THE ANALYTIC CAPABILITIES OF COMPUTATIONAL TOOLS TOWARDS ACHIEVING MORE SUSTAINABLE DESIGN OUTCOMES

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Abstract.

It is apparent that across the rapid growth of ubiquitous technological cities, more buildings are being upgraded and expanded to fulfil a micro-environment within the building space itself, to create thermal comfort for employees to match the override of heat being produced by computer systems and electrical lighting. Of course, this need to regulate temperature and lights in an office space always has a downfall. In fact, the wastage of power and overuse of electrical resources in commercial spaces has had a huge toll on Green House Emissions, just to keep with the demands of cooling and heating the space. However, the amount of energy being used in a building can be reduced by utilizing passive energy (e.g. solar to lighting), as well as by optimizing the material selection. Within BIM (Built Information Modelling) software, the environmental location data of the building can be inputted and assessed, to further shape and increase the sustainable efficiency of the space. This research is a comparative analysis of the solar, thermal and material impacts on building 'x' across three different BIM platforms (Grasshopper, Revit Insight and Design Builder). Through comparing each platforms energy assessment, the research identified what platform has the most detailed, accurate and efficient assessment workflow. The environmental data assessed on 'X' was the impact of the solar/suns light path (lighting) climate (thermal) and physical material impacts (I.e. glaze vs non-glaze.) The solar assessment showed how to increase the spaces use of passive light, to decrease the energy usage of electrical light through sun path analysis and window optimization. The climate assessment showed how to keep a consistent indoor temperature by showing how the climate effects the building thermally, to decrease heat and cooling energy. The input of environment data and its effects on the commercial office was configured into individual assessment reports across each platform, which was further analysed to enhance the passive design. Each program went through two design iteration stages, with each stage applying the previous assessment to upgrade the spatial efficiency Through the various stages of experimentation, the research highlighted that the most efficient application is Revit. The accuracy of the results (I.e. Solar to shading analysis) and the variety of plug ins facilitate the users to cross transfer data to adapt to a buildings design. This research can provide architects and designers insight in how to increase the commercial buildings life cycle, as it shows through computational assessment can provide clients with an efficient, sustainable and comfortable work space.

Keywords: Sustainability, Assessment, Applications

1. Introduction: Research Aims and Motivations

The built environment is a rapid and ever growing category of need due to CBDs needing to house more people, technology and workspaces. Unfortunately, this utopian idealization of having more buildings in a tech driven building culture has its dystopian results. The Green Building Council of Australia reported that the largest contributor to Green House Emissions (GHE) is in fact the built environment, in which 40% of the GHE produced is singularly generated wastage[1]. In fact, going deeper into this study, office spaces contribute to more then a quarter of the GHE released in the commercial buildings sector[2]. This comes from poor design choices such as windows facing walls, resolving in lights needing to be turned on. Or computers constantly running, causing unnecessary heat, meaning air-conditioning needs to be appointed for to create a thermally comfortable working environment. Just one Sydney office building can provide enough energy to run on average 2742 greater Sydney houses a year, and with energy performance systems such as Greenstar, it is possible to drop this down to half the number of houses by involving passive design[3]. In this society, the design of a commercial office space is often focused on functionality and aesthetic. Yet, these two stances can be conducted in a more sustainable way, where the space could rather be enhanced through assessing the environmental energy being imposed onto the building, and how the buildings material properties effect the micro-climate of the office space. By incorporating these small passive design factors onto a building, the space can be more environmentally and thermally efficient. Building Information Modelling (BIM), is a system used by many designers, to calculate the model's information input, manages, analyses and assess what is required.[4] BIM applications have the potential to heighten the efficiency and functionality of a commercial space with the assistance of environmental data, by analyzing the climate and environmental data of the buildings location. The variation of BIM applications is broad and wide, as some application specify in architecture-based analysis, engineering based analysis, or in what would seem more preferable in this case, sustainable based analysis. In a literature review discussed later in this thesis, Towards *a Bim-Based Energy Rating System* by architect
Alam.J and spatial designer Ham. JJ (2014), converse over how coefficient the Australian energy certified software FirstRate5 and the architectural BIM software ArchiCad. With the result across these two applications highlighting

