The role of structures in daylighting retrofits for existing buildings

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ABSTRACT: As a greater emphasis is put on reducing the environmental impact of buildings, the implementation of successful daylighting strategies becomes an integral part of this process as electric lighting accounts for thirty percent of all electricity used in buildings in the United States. Daylighting contributes to two critical factors in the design of sustainable buildings. First, proper daylighting levels within a space reduce the need for electric lighting as well as decrease internal heating loads, thus lowering the overall energy consumption of the building. Secondly, successful daylighting schemes have been proven to improve occupant health and well being, also increasing worker productivity. While new buildings can be designed with favorable orientations, shallow floor plates, light shelves and other strategies for optimizing the use of daylight, existing buildings, particularly those with deep floor plates, must be retrofitted to reduce electricity consumption. The structural systems of existing buildings can both inhibit and support daylighting retrofits, specifically the use of skylights. This paper explores the interactions of structural systems and daylighting through the use of simulation software, specifically the ability of structure to reduce glare by blocking direct sunlight and distributing light more evenly. The development of a parametric methodology for optimizing daylighting based on the existing structure and programmatic goals for the space is explored through the design of a retrofit of an existing 1960s laboratory building that is being converted into office space.

1 INTRODUCTION

1.1 Rationale

The operation of the built environment consumes a large portion of the energy used in the world today. We are confronted with an antiquated building stock, most of which are nearing or past their original design life-span of around 40 years. An important question in the progression of sustainable building practices revolves around what should be done to these existing buildings, which were designed during a time when energy was more readily available than it is today. Should these buildings undergo intense retrofitting to bring them up to today’s energy standards or should they be demolished and rebuilt? If the choice is made to retrofit an existing structure, it is imperative that the rigor involved with the retrofit design process ensures the energy efficiency is of an optimum level upon completion of the retrofit. When the building profession is charged with the retrofit of these buildings it is critical that there are established workflows to ensure high-energy performance designs. The improvement of the energy efficiency of an existing building is a multi-faceted design problem. This includes creating an adequate amount of daylighting in the retrofit of existing buildings. Improving the amount and quality of daylighting is imperative. As a greater emphasis is put on reducing the environmental impact of buildings, the implementation of successful daylighting strategies becomes an integral part of this process as electric lighting accounts for thirty percent of all electricity used in buildings in the United States. Daylighting contributes to two critical factors in the design of sustainable buildings.
First, proper daylighting levels within a space reduce the need for electric lighting as well as decrease internal heating loads, thus lowering the overall energy consumption of the building.

Secondly, successful daylighting schemes have been proven to improve occupant health and well being, also increasing worker productivity. Unlike the design of new buildings, which can be designed specifically to perform at an optimal level, the retrofit of existing buildings requires the designer to conform to a defined set of parameters that were not originally conceived to promote energy efficiency. These challenges include improper site orientation, deep floor plates, and structural systems that are not designed to optimize daylight efficiency. Although these systems may present the designer with obstacles, they may also be used strategically to promote an efficient daylight retrofit. The development of a workflow which can help to understand the limitations and potentials of the existing systems, specifically the structural system, could help inform successful design decisions. A potential workflow utilizes daylighting simulations in the schematic design phase to explore quick iterations early in the design process.

1.2 Daylight simulations and parametric design

Daylight simulations have been available for quite some time, however, until only recently have tools been available to the designer to generate complex design and analysis variations in a reasonable amount of time. Through the utilization of an initial parameter based distillation map, the 3D modeling program Rhinoceros 5, along with the integration of the parametric design plug-in Grasshopper and the Radiance/Daysim plug-in known as DIVA, the designer is provided a tool to prepare a large number of accurate design iterations within a reasonable amount of time. This paper describes the development of a workflow for daylighting design through a parametric design process to be applied to the retrofit of existing buildings with an emphasis on the role that the structural system plays in the development of the design. The development of the design workflow will be described and analyzed, providing insight into the integration of parametric daylight design as a tool for the successful retrofitting of existing buildings.

