A REWARDED-PROJECT STORY FROM JAPAN: COMFORT VS VIEW IN A FANCY GLAZED ATRIUM

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ABSTRACT

Systematic, sustainable design decisions, especially in the early stages, are vital to realizing the project objectives. However, in practice, such decisions seem to be intuitively made. Time limitations and unclear sustainability briefs are some of the causes, yet, the lack of clear decision-making roadmap remains a root issue. In response, this paper narrates an eight-month process of a nationwide-rewarded project in Japan, in which a sustainable design roadmap was developed. The roadmap is demonstrated by sharing a process that sought to balance the thermal comfort and view conflicting qualities; via manipulating the roof and side-shading enclosure parameters.

INTRODUCTION

The effective, sustainable design process requires iterative loops of questions and feedbacks between design teams and simulation specialists. Successful stories recommend that such iterations are to take place throughout the design stages. However, the decision-making roadmaps that govern these iterations are not commonly published. It is observed that even when such decision-making mechanisms are shared, it focuses on solving a particular design challenge and barely concern about the broader design scope. This observation has been crystalizing during the searching for a case study roadmap that is similar to the author's ongoing campus project, especially when searching for Japanese case study projects in English publications.

The authors realized that developing a decision-making roadmap is necessary to address primary sustainable design questions. For example, which spaces/zones should the sustainable analysis focuses on? What qualities to improve in these zones? And which design strategies to implement? Those questions are all to be answered systematically. The systematic questions and answers do not only grant a better work plan for the sustainable designer/analyst, but also help in better conveying these issues to the project teams and stakeholders. Conversely, the answer to these questions seems to progressively occur to the specialist's mind, then passed to the design teams and subsequently being set as the project objectives, tasks, and milestones.

Here, it is to mark an overlooked issue that may be one reason for not establishing the decision-making roadmap from the beginning. That is, the fast pace and the relatively short period of the early design stages urging for taking shortcuts and unsystematic sustainable design decisions. The overlaid dotted line in Figure 1 denotes the typical timespans of the various project phases. The borrowed graph by (Lovins, 1992) is intended to highlight the benefits of integrating sustainable design tasks in the early stages, which is quite true, but in practice, the time in these stages is also very limited.

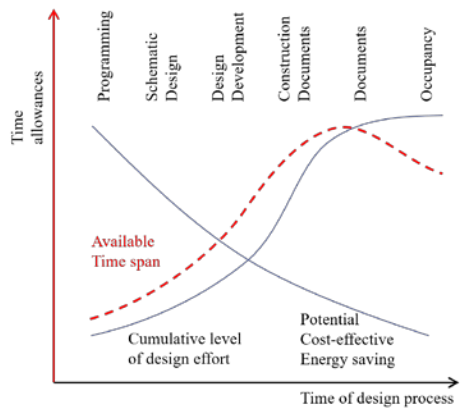

Figure 1 Time allowances for the sustainable design tasks throughout the project lifetime

In brief, we tangent a need for publications that disclose the sustainable design framework and task rationales, together with case studies that elaborate on these

frameworks. This study responds to those needs. In the first half, the paper shares the overall project story and the decision-making framework. The second half illustrates how this framework was applied to conclude the tasks and steps for balancing view and thermal comfort qualities. The reader may adapt the provided framework, and may also benefit from the reported design techniques and findings. For example, how a game engine renderer was sufficient to study the shadow patterns instead of using rigorous but time-consuming light simulation tools.

THE PROJECT BACKGROUND

This project won first place in a design-build competition for a new unit on the Chuo University campus. Later on, it was rewarded, the Ministry of Land, Infrastructure, Transport and Tourism (MILT) – Building Research Institute (BRI) Grant – The Best Four sustainable leading projects (CO_2-led project) in Japan, 2019. The campus is located in Hachioji, 35 km from Tokyo, which has a humid subtropical climate (Köppen climate classification - Cfa). The design is shown in Figure 2. It has an introverted setup, in which a central glazed atrium is the focal point. The atrium is a four-storeys high and with a 16*50 m plinth. The atrium hosts several untypical semi-opened auditoriums.