[1] Mid-tier Commercial Office Buildings Sector Report_FINAL, 2018
[2] Mid-tier Commercial Office Buildings Sector Report_FINAL, 20
[3] New.gbca.org.au, 2018
[4] Aconex.com, 2018

the limitations of FirstRate5 in comparison to ArchiCad due to its inability to fully intemperate the information data of the digital 3D model.[5] It broadens the question of what application is the most reliable in analysing the sustainability of a space, with the less time restraints and the most simplicity. Therefore, the research aim for this thesis is determine the analytic capabilities of Computational BIM tools in achieving more sustainable design outcomes

2. Research Observations and Objectives

The observations that will be explored through this thesis will be that BIM should be able to return an analysis from the digital model provided, which should return a simple, accurate and prompt output variables to enhancing sustainable designs. One important factor of this thesis is determining which BIM application should companies put time and money in using. With this being said, the objectives will therefore be:
1. to uncover the extent of how efficient BIM creates its designs
2. how data can determine the output of a buildings design
3. conduct across three BIM applications (Grasshopper, Revit, Design Builder) a case study of an office floor, to determine which BIM application is the most time efficient for designers

The scope of thesis will compare and contrast different BIM software's, to determine how similar applications regenerate a generic building. As passive design is the key tool in determining the building effectiveness, the overall shape and form will be determined on how the location data of daylight hours and thermal comfort can be increased according to the office floor layout and materials (such as glazing/ shading) The limitations of this project could be that not all BIM software being used have the all of the tool required. Essentially it will not affect the design of the house, but it will not have as an effective result as the other houses created. Another limitation may be that in fact all the houses may look the same. It is by assumption, that each output will be able to change determining on which efficiencies are being tested, but if there is little change to the passive design, there may be little change to the design result. Two individual floor plans will be tested across each of the three BIM applications, to review and discuss the results from each analysis. These tests will highlight the efficiency of each buildings,

5 Alam, J. and Ham, J. (2014). Toward a Bim-Based Energy Rating System. [ebook] Australia: CAADRIA, pp.1-10.
Available at: http://papers.cumincad.org/data/works/att/caadria2014_042.content.pdf [Accessed 10 Aug. 2018].

how the application determine this, and how it represents future changes to be made to achieve the most effective building in the preliminary design

3. Research Questions

To be able to attain a result to the problem of BIM application appropriateness in a rapidly growing city environment, the it is important to determine a question to this problem. There for, this research will uncover:

To what extent does climate/ environmental data and computational methods of modelling analysis assist/ shape sustainable commercial office design?

4. Methodology

In order to get a prompt and a well sought out conclusion at the end of my thesis report, it is important to construct a research methodology, to understand what is needed to be acted upon to get the result. My research project, is to understand if environmental data and computational methods of modelling analysis assist/ shape sustainable commercial office design, wanting the outcome to provide feedback to clients about which fabrication software provide the most efficient designs, with low cost and time. As seen in Figure 1, this diagram represents the methodology. Across Grasshopper, Revit and Design Builder, the office floors daylight and thermal hours will be tested twice with two different floor layouts, to determine which application is the most feasible for designers, and if a space can be altered to provide for a more sustainable design.

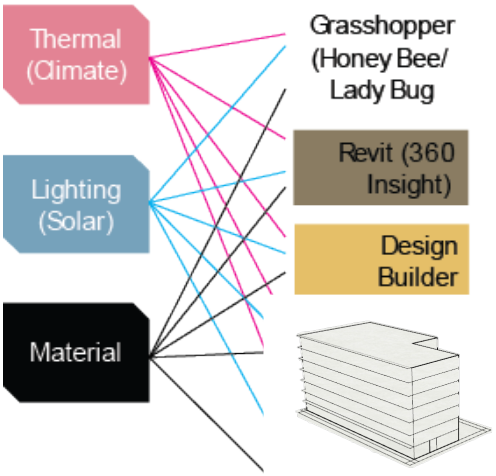

Figure 1

Action research is the act of designing your case around a series of experimentational inputs and output to receive the most accurate result. To find out new ideas and perspectives about a topic, action research is done to both solve a problem, and understand the question (Jean McNiff 2013). In this **case**, my topic problem is the lack of sustainable data analysis on newly designed commercial spaces, and to solve the question which BIM platform produces the most efficient

design based off environmental factors. For me to efficiently organize my action research, planning is key. McNiff states in his book Action Research planning involves asking what, how, why you are doing it, what you strive to achieve, and how you correctly analyses the outcomes presented (McNiff 2013)[6]. With this in mind, my plan in order to articulate the results needed to create a well comprehended design conclusion, will involve a diagram to be drawn up, explaining each step iteration. Because I have three different platforms, I am experimenting the room analysis on, I can easily set up the first part of the experimentation with a clear idea of what tools I will use, what assessments I will do in order to create efficiency, and what sustainable factors I will actually examine. Having the cyclical motion of a strategic investigation allows one to reform generative perceptions based on what has been tested, and retested (Dorothy Gabel 1995)[7]. Having constant evaluation of my project due reciprocated to the amount of input environmental and material data will enable me to really observe the original goal (Gabel 1995) and see how to better improve my result from understanding what I can do better to achieve my question and to solve the design problem.

