torus; cone; pitched roof; and so forth. e) Structural system: a reciprocal frame[*8] construction and three-hinged structural system that resolves wind loads and reducing the overall dimensions thereby creating large allowances to create large clearance for daylight. The reciprocal system is stabilized via stiff paneling that connects frames. I apply simple facet morphology to realize the target, for which this paper shows the result.

## 6. Aesthetics

Architecture is talked about when it convinces men with the reason of its presence through its aesthetics.
An alternative role of aesthetics is to increase chances of human survival[*9]. This research project is not an exception. Firstly, for the purpose of commencing the research it seeks the impact of new architectural design to reason the efforts, that it surpasses the failings of the current mode. Secondly, it is to clarify the new ground for the integral opportunities for human activities; that includes industry, philosophy, design and a whole lots. Thirdly, the aesthetics, in this case on Biomimetics, or Biomimicry, is not the answer, but it provides one philosophy to gain control and share method, approach to solve complex issues. Fourthly, it extending the out reaches of this research outcome by associating external discourses. By sharing the cause and effect of the shapes and logics which this paper promotes with other fields via language, the out reaches will be larger. Fifthly, it is for diversity. The recent trend evaluates Bio-diversity as the ground of solution to a yet unknown sickness. Aesthetical discourses have created diversity in architecture, thus will provide solutions to yet unknown issues.

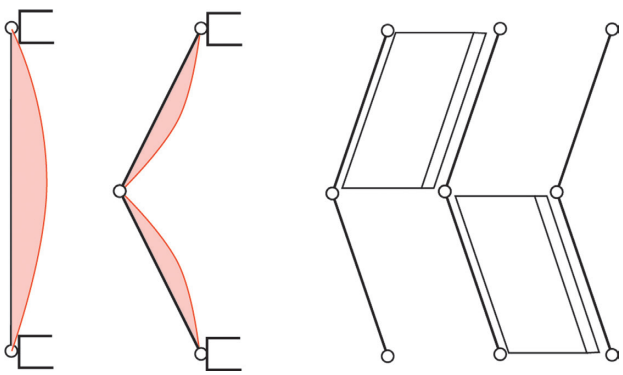

Figure 5: Left, two schemes that represent three-hinged frame facade construction system. The red area is schematic representaion of moment. Right, showig the fixing system of stiff paels with three-hinged frames.

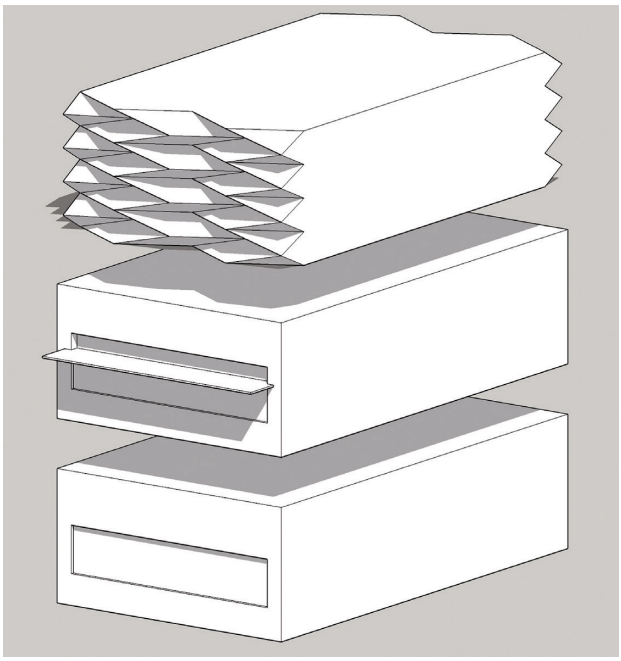

Figure 6: Schematic comparisons of three rudimental facade geometries. from top to bottom: Faceted variants, the system-R and Standard façade opening.

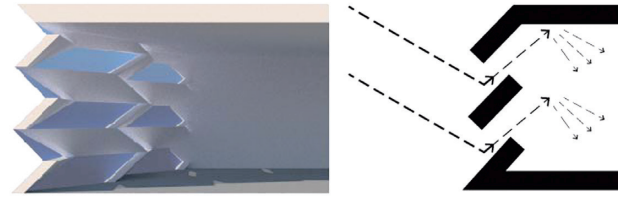

Figure 7: Schematic representation of daylight penetration through the faceted facade system.

## 7. Variations

According to the system and the formal principle set above, I have produced variations that are structured in the following fashion: 1) Vertical or horizontal direction of the three-hinged frame: coded as V or H; 2) The frame can be either 3000mm or 3600mm in the length; 3) The spaces between the frame: 500mm, 600mm, 750mm and 1000mm; 4) The three-hinged-frame have divers depth of the bend: 300mm, 500mm, 600mm, 750mm and 900mm; 5) The geometrical coordination of diagonal line of the folds: aligned (A) and not aligned (W); 6) The pattern of the glazing: next to each other (N) or in the checkerboard pattern (C) and finally the length of diagonal line in length-direction of the frame: 750mm, 1150mm, 1500mm and 1800mm.

The following properties are set as constant: wall, façade finish material both in and exteriors; transparency of the glass panels set in 68%.

This matrix produces in theory 1024 variants. After examining the reasoning exampled here below, only 45 combinations are selected as relevant and being tested. The reasoning are for example: a) There is no point in testing 3m wide horizontal layout for construction bay of 7,2m wide; b) Neither applying 3.6m tall frame to cover 3m floor to floor height; c) Selected a series of reasonable folding angle by taking 90 degree as datum. A sharp folding angle is constructively unfeasible and its construction hinders the fenestration clearance; d) the stiff panels may or may not extend to form eves and spandrels for help reflecting the direct sunlight. And so forth. The variants that tested are shown in the table1.

## 8. Design of tests

The tests are designed to select one or two variants with supreme performance. The tests results are put next to the two of existing types: Standard façade and the system-R.