Understanding that green building rating systems, including the US Green Building Council’s LEED program (USGBC 2005), encourage daylighting simulations, many design firms are reporting that they are in fact using daylighting simulations as a component in their practice (Galasiu and Reinhart 2007). Computer aided daylighting analysis techniques have been available for decades, however, until recently the process has not provided the designer with an ability to perform a multitude of iterations in a reasonable amount of time (Lagios, Niemasz and Reinhart). In the past, the prescribed workflow consisted of a laborious process, which involved the transfer of geometric files into alternate software programs. Due to the extensive process involved, many firms postpone the process, resulting in the data becoming available to the design team too late in the design process for the information to be useful (Galasiu and Reinhart 2007). The integration of parametric design into the daylight analysis workflow greatly mitigates this cumbersome process. Parametric design is defined by Lagios, Niemasz and Reinhart as “a practice of digitally modeling a series of design variants whose relationships to each other are defined through one or several mathematical relationships (parameters) which then form a parametric space which may comprise of dozens or thousands of related but distinct forms.”

Through the utilization of the 3D modeling program Rhinoceros 5 along with the parametric design plug-in grasshopper and the DAYSIM/Radiance integrated plug-in DIVA and the application of the defined workflow the designer is offered a tool for the analyzing of multiple daylighting schemes through a rapid iterative process based on the specified design parameters.

2 METHODOLOGY

2.1 Overview of the workflow

The intention of the workflow was to provide design firms with a process that can be navigated quickly and efficiently, providing a useful tool early in the design phase when it is critical that proper design decisions are made. The process was translated into a parameter distillation map, which provides the designer with an easy to navigate methodological tool. The intention was to prioritize specific design goals in relation to the time it would take to perform and distill a par-
ticular design option. By doing this, design possibilities could be iterated quickly, resulting in a more efficient workflow.

The initial input parameters are based on existing conditions and design goals. This includes climatic conditions at the site, project typology, existing and proposed mechanical systems that would directly affect the daylight scheme, existing daylighting design and existing structural conditions, which includes a study of the existing structural bay size and roof thickness. The next input parameters were the design teams goals and metrics, which include design parameters such as desired amount of direct sun on the workplane, acceptable amount of glare on the workplane as well as illuminance and daylight factor goals. Once these initial parameters have been established, a value would be found determining the amount of available daylighting “real estate”. This would determine a usable range of roof area for the integration of skylights. The initial simulation parameter, based on ease of testing, is the amount of time direct sun is observed on the workplane. This was done as a direct observation of sunlight on the workplane using the Sun feature in the latest service release of Rhino 5. Exact times were recorded and compiled as an overall amount of time the sun was observed on the workplane throughout the course of the day. The input options were derived from the initial existing conditions studies as well as the design teams goals and metrics. The structural system specifically was used as a design tool through the process of selecting possible options. The variants included number of skylights (which directly effected the size of the skylights), skylight ratio and the shape of the skylight. Observing the direct sunlight on the workplane resulted in a number of possible options. The next simulation parameter explored was daylight autonomy and glare. This was chosen due to the quickness by which DIVA produces a visual image describing daylight autonomy visually along with the integrated Evalglare feature in DIVA, which can also be ran quickly. This iteration would be, once again, based on the design team goals and would be explored using variations on the spacing of the daylights discovered in the first parametric iteration. Finally, options would be explored running simulations based on design teams goals for Daylight Factor and Illuminance.

3 CASE STUDY

3.1 Applying the workflow

The Oregon Primate Research center is located in Hillsboro, Oregon as part of the OHSU West campus. It was designed and built by the architecture firm SOM Architects during the 1960s. The existing building has footprint of 170 feet square with a central courtyard. The current retrofit, by SRG partnership in Portland, Oregon, is focused on the creation of a central atrium space, which will replace the existing courtyard. The program is expanding upon the current research lab typology to include open office space surrounding a central, sky lit atrium. The area concerning this study was the central atrium space and the open office area surrounding it, which are oriented axially on the north-south axis (Figure 1).

