

Perkins&Will

Research Journal

2014 / VOL 06.01



SPECIAL ISSUE: INNOVATION INCUBATOR RESEARCH
DESIGN INVESTIGATIONS IN PRACTICE

02.

A CASE STUDY IN REFLECTIVE DAYLIGHTING

Patrick Cunningham, AIA, LEED BD+C, *patrick.cunningham@perkinswill.com*

Paul Zaferiou, IALD, RA, *paul@lampartners.com*

Kera Lagios, IALD, *kera@lampartners.com*

ABSTRACT

This article focuses on the design of the University Crossing atrium at University of Massachusetts (UMASS) in Lowell, where an innovative way to bring daylight deep into the building's north facing, four story atrium was the primary objective of the study. Using a number of physical and digital tools including Diva-for-Rhino, the design team has explored the invention of reflective building geometry to light the building's interior atrium surfaces throughout the year. Working with Lam Partners and other contributors, the team has iteratively explored how daylight can be efficiently, yet dramatically directed down into a space despite challenges generated by planning constraints, site conditions and formal orientation. The case study documents the team's research methodology, design strategies and technical concepts for executing the work as well as general conclusions on the benefits of the collaborative process.

KEYWORDS: daylighting, energy optimization, computational design, simulation, orientation, sustainability

1.0 INTRODUCTION

Building forms are often driven by conditions that work counter to the ideal geometries of daylighting design. The depth of a building's floor plate, the orientation of the existing urban grid and the shadowing of existing site geometry, among other factors, inform decisions that create unique design challenges when conceptualizing spaces inspired by daylight.

Despite these challenges, the benefits to building occupants and the broader environmental context make finding effective and innovative daylighting solutions an imperative. Developing new design methodologies is crucial to effectively designing day-lit spaces in less than ideal orientations. These new design methodologies require the cultivation of strategic partnerships, the exploration of new computational and physical tools as well as new construction assemblies.

The design of the University Crossing atrium at University of Massachusetts (UMASS) in Lowell has allowed the Perkins and Will Boston office to study an innovative way to bring daylight deep into the building's north facing, four story atrium. Using a number of physical and digital tools including Diva-for-Rhino, a software initially developed at the Harvard Graduate School of Design, the design team has explored the invention of reflective building geometry to light the building's interior atrium surfaces throughout the year. Working with Lam Partners and other contributors, the team has iteratively explored how daylight can be efficiently, yet dramatically directed down into a space despite planning and site related challenges.



Figure 1: Finding inspiring, efficient and innovative daylighting solutions for deep buildings is an imperative for sustainable growth.

2.0 TURNING DAYLIGHTING CHALLENGES INTO DESIGN OPPORTUNITIES

2.1 Drivers of Building Form

Daylighting strategies are often diagrammed assuming the most ideal conditions. The simplest strategies are clear for buildings with an optimal east-west orientation, shallow floor plates, perimeter occupied spaces and a lack of shadowing by adjacent structures. The realities of urban infill sites do not often present the conditions that allow these simple solutions. Often, oddly-shaped, poorly oriented urban parcels are developed when the most ideal sites have been exhausted. The desirability

of a site location and prominence may also drive the development of a project with a less than ideal solar orientation. Regardless of the drivers, the principles of sustainable urban growth push us to achieve a density that makes use of challenging sites in creative, thoughtful ways¹.

At the University of Massachusetts in Lowell, the design team was tasked with the design and development of a new student center to be called University Crossing. A number of site-driven and programmatic challenges drove the team to explore a system of reflected daylight within the building's central atrium.

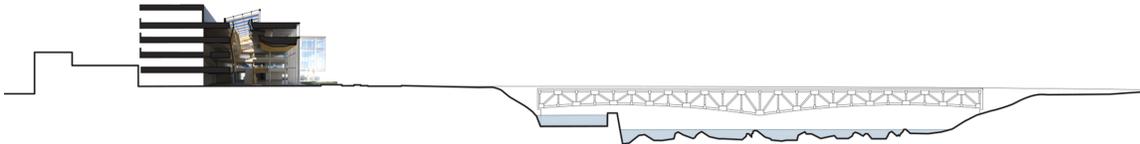


Figure 2: Aerial view of University Crossing looking north over Lowell and the Merrimack River.

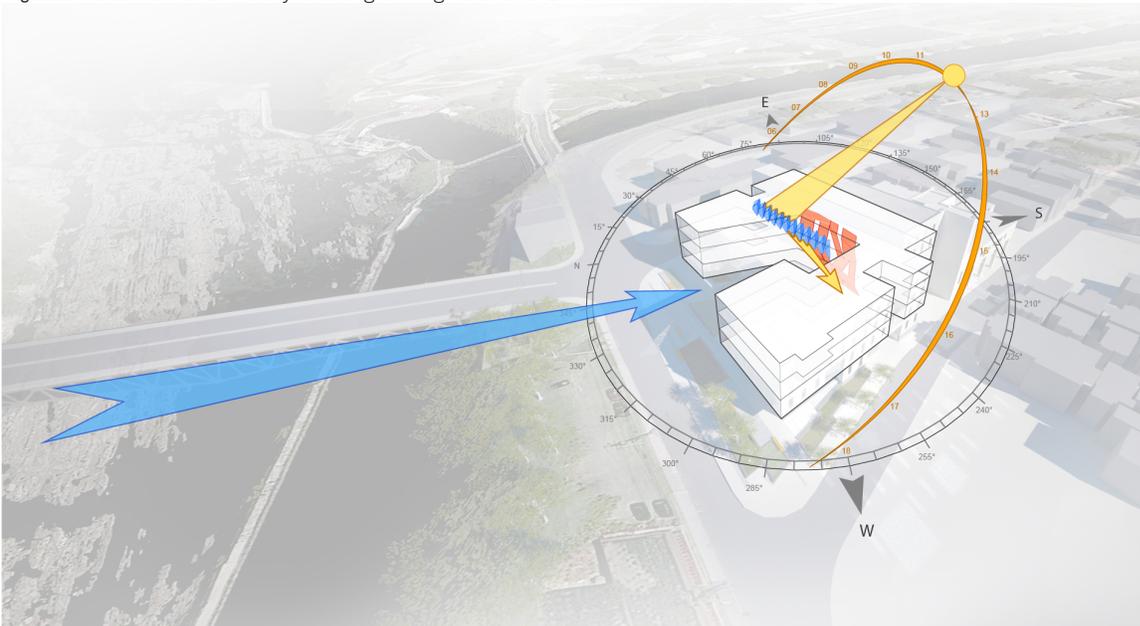


Figure 3: Site and sun path diagram.

2.2 Site Driven Challenges

The project's site is located at the edge of a dense urban neighborhood, remote from the main campus, which lies to its north across the Merrimack River. The primary pedestrian approach to the building is from the new bridge. The location of the building south of main campus and its orientation to the bridge meant that the new structure would be back-lit to students and visitors approaching from the north and that if public spaces were to orient themselves towards the river, they would need to be day-lit primarily from the northern building edge or from above. The dominant urban geometry, 42 degrees off axis from true north, added to the daylighting challenges as traditional horizontal light shelves would prove ineffective for the majority of the day on south-east and south-west facades.

2.3 Existing Adjacent Structures

Adjacent to the site at its southern corner, the six story stair tower of an existing structure stood as a further impediment to a simple daylighting solution. The existing structure and its associated elevator tower would shadow the University Crossing site from the south for the majority of the day.

2.4 Programmatic Requirements

A number of common design pressures drove the architectural scheme towards a solution that can be referred to as a "deep floor plate building". Deep floor plate buildings pose unique challenges when striving to achieve spaces inspired by natural light. Without prohibitively high floor-to-floor heights and large amounts of perimeter glazing, they become challenging to daylight from the building's exterior facades alone.

The scale of contiguous programmatic departments and the functional requirements for their adjacency drove the team to a scheme that maximized the site footprint on four floors and organized the building around a central atrium. The position of the atrium within the building mass was biased towards the northern and most public facade to act as a welcoming space, one that is in scale with the prominent approach axis. By biasing the atrium to the north, the resulting space could be both top lit as well as lit by the northern exterior facade.