The tests are run on the three methods: daylight penetration visualization by means of ray tracing simulation on the V-Ray software; Daylight Factor simulation and flux of illumination simulation made on VELUX Daylight Visualizer software. It produces floor plans, interior visualization, section perspectives that shows the luminosity, the ISO contour, the False color indication and the grid measurements in a fairly easy operation. The dates of tests are set as according to the convention of the Daylight Factor simulation on the March 21st at 12:00.

The test consists of the following four stages.

The first test: Daylight Factor visualized in plan and flux of illumination visualized in perspective of an empty interior. It evaluates necessity to examine the proposed new façade morphology. The Daylight Factor are measured on the conventional work plane, the standard hypothetical horizontal surface placed 850mm above the floor level recessed 500mm inside the interior perimeter, on which the upward looking sensor points are allocated on 100mm grid laid on both x and y directions.

The second test: simulate Daylight Factor of the variety of new façade thereby selecting hand full of variants as according to the target set by the program. The simulations are made on a horizontal surface 850mm above the floor level.

The third test: This test selects two façade variants by simulating the flux of luminous of the selected variants in its floor plan and in its section. The level of achievement to the program of demand scales the simulation results. For this simulation, the ratio of the glazing is reduced so that the final design to satisfy the general recommendation of 30% glazing. These simulations are also made on a horizontal surface 850mm above the floor level.

The forth test: The two façade system are given a preliminary constructive thickness and rudimental materialization thereby scrutinized by means of Interior luminosity, ISO contour and False color representation. These tests are also made on a horizontal surface 850mm above the floor level.

The results form conditions of adjustments, which are taken into a new architectural design. A tentative architectural design and renderings are made to inspect the quality.

## 9. The first test

The simulation results suggested the rudimental effects of proposed façade design in mitigating the negative aspects of the standard façade, especially on effects of direct sunlight and spreading of indirect diffused illumination into the room. The visual impression of the ray tracing simulation gave a pleasant impression of a comfortable room with enough diffused light. The Grid Luminosity Measurements are simulated and confirmed the visual impression. The average grades of

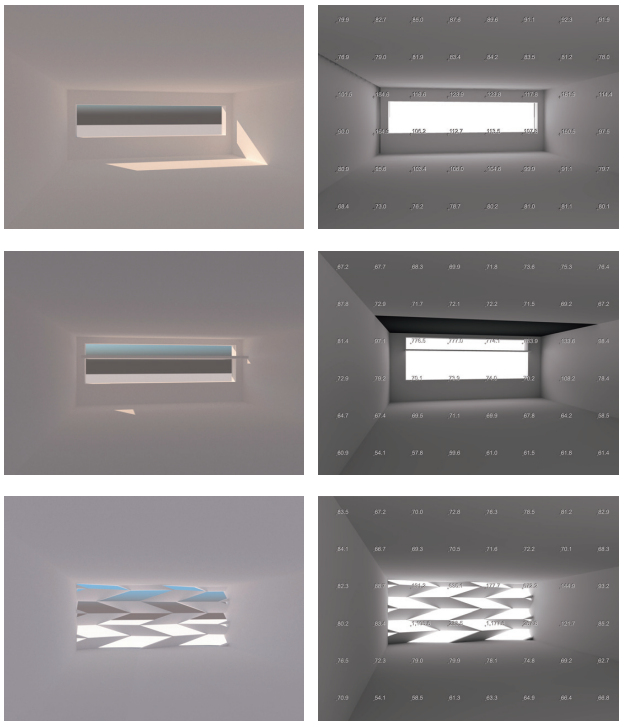

Figure 8: (Three images on the Left) The redner visualization on the 21 December at 12:00. From top to bottom: Standard, the system-R and Faceted variants. The walls, ceiling floors are given one identical material. There is direct sunlight penetration in two cases except faceted variant. Additionally, slight differences in the coloration can be observed.

Figure 9: (Three images on the right) ISO measurements from top to bottom, Standard, the system-R and Faceted facade variant. All interioe materials are unified in to mat white stucco like material except the system-R has reflective surface as it specifies. No artificial lighting are implemented. Measurements sensors on the grid spots are directed on the vector towards the eye. For Calculations the readings from the spots on the window glasses are excluded.

ISO grid reading are: Standard 98.7, the system-R 72.5 and Faceted 79.6. (Exclude the reading of the spots on window glasses.) The result motivated to undertake the remaining tests on the new façade system.

Here, the sensors of luminosity measurement points towards where the camera points at, by which it does not rates the ray of light on work surface, i. e. a horizontally laid paper surface on a desk.

## 10. The second test

The test data ranks the variants primarily by the Daylight Factor performance, that measure light condition of light on the conventional work surface placed 850mm above the floor; secondly by the evaluation of the flux of luminosity according to the program of demand.

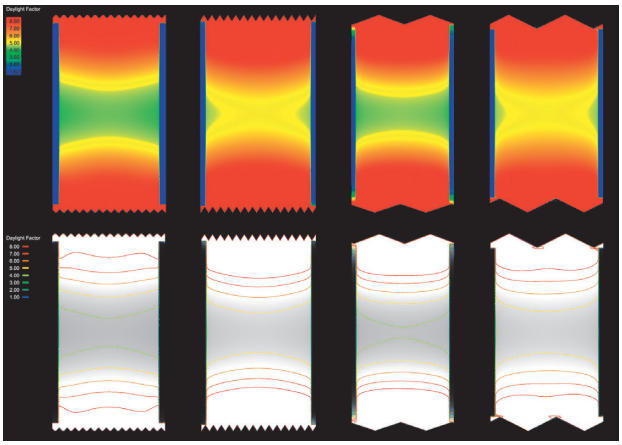

Figure 10: The examples from the Daylight Facot tests on V02, V05, V25 and V35. V02 and V06 are vertical pattern while V25 and V35 are horizontal. The indications are in the False Color representation (above) and ISO contour representation (below) scale 1 to 8. The scale above 5, indicated in yellow, are said to be well lit.

