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DEVELOPING A WORKFLOW FOR DAYLIGHT SIMULATION

Daylight requirements simulation in early design stages to address the Green Star ratings within local regulations.

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Abstract. Daylight simulations are occasionally used as active tools in regards to local governing regulations, which are necessary for providing documentation. Simulation tools have been avoided in the past due to their barriers. Daylight simulation tools are used within documentation design stages as 'passive tools', however they do not have a direct impact on the architecture design decisions, as passive tools are used by engineers usually to derive material and glass specifications. Recent developments within an online community have provided designers with access to daylight simulation tools within a design platform accessible data can be modified and represented with local governing codes to provide designers with relevant information. The paper aimed to develop an active daylight simulation tool within a design platform. Data is filtered with the Green Star benchmarks to export visual information as well as a voxel matrix instead of 2D luminance maps. This paper outlines a workflow of the simulation tool used to evaluate daylight performance of a selected building as a case study in real time. The paper also details potential problems and justified suggestions derived from the analysis for the building to reach the requirements within the Green Star Multi Unit Residential

Keywords. Data-driven design; computation environmental design; daylight simulation; Green Star.

1. Introduction and motivation

Early design stages of building development use energy simulation techniques to analyse a building's performance in accordance to local governing regulations (Elghazi 2014). Daylight simulation is often applied during design process prior to submitting the design concept to the planning authorities, however due to the inconsistency of 3D programs used, the simulation becomes passive and redundant through the development stage. Yet, simulation tools can provide data as evidence to help assist in generating and understanding the consequences of design decisions (Lam et al, 1999), helping the user make informed decisions. Therefore, adjusting the functionality of simulation tools within the workflow can help transform daylight simulations into a data driven project.

Daylight simulations prove, through applying physic rules within a mathematical framework, if a design meets the criteria set by local regulations, however they are not currently used consistently as drivers of data driven design. The Flemish government analysed the results of a questionnaire targeting Flemish architects and revealed "less than 30% of the respondents mentioned simulations…" (Verdonck et al, 2011). Alternatively, another survey on Singaporean design firms supports the use of simulation tools in design (Lam et al, 1999). Simulation outputs enable data driven design to play an impactful role in early design stages. Hence the question persists: Why are daylight simulations not used regularly to achieve local regulations within preliminary design decisions? Government agencies have become more aware with the effects of building construction relating to the surrounding environment. The U.S. Green Building Council and Green Building Council of Australia have acknowledged the need for building design changes and compiled voluntary regulation tools to outline the future of the built environment.

2. Research observations and question

Software is available for New South Wales and Australian regulations including 'State Environmental Planning Policy 65 – Design Quality of Residential Apartment Development' (SEPP 65) and 'Leadership in Energy and Environmental Design' (LEED), however Green Star rating requirements have no tools to test designs against its benchmarks. Simulation software has become necessary for proving a proposed design that meets the minimum criteria for emerging compulsory and voluntary regulations. The lack of design support tools for Green Star generates friction within design from achieving the requirements by using simulations and analysis methods. As a result architects may not be encouraged to aim towards the Australian standard of sustainable design. Daylight simulations currently play impactful roles in design with initiating and performance improvement (Frazer, 2014). Plug-ins within Grasshopper can import EnergyPlus Weather Files (.EPW) to generate environmental information for the preliminary design stage including shadow study diagrams and solar radiation (Roudsari and Pak 2013).

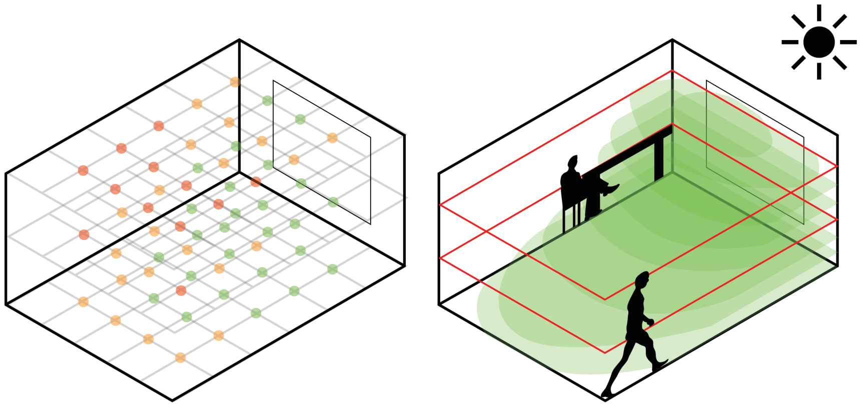

Figure 1. Concept diagrams of 3D daylight simulations. (1) Voxel based simulation, grid representation (2) Mesh representation of lux value contour lines.