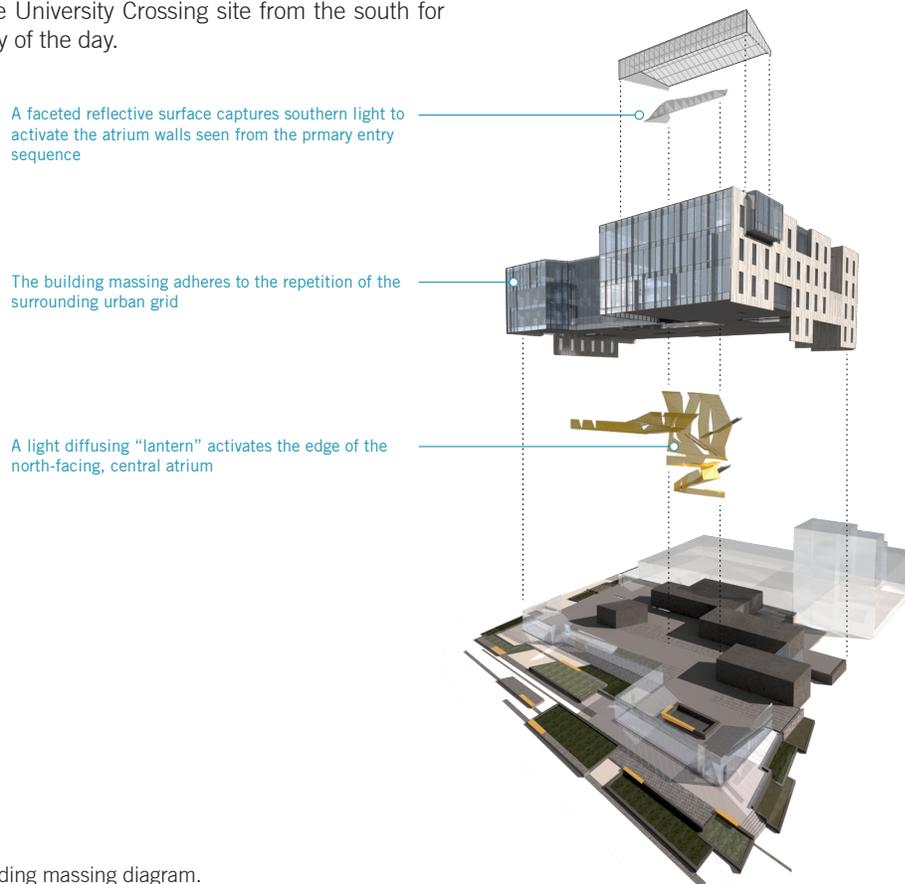


Figure 4: Building massing diagram.

2.5 Balancing Performance and Daylighting

Within a heating intensive climate like the Northeast, a deep and compact building can yield a number of performance advantages². The optimization of the building skin in proportion to the enclosed building volume can yield an efficient mechanical system when coupled with a high performing building envelope. However, this means that daylighting and passive ventilation strategies become challenged by the lack of exterior wall area and general proximity of program to the building's exterior. To further drive down the loads on existing mechanical systems, teams often look to optimizing glazing percentages in relation to the overall envelope area. Similar to optimizing a building's skin to volume ratio, this process tends to drive buildings towards smaller apertures for daylighting.

2.6 Integrated Energy Modeling

As energy modeling progresses in early design and daylighting studies are being performed, the results of reduced lighting loads are typically not accounted for within the schematic energy modeling process³. At this point there are few energy modeling tools that account for the benefits of reduced lighting loads by quantifying them within a 8760, hour-by-hour energy simulation. This makes it difficult to account for the advantages of daylighting in energy modeling and has the potential to cause a design team to reduce a project's glazing percentage based solely on the results of early modeling.

2.7 Minimizing the Atrium Aperture

Even without sophisticated energy simulations that tie the performance gains from daylighting and active dimming systems to energy usage, we can make assumptions about effective top-lighting strategies within deep buildings like University Crossing. The first is that the atrium skylight aperture, if sized strictly for daylighting, would require a substantial glazed opening in the insulated roof system. Traditional formulas developed for the calculation of atrium aperture size do little to calculate the effects on a building's thermal envelope⁴. The weakening of what is typically the most insulated portion of the exterior envelope has the potential to add unnecessary heat gain in the summer and loss in the winter regardless of careful attention to glazing performances. The second assumption is that successful solutions can be found that, at once, minimize the daylighting aperture and maximize the effects of natural light within the building. This is true due to the potency of sunlight. On a clear day the sun's rays offer up to 10,000 footcandles of directional light and on an overcast day can still provide up to a 1,000 footcandles of diffused light.

When compared to the 50-150 footcandles necessary for general illumination, it is clear that a small amount of daylight might effectively be beamed into the building through smaller apertures and then spread out or diffused by larger interior surfaces.

2.8 Optimizing Daylighting

Optimization of building envelopes and potency of sunlight suggest that working with minimal, but carefully designed apertures for daylighting can serve as a guiding sustainable design principle⁵. A unique set of strategies present themselves when coupling this principle with the site challenges of orientation, shadowing from existing structures and the directionality of sunlight. This set of strategies involves the reflection or redirection of sunlight through mirrored or highly reflective surfaces. The following section is a cursory review of a number of projects that use redirected daylight in deliberate, yet elegant ways to daylight and animate the architectural environment.

Many of the projects were the products of successful partnerships between Lam Partners Architectural Lighting and their clients.

3.0 PRECEDENTS IN REFLECTED DAYLIGHTING

3.1 Precedent Analysis

There are a wide range of reflective lighting precedents to examine within the history of the built environment. The following precedent study focuses on buildings that take advantage of relatively small, protected apertures to send potent, but focused daylight deep into building environments. Analytical diagrams were developed based on published building sections and photographs provided by Lam Partners to show the basic design concept present in the precedents. The images show how light is reflected or "beamed" into the building through the use of specular surfaces. Working in tandem with these specular surfaces are multiple light-diffusing surfaces. These surfaces serve to spread the highly focused sunlight over a larger area, allowing for effective functional lighting techniques to be used. The range of precedents selected show simple, fixed solutions using flat surfaces as well as complex arrays of operable reflective louvers. Within this spectrum of cost and complexity there are multiple effective strategies that can be scaled up or down depending on the project design goals. Also included are precedents that combine multiple reflective strategies into layered approaches. These layered approaches allow for light to be conceived of as a playful activator of space as well as

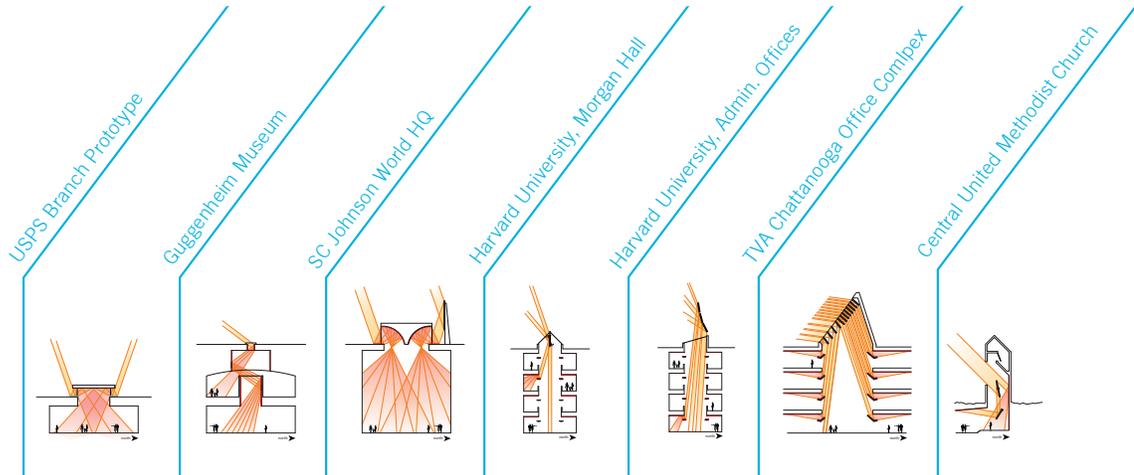


Figure 5: A range of daylighting precedents.

a functional necessity within the same scheme.

3.2 United States Postal Service Regional Distribution Center Prototype⁶

The USPS investigated ways to standardize a new building design for their regional mail distribution centers that would be better organized and more energy efficient. One of the goals was to incorporate daylight as a primary light source. The building design is organized around a series of simple linear bays, with one roof monitor per bay. Through a series of daylight studies, it was determined that the most efficient daylight monitor had a north-south axis with east and west clerestory windows. As an integrated design approach, the roof monitor and ceiling geometry was developed to maximize daylight exposure without allowing direct sun into the building. This was achieved by adjusting the height and position of the clerestory with the shape of the ceilings in each of the bays. By sloping the ceilings up to the monitor opening, the whole bay became a daylight coffer.

The east and west clerestory windows provided ample daylight from sunrise to sunset. The least amount of daylight entered the bays at noon, which coincided with the postal workers lunch break. As part of the integrated design, a spiral duct was placed at the center of each bay below the daylight monitor to condition the space. A simple fluorescent strip fixture with reflector was concealed on top of the duct to provide glare-free indirect illumination on gloomy days and winter afternoons.

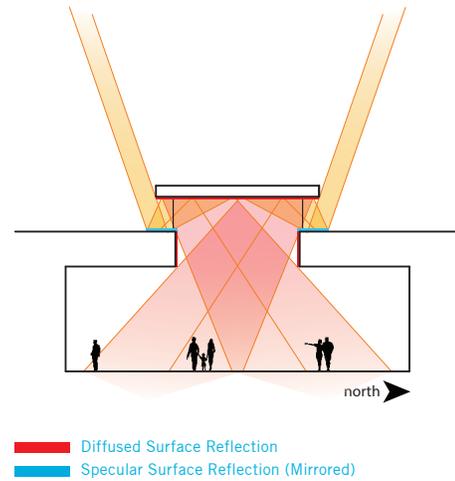


Figure 6: Daylight strategies for United States Postal Service Regional Distribution Center Prototype.