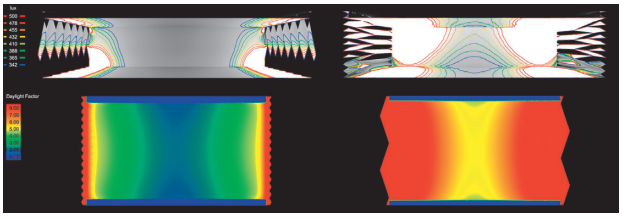

Figure 11: Sample of the resuts shown in the cases of V01 & V33. V01 has lower Daylight Factor distribution across the floor. The ISO graph, that indicating the area with 500-320Lux, shows it compresses the workable area and escalate it towards failrly limited 1000Lux area. V33 has three zones in the room, two zones along th façades are for 1000Lux and in the center one zone for 500-320Lux area.

Among the 45 variations, V21, a variant of vertical frame, and V 42 of horizontal frame seems to work optimally in Daylight Factor. Between the two V42 seems to perform better. The test result filtered 6 variants out of 45: V06, V19, V21, V26, V33, V42 and V47. (see table 1)

The results from the V26 to the V31 are similar. These variants have the horizontal arranged main frames every 500mm in height: the folding length of 1500mm and 1800mm with various depth from 500mm to 750mm. V26 is superior, because its Daylight factor is the highest at 4. Among the variants with the frames mounted horizontally every 750mm V42 performs the best with the depth of 750mm. V47 followed closely V48 from the variants with the larger dimension. V48 is an exception to the matrix, which was decided following

the simulation results of V33. V33 visibly improved from V32 when the pitch and depth are identical. I evaluated V47 above V48. Disadvantage of 1000mm overhung are: a) large overhung reduces the floor area; b) more material for support construction, which reduces the clearance thus the daylight.

| Variation | | | | | | | | Results | |
|---|---|---|---|---|---|---|---|---|---|
| Code | V or H | Frame | Pitch | Depth | Align. | Pattern fol | fold | min. | L |
| V01 | V | 3000 | 500 | 300 | W | N | 750 | 1 | |
| V02 | V | 3000 | 500 | 500 | W | N | 750 | 3 | 126 |
| V03 | V | 3000 | 500 | 700 | W | N | 1150 | 3 | 114 |
| V05 | V | 3000 | 500 | 300 | W | N | 1150 | 3 | 5 |
| V06 | V | 3000 | 500 | 500 | W | N | 1150 | 3 | 2 |
| V07 | V | 3000 | 500 | 600 | W | C | 1150 | 3 | 2 |
| V08 | V | 3000 | 500 | 300 | W | N | 1150 | 3 | 5 |
| V09 | V | 3000 | 500 | 300 | A | N | 1150 | 3 | 18 |
| V10 | V | 3000 | 500 | 300 | W | N | 1150 | 1 | |
| V11 | V | 3000 | 500 | 600 | W | N | 1150 | 1 | |
| V12 | V | 3000 | 500 | 300 | W | N | 1150 | 1 | |
| V13 | V | 3000 | 500 | 300 | W | N | 1150 | 2 | |
| V14 | V | 3000 | 500 | 600 | W | N | 1150 | 2 | |
| V15 | V | 3000 | 600 | 600 | A | N | 1500 | 3 | 20 |
| V16 | V | 3000 | 600 | 500 | A | N | 1500 | 3 | 15 |
| V17 | V | 3000 | 600 | 300 | A | N | 1500 | 3 | 13 |
| V18 | V | 3000 | 600 | 750 | A | N | 1500 | 3 | 39 |
| V19 | V | 3000 | 600 | 750 | W | N | 1150 | 4 | 127 |
| V20 | V | 3000 | 750 | 750 | A | N | 1500 | 4 | 86 |
| V21 | V | 3000 | 750 | 900 | A | N | 1500 | 4 | 54 |
| V22 | V | 3000 | 750 | 900 | A | C r | 1500 | 4 | 136 |
| V23 | V | 3000 | 750 | 900 | A | C l | 1500 | 4 | 135 |
| V25 | H | 3600 | 500 | 600 | W | C | 1500 | 3 | |
| V26 | H | 3600 | 500 | 600 | A | C | 1800 | 4 | 110 |
| V27 | H | 3600 | 500 | 500 | W | C | 1500 | 3 | 6 |
| V28 | H | 3600 | 500 | 600 | W | C | 1500 | 3 | 5 |
| V29 | H | 3600 | 500 | 600 | A | | 1800 | 3 | 5 |
| V30 | H | 3600 | 500 | 750 | W | C | 1500 | 3 | 6 |
| V31 | H | 3600 | 500 | 750 | A | | 1800 | 3 | 7 |
| V32 | H | 3600 | 600 | 500 | A | C | 1800 | 3 | 5 |
| V33 | H | 3600 | 600 | 600 | W | C | 1500 | 4 | |
| V34 | H | 3600 | 600 | 600 | A | C | 1800 | 3 | 1 |
| V35 | H | 3600 | 600 | 900 | A | C | 1800 | 3 | 3 |
| V36 | H | 3600 | 750 | 500 | W | C | 1500 | 3 | 5 |
| V37 | H | 3600 | 750 | 600 | W | C | 1500 | 4 | 135 |
| V38 | H | 3600 | 750 | 600 | A | C | 1800 | 4 | 135 |
| V39 | H | 3600 | 750 | 600 | W | C | 1500 | 4 | 135 |
| V40 | H | 3600 | 750 | 600 | W | C | 1500 | 4 | 135 |
| V42 | H | 3600 | 750 | 750 | A | C | 1800 | 4 | 5 |
| V43 | H | 3600 | 750 | 900 | W | C | 1500 | 4 | 10 |
| V44 | H | 3600 | 750 | 900 | W | C | 1500 | 4 | 70 |
| V45 | H | 3600 | 1000 | 600 | A | C | 1800 | 4 | 128 |
| V46 | H | 3600 | 1000 | 750 | A | C | 1800 | 4 | 113 |
| V47 | H | 3600 | 1000 | 900 | A | C | 1800 | 4 | 55 |
| V48 | H | 3600 | 1000 | 1000 | A | C | 1800 | 4 | 38 |

Table 1: The results on Daylight Factor tests shown in the table of the facade geometry variations. The criteria 'L' stands for the distance to the higher ISO curve measured from the sidewall, the smaller the better. V22, V23 is an identcal form, but the checkerboard-pattern-glazing opens in the opporsit directions.

