LIGHTING THE FUTURE

Optimising lighting and its management through adaptive computational methods.

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Abstract. Lighting in spaces over the past decades has not seen many advancements although technological improvements have introduced an extensive amount of optimisation and benefits in the practice of architecture. We have witnessed the implementation of computational methodology to automate and produce better arrangements, so why hasn't it been implemented in lighting? This research paper will probe the notion and plausibility of using computational design to resolve less optimised, streamlined and costly lighting solutions. The simulations, parametric 'rules' and visual communication will exhibit the potential of computational design to a wide range of audiences. The visual simulations also allows users to quickly understand and engage with their design decisions and make better changes iteratively. This will motivate more users and the industry to adopt computational design practices as well as encouraging further studies.

These simulations which have been paved into computational tools allow for accessible and straightforward configurations which have become more prominent now, will further enhance outcomes that the industry has still not addressed. By employing an action research method for this research it will examine the processes, analyse the next iteration and further develop the process for lighting optimisations. Resultantly, this comprehensive exploration into computational optimisation will demonstrate the advantages and shortcomings of the practice, expediting the principles of this tooling to more of the industry.

Keywords. Computational Optimisation; Dynamic; Parametric Lighting; Modularity; Efficiency

Introduction

Improvements in technology over the last three decades has graced the advancements of the built environment. These substantial changes stemming from technological updates have made developing designs more cost efficient, optimised and 'simpler'. A few decades ago it was conventional to have static arrangements which were repetitive and often done by hand, while these solutions work, newer computational methodologies which implement extensive tools are able to quickly explore and cater for better solutions to a client's request at a fraction of the time. Computer aided design tools have also allowed for a new form of communication and engagement, this means the multitude of configurations and solutions are not only quickly achievable, but are also easily communicated and widely 'understandable'.

This paper will focus on these benefits by utilising the Rhino and Grasshopper platform, a parametric design tool to further fast forward lighting design, optimisation and construction. Whilst it is common to argue that the integration of such tools may 'mar' design, lighting is a major component to all spaces that has barely seen any changes in its development or arrangements. More explicitly, this paper will explore and educate the possibilities of such a tool in interior productivity oriented arrangements, both office spaces and more industrial environments.

One of the factors in lighting resulting in repetitive and less efficient arrangements is that there is a functioning system in place that is configurable and modular already, consequently there has been no incentive to innovate and lighting mechanics are often overlooked. While the system has been operational and is widely implementable, the success ends there. We see the same arrangement in building spaces far too often, and while lighting fundamentally is a straightforward concept but it is never integrated and prioritised in earlier stages of development resulting in our arrangements today. This is due to the handling process for lighting, it would be immensely tedious and expensive to manually develop lighting arrangements for a space, especially at large such as high rises. Simulating and optimising lighting positioning and its wiring management would be extremely difficult to achieve without computational means and so we witness in situ processes that are less pleasing visually, messy and expensive. With more time and research being focused on computational design in the built environment, we are able to progress from these less efficient processes allowing for more comfortable, modular and polished solutions in spaces that are being developed.

With this movement towards computational design integration, we live in an exciting period where users are able to collaboratively innovate and experiment on a platform that can be made sense of by both conventional and newer practitioners in the industry. With software such as Grasshopper the barrier of computational literacy is further mitigated and we witness newfound problem solving cognition. This research will exhibit the ease and accessibility to optimised lighting and its cable management using these methodologies more suited to our time. Given the reference geometry such as a floor plan and type of lighting required, it will generate the layout and wiring diagrams that can be handed over to labourers and constructed efficiently. It will also address the dynamic adaptability to existing spaces or forms. Ultimately, the developed tool is to be implementable throughout the industry with minimal computational literacy, making the process straightforward and engaging.

Research Aims

The primary objective of this project is to facilitate architectural practitioners of all proficiencies with a tool to produce location and purpose optimised lighting in work spaces. These goals are set to work within a 6-week period and stem from the initial obstacles and complications found in earlier development:

Primary:

- Dynamic, re-usable and accommodating tool for both existing analog floor plans and future spaces.
- Optimised lighting adaptations through mathematical algorithms collaborating with different datasets extracted from geometries within the floor plan.
- Visually communicate the optimised lighting outcome for straightforward evaluation and understanding.

Secondary:

- Incorporate technical lighting management concepts for real world application/fabrication

Research Question(s)

The research question for the paper forms the benchmark for the project and envelopes the purpose of this development for a more efficient workflow in managing lighting solutions. It should explore computational methodology prospects and flaws especially as this technology is being implemented into the future.

