Daylighting the Stata Center

A daylighting analysis of the 4\textsuperscript{th} floor of MIT’s new CSAIL building

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In a long line of recently constructed mega-projects on the MIT campus, the Stata Center distinguishes itself as one that is hard to overlook. While proponents of the building call it one of Gehry’s finest works, many critics claim that it is insensitive to the needs of the occupants and inadequate for day to day use. The $285.3 million dollar structure includes 75,000 sqft of glass to foster informal interaction and maintain transparency on the interior that should entice daylight to penetrate deep into the building. However even in some of the most heavily glazed areas, many of the spaces in the Stata Center remain dark and unappealing.

Daylighting studies of these spaces provide a better understanding of the other requirements (apart from mere glazing area) that are necessary to consider when designing for natural lighting. In this paper, we analyze two adjacent spaces in the Stata Center that suffer from similar daylighting constraints. We then propose a retrofit solution using parabolic mirrors that aims to address these daylighting issues for both spaces.
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Context and Description of Spaces

The studied spaces located on the fourth floor of the Stata Center belong to the Computer Science and Artificial Intelligence Laboratory (CSAIL). The first space is a South-facing hallway that connects the café with the elevators, and the second is a West-facing common space connected to the hallway.

The hallway is twenty five meters long, with a six meter glazed volume in the center. The frequency of circulation by the occupants of the building is relatively high during midday. Besides the normal pedestrian traffic, large windows visually connect the hallway with the neighboring atrium. Also, a series of posters line the wall and present information about current CSAIL research. Passer-bys often stop and peruse these posters on their way to the game room or cafeteria.

The hallway consists of three quarters glass, with the ceiling, the back wall, and part of the front wall, all adding to its transparency. Aluminum frames, supported by steel profiles in the roof, enclose the sheets of insulated glass. At the ends of the hallway, the glazing is substituted with white painted gypsum board used on the walls and ceiling. A dark carpet is used for the floor along the corridor.

In contrast, the reading room is a space of thirty square meters with a double height ceiling (approximately eight meters). This area is used for informal meetings or as a social hang-out where colleagues can eat lunch. The space has one glazed wall that looks
out onto the atrium between the towers. The opposite side of the room holds a staircase and a mezzanine that splits the double height in single stories (level 4 and level 5). There is a white board and a deployable screen for small expositions.

In the reading room almost every surface is treated with a different material and a different color. On the floor a blue carpet covers the whole space. The glass wall facing the atrium is held in place with aluminum frames and steel beams. On the opposite wall, a wooden staircase defines the boundary of the reading room. The wall holding the acrylic white board consists of drywall panels painted in white, contrasting with the front wall where drywall panels are painted yellow. A red leather sofa and yellow plastic chairs provide seating in the space.

Direct sunlight has a very minimal effect on both spaces. The sun course simulation and sun path diagrams demonstrate the dramatic masking effect of the towers on the interior of the atrium. In the hallway, there is direct sunlight penetration during only one hour from April to September and half an hour from October to March. In the reading room, direct sunlight appears for three hours from April to September and one hour from March to October.

These sun-paths were made using a 3-D model of the two examined rooms. The overall building shape was also modeled in order to quantify the masking effect of adjacent buildings on the space. The building was drawn in AutoCAD using measurements taken from these two spaces and also from the floor-plans of the buildings. This model was imported into Ecotect, where the direct sunlight penetration was simulated.
Hallway Observations

Thirty five floor measurements were taken with a luxmeter and recorded on a grid. The results obtained mapped the high contrast between the glazed portion of the corridor and the darker ends. At the extremes, the variation differs by 1,200 lux. The highest lux values were in the part of the corridor which has glazing on both the outer wall and ceiling (highlighted in yellow) and the lowest were recorded at the far ends of the hall.

Highest: 1335 lux
Lowest: 72 lux
The above graph illustrates how this illumination varies as you move along the corridor. In addition to high variation in the natural light, the use of artificial light was ineffective at smoothing out the contrast – particularly as incandescent narrow-beam spotlights were used which resulted in large differences in visual contrast and splotchy illumination. The lights appeared to be constantly on – even on bright days when the corridor was adequately daylit. Thus if the design intention was to create a space with dynamic daylight variation, the artificial lighting seems to work contrary to this goal.