5. Literature Review

To gather the ideas and concepts to the importance of BIM in providing a built sustainable environment, this literature review follows three individual reports which outline the preliminary research and practise stages to be put in place to receive a relevant thesis result

5.1. INTEGRATION OF ENVIRONMENTAL CRITERIA IN EARLY STAGES OF DIGITAL FABRICATION

The first article reviewed *Integration of environmental criteria in early stages of digital fabrication* was created with the collaboration between architect Agustí-Juan. I, and civil
engineers Hollberg, A and Habert, G (2017).[8] This article was written to revoke the pre-existing architectural view against using digital design tools to asses building functionality and efficiency. The hypothesis to this problem is that digital fabrication analysis is in fact relevant in the design process of a building, Agusti-Juan et al (2017) sort out to discover how using parametric digital tools in a strategic method can enhance the environmental
analysis of a building during the preliminary design. The methodology behind this was to use a singular building element (fabricated digitally) to evaluate how effective the evaluation of a simplistic analysis strategy is through each individual preliminary design stage. In short, during the

[6] McNiff, J 2013.
[7] Gabel, D. (1995)
[8] Agusti-Juan, I., Hollberg, A. and Harbert, G. (2017).

conceptual stage, the estimation of the environmental impact is based on conventional construction, due to the geometric form lacking data description. In comparison, the final detailed design stage enables a full evaluation of GWP (Global warming potential) impacts, which is more specific due to the complexity of the selected material quantities (Agusti-Juan et al 2017). These assessments are calculated by the digital parameters of element function, structural capacity, material type, hybridised functions and complexity. In correlation to the graduation project, this article uses a strategic method of analysis to enhance the final environmental model result. The article shows that through methodology, the graduation action research plan will provide a more reliable result if organised and assessment in a strategic method, as each stage of analysis enables the designer to design, asses, enhance their design (based off the
assessment), re-asses, then repeat this pattern throughout each stage of the preliminary design. The limitations of both this article and the graduation project is how much can be
analysed. In this report, only one element was used to analyse the strategic method of parametric analysis. The contribution this research provides is only a base to understanding that a strategic method of analysis during digital fabrication can provide a clear estimate for its environmental impacts, which previously would not be assessed, due to uncertain project and geometrical data. From this, the graduation projects action research plan strives to expand one element to a modular commercial floor, evaluating and analysing each material together in one whole space, to understand if computational methods of modelling analysis assist sustainable commercial office design.

5.1.1. Towards a Bim-Based Energy Rating System

The second article reviewed *Towards a Bim-Based Energy Rating System* by architect Alam.J and spatial designer Ham. JJ (2014)[9] is a comparative study between the Australian energy certified software FirstRate5 and the architectural BIM software ArchiCad. This research projects aim is to identify if using a cross model data platform (ArchiCad) will have coefficient energy results with FirstRate5, a system popular in Victoria for analysing the mass market of building construction systems and materials (Alam & Ham 2014). The method of reviewing the results comparatively revolved around using the two different
digital software applications to analyse the energy used in three different building models. In summary, the results for each building type where extremely jagged. The difference of
energy load in the apartment model between the two applications sought to have a 72.28% difference, the double story a difference of 21.98%, and the single storey at a

[9] Alam, J. and Ham, J. (2014).