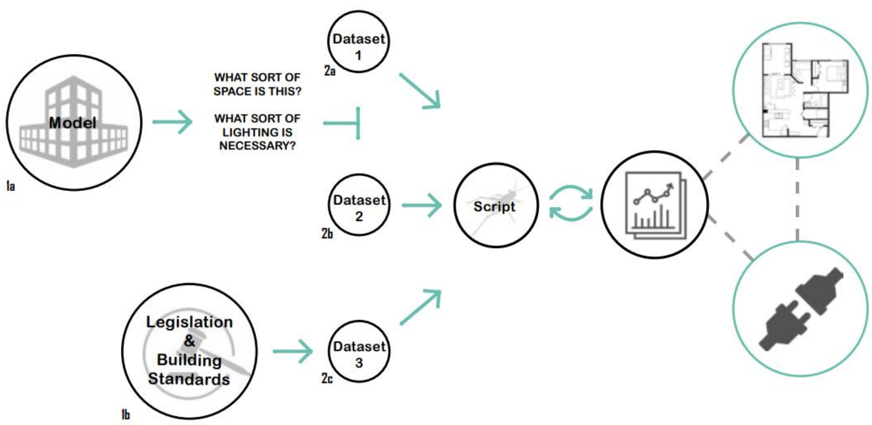
Can the integration of computational tools in lighting management enhance building performance and how will it be implemented into today’s fabrication methodologies?

Methodology

The methodology in this endeavour should resultantly be an implementable tool when finalised and will be achieved through an action research format. This process of work cycle enables successful outcomes through evaluations of various iterations through the project. Enhancements are made to each iteration and further analysis is done to achieve the successful end solution. Traditionally, this iterative process involves a circular 3 steps before a conclusion is reached, the planning, implementation and experimentation, analysis and evaluation.

The initial step is to define the direction for the project. A plan is created to successfully further the research and understanding of the work. Literature reviews and technical analysis of existing processes are done to gain deeper understandings of current lighting implementations in work spaces and will aid in creating a successful computational tool as well as cultivating the industry audience about the benefits of computational design methodologies to create adaptive and optimised solutions. Resultantly, a clear research question is constructed and the paper exhibits a straightforward transition to this changed practice.

Step two is the experimentation, this is where the research and design process is actioned. Given a six week working period, a workflow schematic is established where objectives and time constraints are considered. The workflow depicts the process of when and how the experiment is performed where data collection, principles and issues in the practice are factors. As this paper intends to innovate and educate lighting construction in different spaces, the workflow showcases the different data sets, communication and interaction between platforms and the options for optimisation as needed in varying spaces.



This action based workflow process begins with a floor plan in 3D space, quantitative data collection including room sizes, seating arrangements, and location is taken. These various dynamic & static data are referenced into computational simulations where a grasshopper script will then showcase an overview of an optimised lighting arrangement ready to be constructed and managed in that space. The results are then collected for further analysis in the next step.

Step three is where the results are arranged and analysed, charts and diagrams of the process are generated to identify further areas of improvement. As this lighting and comfort oriented project is difficult to convey textually, the results are primarily visual and observational. Issues in the optimisation are identified and documented on diagrams and renders for the next iteration to resolve. This procedure repeats until either a successful or incomplete conclusion is evident.

The last stage, step four is where conclusive reflections are drawn. These evaluations are shared to the public and communicate the success and shortcomings of the research. This outcome will constitute further probing and questions where additional controversy will lead to further work.

5. Background Research/Literature review

This With demand for modern commercial spaces increasing, the development of automated lighting solutions is necessary now more than ever. As interest and innovation in contemporary workspaces continue to grow, emerging evidence suggests that models are being designed to "produce specific performance outcomes, such as productivity and innovation". (Waber, B. et al 2014) Lighting has a critical role in the way people experience a space, Richard Kelly putting it as what "excites the optic nerves, …stimulates the body and spirit, sharpens the wit." (1952) The objective then is to be able to automate the creation and arrangement of lighting in spaces in a manner that is more organised, human centric, and less resource intensive.

Although current lighting arrangements are functional, it is heavily manual, labour intensive and inefficient. Many existing approaches suffer from several design flaws ranging from a fixation on aesthetics (Moeck, M. 2001) to lack of integration into the 'building life-cycle process' (Hitchcock, R.J. 1995). Significant progress has been made in relation to computational architecture and design optimisation, however, a noticeable gap and opportunity exists for the architecture community to address. It is crucial to understand that a one size fits all approach has not been, and is not practical, considering that different commercial spaces have different requirements (Luther, L.B. 2017), and that the benefits of optimised/adaptive lighting have been thoroughly researched and realised. As such, it is only natural that along with the research, design practices and methodologies must adapt and evolve concurrently.