3D based simulations are not traditionally used within design stages, however they have the ability to identify design effects in which traditional software would not be able to show (Gianni Botsford Architects 2008). Volume based simulation can identify the levels of daylight in a specific point, allowing designers to understand the consequences of façade and roof openings (Frazer 2014) to further improve and understand the design. The project will experiment with volume simulation within a matrix to improve traditional simulation tool which outputs 2D graphical representations such as Ecotect and Autodesk Green Studio, and assisting in providing a greater understanding of a projected model's relationship with its envelope and interior.

The project aims to create a daylight simulation tool to assist with reaching Green Star Multi Unit Residential benchmark requirements. The decision support workflow is intended for the early design stages, when the building's form has been designed and an elementary layout is generated. Most industry standard tools require multiple resources, requiring both the cost of the software and user training (Verdonck et al, 2011). The project will use accessible technology available through open-source software to develop a workflow aimed at assisting in reaching the Green Star daylight requirements.

Daylight requirements from the Green Star Multi Unit Residential require computer simulations to prove an evaluated building meets the minimum requirements (Green Building Council of Australia 2015). The project needs to provide useful information to designers; raw data will confuse rather than inform designers. Data from the daylight simulation will be compared with Green Star daylighting requirements and projected visually into the model giving a detailed analysis.

Based on these observations the paper aims to develop an active daylight simulation tool, acknowledging Green Star requirements by: presenting a workflow intended to help designers address daylight requirements defined by Green Star Multi Unit Residential to identify design concerns in an early design stage within a voxel based daylight simulation.

3. Background research

Verdonck (2011) argues that, the majority of architectural practices had negatively portrayed simulations. Justifications for not using simulations dominated the benefits of applying simulations and simulations tools were also resisted due to the complexity and cost for running simulations.

Velux and Ecotect are existing daylight simulation tools that can help assist in the developments of buildings. The tools export the necessary information in 2D images to help impact the developed design stages and provide adequate information for documentation of regulations but do not apply the regulation layer. Data within the software cannot be extracted without the help of a third party application, making it difficult to manipulate the generated data into visual information by designers.

Geco is a plug-in recently designed for Grasshopper and Ecotect linking the 3D modelling tool and energy simulations in a reduced feedback loop, assisting in reducing the missing gap between simulation and modelling (Grabner and Frick 2013). This solution helps achieve a fluid workflow between modelling and simulation, actively reducing the time needed for design improvements. Preliminary daylight simulations are used to assess the initial framework of the design, to the surrounding environment, however they are currently not addressing regulations. Light House by Gianni Botsford Architects (2008) used a daylight simulation to analyse horizontal planes at different elevations to visualise the daylight and solar data in the building. The simulation data influenced a reversed traditional housing layout, granting daylight priority to the living rooms and open private areas on the higher level. The unique layout of the house was a result of positive data driven design through the use of 3D daylight simulations.

Green Star requires either daylight factor or annual dynamic model simulations in the documentation application. Daylight factor models are considered a subpar measuring method, because they do not consider building orientation, sky options and operating schedules (Welle 2009). An annual dydynamic daylight model will be preferred due to the consideration of the sites geographic location and more control over simulation data. This brings the research to the topic of compliance and validation tools currently used. In Australia, the New South Wales regulation 'State Environmental Planning Policy 65 – Design Quality of Residential Apartment Development' (SEPP 65) is compulsory for all new multi residential buildings. Sefaria is a performance design plug-in used for the modelling tools to generate reports identifying the design consequences in comparison to SEPP 65 requirements (Sefaria 2015). Sefaria is used to help achieve an improved workflow to assist the designer in achieving the SEPP 65 requirements. Existing tools in design programs perform early stage assessments of their rating systems including LEED. The paper wants to conclude the background research by briefly discussing topic of feedback loops.

Due to constraints including cost and time in the design stages, outsourcing simulations for building analysis is costly and takes time to develop, urging the need for immediate feedback tools (Morbitzer et al, 2001). Decreasing time consumed in the feedback loop will help assist designers by drastically reducing time constraints. Without the access to a reduced and customised feedback daylight simulation tool, designers attempting Green Star requirements need to use experience and rule of thumb techniques.

4. Research methodology

Drawing from existing knowledge in literature in sustainable design, design tools, compliance and validation; the research develops a workflow that aims to increase the accessibility of daylight simulation techniques through Grasshopper plug-ins *Ladybug* (Roudsari and Pak 2013) to import .EPW / EnergyPlus Weather Files into *Honeybee* that runs an energy analysis simulation.