## 11. The third test

For the simulations, the glass surfaces of selected 7 variants are reduced to ca. 40% by changing glazing on the lowest row into closed paneling[*10]. The variants' flux of luminous is simulated in both ISO contour and in False Colors to identify the expanse of floor area according to the program. All selected variants of the faceted façade system fill the interior with more than 320 Lux, most of them close to 500Lux. This is a formidable result. The lowest luminosity by means of daylights of the standard and the system-R variants are lower than 320Lux.

The variants in this third test are in the sketch design level; The windows and facades have no thickness. The window clearance will reduce during final design phase as it will be given the thickness. With this reason, the criteria were set to choose the variants with higher performance than what the program demands. The overlit can be reduced locally with relatively simple shading devices. By considering the loss of performance due to materialization during the final design phase, the variants with more area of between 320Lux to 1000Lux are prioritized above that of 500 to 320Lux. In addition the total area with more than 1000Lux are added to the evaluation criteria to see potential to recover from the los of luminosity. The evaluation searched for the variant that divides the floor in three distinctive parts; the areas above 500 Lux; the area between 500 and 320 Lux.

The evaluation was made in the following criteria, written in the order of priority: a) higher minimum luminosity, b) lower contrast of luminosity across the room, c) higher maximum luminosity, d) the floor area with the luminosity more than 320 Lux, e) the floor area with the luminosity between 1000 Lux and 320 Lux, f) the floor area with more than 1000 Lux. The simulation test results by the Daylight Visualizer are brought into Autocad CAD program to trace the contour lines in order for the test to measurer the precise square meters of each zones specified here above[*11].

| variant | contrast | | | Area by Luminosity (m2) | | | |
|---|---|---|---|---|---|---|---|
| | Min. (Lux) | Max. (Lux) | Delta (Lux) | 320 (Lux) < L < 500 (Lux) | 500 (Lux) < L < 1000 (Lux) | 1000 (Lux) < L | SOM |
| V06 | 125 | 1660 | 1535 | 33.40 | 36.66 | 6.24 | 76.30 |
| V19 | 365 | 1325 | 960 | 23.09 | 38.26 | 12.52 | 73.87 |
| V21 | 388 | 1325 | 937 | 12.35 | 42.91 | 6.23 | 61.49 |
| V26 | 250 | 900 | 650 | 25.10 | 44.00 | 7.99 | 77.09 |
| V33 | 342 | 1325 | 983 | 26.02 | 38.45 | 10.45 | 74.92 |
| V42 | 340 | 1100 | 760 | 12.35 | 43.88 | 17.28 | 73.51 |
| V47 | 250 | 1200 | 950 | 20.52 | 39.80 | 11.27 | 71.59 |
| VDDD | 128 | 1995 | 1867 | 7.77 | 3.55 | 4.96 | 16.28 |
| VS | 125 | 1325 | 1200 | 11.65 | 9.25 | 6.45 | 27.35 |

Table 2: the resultof test three. V01~21 are vertical, V27~47 are horizontal frame arrangement. Minor differences of Flux of Luminous is given lower priority. Similar values are marked in box. The V42 was evaluated above V33 due its larger area that is lit more than 1000Lux.

The result showed V21 performs the best in the minimum luminosity and the smallest contrast amongst the vertical three-hinged-frame variants. V21 is not the best in the maximum luminosity yet it produced well over 1300Lux. V19&V21 are lower contrast. In terms of

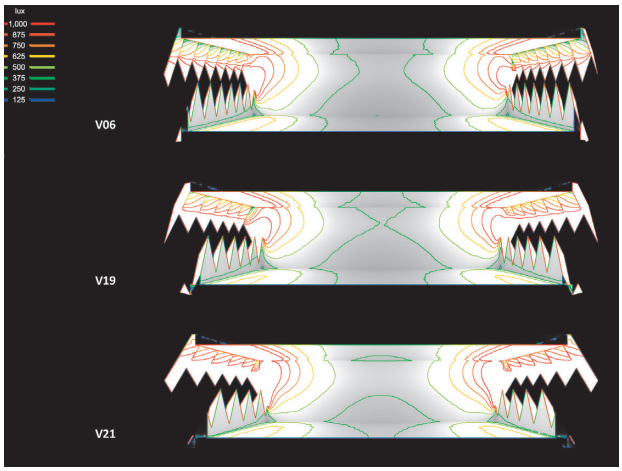


Figure 12: the ISO Graph showing the contour lines of the flux of luminous. The area above 375 Lux in section forms a continuous band in V21. This means V21 brings more daylights in and fill the room with more lights than V06.

the flux of luminous the order is V06- V21- V19. V06 has the highest contrast. I have then run the simulation on sections to detect the amount of flux of luminous that daylight brings into each room. The result shows V21 is brighter than V06.

From the variants of the horizontal frame, V33 and V42 match well on the performance on the lowest luminosity, while V42 performs better on contrast. The contrast of V26 is the lowest yet it failed to achieve 320Lux in all parts of its floor area. V42 illuminates the floor the brightest.