The process whereby lighting, and cables are configured can be simplified and automated. By accounting for the requirements of the space (e.g. desk sizes, room sizes), location of building i.e. to conduct light analysis, and type/s of lighting to be used in the building, this tool seeks to systematize and streamline the following:

1. How many lights should be set up
2. How the lights should be arranged
3. The best path for cables to be wired through the structure

Analysis of the different light (lux) level recommendations for different commercial spaces in the 'The Internet of Lights: An Open Reference Architecture and Implementation for Intelligent Solid State Lighting Systems' (2017) further highlights the fact that a default template for lighting arrangements is simply not feasible. An evaluation reveals the sheer disparity between lux requirements, for example, with an office, 500 lux is required, compared to corridors/rest areas (<100 lux), restroom (100-300 lux) or precision/workshop lighting (1000 lux). It is evident that a manual process is required every time in order to plan out the lighting arrangements depending on the layout of the floor, rooms, desks, amenities and more. With this tool, the arrangement process will be automatic whilst also leveraging natural light and existing workplans where possible.

Table 3. Lux requirements in various conditions.

Lux Level	Area or Activity
20–30	Car parks
<100	Corridors, rest areas
150	Stairs and escalators
200	Lounges and dining rooms
300	Background lighting (e.g., IT office, classroom)
500	General lighting (e.g., office, meeting room, kitchens)
1000	Precision lighting (e.g., quality control)

Figure 1. Lux Level Table

As well, this script aims to be reusable and adaptive to different geometries/commercial spaces so as to identify, arrange and construct the most efficient, aesthetic and organised arrangement of lights and cables. Doing so allows for integration and prioritisation in the building life cycle, reduced costs and manual intervention to ascertain the cabling for every light, and provides an option besides the default path of checkerboarding lights across the whole floor, in areas where:

a. The lights will not need to be used as much e.g. due to abundance of natural lighting, or space is used for purpose that does not require much light e.g. stairway/storage
b. There is an opportunity to be more ecologically and economically friendly e.g. one light between desks as they positioned close to windows/where there is natural light
c. Other solutions such as sunroofs, motion sensor lights, solar powered lights, could be utilised e.g. on roof tops, aisles/walkways, outdoor spaces

Mark Luther (2017) notes in his ‘The Application of Daylighting Software for Case-study Design in Buildings’ study of several commercial spaces over ten years (studio, university office building, school library and gymnasium) that “the use of even the simplest software, can guide and inform design decisions in daylighting.” This not only emphasises the importance of incorporating light analysis into architectural pursuits, but also how simple it can be to do so with basic tools such as Google Sketch Up, Desktop Radiance, 3D Studio Max etc.

Management of architecture projects are known to be quite resource heavy and require manual planning, inputting of geometries of buildings, as well as mapping of floor plans. The rise of computational design and simulation generation have helped to visualise project plans, and to communicate progress throughout the execution of said ventures. Automating the process of generating light arrangements has many benefits, the most prominent one being that a seamless solution is generated for commercial spaces, and ready to be used promptly. Additionally, parametric tools can be reused so this automated lighting configuration tool could be utilised again for another space, reducing the time and cost of developing new designs and minimising the effort required for standardisation. (Matthews, E. et al 2017) This also addresses the industry’s lack of proactivity and innovation as seen when there is little to no prioritisation for lighting set up earlier in building design phase which can lead to scope creep and unexpected or higher costs. Solid State Lighting (SSL) i.e. LED lights will be utilised for their reduced operational costs, energy consumption and wellbeing benefits in this tool, thereby making this solution not only more efficient compared to current default lighting practices, but holistically cheaper and economically viable too.

Case Study

As the research probes the notion of using computational tools to create lighting solutions from floor plan geometry, the case study will be separated into three areas of focus:

> 6.1 The extraction of data from the linework in floor plans into Rhino/Grasshopper from which the quantitative/numerical data can be used in script and 3D forms generated.
>
> 6.2 Exploring the optimisation options available within grasshopper simulations and scripting.
>
> 6.3 Preparing this arrangement to be fabricated in a real world application.

6.1.1 Data extraction from floor plans

Figure 2. Existing floor plan in PNG format

To begin lighting optimisation for a space, the floor (Figure 2.) plan needs to be reconstructed within rhino. By obtaining an accurate re-creation of the space, more datasets can be used to sort and create rules for the optimisation process. As most floor plans are either in PDF or an image format, we are able to import the file with the PictureFrame tool.

Right away it is apparent that a lot of manual labour is necessary to extract data from an image to use in grasshopper. The manual recreation of each space is not feasible in real industry practices as it's extremely time consuming. As the project aims to be implementable across the industry, my attention is directed to constructing a system to accept and recreate geometry of the floor plan efficiently. Regardless of which platform a space is developed in, all mediums are able to produce the floor plan in an image output. Here I implement the 'Image Sampler' component within grasshopper to recreate the geometry. The component recreates images through colour contrast and brightness into line and point work.