To study luminance in the space we used High Dynamic Range Imaging (HDR) a method that involves taking identical photos with a fixed aperture but varying shutter speeds. By combining these images with Photosphere, it is possible to make a luminance map of the
space. Superimposing the HDR photos on an image of eye sensitivity areas gives an indication of where glare spots and discomfort may occur. For example, two highly contrasting luminance values occurring close to each other in the central field of vision may be uncomfortable for the viewer since this contrast would be read by the eye’s ergorama.

In the hallway, the luminance map shows that possible discomfort could be caused by the stark contrast of the darker non-daylit sections of the hall with the bright central area. The contrast in the ergorama was calculated at 1:51 compared to the allowable contrast of 1:3. The shortened length of the hall requires the eye to quickly adjust as it moves from dark to light to dark again. On bright days, our group deemed this contrast a nuisance, and an additional reason to address the variability in the space.

Finally, from an aesthetic point of view, our group found the hall lacking in intrigue. While the view out to the atrium seemed important to sustain the open feeling of the space, the other glazing in the hallway didn’t seem to be working hard enough. In some instances, this glazing even seemed to be a detriment to the space. The flat glass roof, for example, is decorated with debris and dust and requires regular washing. Dirt, leaves, and a dead bird were noted during our study, demanding a design solution that would distract attention from this ceiling plane.

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**Hallway Objectives**

Our objectives for the hallway are derived directly from the previous observations:

**Even out the natural illumination so it varies by no more than 300 lux from the start of the hallway to the end of the hallway.**

Due to the short length of the hall and its connection to shared spaces such as the game room, the cafeteria, and the reading room space, we felt the hall was not isolated enough to achieve the dramatic effect possibly intended by the variation in illuminance. The
difference between the brightest space in front of the windows and the artificially lit spaces at the ends of the hall seemed somewhat accidental and thus almost annoying as a pedestrian’s eye is forced to adjust to the abrupt change in illuminant color and quality. Thus, our first objective was to disperse the amount of the light received in the center of the hall to the ends so that they would not have to use artificial lighting. If the whole hall could be day lit, we could still achieve an interesting contrast in the middle allowing the side windows to open up to a broad view of the surrounding buildings, while not changing the entire feel of the space.

**Achieve a minimum of 250 lux throughout the hallway.**
One of the delights of design work in a hall is that it is largely free from task-related constraints. However, even though a hallway is usually required to only have 70 lux, we felt that a dim hallway may negatively impact the adjoining glazed lab. Also, using daylight consistently throughout the hall would elongate the space, making it feel more like one graceful entity instead of several mismatched pieces. Some of the darker parts of the hall are currently receiving around 70 lux. This amount of illumination is not adequate, demonstrated by the fact that the artificial lighting is constantly turned on in the end of the hall. Our goal is to triple the amount of illumination that reaches the back of the hall in order to avoid the use of artificial lighting during the day.

**Improve the efficiency of the artificial lighting.**
The Stata center hall uses 120 W incandescent point lighting. These lights are highly inefficient as their lumen to watt ratio is strikingly low. A high proportion of the energy they use is turned to heat instead of visibly usable light. To compound this inefficiency, the game room lights are on the same circuit as half of the hallway lights. Since the game room is constantly dark and constantly in use, half of the hallway lights are always on even though there is usually no need for extra illumination in this area. Our proposal aims to address these inefficiencies.

**Add visual interest to the space.**
An important aspect to our proposal was that the daylighting solution should also be a visual asset to the space. We also hoped that the solution would be instructive as to how light was being propagated throughout the space. The nature of a hall as a path for travel implied a repetitive element to achieve these means.

**Hallway Proposal-Illumination**
Our initial concept for the hallway was a series of long angled mirrors that would capture light entering the central glazed ceiling and reflect it deeper into the ends of the hall. We hoped this system even out the variation in the hall, increase the overall illuminance in the ends of the hall, and be aesthetically interesting. Originally we considered using flat mirrors, however, due to the abysmal amount of direct light reaching the ceiling plane, it was much more appropriate to focus on redirecting diffuse light. Thus, we switched to a series of parabolic mirrors that could focus the diffuse light more efficiently.