3.3 Guggenheim Museum, Bilbao, Spain⁷

In Frank Gehry's museum of modern art, simple geometric design strategies were developed to bring daylight down through the building to illuminate lower level spaces. One wing of the museum contains the "classical galleries," which are square galleries double-stacked and connected in a row. The upper level of each set of the classical galleries has a skylight centered in a deeply vaulted ceiling cavity. The center of each upper gallery contains a light well that provides natural light to the lower classical gallery. The walls that form the light well create a white box-like element for hanging art. The height of the box walls is set in such a

manner so direct sun from the skylight above can never reach the perimeter walls of the upper gallery. Visitors in the upper gallery are not aware that these walls form a light well to the gallery below.

A pair of motorized shades concealed in the top of the light well can be activated to create soft diffuse light to the lower level gallery or close off daylight to the lower gallery when required by special exhibits.

The galleries that surround the central atrium in the museum “borrow” daylight from the sky-lit main space through small openings. Gaps in the floor plates allow daylight to filter down to the galleries and circulation spaces below.

3.4 SC Johnson World HQ, Racine, Wisconsin⁶

This large office building is shaped like a square donut with a litrium at the center. The raised roof over the litrium allows for clerestory windows on all four sides. Curved plaster light scoops behind the clerestory windows redirect sunlight on the east, south and west elevations down to the interior elevations of the central space. Interior light shelves then redirect this sun-light to the open office ceilings. To help balance the daylight

on all four sides of the litrium, special “sun catcher baffles” (a term coined by lighting designer William Lam) were installed as outriggers on the north, east and west sides of the upper roof. These architectural baffles are mirrored on the backside and have an architectural finish on the outside face. These baffles function in the following way: when the sun is in the east, the east clerestory admits ample sunlight and on the west side, the suncatcher baffle captures a small band of direct sun and redirects it to the scoop below. This strategy maximizes the daylight potential in the building and creates a more balanced illumination in the spaces. The building also employs exterior light shelves on the east, south and west facades to amplify the natural light at the office perimeter zones.

Upside-down, wing-shaped reflector system was installed on the south side of this high-rise office building to redirect sunlight through a light shaft to a second set of mirrored reflectors on the ceiling of a central atrium. The second array then redirected the sunlight down through the building, through a large glass day light to bring natural light to the public passage under the building.

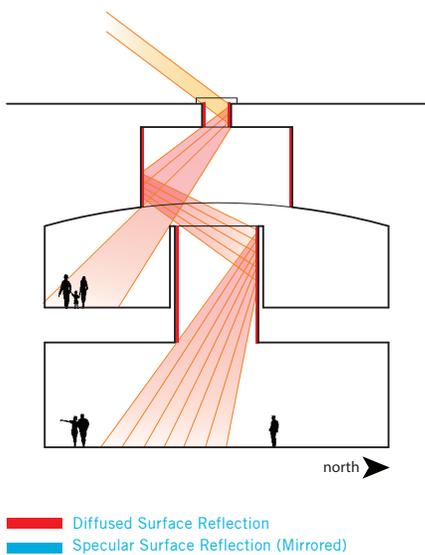


Figure 7: Daylight design strategies for Guggenheim Museum, Bilbao, Spain.

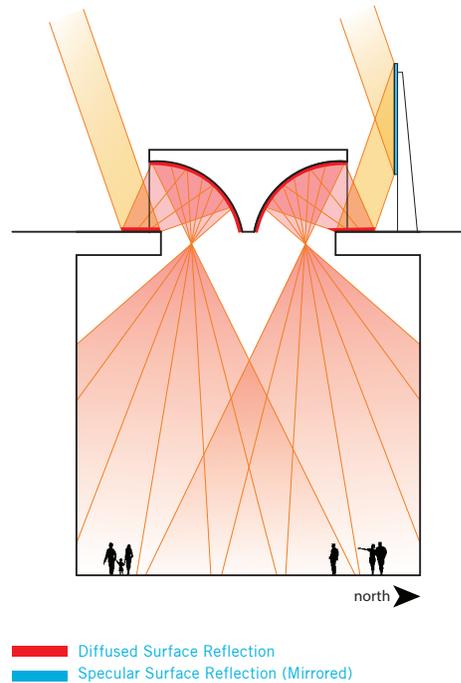


Figure 8: Daylight strategies for SC Johnson World HQ, Racine, Wisconsin.

3.5 Harvard University, Morgan Hall⁶

This building has a small, central sky-lit atrium with two 11' wide light wells on either side. Simple gable skylights cap the four story light wells. The axis of the light well is east-west, which creates a long southern exposure for the skylight. Adjustable mirrored panels below the skylight redirect southern light down the light well to the first floor. Light shelves on second to fourth floor capture a bit of the redirected sunlight and bounce it up to the open office ceilings that flank the light well. The mirrors are motorized and can be adjusted weekly to accommodate changing sun angles throughout the year. As a special feature at noon, the mirrors do a simple rotation to send light down the walls of the light well, across the floor and back up the other side, and then default to their regular position.

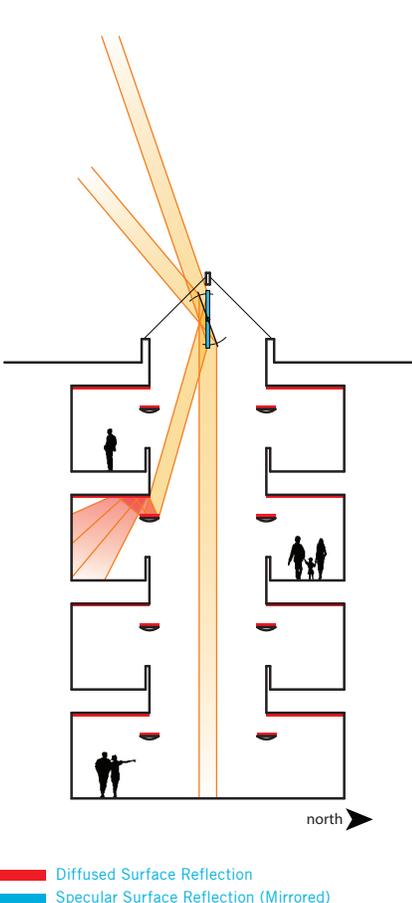


Figure 9: Daylight design strategies for Harvard University, Morgan Hall, Cambridge, Massachusetts.

3.6 Harvard University, Administrative Offices⁶

This project involved two adjoining buildings embedded within a deep block behind Harvard Square. A full renovation to convert these four and five story buildings into office space was implemented. The buildings have few windows at the short ends and have very little daylight access. A skylight was cut into the center of the roof and a narrow light well was created below to allow daylight into the center of the building. Glass-front offices face the light well to have some connection to daylight. Fixed polished stainless steel reflectors were installed on the roof on the north side of the skylight to redirect sunlight down into the light well. Three reflectors were used and set at different angles to maximize various sun angles. The three mirrored reflectors are set to optimize summer, equinox, and winter sun angles.

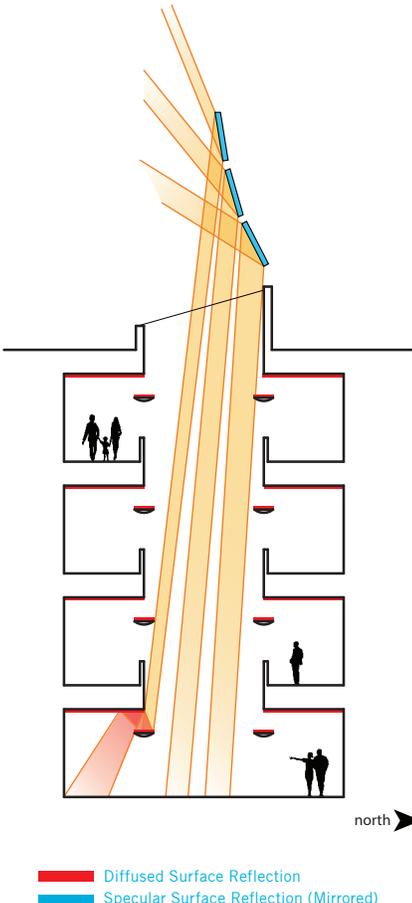


Figure 10: Daylight design strategies for Harvard University, Administrative Offices, Cambridge, Massachusetts.

3.7 Tennessee Valley Authority, Office Complex, Chattanooga, Tennessee⁸

The TVA is a government agency in the energy business. In the 1980's they set out to build a new office headquarters with 1.2 million square feet that would be a model of energy conscious design for all of its facilities. Through a team process, a building design was developed around an array of six to seven story office blocks facing south, with atria and litria in between to maximize access to daylight and natural light in the work environment. The litria concept was further developed to incorporate a strategy of beamed sunlight. This strategy was based on a south-facing litria with sloping glass and an array of one-way tracking mirrored louvers mounted below the glass. The litria were located between two office blocks. The floors of the office blocks were terraced so that they extended into the litria deeper on the lower floors and less on the upper floors in a V-shaped configuration. The edges of the floor slab held a plaster-formed outrigger with a fixed mirror surface facing up at a 45 degree angle. The one-way tracking mirrors below the litrium glass roof were set to beam sunlight straight down. This sunlight was intercepted by the secondary mirrors at the edges of the floor slabs, which redirected the sunlight to the ceiling of the office spaces.