Once adjusting the settings to 'round' all gradients on the image to a '0' value depicting white and '1' meaning black, we are able to sort and utilise the points generated to create a near perfect representation of the space. However this 'off the shelf' component suffers when the space is less conventional where walls are curved, there is 'interference' around non-linear spaces and extra points are created in a staggered formation. However, further trialling of this process exhibits that it is still accurate enough to be used in this industry lighting application.

Through this successful process, all floor plan data is effortlessly converted into a medium where spatial data can be extrapolated for grasshopper to utilise. (Figure 3.)

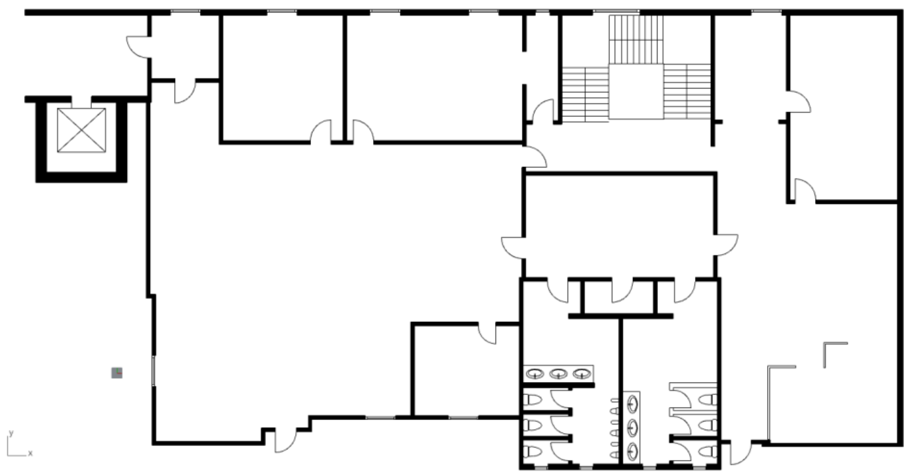


Figure 3. Static Floor Plan Geometry converted into Rhino line work

6.2.1 Grasshopper simulations and optimisations

ITERATION 1

The first attempt focuses on achieving lighting positioning in the space. As the static geometries have successfully been constructed, I move onto the importation of desk and seating arrangements.

This was performed by moving all static line work such as walls and windows into a Rhino layer and then isolating the rest of the geometry inside. The left over point geometry is referenced into grasshopper and used to generate spot lighting positions in the ceiling.

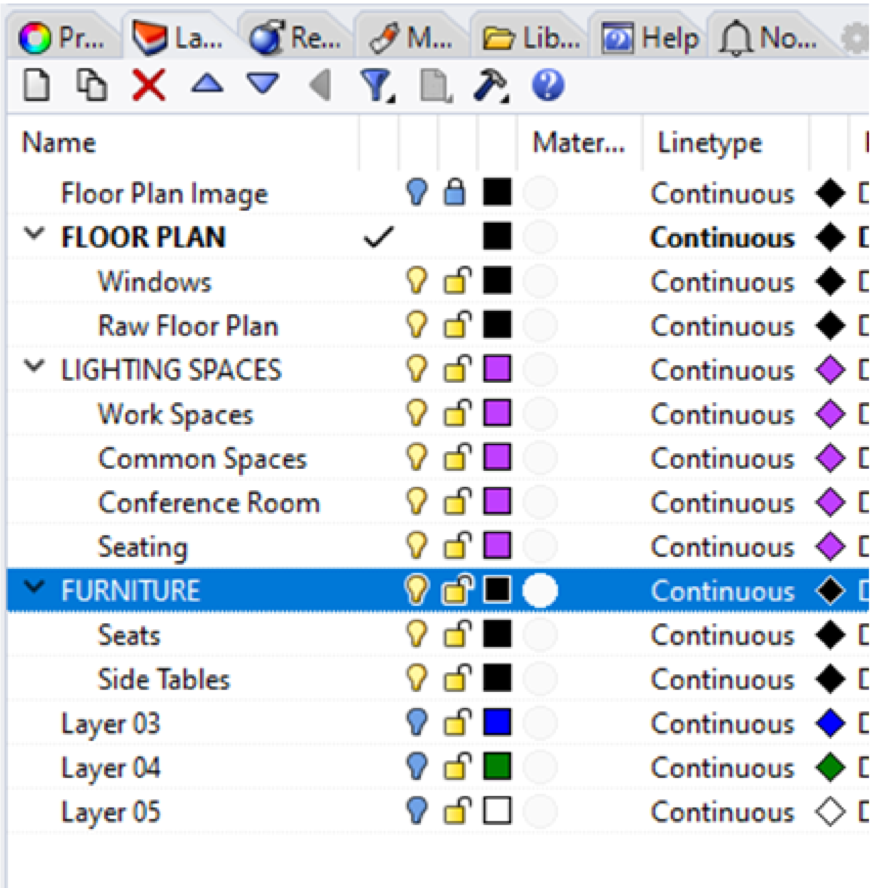


Figure 4. (Extracted geometry sorted into Rhino Layers)

Although this first iteration proves to be a successful stepping stone for the concept, it is not flexible enough to be implemented in real world applications. At this point, lighting is being placed directly above table spaces and there is no adaptive mechanism in the script to address different types of lighting and spatial dimensions such as desk sizes and ceiling heights, consequently there is no verification that the lighting will cover the space adequately.