more coefficient 10.44% difference (Alam & Ham 2014). This is due to the fact FirstRate5 analysis's a set of floor-plan drawings, and judges the outcome, rather than BIMs ability to read the data input to produce a more accurate result. Therefore, this study highlights the limitations of using FirstRate5, as it gives limited response, unlike ArchiCad which reads the data integrated into the digitally fabricated model. This research paper relates to the graduation project as it highlights the way to properly compare and contrast two individual programs that have very separate tools to analyse. The report shows that using tables and diagrams to compare, with the written observation to contrast will produce an easy way to understand the limitations and strengths between programs. It shows that BIM is a more diverse program for architectural design and energy analysis, as this report concludes ArchiCad should be the most dominate program for assessment, as it runs the building
through a clear process of analysis from conceptual to the developed design. The graduation project can build on this for hypothesis purposes, understanding that using BIM in the preliminary of the commercial buildings design can enable elements to be tested and redesigned with the simplicity of purely transferring data across one platform to another. Using FirstRate5 also enhances the idea to use Design Builder as one of the BIM platforms researched in the graduation project. Design builder is an individual BIM program, where parametric design is limited, but still effective. Therefore, the graduation
project can determine if modelling a building on a non-cross platform is worth the extra time and cost, depending on how efficient and reliable the environmental analysis is. This will be reviewed depending on the coefficients of the BIM software Grasshopper and ArchiCad which will also be used for assessment. In conclusion, *Integration of environmental criteria in early stages of digital fabrication (*Agusti-Juan et al (2017) and *Towards a Bim-Based Energy Rating System* (Alam & Ham
(2014) have posed as strong articles to direct the graduation project, regarding how to receive the aim result wanted through strategy, and the relevance and importance of effective comparison.

6. Case Study

To gather a reliable result in determining the question *"To what extent does climate/ environmental data and computational methods of modelling analysis assist/ shape sustainable commercial office design?"* A criterion of establishing the "most suitable" BIM application needed to be created. The BIM criteria in which each application was compared to were as follows:

1. Its simplicity of use
2. The readability of results
3. The Simplicity to change designs

4. The Cross-transfer accessibility

The following table in figure 2 represents the reasoning for each of the applications in which were chosen. The scope of software had to be narrowed, due to the extensiveness of platforms, which may cause defocus from the problem being addressed.

Grasshopper	Revit	Design Builder
- New and "Advent" style of architecture - Calculates Information and data with minimal data loss/gain - Advanced plug ins (such as Ladybug and Honey Bee	- Architectural based platform - Accesses to 360 cloud - Highly regarded for design, so is this application worth the analysis also?	- Run by Energy Plus - Analytical based application rather then designs - Wide variety of results

Figure 2

Grasshopper was chosen because does a platform with multiple plug in advances create a more innovative BIM application?

Revit was chosen because does an architectural based program have the capabilities to also provide a preliminary design analysis?

Design Builder was chosen because does a high resulting Energy application actually have the ease of design and transferability as other BIM applications?

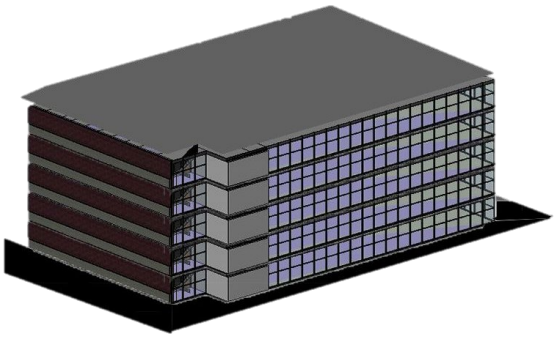

Figure 3

Figure 3 represents the 3D model of the digital model applied upon all three software. Through testing and prodding, this Office blocks data location was set to Central Park New York. The reason behind this was due to the fact that

all Australia's data systems was not relevant across all platforms. In Revit and Design Builder, the location data was read, however Grasshoppers plug in Ladybird could not determine the proper weather files unlike it could New York. In defense for New York still being a sincere choice, the "concrete Jungle" has a vast majority of office buildings, and essentially has such a broad weather window which could provide a range of results.

Another Criteria to put into place was what questions would need to be asked to determine the analysis needed to be conveyed. They were the following:

- Can light energy be enhanced in passive design according to an office floor layout?
- Does the materials used in a building effect the thermal effect of an office space?
- To what extent does shading have on the overall temperature/ light produced around an office space?

The first office space plan ran through each application was figure 4. This is the static building shape, where no office spaces have been placed, yet the stairwell, bathrooms and elevators stay intact. The glass windows on this first model have no glaze and are 3mm.