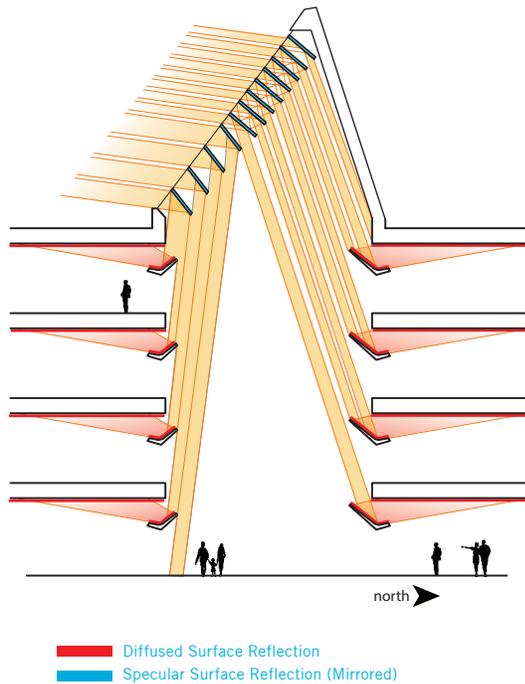


Figure 11: Daylight design strategies for Tennessee Valley Authority, Office Complex, Chattanooga, Tennessee.

The primary mirror louver system was designed with a white surface on the underside so that in summer, the mirrors could be set to reflect direct sun and create a diffused daylight component off of the white back surface of the mirrors. On winter nights, the mirrors could be closed down to help prevent heat loss.

3.8 Central United Methodist Church, Milwaukee, Wisconsin⁸

Working with the congregation, William Wenzler & Associates developed a new church design that preserved much of the site, and incorporated a special sunlight strategy that served as a practical and metaphorical statement about lighting in a religious facility. The bulk of the church is largely below ground, with berms on three sides, which frees a good portion of the site for a beautiful landscape full of wild flowers. The sanctuary below is oriented with the altar to the north. A large daylight monitor or “suncatcher” rises above the altar and forms a sculptural element in the landscape above. Structural beams gently radiate from the area under the suncatcher to the back and sides of the sanctuary. The south-facing suncatcher concept began as a passive solar strategy to collect solar energy and bring daylight into the altar area.

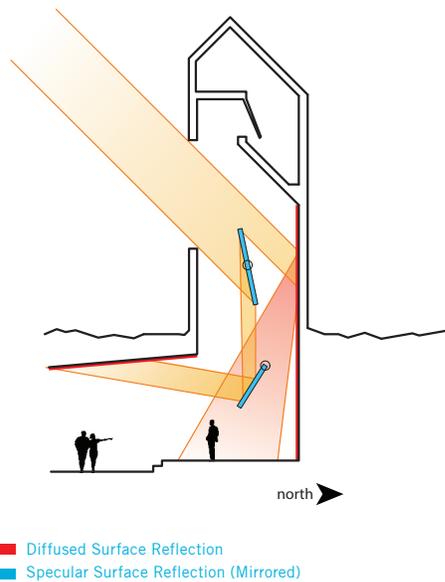


Figure 12: Daylight design strategies for Central United Methodist Church, Milwaukee, Wisconsin.

With its large south facing glass, a shutter was proposed to isolate the upper cavity of this tower from the rest of the church to avoid excessive heat gain in summer. This early shutter concept was modified and transformed into a sunlighting strategy, in which the shutter became a primary tilting mirror to capture as much sun as possible. This primary mirror delivers sunlight to an array of secondary mirrors mounted between the radial pattern of concrete beams below. The secondary mirrors send sunlight streaming down each bay with dramatic effect.

3.9 Additional Precedents

The following are additional precedents that were investigated and discussed during the research process:

Asian Cultural Center, South Korea⁶

This project was a large urban renewal project involving a major site that was cleared and redeveloped as a cultural and innovation center in an urban center. The bulk of the construction is below ground so that the top of the site could be developed as a park, a desperately needed green oasis in an otherwise dense city.

A large cut in the site was created on the south side to expose the new below-grade building to sunlight. A narrow canyon-like cut on the west side opened up the below-grade floors on that side to stepped courtyards for access to daylight. In the center of the development, special skylight wells were created to capture and reflect sunlight down into light shafts that distribute light three levels below grade. The skylight wells, or “light crystals” as they were called, create sculptural objects in the park, with care taken to position adjacent trees to avoid blocking direct sun to the skylights. The light wells are mirrored at the top with diffusing surfaces placed at various levels below for light distribution.

Blue Cross Blue Shield HQ, Connecticut, USA⁶

In this older project, the generous site allowed for proper positioning and massing of the building to maximize sunlight penetration into the office building. The building is organized into two east-west blocks with an atrium in-between. Bill Lam coined the term “litrium” to describe a daylit space that is designed specifically to maximize the capture and redistribution of sunlight as useful illumination. The north block of the building rises above the south block, creating a simple, but effective clerestory window facing south. A scoop-shaped upper wall in the litrium redirects sunlight throughout the space. Interior light shelves at the edges of the office floors facing the litrium capture a bit of sunlight and bounce it up to the open office ceilings for useful ambient lighting. The building also has exterior light shelves

on the south side to maximize sunlight penetration on that elevation.

Hong Kong Shanghai Bank Building⁹

This project is an interesting case study of how southern exposure was used to create an active sunlight system for this office building. Norman Foster’s team uses a large, upside down, wing-shaped reflector system installed on the south side of this high-rise office building to redirect sunlight through a light shaft to a second set of mirrored reflectors on the ceiling of a central atrium. The second array then redirected the sunlight down through the building, through a large glass skylight to bring natural light to the public passage under the building.

US Embassy, Ottawa, Canada⁶

This embassy building is shaped like a large boat with a north-south axis. SOM Architects used a central atrium to organize the main public spaces in the building. To the north and south of the building are five story light wells that bring daylight down to the offices on both sides. In essence, this building is similar to Harvard’s Morgan Hall building, except turned 90 degrees. The fact that the skylights over the light wells were facing east and west is critical to the daylighting strategy. Given the high latitude of the site, east and west sun angles play a very important part of capturing sunlight. In this design, a multi-faceted mirror lined the tall upper portion of the light well. The mirrors were set in a splayed position so that with each “bounce” of sunlight, the sun penetrated deeper into the light well. By doing so, sunlight is pushed to both sides of the light well and all the way to the bottom level. The glass handrails of the corridor spaces surrounding the floors below the skylight were made of diffusing glass and set at an angle (rather than straight up and down) to intercept the sunlight streaming down from the mirrors above. This created an ambient glow in the entire light well.

David L. Lawrence Convention Center, Pittsburgh, Pennsylvania¹⁰

While this large convention center space is not multi-story, its design represents one of the largest enclosed daylit convention spaces in the country. Vinoly Architects employed large strip skylights following the curve of the cable suspension roof system to fill the space with natural light. Two motorized shades below the skylights provide a diffusion layer to soften the daylight and a second black-out shade to dial down the daylight to very low levels when necessary. A Bird-Air translucent fabric membrane forms the south facing “clerestory” for a large dose of supplemental diffuse daylight.

4.0 LIGHTING ANALYSIS TOOLS AND METHODS

4.1 UMass Lowell University Crossing

The atrium at University Crossing uses a pairing of two primary daylighting techniques, a large north-facing window for diffused general illumination coupled with a south facing mirrored reflector hung within the atrium skylight. The mirrored reflector is aimed primarily at the north face of the atrium interior. The glazed north face gives effective general illumination to much of the atrium, while the reflector allows for a play of light to activate the primary sculptural surface that defines the space.

The reflector at University Crossing was designed through a highly iterative process between Perkins and Will and Lam Partners. It is composed of a fixed series of surfaces that is calibrated to reflect and aim multiple incident solar rays over the course of the day and year. As in other precedents, there is a diffusing partner to the reflector. At University Crossing a sculptural wood-slat surface is hung on the interior north face of the atrium between the reflector and the primary balcony lounges. This surface acts as a baffled lantern, diffusing and filtering the daylight as it plays off its surface. The result is a play of intense and animated daylight on what would normally be a simple, artificially lit surface.

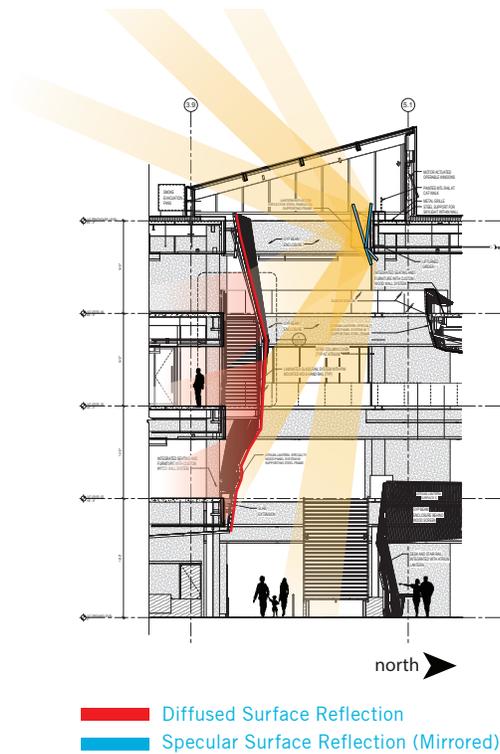


Figure 13: Reflected daylighting parti.