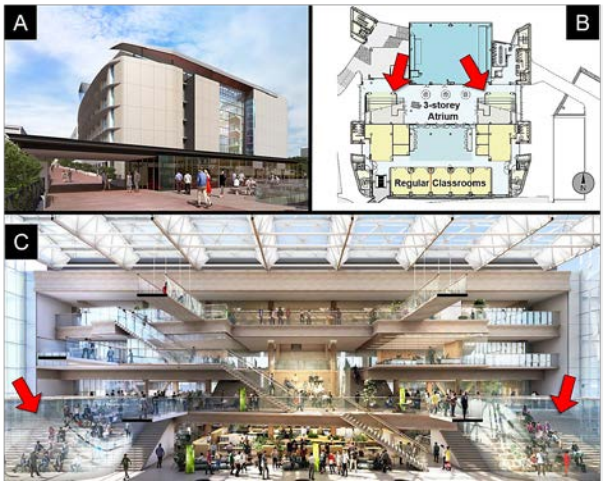

Figure 2 Chuo University- the Case study unit;
A- External view
B- 3rd floor Plan (atrium's plinth floor).
C- Cross-section in the atrium. Red arrows are pointing to the "see-through" auditoriums

In the kickoff, the main concern for the architects was to assure that the untypical exposed-auditoriums are environmentally acceptable; in terms of thermal comfort and sight, alike. The sustainable design team was then invited to participate in the project from the very early sketches, and the collaboration with the design teams lasted until the construction documents stage. During this period, most of the typical sustainable design exercises were carried out, starting from the climate analysis and up to evaluating the effect of the mullions details on the cold drafts currents.

This paper shares the critical parts of this extensive collaboration. The next section gives an overview of the decision-making framework, which is used to define the tasks, goals, and working hour management plans. It was also used to substantiate those decisions to the other project stakeholders. The following section, headed (Comfort vs. view to optimize roof and side fins enclosure), is a demonstration on how the proposed framework can be integrated.

SUSTAINABLE DESIGN METHODOLOGY: DECISION-MAKING FRAMEWORK

The derivation of the sustainable design subjects (targets) were systematically developed through a framework shown in Figure 3. The framework has two stages, broken down into a series of headers (leading) questions. Stage [A], the Contemplation and Objective Definition, is concerned with the scope of work of the sustainable design team. In stage [B] the Application and Tasks Identification, the necessary technical tasks, and their estimated time consumption are concluded.

The framework starts with the leading question: which part(s) of the building to include in the analysis. Some answers (suggested selection criteria) were provided in bullet points under each question. For example, the target space could be a unique space, dominant, repeated etc. The central atrium has, therefore, been set as an analysis subject because it satisfies most of the selection criteria. The classrooms were also included in the analysis because they are repeated over the project. The framework moves to the second leading question, i.e., which environmental qualities to look after in these selected spaces? Qualities, like daylight, comfort, and energy-saving, were then discussed among the project design members. The process of identifying sustainable design objectives go downstream, likewise.

It is to note that the shown bullet points (hints) are for mere illustration, and they change in response to the challenge being addressed. The provided example in Figure 3 traces a single thread of answeres that assumes [daylight] is being set as the sought [Environmental Qualtiy]. Then, [Quantity of daylight] is the assumed to be the answer to the third question, and the [Daylight Autonmoy] is to answer the fourth question, i.e., [What Evaluation Metric], and so on, until deriving at a [>100lux] as a concluded evaluation criteria and as a specific target to attain.

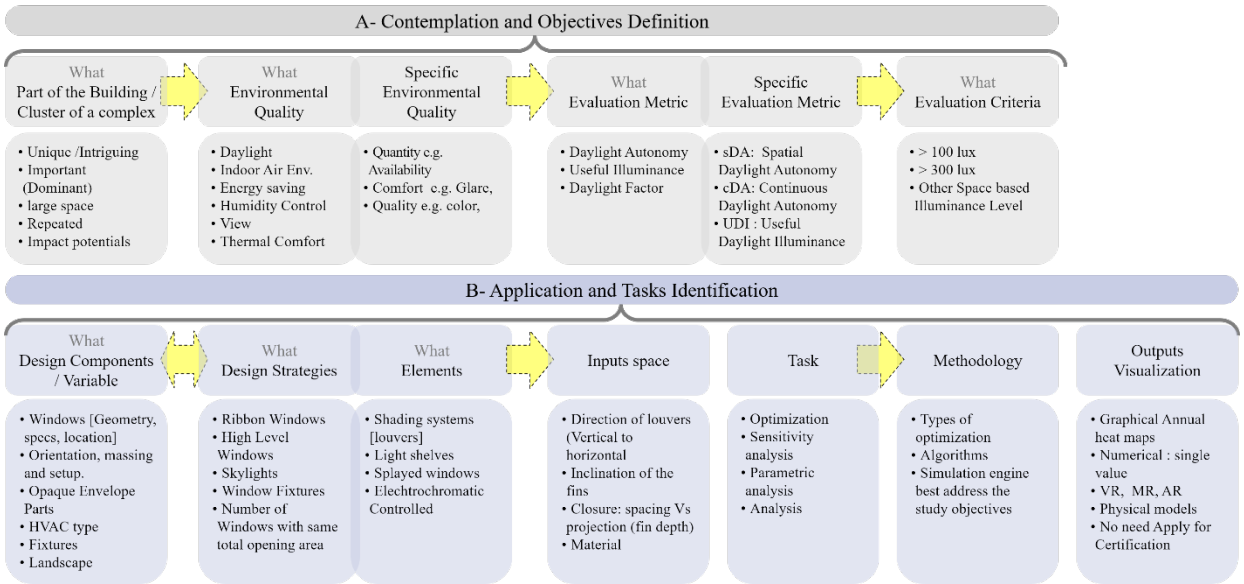

Figure 3 The proposed framework for the sustainable design process and the means of its attainment.