ITERATION 2

The second iteration takes a different route to address the technical aspects of lighting. As the first iteration administers a linear solution, other dynamic parameters and data need to be incorporated to further the employment and optimisation of this tooling. Many major factors were added and reworked as inputs and mathematic algorithms into this second iteration of script to ensure that the projected lighting coverage is sufficient.

- Using geometry instead of points
- Lighting technicalities and specifications
- Location and lux simulations

Using geometry instead of points

Previously lighting positions were extracted from point geometry where the points indicated the centre of a desk. The issue with this method is prominent when a visual evaluation of the projected light is being conducted. Without the desk geometry being incorporated into the floor plan, there is no geometry for grasshopper to resolve. Furthermore, the absence of a desk graphic in the floor plan means there is also no visual communication of what the light is covering.

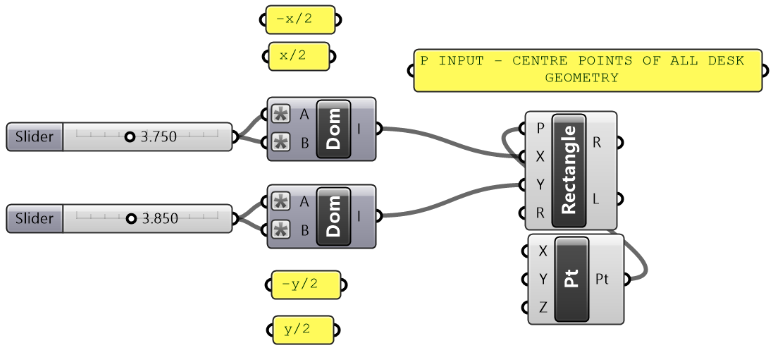


Figure 5. Successfully reworked Rectangle component to form geometry around a centre point.

As grasshopper does not have a rectangle around centre point component allowing the geometry to expand in –x, x, -y and y-axis simultaneously (Figure 5.), mathematical algorithms are implemented through domains to reconfigure the 'Rectangle on plane' component, where the first domain is the width of the table and the second set is the length. This configuration where the domain inputs to X & Y similarly utilise –x/2 and x/2 equation to redirect the length in both positive and negative directions of the axis is important to the accuracy of the light positioning as the process now works off of a desk area based arrangement and retains the centre point. (Figure 6.)

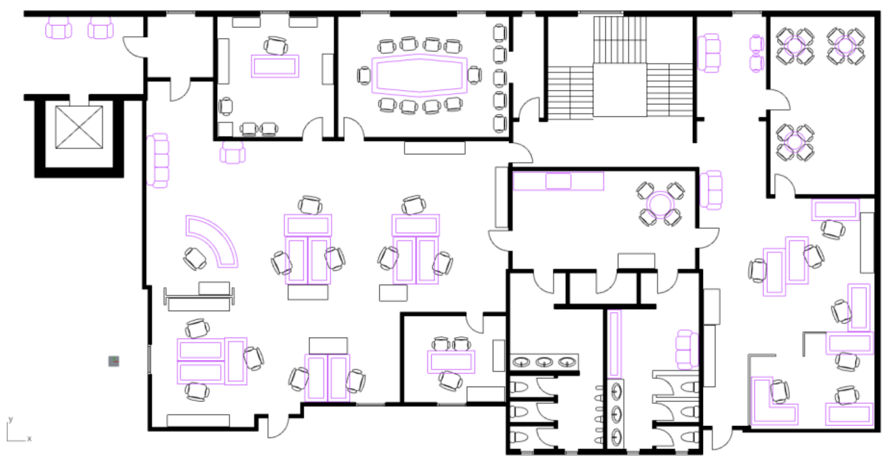


Figure 6. Using reworked component to form work spaces on the floor plan.

Types of lighting

In this step, the technical specifications of different lighting is accounted for. The first lighting solution we configure is LED down lights as they are the least intrusive, quick to install and output 700-900 lumens, making it a cost effective option. Manufacturers specify that the lighting spread and focus is determined by the ceiling height. In office spaces where ceiling height is predominantly 2.7 metres, the light focus is at a 2 metre diameter. Using these specifications we create a linear scale that adapts to different ceiling height inputs to scale and cast an accurate representation of the light projection onto the floor plan (Figure 7.) In this way, we also establish the maximum spacing between the down lights to be 1.5m to ensure some overlap and even coverage which can be implemented into spaces where full coverage is required.