The simulation in sections reveals that the flux of

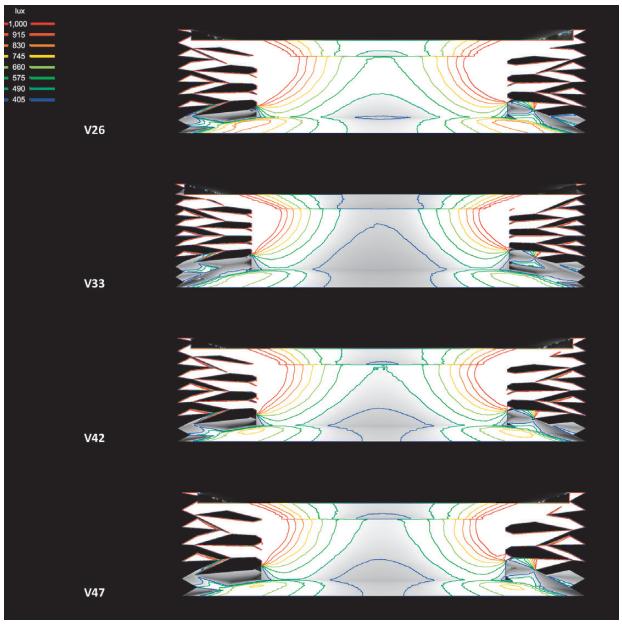


Figure 13: The simulation on the flux of luminous in sections. The V42 and V47 performs better as they have less dark areas.

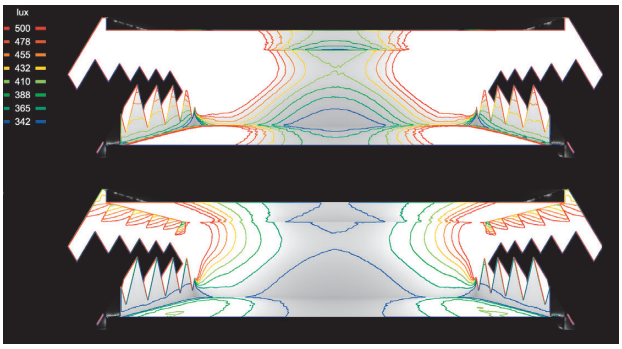


Figure 14: The results showing ISO contour tests of V21 between 320 and 500 Lux (above; desk works) & between 320 to 1000Lux. (below; 1000Lux for workshop).

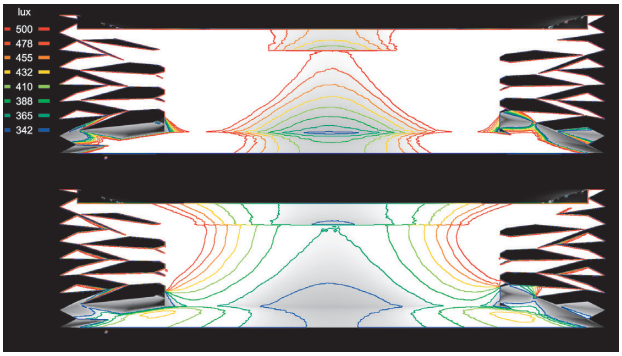


Figure 15: The ISO contor tests of V42. The middle part is suited for desk work and near facades are for more detailed workshop activities. The sensors are looking upwards.

luminous on V42 and V47 are higher than V26 and V33. I evaluated V42 above V47, as V42 has higher flux luminous. V26 and V33 in section show the darker ISO contour lines from which I evaluated V42 above V26 and V33.

From the vertical variant V21 performed the best among the selected. V42 and V47 were close among horizontal variants, from which V42 was chosen because it is better than V47. I present the performance of the two variants in sections (figure 14, 15), which this third test evaluated as the most effective.

## 12. The fourth test

The test is designed to simulate the loss of lights during the final design phase. I used a rudimental hexagon frame of 120mm x 70mm for constructing the three-hinged-frame. The variety of construction thicknesses for the stiff panels is tested: 100, 150, 200mm. The façade thicknesses are defined with the idea to equalize the value of insulation with the standard façade system. The test assumes conventional 400mm built-on-site façade system for the standard as well

as the system-R, which has the build up of 100mm brick, 50mm ventilation, 100mm isolation and 150mm concrete. The new faceted façade in testing takes at least identical solation thickness, 100mm, within the light metal sandwich panel[4]. The simulations with thicker façade panels are implemented just for the sake of impression to see the effects. The test results are evaluated in-group for the variants with vertical frame and the variants with the horizontal frame.

V21 is a variant with three-hinged-frames placed vertically every 750mm. The first parameter is the thickness of the stiff panel: 100, 150, 200mm. The second element of differentiation is the lower façade mount elements that stabilize higher frames to the floor, which I call spandrel. As the outer wall parallel to the upper panel, reflecting daylight on them could bring diffused light to interior. The height of the spandrel is limited at 850mm from the floor to give function of baluster, for which the deeper variants has profile resembles to teeth. Thinner variants let the folding line visible and forms zigzag profile. The table 3 shows the result. V214 performed the best.

| code | Façade | Spandrel | | | Area by Luminosity (m2) | | | | Luminosity | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Thicness (mm) | hight (mm) | depth (mm) | form | 300 (Lux) < L < 500 (Lux) | 500 (Lux) < L < 1000(Lux) | 1000 < L (Lux) | SOM | Min. (Kux) | Max. (Lux) |
| V21 | 200 | 850 | 345 | Teeth | 19.42 | 6.43 | 0.00 | 25.85 | 126 | 660 |
| V212 | 150 | 850 | 345 | Teeth | 4.32 | 0.00 | 0.00 | 4.32 | 63 | 400 |
| V213 | 100 | 850 | 220 | Teeth | 23.10 | 18.77 | 0.00 | 41.87 | 195 | 850 |
| V214 | 100 | 850 | 120 | ZigZag | 26.31 | 21.16 | 0.00 | 47.47 | 240 | 1000 |
| V215 | 100 | 1218 | 220 | ZigZag | 22.34 | 17.69 | 0.00 | 40.03 | 188 | 915 |
| VDDD | | | | | 7.77 | 3.55 | 4.96 | 16.28 | 130 | 1325 |
| VS | | | | | 11.65 | 9.25 | 6.45 | 27.35 | 165 | 1325 |

Table 3: Variuation of materialization on V21. Facade thickness indicates that of stiff panels. Spandrel points at the lower construction that holds heigher frames. Teeth pattern indicates that there are cutin gaps between the two spandrels.