COMFORT VS. VIEW TO OPTIMIZE ROOF AND SIDE FINS ENCLOSURE

Methodology overview

Three subjects were concluded as the sustainable design scope of work;

1- The atrium's shading fins (on east-west facades),

2- The atrium's rooftop coverage ratio and pattern,

3- The south-facing classrooms shading overhangs.

The thread of questions that led to the derivation of these subjects is summarized in Figure 4. Due to pages limitation, this paper focuses on subjects 1 and 2, as both are concerned with atrium enclosure. The view and comfort qualities set as the target qualities (Q2). Hence, the fins and the roof enclousure were chosen to realize that target (Q3). The required optimization process (Q4) is detailed in the rest of this paper. However, as also seen in Figure 4, the other three critical studies interfered with the atrium's enclosure optimization, and are briefly discussed as follows:

- The heat gain through the atrium's glazed roof was a primary concern because the HVAC system's maximum capacity and cost were predetermined. Therefore, the kick-off tasks were basic hand-calculations and detailed CFD (Computational Fluid Dynamics) simulations that estimated the solar gains. The CFD studies also intended to evaluate the hot air accumulation on the upper floors and the risk of the travel of that thermal stratification (above 28˚C setpoint) from the atrium's basin to the adjacent spaces. The conclusion was to keep the roof glass below 50%.
- There was no concern about shortages in daylight availability (adequacy) inside the atrium and in the exposed auditoriums. That is, even with a fully closed roof and a very dense side-fins, the results of the sDA (spacial Daylight Autonomy) and ASE (Annual Sunlight Exposures) (IES, 2012) were high; i.e., the minimum ASE (ASE1000lx,250h) inside any auditorium was above 64%, and the sDA (sDA300lx,50%) was always above 70%.

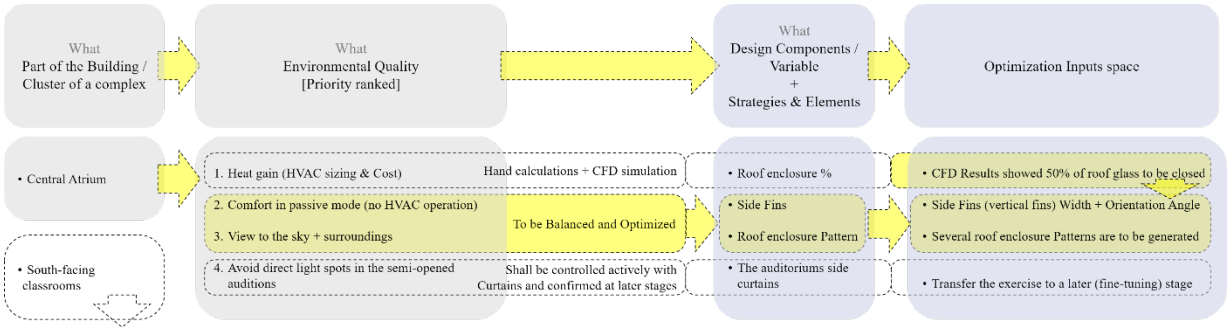

Figure 4 the decision-making for balancing comfort and view via controlling side shade (fins) and roof enclosure

This conclusion meant that the side-fins parameters (input space) could be freely manipulated without concerns of dimming the auditoriums.

- The risk of glare inside the auditoriums had the least priority because the blackout curtains ought to be installed. Hence, the curtains' efficiency in obstructing direct light was left to later stages, i.e., the fixed shading systems (fins and roof) are to be optimized firstly, and curtains are to supplement.

With the conclusions above, the fins parameters plus the roof enclosure ratio and the roof cover pattern are the parameters that can be manipulated to attain the optimal view and comfort needs. The optimization was conducted in Grasshopper - Rhinoceros using Ladybug (LB) - Honeybee (HB) tools (Roudsari and Pak, 2013).

Comfort Evaluation Method

The Universal Thermal Climate Index (UTCI) is used for outdoor comfort evaluation (Zare *et al.*, 2018), but it was employed in the initial explorations for its rapid calculation in LB. The goal was to have an idea about the contribution of the direct solar radiation on the Mean Radiant Temperature (MRT). Also, to identify the spots where radiation is likely to yield discomfort. Next stages demanded sophisticated indoor comfort metrics that account for factors like the attire changes.