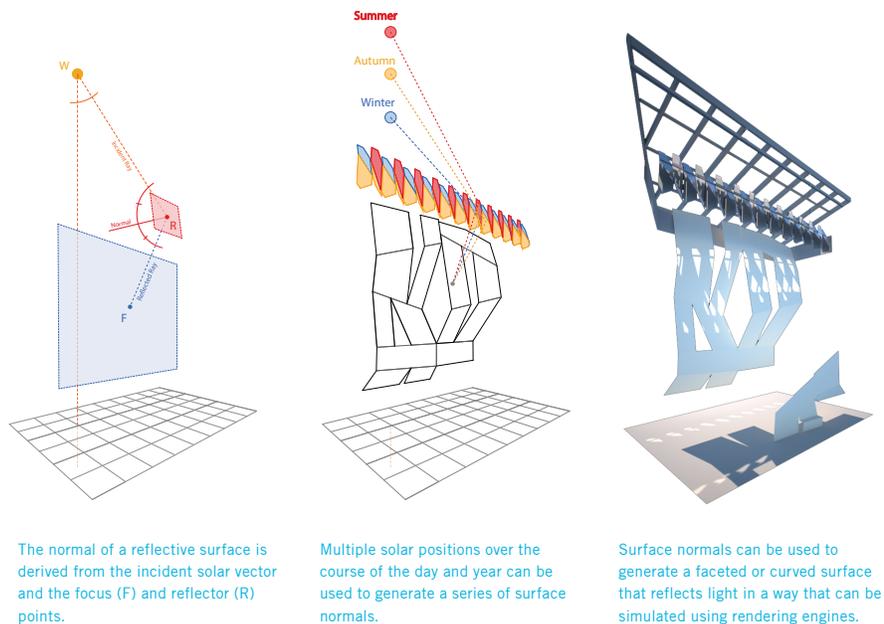


Figure 14: Daylight redirecting strategies at University Crossing.

4.2 Design Process

In studying the reflective and diffusing surfaces of the UMass Lowell Atrium, the team used a number of different tools and processes through the design phases. The following is a summary of the most effective tools used for the design and analysis.

4.2.1 Angular Studies in Reflection

The architecture of the UMASS Lowell Atrium can be conceived of as a “building scale” light fixture. The lighting source, reflective housing and diffusing materials are all present in the design. The source of this fixture is obviously not static. The dynamic angles of solar lighting require a rigorous, iterative and experimental approach to redirect daylight. The process starts with an understanding of the fundamentals of reflected sunlight.

Reflective design surfaces can be angled to aim the most subtle changes in incident vector that result from changing solar position.

Two vectors are needed to define the angle of the reflective surface, the first is the angle of incoming light known as the incident vector. The incident vector of incoming sunlight can be identified through various computer simulation tools or by using the altitude and

azimuth from a typical solar chart. The second vector is defined by two points, the target focal point within the building and a specified point of reflection. The bisecting vector between these two lines will be normal or perpendicular to the tangent of the reflective surface¹¹.

Targeted reflected vectors from multiple days during the year and times during the day must be identified to set loose guiding geometric parameters for the reflective and diffusing surfaces of the space.

4.2.2 Physical Modeling

Early in schematic design the team began studying the design through a physical modeling process. A large scale model was built and placed on a heliodon to simulate real solar angles. Physical modeling of daylighting strategies early on can be an incredibly effective method of exploration for the team. It can provide a rapid design, prototyping and evaluation loop that can be achieved with multiple team members present. The lack of specificity in the process liberates the team from the focus on precision that drives the typical computer simulation process. Video and photography can be recorded from the process and then presented in a way that engages the client without the level of abstraction and technicality associated with computational simulation.



Figure 15: Physical models.

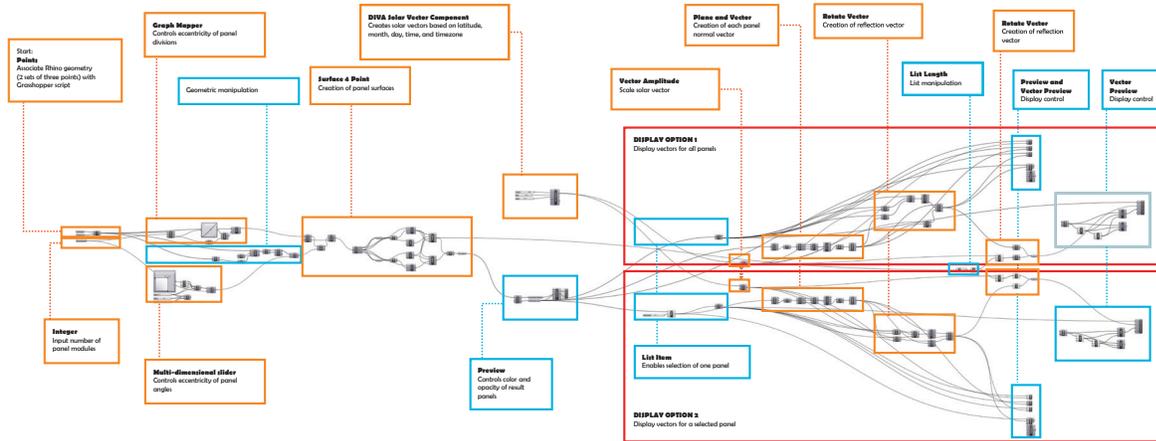


Figure 16: Grasshopper definition parametrically defining reflective surface geometry based on the visualization of solar incident angles.

4.2.3 Parametric Study

After studying potential reflective solutions loosely in physical model, the team moved to the computer to refine the design. At this point, a general scheme had been developed and the next step was to determine the specific panel dimensions and angles that would produce the desired redirection of light onto the lantern. Time constraints required that the team find a quick way to try out numerous variants and test their effectiveness. Lam Partners opted to model the reflector in Grasshopper, a plug-in for Rhinoceros, because the designers could create loose, parametric models that could be used to “sketch” digitally, allowing them to quickly change geometry and generate multiple variants in a short period of time. Grasshopper also allowed for a direct interface between building geometry and incident solar angles through the utilization of DIVA, a daylighting simulation tool built for the Rhino platform. By using a plug-in for Grasshopper, called DIVA-for-Grasshopper, the team was able to visualize the direct relationship between building geometry and the reflected rays of light generated at a given moment during the year.

Having selected this platform, the team needed to determine what simulations to use to evaluate the model. The most typical daylighting simulations’ results (values for illuminance and daylight autonomy, which simulate daylighting levels in a space) were less valuable to the study. In this case, the design goal was not to increase overall light levels in the space (light levels were high in general, given the skylight configuration and the north

glazed wall). Instead, the objective was to determine which reflector panel orientations would redirect sunlight onto the scrim and balcony lounges beyond. Lam’s team might have generated RGB or false color images that would show how the light was redirected with each reflector variant, but these simulations can take several minutes to run for each geometric variant. For this stage of the process, what was needed was to create a model that could give rapid feedback based on what panel orientations were most effective for particular sun angles.

The solution was a Grasshopper-enabled Rhino model, which displayed the direction and angle the sun would hit the panels at any given date and time, and would show the direction and angle of the reflected light. To create this, Lam’s designers used the solar vector component in the DIVA plug-in to generate the incident solar vector at any date and time throughout the year, and from there developed the model to generate the resultant reflected vector. The generated script also allowed for the display of incident and reflected vectors. Because this model does not involve light level simulations, the results could be reviewed in real-time as the date, time, or the geometric configuration was changed. There was another important value to developing the reflector model in this way. As integral members of the design team, the daylighting consultants wanted to create a “flexible” model that would be useful to the architectural team as a design tool. The model needed to be sufficiently adaptable so that it was still usable even if the design changed. The model could have been gen-

A Case Study in Reflective Daylighting

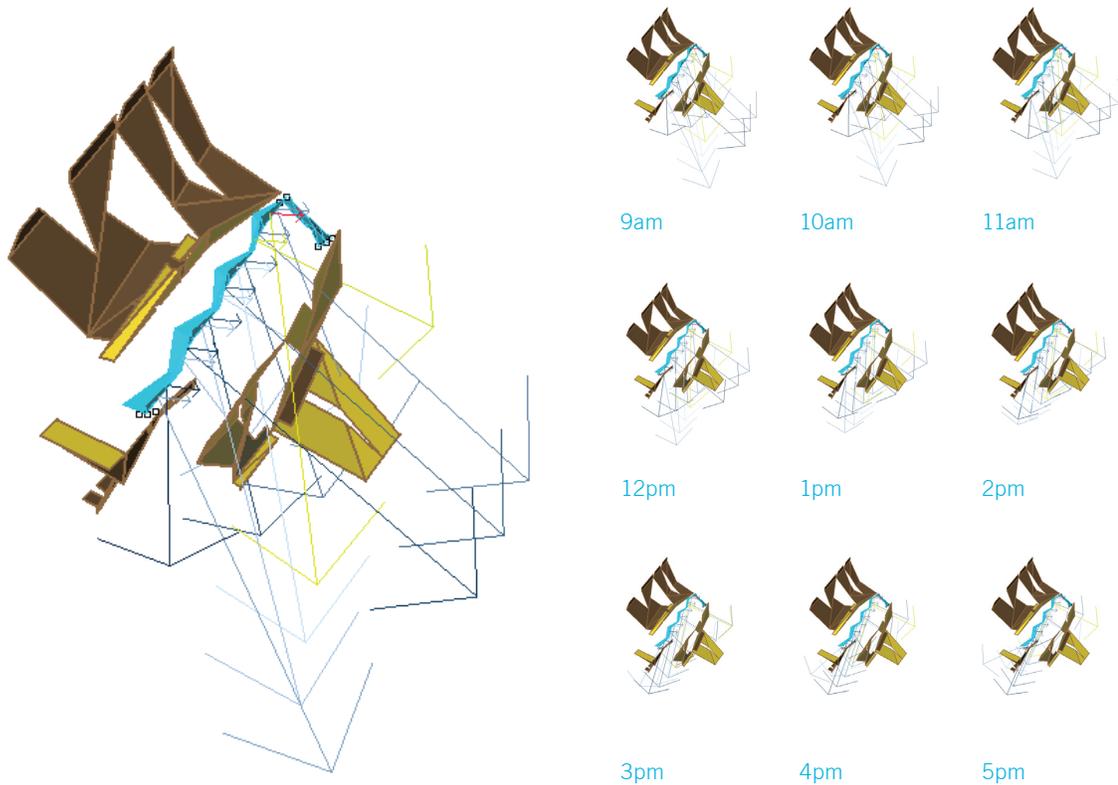


Figure 17: Using the DIVA plug-in, the solar vector component was used to generate and display the incident solar vector as well as the resulting reflected vector in real time.