Parabolic mirrors are shaped such that reflected light from an angle parallel to the rotation axis is redirected to the parabola’s focus. Thus the light is concentrated, creating
a strong beam used for a range of purposes from outdoor mirror ovens, to hot water heating, to lighting the Olympic torch. Diffuse light is also concentrated with these mirrors, though not to a single point.

Using TracePro, Ecotect and Radiance, we hoped to test the difference between two feasible design schemes. The first used single parabolic mirrors to capture and redirect light to the edges of the hall. The second used a large mirror to capture the light and focus it onto another smaller mirror that would redirect the light in the appropriate direction. Our hypothesis was that this larger collection device would more effectively capture diffuse light due to the added space between the mirrors and its ability to see a larger portion of the sky. We felt these advantages would outweigh the light lost through the added reflection, especially as mirrors generally achieve 90-95% reflectivity. It also seemed the double parabolic may be able to redirect the light farther into the hall.

To design these systems we used a forward ray tracer called Tracepro. Tracepro has the ability to model diffuse light by varying the angle of the beam spread. It is also capable of modeling and modifying parabolic mirrors fairly simply so it can be used as a design tool as well as a verification tool. In the design of the parabolic system, several factors contribute to the efficiency of redirection. The parabola’s curvature, for example, can be manipulated to focus the light closer to the curved mirror (to the left of the focus point) or farther away from the mirror (to the right of the focus point). Also, the angle or rotation of the parabola determines how much of the sky each collector can see, and thus collect from. They also determine the direction the parabola reflects its light. These two factors must be balanced to achieve optimum results.

Using the daylight factor map feature in Ecotect, we were able to simulate the theoretical daylight factor throughout the room with the two different mirror systems. The model was developed by assigning particular material properties to specific elements in the space which described reflectivity, transmissivity, and absorptivity. These parameters would allow the model to behave in a similar manner as the existing structure.
In the mirrorless model, we can see that a 40% (very high) daylight factor is shown directly beneath the flat glass roof that was open to the sky. When compared to the results with mirrors, we observe an overall reduction to the daylight factor in the area under the skylight, but no noticeable change in the beginning nor end of the hall.

We also used Radiance to simulate what the illuminance values would be in the parabolic designs, and compared these values to those of the normal hallway. Our results coincided with the daylight factor results. There was a decrease in illuminance in the center of the hall, but no noticeable change in either end of the hall.

Our results can be visualized in the following images. Yellow represents a daylight factor of 40%+, and blue represents a daylight factor of 0%.

The values shown in the daylight factor map are scaled to the highest pixel, a 40% daylight factor. Because 40% is so high, it may make small differences in the edges of the hall harder to pick up. Especially as we would only expect a daylight factor increase of 2-3%
However, there also may be a problem in the design of the parabolics themselves. Since the zenith is the brightest portion of the sky, each parabolic system should focus on collecting from that direction. Nevertheless, it is also possible to overly emphasize the importance of the zenith direction and thus to miss many of the other angles of diffuse light. It seems that while trying to efficiently collect all of the zenith rays, the parabolas in the following two systems were positioned too close to each other, reflecting incident rays at other angles. Though the beam spread was set to 15 degrees, the models were tested with beams that originated very close to the parabolic system, and thus the spread was probably not actually influencing the tracing of the rays. Thus we would assume that while the parabolas would perform very efficiently in direct light, the design is inaccurate for diffuse light.

This design flaw helps to explain why the results in TracePro are so remarkably different from those in radiance. While the TracePro model predicts added illuminance of 250 lux in the ends of the hall, the Ecotect model acts as though the parabolic system is merely an obstacle for light with minimal redirection effects.

**Hallway Proposal Artificial lighting**
To address our initial artificial lighting objectives, we propose a modest rewiring of the space, so that the hallway and ping-pong room are on separate circuits. We also propose to change the narrow beam lights to fluorescent lights that will be hidden above the mirrored parabolics and redirected to the ends of the hall in the same way as sunlight. These two revisions reduce the energy usage by 600%.