The Standard Effective Temperature (SET*) was used because it considers solar radiation under the sun as well as under the shade (Gagge, Stolwijk and Nishi, 1972). Besides, it is commonly used by the Japanese community, where it was first invented, and many surveys have looked into the locals' comfort perception and its relation with the various factors.

The atrium's SET* was calculated with the values shown in Table 1. The Dry Bulb Temperature (DBT), the MRT and the Clothing insulation value (clo) have been set to dynamic calculations, viz.;

- The atrium is unconditioned; hence, its DBT [Ta] is assumed to be at average temperature between the outdoor temperature [Tout] and the adjacent rooms setpoints (26 ˚C summer and 22˚C winter).
- The MRT can be calculated in several ways in LB & HB. The most precise way is to run a thermal simulation to get the surface temperatures, then associate them with the view factors to get the MRT map. However, this method needs detailed envelope specifications and takes long computation time in EnergyPlus. Hence, the surface temperature was set to equal the DBT then corrected using the MRT. The MRT was computed using the [SoalrAdjustmentTemperature] LB that was linked with sky radiation values of the Cumulative Sky Matrix – Radiance [genCumulativeSkyMtx], (Ian and Greg, no date),
- The Clothing (clo) was calculated dynamically upon (Oi *et al.*, 2003) equations. It predicts the daily Japanese (clo) based on the genders' occupancy ratio and the day-average outside temperature (T_{out}).

The SET* hourly values were calculated within the occupancy periods and for the various shading (fins and roof) scenarios. The targeted spaces were the semi-open auditoriums, plus the main corridors (where users may stop for transit periods). These areas were subdivided into a grid of (0.5 * 0.5 m) at a 0.7 m above the floor.

Table 1 SET simulation parameters*

PARAMETER	INPUT
DBT	・IF Tout >26℃→Ta =(26+Tout)/2 ・IF Tout <26℃→Ta =(22+Tout)/2 ・IF 22≦Tout ≦26℃→Ta =Tout
MRT	Calculated using GH-LB components
Clo	Adaptive (seasons & gender based)
Relative Humidity	50% (Averaged)
Metabolic Rate	1.0 (Averaged)
Wind Speed	0.1m/s (Typical for indoor env.)

The SET* between 22.2 – 25.6˚C is found comfortable for 80% of the local users (FUKAI *et al.*, 1992). However, it was argued that comfort ranges could be extended (up to 30˚C and down to 17.5˚C) because the atrium is not air-conditioned and highly exposed to the outside air. That is, the slightly-warm and slightly-cool perceptions were argued to be acceptable in such un-air-conditioned and semi-closed space.

Table 2 SET perception as translated from (FUKAI et al., 1992) alongside the devised scoring methods*

SET*[℃]	THERMAL PERCEPTION	DISCRETE SCORE	CONT. SCORE
＞37.5	Very hot, Very Uncomfortable	0	0
34.5~37.5	Hot, Unacceptable	0	0
30.0~34.5	Warm,	0	0
25.6~30.0	Slightly-warm	**1**	**= (-1/4.4) X +30**
22.2~25.6	**Comfortable, Acceptable**	**1**	**1**
17.5~22.2	Slightly-cool	**1**	**= 0.2 x +17.5**
14.5~17.5	Cool, Unacceptable	0	0
10.0~14.5	Cold, Very Uncomfortable	0	0

Based on these temperature-comfort bins, each grid point can either be comfortable or not (Fasle=0 or True=1); in every occupancy hour. The annual sum of the [True=1] comfort hours was then obtained for all the grid points. Subsequently, the total score for all the points yielded a single value that was deemed to represent the overall spatial comfort. The spatial-value was directly used for comparing the various shading scenarios. However, this [0/1] Discrete (binary) scoring method produced nuanced differences between the various shading scenarios. Hence, a simple Continuous Scoring method was developed to give a fractional score instead of the full score for the slightly-warm and slightly-cool temperatures. The linear equations that gradate the Continuous Scoring are provided in Table 2, alongside their corresponding SET* ranges and perceptions.

Results and Discussion of Comfort Evaluation

The continuous scoring had clarified the variation between the shading scenarios. Figure 5 shows the annual – hour-by-hour scores in one example, gridpoint. The Discrete method overvalued the comfort hours by 20% when compared to the Continuous Scoring.