V213, V214 and V215 performed superior to the standard façade as well as the system-R, by delivering twice to three times more workable area. These variants consist of 100mm façade panels. These three variants deliver more uniform illumination in respect to the standard and the system-R.

V42 is the variant with the three-hinged-frame mounted vertically to the façade. V423 is identical to V422 except the material of the façade panels is specified as aluminum instead of the default mat plastic. The performance improvement by aluminum is about 20%. V 422 performed the best amongst the variants with 600mm pitch. V42 has one row glazing less than V422 and it scored similarly. The test inspected V47 because the result of test 3 suggested the V42 & V47 performed similarly. The test shows V471 performed best among the 750mm pitch[*12]. Between the V422 and V471, V471 performed better.

| code | Façade Panel properties | | | | Glazing | | Area by Luminosity (m2) | | | | Luminosity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Thick -ness | Mate -rial | row | position | No. of row | % | 320 < L < 500 | 500 < L < 1000 | 1000 < L (Lux) | SOM | Min. (Lux) | Max. (Lux) | Delta (Lux) |
| V42 | 100 | mat | 8 | top, bottom | 6 | 37.5 | 31.06 | 6.1 | 0.00 | 37.16 | 188 | 660 | 472 |
| V420 | 200 | mat | 8 | top, bottom | 6 | 37.5 | 0.68 | 0.00 | 0.00 | 0.68 | 120 | 500 | 380 |
| V421 | 150 | mat | 8 | top, bottom | 6 | 37.5 | 22.48 | 0.00 | 0.00 | 22.48 | 160 | 500 | 340 |
| V422 | 100 | mat | 8 | bottom | 7 | 43.8 | 30.95 | 6.7 | 0.00 | 37.65 | 200 | 688 | 488 |
| V423 | 100 | uminu | 8 | bottom | 7 | 43.8 | 25.48 | 23.94 | 0.00 | 49.42 | 240 | 830 | 590 |
| V47 | 100 | mat | 6 | bottom | 5 | 41.7 | 22.3 | 18.5 | 0.00 | 40.79 | 188 | 800 | 612 |
| V473 | 200 | mat | 6 | bottom | 5 | 41.7 | 23.4 | 0.00 | 0.00 | 23.43 | 170 | 450 | 280 |
| V474 | 150 | mat | 6 | bottom | 5 | 41.7 | 28.6 | 5.30 | 0.00 | 33.89 | 188 | 550 | 362 |
| V471 | 100 | mat | 6 | bottom | 5 | 41.7 | 22.32 | 23.49 | 0.00 | 45.81 | 200 | 840 | 640 |
| VDDD | | | | | | 36.1 | 7.77 | 3.55 | 4.96 | 16.28 | 128 | 1325 | 1197 |
| VS | | | | | | 36.1 | 11.65 | 9.25 | 6.45 | 27.35 | 125 | 1325 | 1200 |

Table 4: The results of test 4 concerning the variants with ertical frame arrangements. The improvements on the daylight lit surface area buy the new facaade geometry is visible.

## 13. Conclusion

The tests found *VERY* encouraging performance of the faceted façade system.

It is noticeable that within the targeted insulation build-ups, the faceted façade geometry performs better

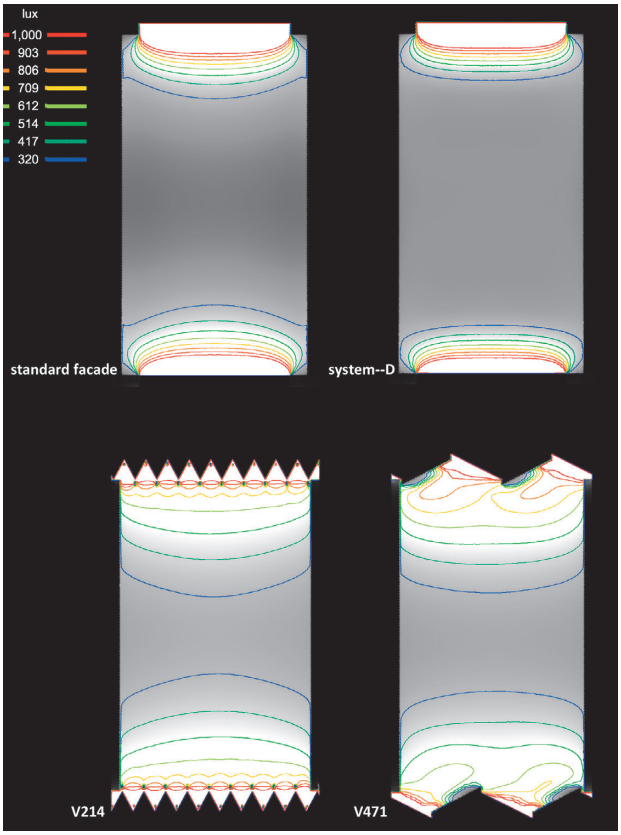


Figure 16: The result showing the floor area with the degrees of the flux of illumination between 320 Lux (dark blue) and 1000 Lux (red). 320~500 Lux are suitable for deskwork, 500~1000 Lux are for detailed work such as drawing or work on machines. Both V214, V471 illuminates large expanses of interior floor area with usable gradual daylight.

than the standard facade as well as the system-R. The most extreme case the faceted façade out-performed the system-R by as much as ***6.6 times improvements***. This can be found in the area between 500 Lux and 1000 Lux. Between 320 to 500 Lux the faceted facade out scored the standard façade by ***twice***. The brightest work floor of the standard system is 10.6 times brighter than its darkest area, while the faceted façade reduced the contrast to 3.4 times. This means the faceted façade ***reduced the contrast to 1/3*** of the standard system. The minimum daylight illumination of the faceted façade is ***improved by 160%***.