The Stata center 4th floor hallway currently uses six 120W incandescent lights. Incandescents unfortunately turn much of their energy to heat, contributing a measly 10 lumens/watt of electricity compared to daylight’s 110 lumens/watt. Also due to their shared wiring with the game room, they are almost always on, even when the hallway is adequately lit. As a result, these lamps contribute only 7200 lumens to the space, though they consume over 6,300 kWh/ year.
Fluorescents, on the other hand, boast an efficiency of 70 lumens/ watt, seven times more visible usable light than the incandescent bulbs. Also, taking our wiring revisions into account, we can assume that the hallway lights would only need to be on for fourteen hours a day. Consequently, we would have almost 17,000 lumens in the hall space for around 1200 kWh/ year, six times less energy. This one isolated change would save the Stata center $400 a year in electricity bills.

**SPACE 2**

**Observations-Reading Room**

The lux-values in the reading room were measured for both vertical and horizontal surfaces. The values shown in the diagram below are measurements at floor level and the area highlighted in yellow is lux values at table level.

The lux variation in the Reading Room was not significant – with little variation even at the point furthest from the windows. Overall the lux levels were thought to be too low, particularly as the table is used both informally and as a work-plane. It was hoped to increase the values to between 500-750 lux, an almost 100% increase.
A HDR image was made for this space also in order to study any visual contrast issues that may be present in the space. It was noted that a particularly low luminance value on the furniture and high luminance from artificial lights resulted in the highest contrast levels (a range between 20 lux/sr and 175 lux/sr).

**Reading Room Objectives**

Our objectives for the reading room are derived directly from the previous observations:

**Raise the task lighting to 500 lux on the table and white board.**
Currently the working areas in the reading room are receiving around 250-300 lux. The recommended illumination level for reading and writing is 500 lux, so our goal would be to capture more light to project onto these spaces.

**Achieve a minimum of 250 lux throughout the reading room.**
Some of the darker parts of the reading room are currently receiving around 150 lux. These spots of lower illumination are not extremely problematic, but as a whole the space feels dark for the amount of glazing it entertains. Also, due to the versatility of this space, we require a minimum of 250 lux so it can be used for many different functions.

**Bring visual contrast down to an acceptable ratio.**
While in most spaces, high visual contrast resulting from dark furniture or highly illuminated walls may not be problematic, the reading room is a special circumstance. Because of the diversity of materials and finishes in the space, the distributed light reacts...
to all of these surfaces in very different ways. As a result, the quality of light in the space is constantly changing and constantly affecting the way an occupant’s eye responds to the space. Therefore, reducing the amount of visual contrast in the space would create a less chaotic atmosphere and overall a more comfortable study room.

**Reading Room Proposal- Illumination**

The initial concept of the reading room was to utilize the same parabolic elements of the hallway design in a way that would boost the illuminance in the room. Unlike in the hallway, the reading room did not have an abundance of light, so the collection and redistribution could not occur in the same space. Instead, we needed to harvest light from other spaces to project into the reading room. Thus, by its very nature, this design needed to be sensitive to the other spaces it was affecting, and to create an asset to the whole building, not just the room itself.

Since the parabolic mirrors were to be positioned inside the atrium space, they would be collecting light that would otherwise be projected to the bottom level of the Stata Center. This could have been problematic, if we would be negatively affecting the lower floor’s access to daylight. However, the atrium is designed such that there are several protrusions and boxes that jut out into the open area and inhibit the sunlight’s ability to reach the bottom floor. By extracting daylight factor maps of the lower floor before and after the addition of the parabolic mirrors, it is clear that the mirrors do not adversely affect the lower floor’s access to daylight.

The other space that could be adversely affected was the reading room itself. We wanted to avoid obstructing the view into the atrium and to minimize the amount of incoming light the parabolic system would block from the large glazed walls. In order to do this, we positioned the parabolics as close to the reading room and as high above line of sight as possible. We also planned to attach the parabolic mirrors to existing beams and frames so they would not further detract from the transparency of the atrium ceiling.
Ecotect was used to create a daylight factor map of the reading room for an overcast day with an outside value of 6000 lux. A basic model of diffuse light was chosen as this would significantly reduce the length of time required to compute a result. An analysis grid was chosen at floor level of this space and the range of values was scaled with 40% being the highest value (yellow) and the lowest 0% (dark blue).