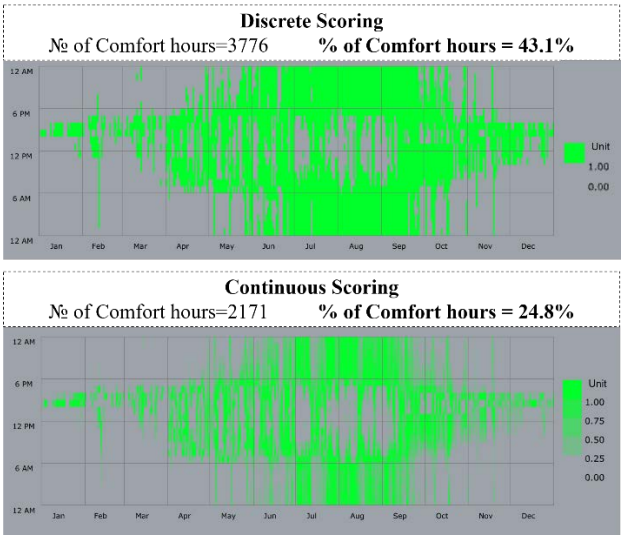

Figure 5 Discrete Vs. Continuous comfort scoring

The discrete SET* scores were plotted on the examined gird. The product is a spatial representation for comfort (Spatial Comfort Autonomy) that visualizes the influence of the design scenarios on comfort. For example, Figure 6 compares a fully closed scenario (with opaque roof and vertical fins) against a fully exposed scenario (fully glazed roof and with no side fins). It is seen that comfort hours are decreased by almost 10% near the glazed sides and beneath the glazing roof.

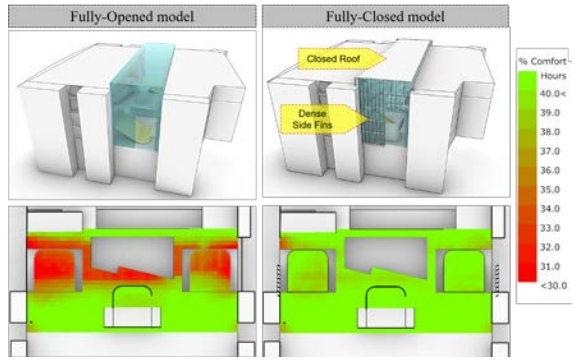

Figure 6 Comfort comparison for two scenarios

Because the initial CFD studies have already limited the roof glass to 50% at max, the Spatial Comfort Autonomy results were utilized only to optimizing the vertical fins parameters and hold the fine-tuning of the roof-cover ratios to latter stages. The fins parameters were; the depth (ranged from 0.5m to 0.8m) and the zenith angle (10 to 40 Degrees). The comfort maps are shown in Figure 7, which will be interpreted alongside their corresponding view results – in the next section.

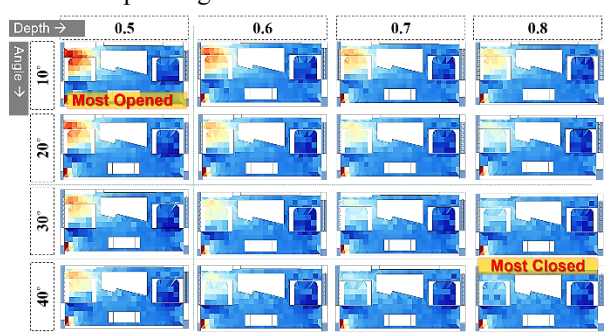

Figure 7 shading fins parametric study - with comfort

View Permeability Evaluation Method

The view permeability was estimated using the LB view evaluation component [ViewAnalysis], which offers five methods. Only the Sky Exposure and Sky View methods were utilized because they evaluate the hemispherical dome. In contrast, the other three methods have either a partial view angle or look at the entire sphere. The Sky Exposure measures all the view vectors equally. But the Sky View gives more importance to the vectors perpendicular to the evaluation plane; i.e., for the atrium, it will give more credit to the openness of the roof glass as compared to the side glass permeability.

Both Sky View and Sky Exposure methods were adopted in the initial analysis. Figure 8 compares their outputs under two scenarios; a fully-glazed roof sceniron and a fully-closed roof scenario (side fins fixed to 0.7m depth @ 30˚). The Sky View gave 4%

less score for the closed-roof model as compared to the Sky Exposure results, despite that both methods gave similar results for the glazed roof. It was deduced that the Sky View method better serves the purpose of the study because it is more sensitive to the roof's enclosure, noting that the roof glass is the only vista that grants an outside view for the deep parts of the atrium.