erated based on a pre-determined time of day or year for the purposes of optimization, but that kind of model would have become restrictive if the design criteria had changed along the way. The team also wanted to maintain freedom in the model to adjust panel dimensions and angles as the process moved into the fabrication and costing stage. In essence, the team wanted to develop a system for collaborative design rather than a set of results. Using this model, both the architectural team and the lighting consultants could work together to determine the most effective and desirable panel angles. The solar vector display model developed here is evidence of a new way for architectural teams to collaborate, in which constraints and parameters are established by one party and modified by the other. Working in this way builds a common model in which the design is informed by the goals and constraints of each team member, but also allows the team members to

explore a wide variety of design solutions that satisfy those criteria.

4.2.4 Rendered Prototypes

Once the reflective geometry and the diffusing geometry was modeled and tested using Grasshopper and DIVA, the team used a number of ray-tracing rendering engines to further test the design. In this stage, the team also used conventional rendering techniques to confirm the aiming of the reflector panels. The project had proceeded far enough along to allow for a costing cycle to be complete and the reflector and diffuser geometry was simplified and technically developed.

To confirm the effectiveness of the reflective geometry, the reflector was set to a mirror finish allowing the target of the reflective light to be easily seen in the rendered images.

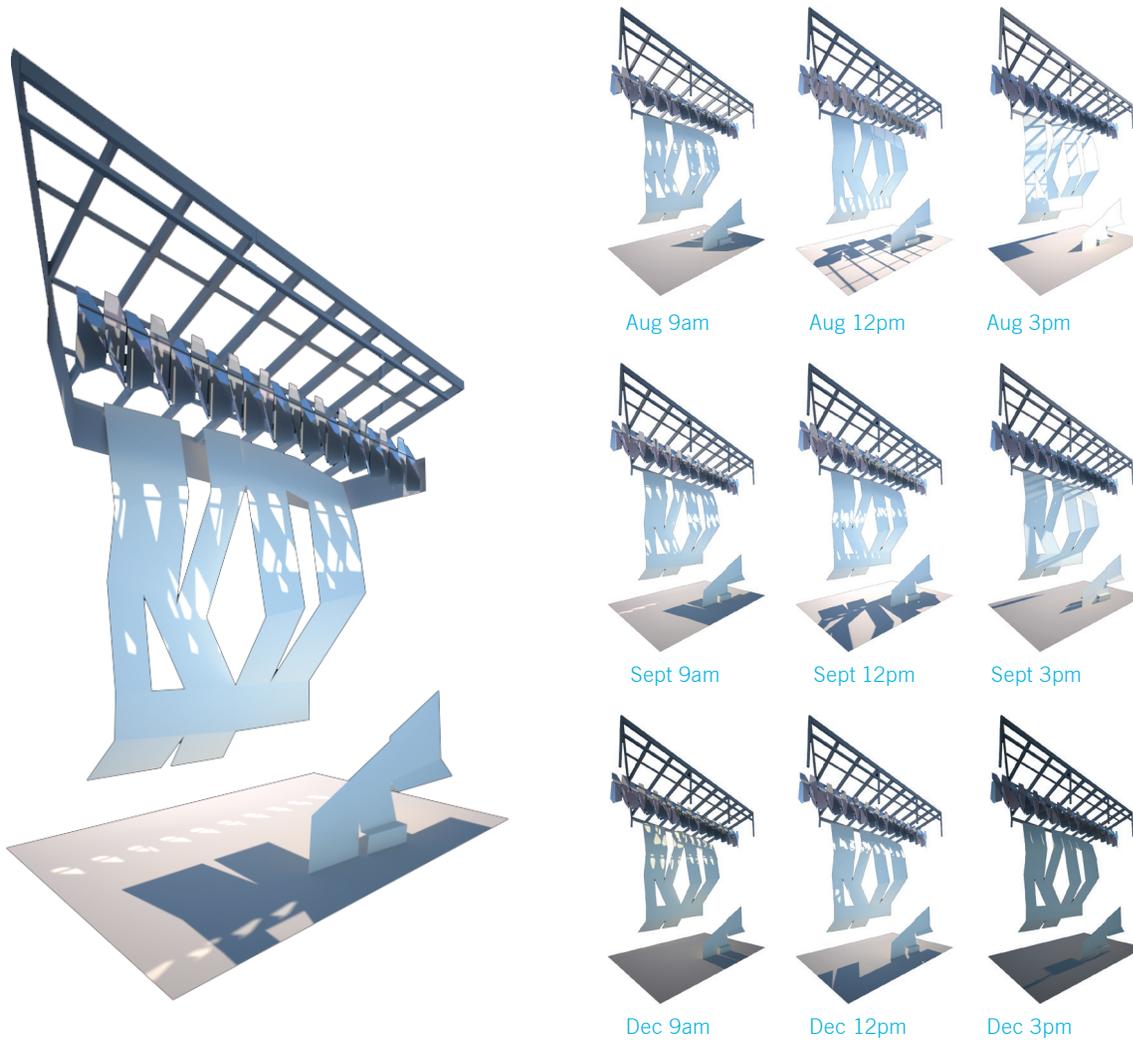


Figure 18: Rendered prototypes allowed the reflected light to be more accurately tuned.

5.0 MATERIALS AND CONSTRUCTION

5.1 Construction

In parallel to the geometric development of the reflector and diffusing lantern, the team explored various methods of fabrication and construction. The following section discussed the critical set of issues evaluated during the design process.

5.2 Reflector Location

Early on in the process, the team discussed the advantages and disadvantages of the physical location of the reflector. Key to this discussion was the building massing and orientation. The reflective geometry was largely driven by the orientation of the atrium and its skylight. Taking advantage of the linear skylight, it was determined that the most effective scheme was a linear reflective surface located on the south side of the atrium skylight. The angular analysis showed that the reflector geometry might have been developed inside of the

honeycombed panel substrate was selected to keep the supporting structure as minimal as possible. Operability was unnecessary since the variability of incoming solar angles was resolved with a varied geometry. However, the ability to tune the final angles of the hung structure was important and was accomplished through a simple adjustable horizontal cable system.

5.4 Reflective Materials

The surface of the reflector itself was an important variable within the design. A primary design goal for the reflector was to produce an active play of light over the lantern surface. With this goal in mind, the team selected a hammered aluminum panel with a mirrored finish. The concave, yet specular dimples of the metal surface act like small lenses allowing for a reflection of light that is diffused without a significant loss through absorption. The aluminum was light, inexpensive and could be veneered to the hung honeycomb panels. Aluminum, when polished, reflects the vast amount of the visible spectrum.



Figure 20: Expanded aluminum honeycomb substrate used for the reflectors.