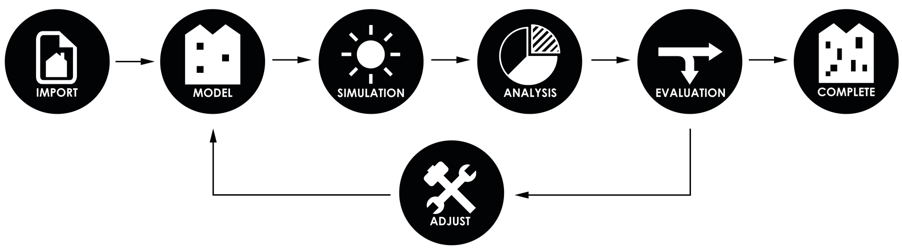

Figure 2. Projected simulation tool flowchart.

The data from the simulation will be compared to a benchmark tool developed in this research with requirements from the Green Star daylight requirements to produce a report to check if requirements are fulfilled. In the workflow, the model is first prepared for daylight simulation by the user applying specific material properties to the surfaces of the building. Test points are generated on the surfaces, representing the room's floor and multiplied vertically to generate the one-meter voxels matrix. The data are used to calculate statics when compared to the Green Star daylight requirements. The user is given the choice to improve the simulation by adjusting the model inside Rhinoceros. Further, the simulation will not only show compliance with local regulations, but also represent the data extracted to highlight strengths and weaknesses in the design, providing an analysis for improvement in the early design stages in an improved workflow.

5. Case study

Summer Hill Flower Mills Apartments is a proposed multiple residential building in the inner west suburbs of Sydney, Australia. The buildings designed by HASSELL Studio are inspired by the site's previous flourmill architecture, an adaptive-reuse of concrete silo into multi-residential building. Within stage 3 of Flower Mill development, building 3C was chosen to test daylight simulations. The building has problems with natural light entering the building. The daylight lighting problems associated with Building 3C will generate the greatest conflicting results, outlining the possible benefits of the workflow developed in this research. Building 3C is currently not aiming for Green Star certification.

Multiple problems relating to daylight are inherited from the existing site conditions; making it difficult to improve the volume of daylight. Areas pertinent to Green Star within building 3C have difficulty reaching the minimum daylight requirements as prescribed in the Green Star Multi Unit Residential. Multiple simulations are used to compare and evaluate the efficiency in the placement of rooms. Simulations were run using a) only structural and external walls and b) the building as it is currently designed. Comparing the data identifies the effects of the different design elements on daylighting.

5.1. RESULTS

The daylight simulation has shown that Building 3C has poor access to natural daylight. Rooms adjacent to windows occupy a small percentage of the area in which successfully passes and contribute to the Green Star requirements. While the internal walls restrict the movement of daylight, the design of the buildings core foundations has created natural resistance to receive natural lighting. The limitations on the structural walls and windows create great difficulty to increase the levels of daylight to achieve the benchmark requirements. The initial simulation shows large red areas (low daylight levels) in the middle, demonstrating an efficient placement of space when judged from a Green Star compliance perspective. The Green Star daylight requirements only require nominated areas to be measured. Nominated areas exclude bedrooms, sleeping areas and bathrooms and include internal habitable areas including kitchens and living rooms. In building 3C, the western apartment has problems with daylight reaching the nominated areas, however the bedrooms receive a large amount of daylight and would achieving the criteria if they were nominated.

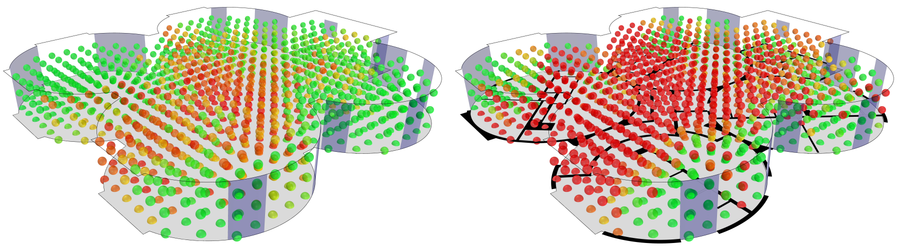

Figure 3. Level 8 of Building 3C. Left: Voxel daylight simulation results before internal walls are accounted; Right: Voxel daylight simulation results after internal walls are accounted.

Restructuring the apartment room layout would increase the amount of daylight entering the nominated areas, the kitchen and living room, by using the existing window's exposure in the bedroom. The suggested restructuring is unlikely to proceed due to the bedrooms having no access to windows and natural light.