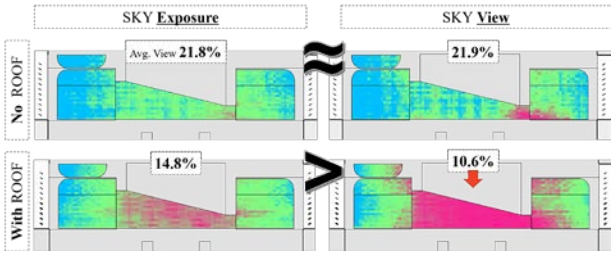

Figure 8 Sky view and Sky Exposure comparative study

Based on the study of (Byun et al., 2013), it was considered that 24.5% of view openness is deemed adequate. This study used a projected solid angle for the view evaluation, which also gave more credit to the vertical panoramas. Hence, the discrete scoring was obtained for the grid points were (25.5% ≤ view = True =1). Next, the Spatial View Autonomy was developed in an analogy to the Spatial Comfort Autonomy.

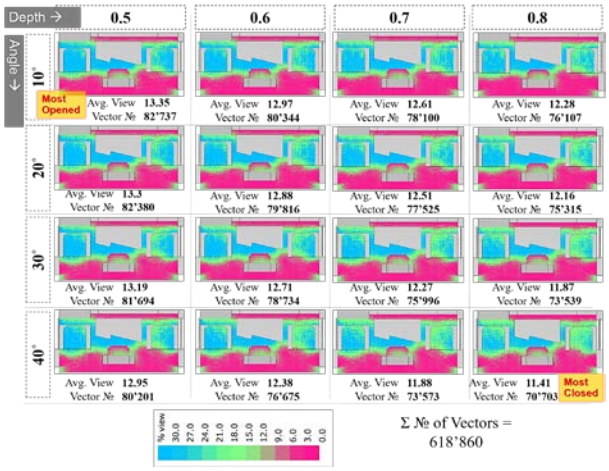

Figure 9 shading fins parametric study - with view

Results and Discussion of the View Simulation

Figure 9 is an analogy to the study that visualized the influence of the fins parameters comfort. The overlay of Figure 7 and Figure 9 was used to optimized the fins. It was confirmed that the initial fins parameters, 0.7 depth @ 30˚ azimuth, favored and suggested by the design team, satisfies the view and comfort together. These parameters indeed yielded only an average of 12% of view allowance to the outside, but it was clear that the southern lobby does not improve at all. The following steps have excluded this area out of the examinations and focused on the northern parts, in which manipulating design parameters was informative.

Roof Cover Ratio Fine-tuning

The next stage was to revisit the early defined 50% roof cover; the ratio is to be fine-tuned or further increased if the combined view-and-comfort results suggest so. View and comfort were evaluated using the same methodologies aforementioned, for five roof cover ratios, but with fixed fins; 0.7m @ 30˚. The aim was to create a trend-line for the roof cover ratio effect on both qualities. The results of these investigations are shown in Figure 10. The view permeability ranged from 7.7% to 28%, and their corresponding comfort ratio was 38.7% and 35.4% of the fully covered and the fully opened roof scenarios, respectively.

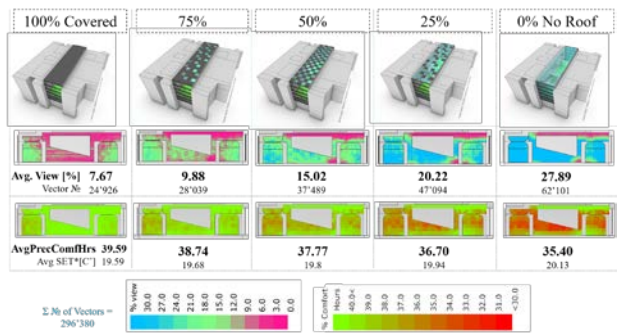

Figure 10 Roof Cover effects on comfort and view

At the Detailed Design stage, the structural truss and the maintenance passages (catwalks) were added to the simulation models and has obstructed 25% of the roof glass. Hence, only 25% of the glazing panels could be manipulated to maintain the 50% cover ratio. On the other hand, some design changes like relocating elevators while adding more windows to the south-facing lecture rooms have significantly improved the view panoramas. The view and comfort results of the updated roof cover models are presented in Figure 11.

The view results for the 50% roof cover was satisfactory as it passed the 20% threshold. For comfort, despite the lack of the evaluation metrics that defines passing the threshold for the Spatial Comfort Autonomy, it was also deemed that the 50% cover is the optimal ratio for two reasons. Firstly, and as can be seen in Figure 11, the improvement in comfort is limited; i.e., the spatial comfort only improved from 36.9% for the fully glazed roof to 38.6% for the fully closed roof. Secondly, increasing the roof cover above 50% will pull the view results below the passing threshold - which has barely passed the acceptable range. In other words, having less than 50% of roof

glass seemed to abolish the whole idea of incorporating a glazing atrium, and occupants would have a very limited (less than 20%) vista to the sky.