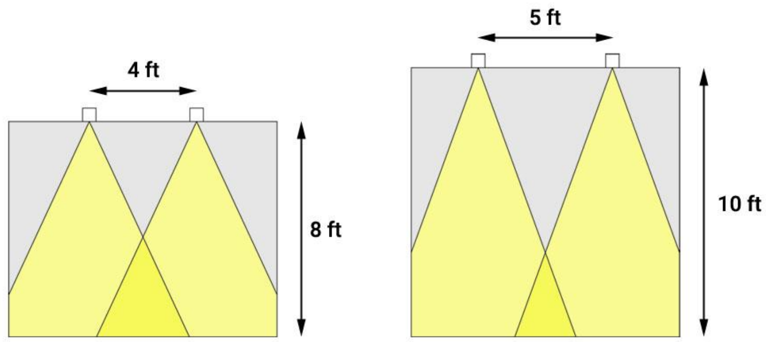


Figure 7. Downlighting spatial arrangement

Location and Lux Analysis

The platform used for daylight simulation and light analysis in the research is Ladybug & Honeybee, a package plugin that is freely accessible. The geometry is imported the ladybug engine where locational simulations are performed by importing a location file. Diagrams such as sun-path, radiation and shadow analysis are produced at this location. Honeybee is able to further the simulation through validated simulation engines such as EnergyPlus and OpenStudio for lighting and energy simulations and provides visuals for the analysis. (Figures 8 and 9.)

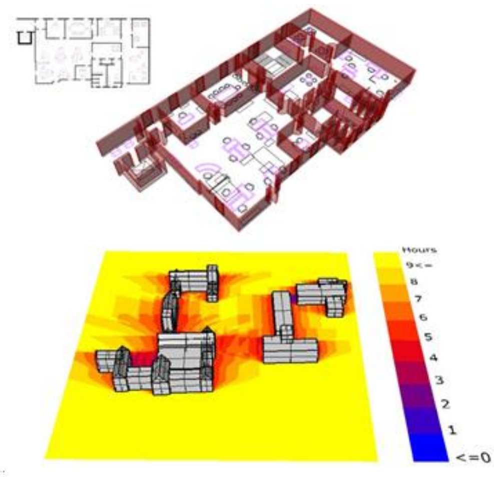


Figure 8. Ladybug - Hours that exterior walls are receiving sunlight.

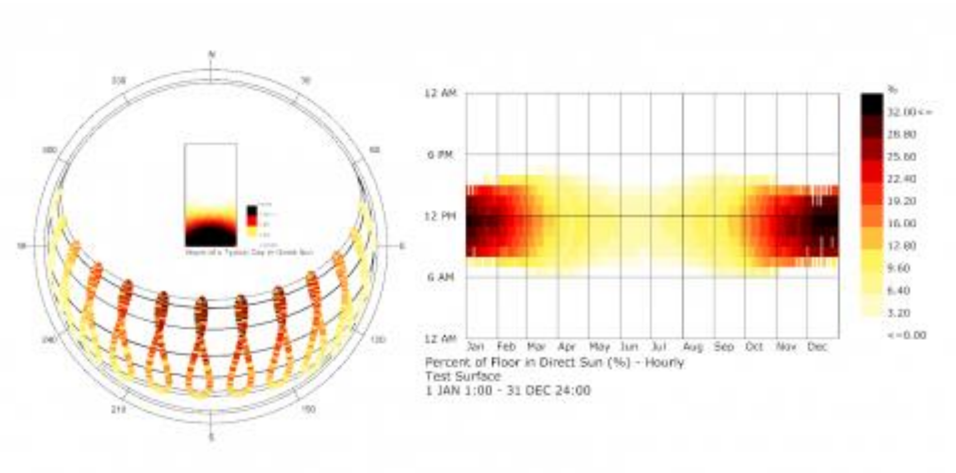


Figure 9. Honeybee- Percentage of that is receiving sunlight.