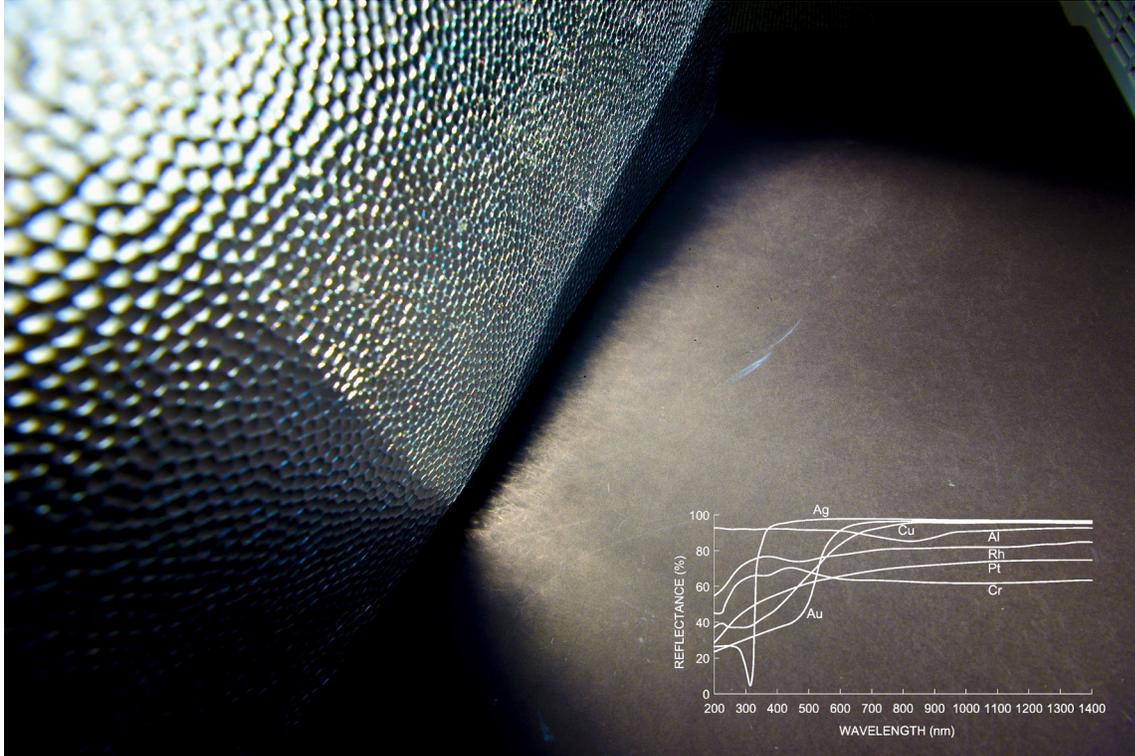


Figure 22: The concave dimples of the polished, then hammered, stainless steel surface act as small lenses allowing light to reflect and diffuse without significant absorption¹².

5.5 Material Considerations

The expansion of the metallic surfaces when heated by the sun was considered in the detailing. Each hung panel was kept isolated to avoid an aggregate of smaller expansions¹². The panels were designed within the dimensional constraints of typical metal coil widths to minimize waste in construction.

5.6 Diffusing Lantern

The surface receiving and diffusing the redirected sunlight acts in two directions. From within the atrium, the lantern is an architecturally unifying element and re-

ceives the play of light over the course of the day. It further reflects diffused light down to the atrium floor. Since the lantern surface is articulated as a visually permeable wood slat system, it allows a filtered patchwork of light to penetrate the balcony lounges. This warm, diffused natural light splashes the north facing student lounges at different times of the day during the year. Alternatively, the team considered stretched fabric panels, translucent glazing, metal mesh and other materials as alternatives for the diffusing lantern. The diffusing material needed only to reflect and scatter light to be considered within the lighting scheme.

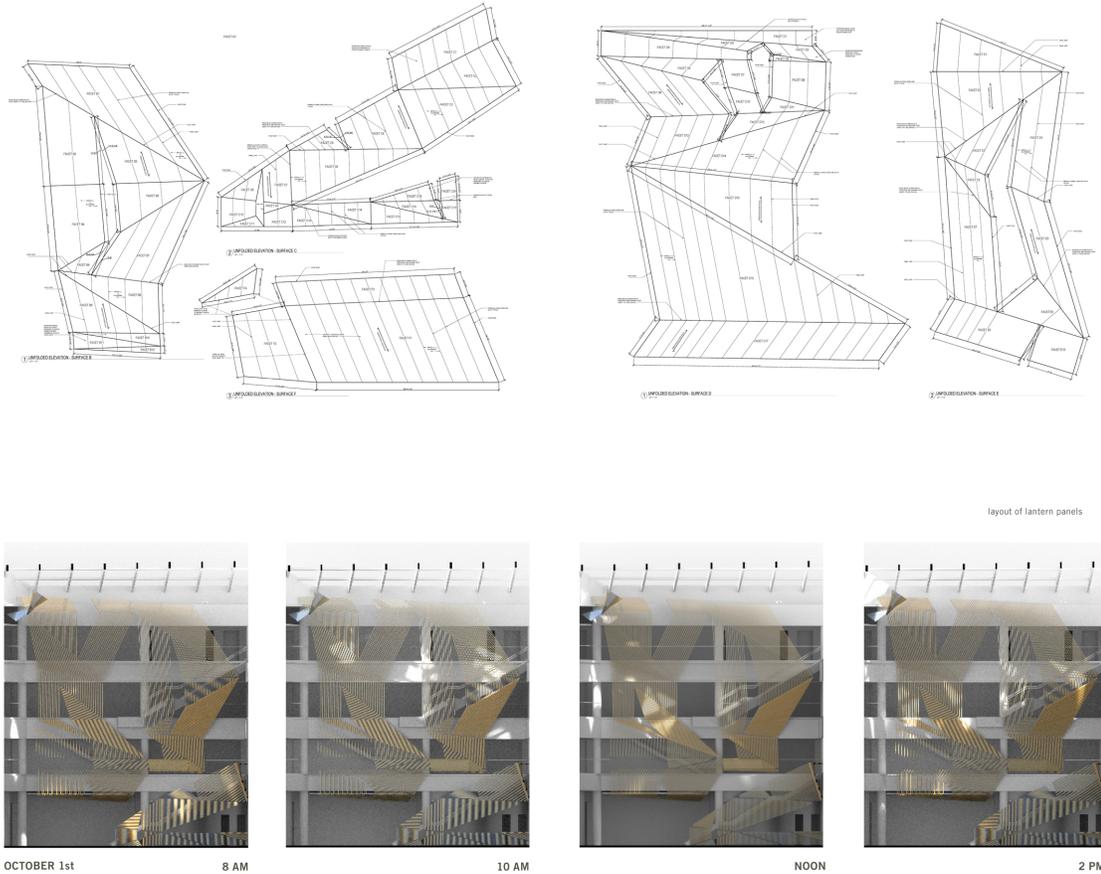


Figure 23: Final studies were rendered to test the reflected light on the lantern.

6.0 DESIGN METHODOLOGY

6.1 Iteration and the Collaborative Design Process

While working on University Crossing, the team engaged in a highly collaborative and highly iterative design process. After the design was complete, it became apparent that the process was crucial to the team's success and key attributes are described in the following section. We start by defining an iterative creative sequence: an iterative design process can be described as having four crucial phases, each phase is present in each successive cycle of non-linear design thinking¹⁴. The speed at which the team can cycle through a design iteration is crucial to the resolution of the design. The rate of iteration is likely to change over the course

of the design, cycling rapidly at first and lengthening as the design becomes more resolved and more complex.

6.2 Iteration and Research

Iterative design is a process-based design methodology. Within an iterative design process, research is embedded and research tools must be invented to help the entire team explore as a collaborative unit. Lam Partner's work in inventing scripted geometry to govern the reflective surfaces of the project was a critical example. As a cycle of iteration moves a concept forward, questions emerge out of the process of design evaluation. These questions alter the concept, defining subsequent design cycles. As a result there is both the opportunity for iterative waste as well as iterative progress in resolving the design. Within this process, waste can be defined as study or studies that fail to inspire decision

or redirection. Rapid and direct feedback from Lam's scripted geometry allowed the team to minimize design waste and quickly cycle through effective iterations.

6.3 Iteration and Invention

Crucial to a collaborative design process is the invention of common tools for exploration. Common tools allow for shared experiences, and therefore shared conclusions. They allow for a common and specific language for describing the design, and most importantly, they allow for the cycles of iteration to be started by one mind (or set of minds) and finished by another. In the case of University Crossing, the team used a number of cross-

disciplinary tools. Rhino, Grasshopper and Diva were used as a digital platform and physical models were exchanged. This freed the team to allow for multiple minds with different priorities, experiences, focuses and thought processes to iterate on another team member's progress.

Common tools and collaborative teams allow for conclusions to be drawn together rather than separately. Successful teams iterate based on common values, not based on active attempts to counterbalance another's design position.