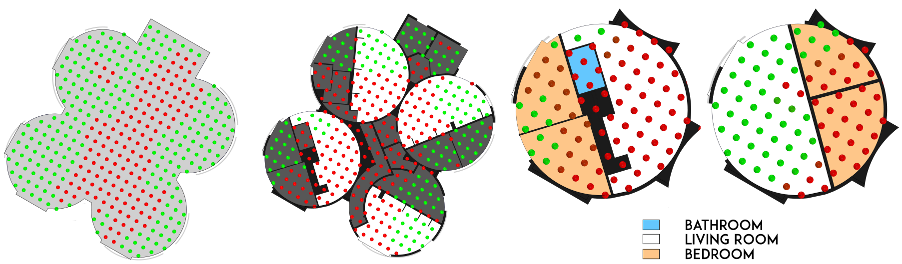

Figure 4. Level 8 of Building 3C. Daylight simulation of the level before and after the internal walls are accounted. Building 3C level 8 west apartment. Designed layout again proposed layout, giving larger priority to Green Star nominated areas.

5. Limitations

The simulation increases in time based on the number of points. This is a function of distance between each point the area being tested and the floor to ceiling height i.e. $O(n^3)$. A balance between density of points per volume and consumed time is required to create the most effective use of the tool. Voxel simulation consumes a greater amount of calculation time than 2D daylight simulations. An experiment method to decrease calculation time was derived from generating lower density voxel to select the targeted areas and creating a targeted point cloud, decreasing the amount of calculated points by approximately 20%. Reducing points through this method is directly related to the volume of targeted points.

The workflow heavily relies on the input geometry to be created within Grasshopper and Rhino. Imported geometry from other modelling software including Revit, can create errors with the simulation workflow. Incompatible geometry needs to be recreated manually to allow the user to run the successfully simulation. The model transfer from Revit to Rhino created geometry that gave the simulation difficulties. The bathroom in the west apartment initially revealed incorrect of daylight within the area enclosed because surrounding walls were incorrect. This decreased the overall accuracy of the analysis. When the geometry was recreated in Rhino and Grasshopper, the simulation was successful in providing accurate results. Simple geometry generated within the modelling software is more likely to be successful than imported geometry from Revit.

6. Evaluation

The daylight simulation tool successfully analyses the space and building within a voxel matrix. While the information generated on several level can help in the early design stage to find design impacts, the simulation is unnecessary towards the documentation process, Green Star only requires measurements on the finished floor level. Results from the simulation formatted into a voxel grid provide daylight information within a 3D space. The workflow needs further evaluation on the potential impact within the early design stages by testing on a building in preliminary development. Building 3C is well within the documentation stages, therefore changes to the buildings structure cannot greatly impact the design. Proposed suggestions are recommended derived from the information gained from the daylight simulation data. The method in which Honeybee runs the simulation does not enable a continuous data stream. Comparing the designed tool against existing software is hard to determine the effectiveness due to the different designs stages. Considering the programs in use accessibility, the simulation was successful in providing an alternative to existing market programs for daylighting analysis.

Intermediate skill knowledge of Grasshopper and Rhinoceros is required to use this tool to create the proposed geometry. The use of layering systems in practice will increase the time efficiency of the workflow. While the majority of the work is automatically processed, different level of user inputs are required to complete a daylight simulation and analysis. The number of geometries also created some inconsistencies within the simulation results, rare occasions include not picking up surfaces. The numbers of inputs are lower than traditional energy simulations due to the pre-defined nature of Green Star requirements, making it quicker for experienced users. An evaluation though practice will help redefine the complicated stages of the workflow to increase the usability. The proposed tool only commits an analysis on daylight requirements within the Green Star. Local regulations have multiple criteria that are necessary to receive certification. Adjusting the levels of daylight interacting with a building can affect other building properties including energy performance and natural ventilation. Existing projects and software compare the different regulations categories, allowing the designer to identify the non-daylight consequences in their designs. The software may negatively affect other aspects of design due to a tunnel-vision effect, not increasing the designs overall value.

7. Significance of project

The research team concludes that this research is significant as it: (1) Provides an accessible daylight analysis tool that can influence design decisions to achieve the minimum requirements Green Star Multi Unit Residential benchmarks. (2) Investigates the openings of façades/roof and the relationship between the interior volume and the façade within early design stages. This is relevant as most other scripts that are developed computationally are superficial and the process of this research address this issue and enable designers to create informative design decisions and being more aware of green design and building performance.

8. Conclusion

The tool is successful in providing an accessible daylight simulation and comparing the results to the Green Star daylight requirements. The importance of a Voxel daylight simulation was not enhanced with Building 3C due to the overall design. With further developments, the project will evaluate the accuracy and effectiveness with existing tools accessing the industry standard tools to the developed workflow. Additional further developments include investigate in different methods to reduce time needed to generate the voxel results including selective point cloud simulation testing.

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