I describe here below the several attention points that this research have found: 1) handling of Daylight factor and its evaluation results, 2) software limitation that Daylight Visualizer has.

1) The conclusion of Daylight Factor calculations on well-performed variants in comparison to the standard system and the system-R is worth paying attentions. The results of this paper shows that the faceted façade distribute daylight toward interior more, more efficient and more evenly. Yet, in terms of Mean Daylight Factor there are small differences between them. It is because the Daylight Factor can rise as much as 20 or more under the overlit daylight. In the Mean cal, this higher rate compensate the low Daylight Factor that spread widely. It is worth noticing that the Median Score of the standard and the system-R is just about 66% of almost all faceted façade variants, which says the majority of floor area of the standard and the system-R are darker than the selected faceted façade. (table5)

| Day Light Factor | VS | VDDD | V213 | V214 | V42 | V422 | V474 | V471 |
|---|---|---|---|---|---|---|---|---|
| Meam | 4.26 | 3.81 | 4.59 | 4.77 | 4.01 | 4,02 | 3.89 | 4.87 |
| Median | 2.62 | 2.30 | 4.08 | 4.32 | 3.77 | 3.79 | 3.64 | 4.39 |
| Minimum | 1.47 | 0.47 | 0.67 | 0.98 | 1.89 | 2.36 | 1.67 | 2.33 |
| Maximum | 21.80 | 18.58 | 10.46 | 9.66 | 7.66 | 7.62 | 6.66 | 10.08 |
| Uniformity 1 (min/mean) | 0.34 | 0.12 | 0.15 | 0.20 | 0.47 | 0.59 | 0.43 | 0.48 |
| Uniformity 2 (min/max) | 0.07 | 0.03 | 0.06 | 0.10 | 0.25 | 0.31 | 0.25 | 0.23 |

Table 5: The summary of Daylight Factor simulation on VS (standard façade), VDDD (the system-R) and six variants from the faceted façade. V474 scored the smallest Daylight Factor is

2) Improvements on testing method are dependent on the software. This research employed Sketchup for modelling, VELUX Daylight Visualizer and V-RAY for simulation and Autocad for quantifying the findings. Daylight Visualizer is a user-friendly simulation software. Here I can mention that the VELUX Daylight Visualizer can be more effective by improving possibility to quantify surface areas for finite comparison: a) to measure floor area within a specific ISO contour line of illumination or a specific Daylight Factor. It is very advantageous to have capacities to quantify the floor area such as between 320 Lux and 500 Lux. b) to equip capacities to direct the sensor in a free directions. c) to have capacity to position sensors in a vertical surface in section drawing so that it can show how the light travels through the room.

The numbers that this paper presents are convincing enough to initiate further research into the architectural innovation for the 21st century. This research by design found the faceted façade visibly improved the effect of daylight illumination performance of building façade. The result suggests to further inspect the capacities of the façade geometry to improve on three aspects: energy use, new potential for architectural expression and the implication to a good healthcare via improving Circadian cycle. This paper asserts that this façade provides ground to discuss its commando on the daylight. In the field of health the result is limited, but the consequence to live in the circadian rhythm is imaginable. The research concludes that this paper give very firm reason to push the research further with this faceted façade geometry.

In the field of exterior impression I add two tentative design impressions.

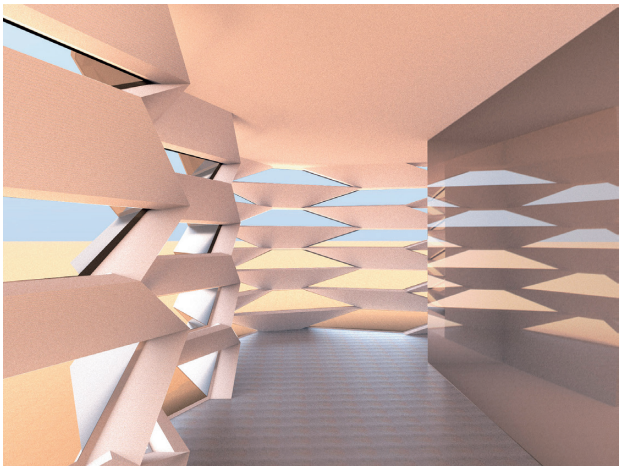

Figure 17: A tentative interior design of the facade V42.

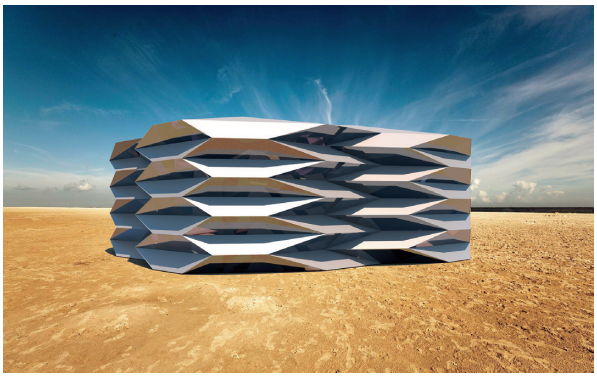

Figure 18: A tentative design of s survival cell with facade variant V42.