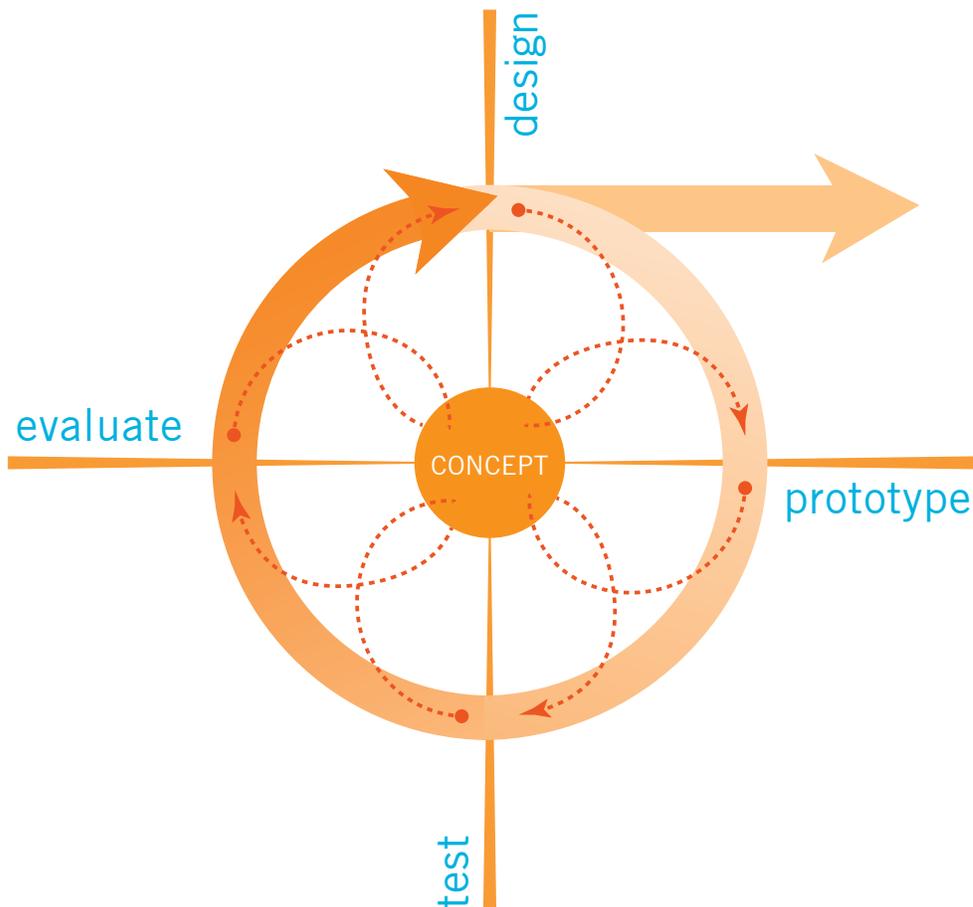


Figure 24: An iterative design process was critical to balance the technical and visual goals of the design concept. Each iterative cycle advances and influences the concept. At times multiple cycles may be running concurrently¹³.

Schematic Design

Design- Define the lighting concept and objective for the atrium and surrounding tributary spaces.

Prototype- Model various skylight aperture sizes and configurations based on lighting concept weighing section height, floor plate depth.

Test- Test the skylight aperture sizes through radiance-based simulation and building energy performance.

Evaluate- Evaluate the benefit of reduced lighting loads and quality of environment against heat loss and solar gain through glazing.

Early Design Development

Design- Configure atrium defining surfaces to receive, or further diffuse light. Determine the focus of directed light and propose reflector configurations using angular analysis.

Prototype- Model various skylight aperture shapes and reflector configurations to support earlier evaluations.

Test- Use radiance-based daylighting platforms and physical models to test effectiveness of focus points for multiple dates and times during the year.

Evaluate- Review the daylighting effectiveness and focus of the lighting to validate that it supports the initial design concept.

Late Design Development/ Construction Documents

Design- Begin conceptualization of tectonic approach to reflector language.

Prototype- Build physical models of the reflector and diffuser languages.

Test- Test the diffusion and reflectivity of the materials with realistic distances and lighting levels to confirm earlier simulations at a smaller scale.

Evaluate- Confirm that the physical simulations support the desired effect of the concept.

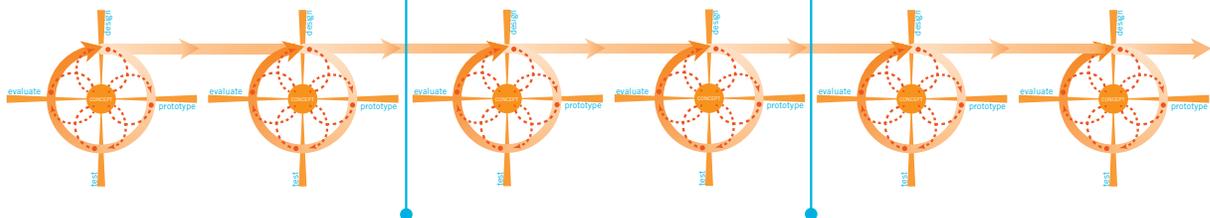


Figure 25: Design studies, prototyping techniques, testing and evaluation methodologies were present in each development cycle.

7.0 CONCLUSION

The design of University Crossing for the University of Massachusetts in Lowell provides a meaningful precedent for daylighting, both in process and in its built form. The team's exploration moved beyond the common simplicity of published rules for daylighting to test an expressive design language rooted in the challenges of sustainable urban growth.

As urban communities continue that growth, pressures will increase the need for sustainable, highly connective sites. Design opportunities like the one at UMass Lowell will become more prevalent and more relevant to the design of daylit buildings. It is imperative that designers explore new tools and new processes to tackle the challenges and complexities of daylighting deep footprint buildings on challenging urban sites.

Fundamental to these processes, is the work of creative, collaborative, multidisciplinary teams. As groups of professionals come together with differing skill sets, vantage points and creative ideas, they must use and invent common design platforms and processes to progress a design language. Advancements in customizable modeling tools, parametric design, rendering and rapid prototyping (as well as the tried and true methods of physical modeling) make true, interdisciplinary daylighting design an achievable goal. The linking of traditional and contemporary daylighting tools allows multiple generations of minds to contribute to the wealth of a design idea by balancing one group's knowledge gap in historical precedent with the other's in digital exploration. Studies of precedents set the creative groundwork for healthy iteration, priming the team with the fundamentals of tested ideas. This process pushes them to expand the architectural dialog with ideas formed from innovation, rather than simple improvement.

Digital daylighting tools continue to evolve. Prototypes built on a platform that can be used between multiple disciplines allows for an iterative process in which designers of each point of view can participate regardless of the specific stage in the iterative cycle. This allows for an efficient, creative exchange of ideas in which variations are prototyped, tested and evaluated against project aspirations in a fluid process. When explored efficiently, ideas that are tested, evaluated, but rejected become crucial to maturing the final design. The digital outcome of a highly iterative design process has the potential for direct translation to the growing computer aided fabrication industry. Physical prototyping along the way allows for practical tests of constructability and

helps in finding buildable solutions from traditional and current fabrication technologies. They help dissolve the risk of a complex daylighting solutions failure if the efficiencies of mass-customization do not prove a reality. The goal of smart, dense urban growth coupled with ambitious, varied design aspirations demands an exploration of daylighting that moves beyond the traditional methodology of simple implementation. It propels us to practice in a way that embraces the iterative processes of innovation and engage in the practices of prototyping and digital fabrication. With these aspirations we find daylighting can form the foundation to more expressive, sustainable design.

Acknowledgments

In some cases the creative process might occur as a focused individual study that can be described through monolog. The design of University Crossing at University of Massachusetts Lowell is not the case. It is the result of a passionate collaboration of many minds, many rolls and many disciplines. It follows that this case study represents the product of a large, talented team striving to contribute to an open, collaborative environment. The primary contributing design team members are listed below:

Perkins and Will: Dana Anderson (Principal), Brian Healy (Design Director), Patrick Cunningham (Project Designer), James Forren (Designer), David Damon (Associate Principal), Andy Goetze (Project Architect), Christina Long (Project Manager), Emily Lammert (Designer), Jennifer Rheaume (Interior Designer), Christine DiLallo (Designer), Sam Williams (Designer), Jessie Greenberg (Interior Designer), Edward Dudley (Designer).

LAM PARTNERS, ARCHITECTURAL LIGHTING DESIGN: Paul Zaferiou (Principal), Kera Lagios (Designer), Nathanael C. Doak (Designer).

REFERENCES

- [1] Ng, E., (2010). *Designing High Density Cities*, Toronto, Canada: University of Toronto Press.
- [2] Straube, J., (2012). "The Function of Form-Building Shape and Energy", Building Science Insights, Retrived on 3/2014 from <http://www.buildingscience.com/documents/insights/bsi-061-function-form-building-shape-and-energy>.

[3] Guglielmetti, R., Pless, S. and Torcellini, P., (2012). "On the Use of Integrated Daylighting and Energy Simulations To Drive the Design of Large Net-Zero Energy Office Building", Proceedings of SibBuild 2012 Conference, Retrieved on 3/2014 from http://www.nrel.gov/sustainable_nrel/pdfs/47522.pdf.

[4] Dekay, M., (2010). "Daylighting and Urban Form: An Urban Fabric of Light", *Journal of Architecture and Planning Research*, Vol. 27, No. 1, pp. 35-56.

[5] Ander, G., (2003). *Daylighting Performance and Design*, Hoboken, NJ: Wiley.

[6] Lam Partners Lighting Design, Project Design Archives.

[7] van Bruggen, C. and Gehry, F., (1997). *Guggenheim Museum Bilbao*, New York, NY: The Solomon R. Guggenheim Foundation.

[8] Lam, W., (1986). *Sunlighting as Formgiver*, New York, NY: Van Nostrand Reinhold.

[9] Williams, S., (1989). *Hongkong Bank: The Building of Norman Foster's Masterpiece*, Boston, MA: Little, Brown and Company.

[10] Jodidio, P., (2011). *Rafael Vinoly Architects*, Munich, Germany: Prestel.

[11] Unpublished Presentation, "Basic Principles of Surface Reflectance", Retrieved on 5/2013 from <http://www.cs.cmu.edu/afs/cs/academic/class/15462-f09/www/lec/lec8.pdf>.

[12] "Mechanical and Physical Properties of Metals", Retrieved on 3/2014 from http://www.worldstainless.org/what_is_stainless_steel/Mechanical_and_physical_properties.

[13] "Digital Eskimo", Retrieved on 3/2014 from <http://www.digitaleskimo.net>.

[14] Gould, J. and Lewis, C., (1985). "Designing for Usability: Key Principles and What Designers Think", *Communications of the ACM*, Vol. 28, No. 3, pp. 300-311.