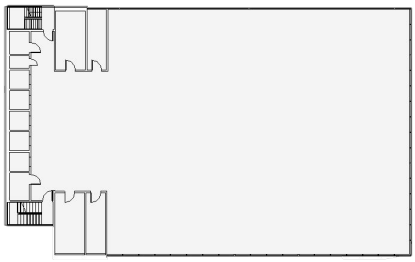

Figure 4

Running this space on grasshopper in order to get the daylight hours required great patients and skill knowledge. As seen in figure 5, the ladybird plugs in for daylight analysis was not prompt at defining the difference between glass windows and walls. The full space was set out with no sunlight hours on a daily basis. The problem received with this result is the frustrating knowledge to the user that either the code is wrong because of how inaccurate the results are. With many attempts to try and reattempt this procedure, the conclusion drew from this analysis that grasshopper is not a simple tool to use, without full well knowledge of the task at hand. To determine thermal comfort on

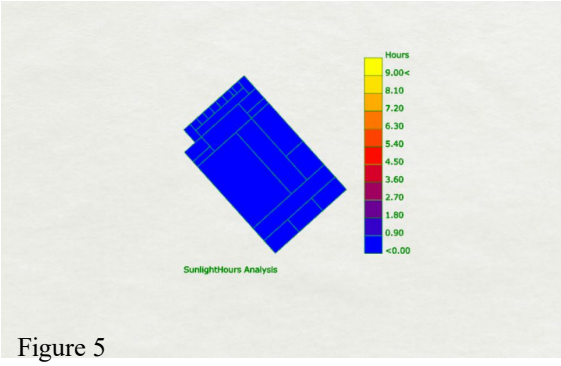

Figure 5

this zone in collaboration with how the glazing effects the room temperature was in fact a different complexity level, seen in figure 6. By purely plugging in ladybugs thermal comfort parameter plug in and the thermal comfort analysis file, the data represented was on the hour every hour for the full winter cycle, with the result output as an average of 20.9 degrees Celsius in the space on average over the winter. This result allows the user to enable new design prospects in order to make the space just a little more comfortable for the clients.

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                                                                {0;0;0}
 0 key:location/dataType/units/frequency/startsAt/endsAt
 1 New York Central Prk Obs Belv_NY_USA
 2 Adaptive Target Temperature
 3 C
 4 Hourly
 5 (1, 1, 1)
 6 (12, 31, 24)
 7 20.9
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Figure 6

The analysis in Revit, for determining the sun value Required the model, and a location and a simple click of the insight “Lighting tool”. As you can see in figure 7, the result is clear and straight to the point about how much sunlight hours is achieved in a day. Although the sunlight hours are represented well, one consideration noted in terms of “how realistic is this result” Is by looking at the location sun path in figure 8, the higher levels of sunlight happen to be on the opposing side of the sun path. To what extent would this be reliable data?

For the Floors thermal comfort, again, this was an easy and quick way to gather the result needed, by purely asking Revit to do an energy analysis of

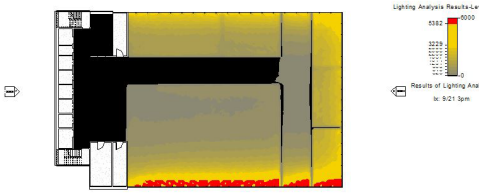

Figure 7

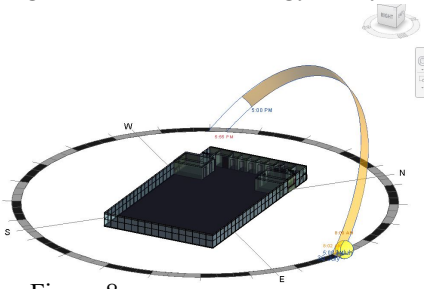

Figure 8

one particular floor. The result unlike in Grasshopper, automatically revels the heating and cooling results for the whole year. As you can see in the graph in figure 9, the material load of the glaze does dramatically effect the thermal comfort of the building, as

in winter the glazing surpasses a dramatically low cool air between the windows, and does not retain during summer.