The climate is the typical Marine west coast climate associated with and around Portland, Oregon. The structural system is steel based on a 5-foot bay spacing that is axially oriented north south. Four large air-handling units are being introduced during the retrofit and are centrally located around the atrium space and it’s respective skylights, which consist of four 6-foot by 6-foot skylights. The roof has a typical thickness of 2 feet with a designed suspended ceiling, which extends the daylight depth over the open office space to 3 feet. The total square footage of the roof is 28,900 square feet. The design goals and metrics consisted of minimal direct sun on the workplane, minimal glare on the workspace, a daylight factor of 4 80% of the time, and a target footcandle value between 30 and 50. The available skylight real estate ranges from 434 square feet based upon a skylight ratio of 2% to 723 square feet based on a skylight ratio of 3%. The first step in the development of the workflow was to input all of this information into the parametric distillation map (Figure 2).
The second step was to import the Revit model provided by SRG into Rhino 5. A grasshopper definition was written based specifically on the existing 5-foot structural bay to explore the potential inhibitors as well as benefits of the structural system (figure 3). Initial iterations were done using the Sun feature in Rhino 5 to observe the amount of time direct sun was present on the workplane (figure 4). Rectilinear skylights running parallel to the structural bay on the north-south axis were found to deliver an excessive amount of direct sun on the workplane and were therefore eliminated as an option. Six square skylights over each open office space produced a minimal amount of direct sun on the workplane. The most effective option was to orient rectilinear skylights on the east-west axis, perpendicular to the structural system. The advantage of this orientation was that the structural system could provide an embedded baffle system, which allowed for shading during the morning and the evening. Variations of these two options were then studied using the visualization simulation in DIVA (figure 5) along side of the Evalglare feature in DIVA (figure 6). This resulted in 2 options that the design team chose to explore further. These 2 specific options were explored based on the design teams daylight factor and illuminance goals. Option A included six 4 foot by 4 foot skylights over each office space. Option B included two 4 foot by 17 foot skylights oriented on the east-west axis at 14 feet on center.
Figure 2. Parametric Distillation map.

Figure 3. Grasshopper definition built to respond to the existing 5 foot structural bay.
3.2 The role of structures

The evaluation of the two final options offered insight into the role of structures in the daylight design of the retrofitting of existing buildings. Option A consisted of six 4 foot by 4 foot skylights placed over the open office area. These skylights fit in between the structural bays, exemplifying how existing structure could inhibit the design process. Option B included two 4 foot by 17 foot skylights oriented on the east-west axis at 14 feet on center. The structure was used to act as natural baffles from early morning as well as afternoon sunlight. This option exemplified how structure could help promote a successful design solution. This particular scenario describes how an iterative workflow can inform design decisions for schematic design that can take advantage of the existing structural system.

4 CONCLUSIONS

As the retrofit of existing buildings, specifically those which are nearing their original projected life-span of 40 years, become an increasing percentage of the current project bank for the building industry, it is imperative that new workflows are developed to ensure projects with an optimize energy performance standard. The development of quick, iterative workflows have the po-
tential to be beneficial to design firms to ensure use in the schematic design phase due to the general lack of time to develop effective energy efficiency studies in the short time span associated with the schematic design phase. The workflow described in this paper utilizes the common 3D modeling program Rhinoceros with the parametric plug-in Grasshopper and the Radiance/DAYSIM plug-in DIVA to explore an iterative workflow for daylighting design specific to the retrofitting of buildings and the effects existing conditions, specifically existing structural systems, have on daylighting in retrofit projects. A parametric distillation map was constructed to inform the simulations with accurate and useful information. The workflow was then designed with efficiency in mind, beginning with a simulation that could be quickly iterated to reduce the number of possible options. This quick distillation of potential options is intended to create a usable workflow for schematic design. By combining this iterative workflow with the knowledge of existing conditions, specifically structural systems, the designer is offered a tool to intelligently inform design decisions.

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6 REFERENCES