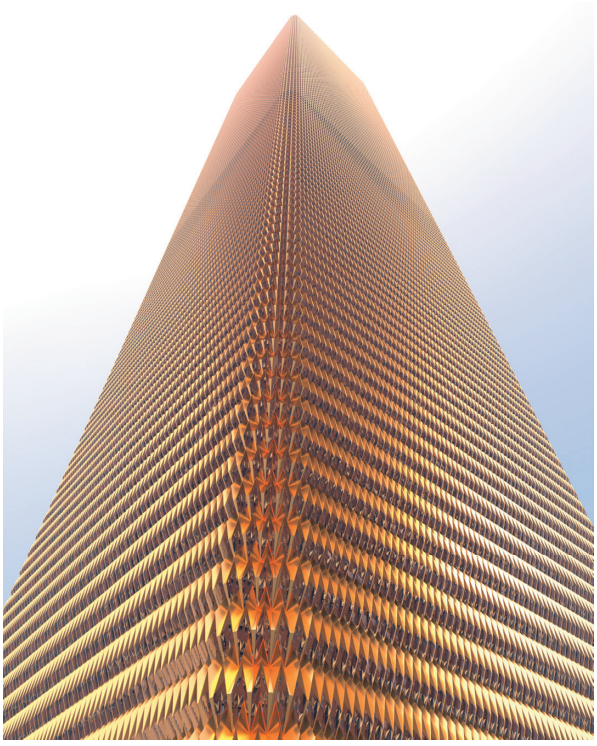

Figure 19: A tentative façade designe for a skyscraper by V21.

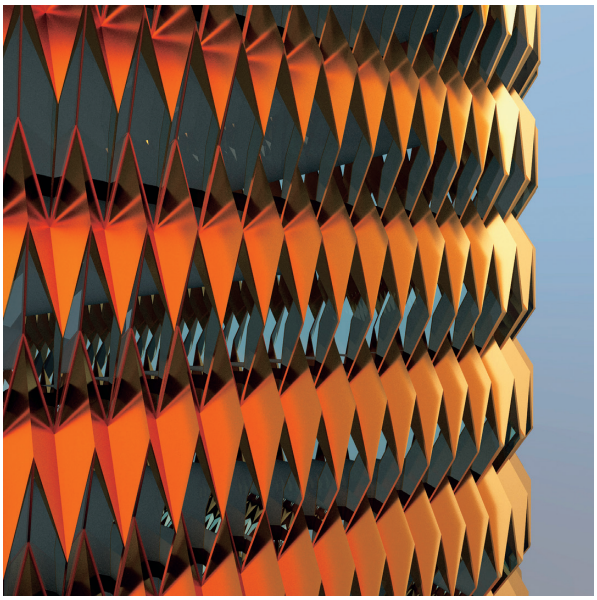

Figure 20: A tentative faacde design by the variant V21.

This paper forms a part of the **KAKEN** research on a new building that support human habitation in the extreme life environment.

## Reference

1) Transition to sustainable building Strategy and Opportunities– EXECUTIVE SUMMARY, 2013, p3

2) Anne Kathrine Frandsen, *The healing potential of daylight in hospital settings*, thedaylightsite.com, 2011. <http://thedaylightsite.oxmond.com/wp-content/uploads/symposium/DS2011/DS2011%20The%20healing%20potential%20of%20daylight%20in%20hospital%20settings.zip>,. Frandsen A.F. is a researcher at Aalborg University and member of Danish Building Research Institute.

3) Russell G Foster, *Body Clocks, Light, Sleep and Health, thedaylightsite.com,* 2011. <http://thedaylightsite.oxmond.com/wp-content/uploads/symposium/DS2011/DS2011%20Body%20Clocks,%20Light,%20Sleep%20and%20Health.zip> Russell G Foster is a Professor of Circadian Neuroscience and the Head of Department of Ophthalmology at Oxford University. <https://www.ndcn.ox.ac.uk/team/russell-foster>

4) Cf. Kingspan BENCHIMARK, RUUKKI Energy Sandwich panels. <http://www.kingspanpanels.us/benchmark/products>; <http://www.ruukki.com/b2b/products/sandwich-panels/energy-sandwich-panels>

## Footnotes

*1 Transition to sustainable building, Strategy and Opportunities to –EXECUTIVE SUMMARY, iea International Energy Agency, 2013, p.4, "Achieving the goal of limiting global temperature rise to 2oC (Energy Technology Perspectives 2012 [ETP 2012] 2oC Scenario [2DS]) would require an estimated 77% reduction in total $CO_2$ emissions in the buildings sector by 2050 compared to today's level.", "Improved building design can also offer significant potential to reduce the demand for lighting in buildings, through building orientation and advanced fenestration technologies such as dynamic windows."

*2 It firstly define the demands of the involved actors, then to form concept of how space and building

construction before work be done on design.

*3 The standard I refer is the fenestration implemented widely by the practice in the North American as well as European architecture. It takes fenestration in a flat wall surface at the height of 850mm above the floor with 1300mm window clearance heights. Width is limited by structural necessity and the 30% of façade clearance surface area as according to the building physics energy performance demands.

*4 It is taken from the Device of Daylight Deflection.

*5 Bartenbach is the engineering firm that put efforts on the advanced use of daylight thereby contributing to make (large) buildings comfortably habitable.

*6 The office of Parlament Members of the Federal German House of Parlaiament Jakob-Kaiser-Haus, Collective architects de Architecten CIE, Gerkan Marg und Partners, Schweger und Partners, Partner, Busmann und HabererPartners and Thomas vande Valentijn. The author of the paper is one of the project architect at de Architecten CIE.

*7 This is a very standard dimension of an European office floor.

*8 AIMOCHI (相持ち構造), reciprocal frame construction is a class of self-supporting construction system that consists of collection of beams that creates a large span or space.

*9 "Outside the realm of ideas, beauty rules. … We can say that beauty is dead, but all that does is widen the chasm between the real world and our understanding of it." Nancy Etcoff, Survival of the Prettiest – the science of beauty, New York, Doubleday, 2000

*10 A commendable recommendation from the point of building physics suggests façade opening at around 30%. Yet Here I chose 40% because the clearance will reduce during the materialization phase.

*11 The second test are designed to select candidates for the further closer inspections, for which the test results from rudimental Daylight Factor and linear scale makes next to the visual inspections are enough. The third and the fourth tests are designed to compare the performance between the variants/ candidates more precisely. Here fore the described method has been chosen. This paper lays road map to the next phase in the conclusion.

*12 V47 was tested following the evaluation from the third tests.