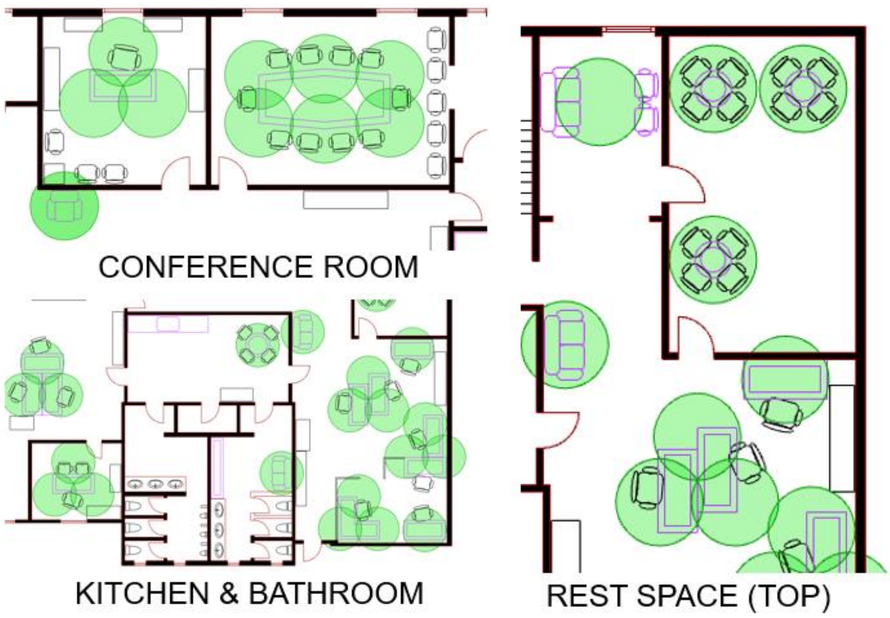


Figure 9. Successful lighting coverage (Green circles indicate light projections)

In Figure 9 we witness the first successful optimisation where all datasets have been fed into the tooling other than ladybug & honeybee. It is visually evident that the optimisation has sufficiently covered desk spaces of all orientations and further accepts all geometries by utilising a boundary box around less conventional forms such as bathroom cubicles and lounge spaces. The area component is then applied to the boundary box where a dispatch list function sorts them into different sizes and hence different amounts of lighting are applied.

If need be, manual spot lighting adjustments can be added by simply constructing a point on the floor plan requiring extra attention.

A second option 'tracked lighting' where multiple lights are angled out from a centre point is introduced at this point. (Figure 10)

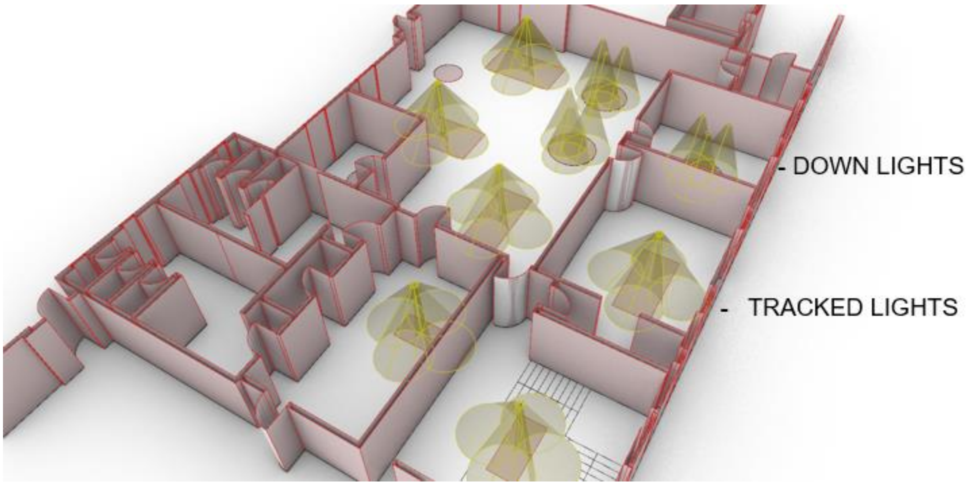


Figure 10. Tracked and Downlight options

Real world application and technicalities

To further the application of this tool in the real world, the next step is to understand the electrical system and technicalities of lighting applications. Fundamentally there are two methods of 'daisy chaining' electrical components, and that is either in 'series' or 'parallel'. A light bulb can be said to have 1 input and 1 output, positive and ground.

A series circuit method is when they are joined through interchanging the positive and ground, the current passes through the positive of the first bulb and out the ground, where the positive of the next bulb is using the 'left over' power the initial bulb has not used. This method would mean over a longer circuit the bulbs would get indefinitely dimmer. Furthermore if a bulb on the circuit was to break, the circuit would no longer be functional and all lights would be dysfunctional and thus not suitable in this application.

A parallel circuit occurs when all positives and ground are joined in uniform and hence cannot be interrupted by a broken bulb.

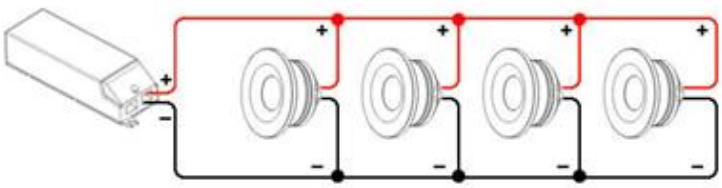


Figure 11. Parallel Circuit with power source at beginning.

This means as long as a two core wire is thick enough to adequately support the amount of amperage being drawn from all the lights on at the same time, a single dual core cable can be run around the ceiling as shown in this generic wiring diagram. (Figure 12.)