There was not a significant difference between the reading space before and after the addition of single parabolic mirrors.
For the double parabolic mirrors, a slight increase in the amount of light entering nearest the window was observed. Besides this change it is difficult to pinpoint other differences between the two daylight factor maps.

Ecotect was used to position two cameras in the 3-D model in locations that showed relevant views of the room and this information was exported to Radiance. The aim of the simulation was to compare how the room looked with each of the new parabolic designs under an overcast sky. The number of inter-reflections chosen was five. The three different scenarios produced images in Radiance which allowed specific lux values to be measured at identical points on each image and then compared.
The main increase observed was with the single parabolic mirrors. There was an increase in illuminance by a value of approximately 200 lux near the window, although this variation may be in part due to inaccuracies measuring the lux value at an identical location.
**Reading Room Proposal- Visual Contrast**

A minor issue in the reading room was visual contrast. The dark red couches were observed to have the lowest luminance values, on the order of about 20 lux while the other eye-level objects in the space ranged from 50-170 lux. The current couches were found to have a reflectance value of about 0.18. By introducing couches with a higher reflectance value (somewhere around 0.5), we could achieve a luminance value between 50-60 lux. This reduces the visual contrast ratio from 1/9 to 1/3.

Left: Luminance values of in the room. Right: Predicted luminance of a different chair.

**Conclusions**

In the hallway we wanted to achieve a variance of less than 300 lux, a minimum of 250 lux throughout the whole hall, a more efficient artificial lighting configuration, and an aesthetically interesting design solution. While we did design a visually interesting daylighting solution and a well-incorporated, efficient artificial lighting scheme, the actual capture and redistribution of daylight in the space was lacking. The daylight factor analysis shows that though the variance throughout the hall was lessened with the addition of the parabolic system, this was mostly a result of blocking the light coming through the glazed ceiling.

In the reading room we attempted to achieve a minimum of 250 lux throughout the room and 500 lux for task lighting around the table and the white board. While the radiance models show that we achieved lux values in the 400-600 range even without mirrors, by comparing these to our measured quantities, we find they are double what we would expect. Granted, we measured the room on an overcast day, however, the models are also
analyzed with an overcast sky so the difference should not be so great. Thus, it seems necessary to divide the radiance model values in half in order to be conservative.

In doing so, we find that the parabolic mirrors did not significantly contribute to the overall illuminance of the space. By changing the material of the parabolics to a non-reflective surface, such as concrete, we verified this conclusion. The spaces using reflective parabolics were not significantly brighter than those with concrete parabolics.

However, this does not mean the design has failed altogether. The poor results could be caused by a number of factors:

1. There is not enough diffuse light to adequately distribute throughout the hall. Since the atrium space is littered with obstructions, only a very small portion of the sky contributes to the diffuse light in the space. To redistribute the light effectively, perhaps we needed to capture a larger portion of the sky.
2. The design of the parabolics did not correctly take into account diffuse light. As discussed in the hallway section, the spacing between the parabolic elements was very tight in order to focus on light from the zenith direction. Spacing these elements so they catch a diverse range of angled rays could make them more efficient.
3. The amount of light being redirected into the space is not significantly greater than the amount of light being blocked by the reflectors. Especially in the case of the reading room, the reflectors could be blocking light that was previously entering the space through the top of the window.
4. The images are not sufficiently refined. In the interest of time, we chose for radiance to model our conditions under the lowest amount of diffuse light. Perhaps the light contribution under these conditions needs to be refined much more precisely in order to see the difference.

**Future proposals**
If we were to continue this project, we would target these possible flaw-contributing factors and try to isolate which is the true problem. One solution that may ameliorate most of the problems is to use a larger parabolic mirror placed on the patio of the fifth floor. We imagine this parabolic mirror to act as a sunshade for the patio while collecting...
light that would be redirected to the reading room. This type of system has the added bonus of not blocking any incoming light that would have entered the reading room. However, we also feel it is less elegant, and would first try to correctly space and reconfigure our existing system so the effects are more noticeable.

Parabolic mirror not blocking reading room view