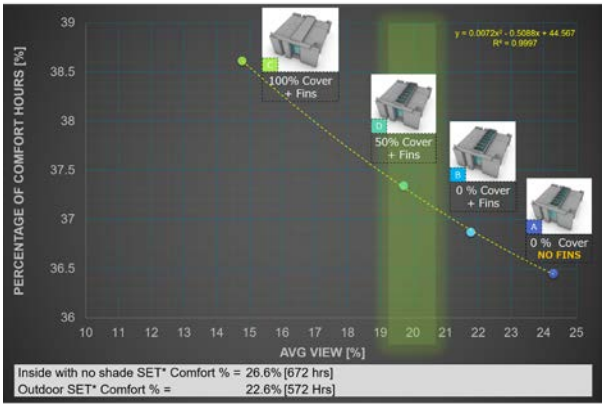

Figure 11 Final view and comfort optimization curve

Generating the Roof Pattern

It was noted that the view permeability is only influenced by the roof cover ratio, regardless of the coverage pattern. However, comfort is influenced by both: the roof cover ratio and the roof cover pattern. Therefore, the next target was to improve the –debatable- Spatial Comfort by manipulating the roof cover pattern and switching from the regular (check-board-like) cover pattern, to a more sophisticated (randomly-seeming) patterns that are informed by the comfort of the space beneath.

The process started by recalling the grid-based comfort results at the occupant's level. Meanwhile, the roof surface was also subdivided into a 0.6m x 0.6m grid cells. The main idea was to determine the most influential roof cells that improve/weaken the comfort, then to maintain the most beneficial 25% roof cells. The cells' influence magnitude was determined with a logic similar to the Degree Days (DD) calculation technique.

That is, for any given occupancy hour, the solar rays are passing through a single roof cell, and reaching a number of comfort grid cells, each ray was then tagged with the SET* result of the cells that it reaches. The average of SET* hourly values were obtained, and the deviation from the Comfort range (17.5-30 ˚C) was calculated. The sum of the annual-deviation magnitudes was obtained, and it determines the benefit/harmfulness of each roof cell, compared to others. Meaning that a cell was counted harmful if it blocks a vast amount of the solar rays from reaching an occupant during winter or vice versa for the summer if it allows many harmful rays to pass through. The described process was made in Grasshopper and utilized the LB [ComfortShadeBenefit] component that mimics the DD calculation concept (Mackey, Roudsari and Samaras, 2015).

Results and Discussion of the Roof Pattern Generation

The results of the benefit/harmfulness were plotted on the roof surface. The Degree-Days-like scale showed slight variations between the roof cells (ranged from 1.2 to -1.4%), which was attributed to averaging of the SET* results over a year. However, this minor variation can still be used to identify the roof optimal coverage locations. The growth of the most beneficial cells is visualized in Figure 12, where it was noted that the optimal cover is right above the examined auditoriums, located on the southern side of the 3rd floor.

The optimal cellular cover with the 50% ratio was used to inform the final rectangular-roof pattern. The opaque roof panels were dispersed above the optimal area using a Grasshopper logic. The logic was to use the center of concluded cells as "magnets" (attractors) for 21% of the opaque panels and let the remaining 4% randomly float in the glazing area to produce a balanced visual effect, as shown in Figure 13. Reminding that 25% of the roof is already covered by opaque structural components.

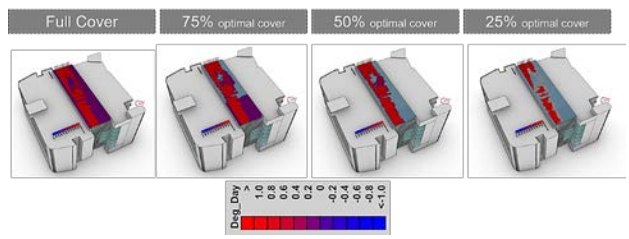

Figure 12 the optimal roof cover location

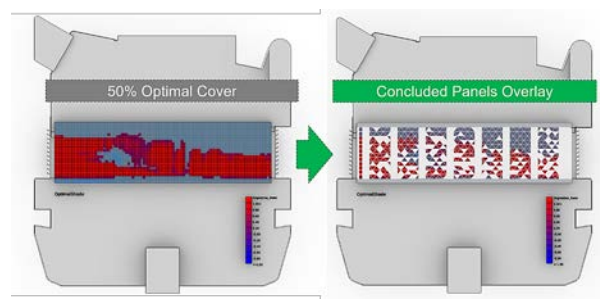

Figure 13 the concluded roof pattern

Final Shading and Rendering Studies

To this point, some sun-blocking parts like the context, nearby hills, and internal curtains were not included in the analysis due to their complex geometries that demand excessive computation time. Still, in the final design stages, there was a need to assess their hourly shading effect. Using Radiance to render 8760 images for every curtain design was unfeasible. The other options were Lumion and Unity, as they provide quick renders, but they lack the scientific reports on their solar position and accurate shading calculations.