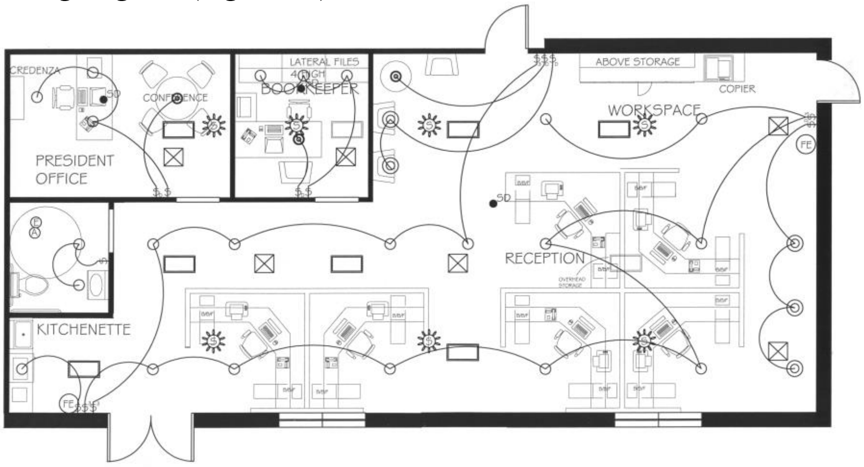


Figure 12. Generic wiring diagram for lighting

As the 'attic' in between floors is quite unobstructed, we are also able to pre-emptively generate a wiring diagram to simplify and cheapen installation. The point location of each light can be re-referenced and by interpolating its closest points we are given the 2 closest lights we have the option of routing to (Figure 13.) This notion of modularity can evolve further by adding a splitter at each node (like a power board), ready to accept expansion in the future.

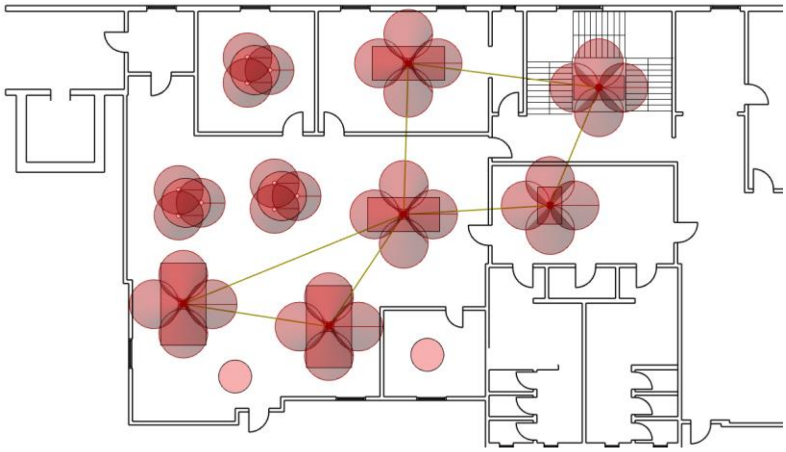


Figure 13. Cable management and routing

Discussion

As the overarching aim of the project was to develop a lighting optimisation tool to be applicable to work spaces, the findings have been mostly successful. The outcome is visually straightforward and allows for engagement from older users with less computational experience as well as new-comers to this changed era.

The first objective was to convert all design platforms to a Rhino line work medium which grasshopper can then utilise data from. While some manual filtering and sorting is still necessary, the process can be achieved autonomously given more time. This is heavily beneficial to this stage of architectural practice where we are really able to leverage 3D space and simulations for the best outcomes.

The second task was to utilise inherent data already embedded in a floor plan to better the space. Different datasets were setup through mathematical resolutions with quantitative data successfully extracted for the script to take advantage of. Focused lighting coverage was achieved and although this brings an asymmetrical solution into the space, it produces the opportunity to be more economically and ecologically friendly. When breaking down the experiment there are undeniably shortcomings, the biggest one being the failure of utilising Honeybee & Ladybug data, this was due to the inability of converting the simulation to numerical values to then implement, however given this was successful, the script is ready to accept these parameters where if/then and dispatch functions to further enhance the space.

It becomes apparent that many design barriers can quickly be addressed and amended to an extent with such computational methods. Further development into this tool would reinforce this, nonetheless collaborative open source development tools like Grasshopper are extremely accommodating, offering endless configurations and quickly benefit the wider industry of the built environment.

Conclusion

Innovative computational methods for lighting optimisation and management in spaces allow for quick and accurate solutions unparalleled with anything in the last 30 years. The parametric and dynamic nature such tools envelope allow for industry wide applicability and can be understood by all design practitioners while still incorporating further complexity problem solving capability. The modern computational tool collection provides optimal predictions with room for more configurability to each client’s needs and hence showcases its extensive functionality making it imperative to today’s design industry.

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