Therefore, an initial comparison between Radiance, Lumion, and Unity renderings was made with the scenes setups being matched to the best possible. Three roof panel colors were tested; the input of the RGB colors values and other surface properties are being matched whenever available. It is noteworthy that the sun position in Lumion is only accessible via a post rendering effect named [sun study]. Also, Lumion's solar time is one hour later than Radiance; i.e. the noon in Lumion matched 11:00 am in Radiance settings.

Results and Discussion of the Final Shading and Scenes Rendering Studies

Figure 14 is the rendering matrix of Radiance, Lumion, and Unity for three roof colors. The main variation is the glass rendering, where, in essence, Lumion does not offer some comprehensive properties like the glass refraction. It was also seen that Lumion produced the darkest color value, and Radiance images were the brightest. However, the important note is that Lumion's shadow outlines were well-conformed with the Radiance renders - observe the hyperlight stripes on the left column. Unity renders seemed to limit the specular light to a very close distance, and it blurs it on remote objects. The excellent matching of the shadow patterns between Radiance and Lumion was satisfying; hence, Lumion was utilized for the comprehensive shading studies.

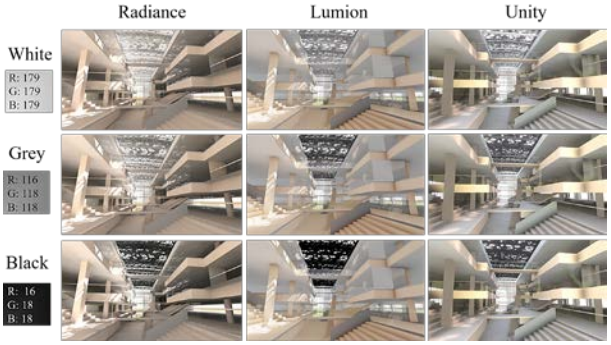

Figure 14 comparing several rendering engines

Several cameras were placed to observe the hourly shadow extents inside the auditoriums. Figure 15 is an example of a camera down looking at the central auditorium, on the 21st day of each month at 6:00 am. Similar sets were made for hours between 5:00 – 19:00 and different views. The renders were very useful in confirming that using curtains, and combined with newly-included contexts, had significant impacts in blocking direct sunlight from reaching the auditorium's seats and screens (boards). In turn, it was assured that the concluded roof enclosure pattern and side fins setups - when coupled with the other elements - were sufficient to provide the necessary shading for the auditoriums.

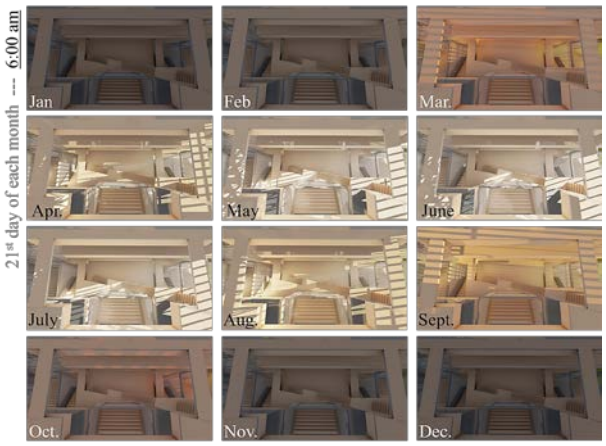

Figure 15 example of the annual shadow analysis

CONCLUSION

The study introduced and discussed many topics, some of which, like the last comparison between the three rendering engines, are primary and understood to be lacking rigorous evaluation. However, these shortages were thought of as good venues for research, especially for the tools developers. Meanwhile, the provided approach was the most practical within the given timeline and resources. It eventually worthed a national award. In the end, it is aimed that this process is shared with the sustainable design community; researchers and developers, as to advance and ease conducting similar methods. Below are three takeaways:

- The early dialogues and data sharing between the project teams are indispensable for delivering a meaningful, sustainable design. The proposed framework is one of the mediums that promoted such discourse, especially when non-technical members are involved in the design decisions. The framework made all members actively engage in formulating sustainability objectives and tasks.
- The use of the LB and HB was central in the study. The availability of those tools in the GH environment has facilitated the design parameters exploration and simulating thousands of design scenarios that would otherwise be undoable.
- The initial prioritization of the environmental qualities (e.g., reducing the roof heat gain as a top priority) helped in building a sequential process, were the results of the upstream (critical) optimizations are passed to the following (less critical) subjects. This flow served in avoiding the multiobjective optimizations; in which the sought parameters would cross multiplied and will yield in excessive calculation time and intricate outcomes.

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