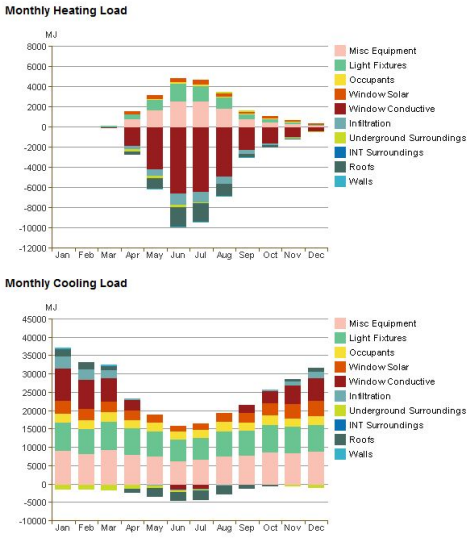

Figure 8

Design Builder had a similar way to representing the daylighting as to Grasshopper, however it had a greater potential of accuracy and credibility. As you can see in figure 10, the solar has distributed evenly across all of the glass faced walls. One thing to notice however, although it reveals the location in which sunlight is essential to within this building, it doesn't offer much of an insight as to why the sunlight cannot reach any further, giving the open space in the middle little to no light at all. In addition to comparing this result to Revit, It is interesting that the majority of the sun is following the solar light, which makes design builders analysis feel more realistic.

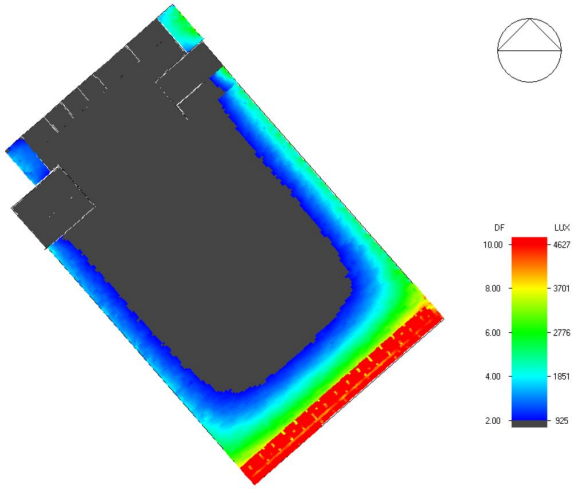

Figure 9

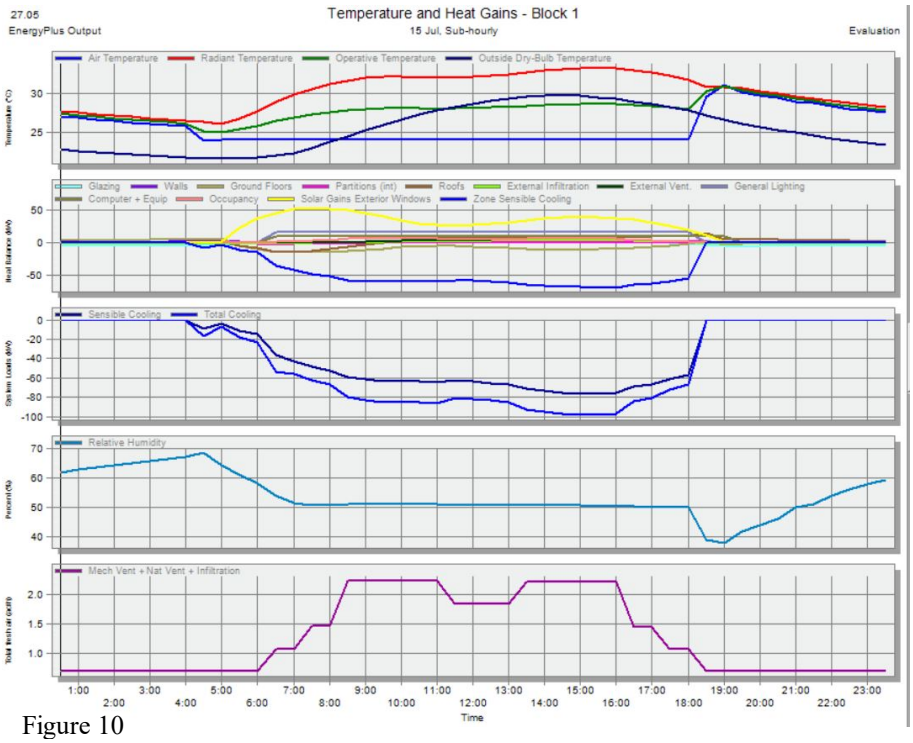

Figure 10

To evaluate the thermal comfort of this space in Design builder was represented in a series of heat and loss diagrams, as seen in figure 10. The second graph shows that the sensible cooling is dramatically low in result to the poor cooling load implemented in the windows. Through looking at this graph in comparison to both results in grasshopper and Revit, across all platforms have a steady representation that glazing effects the heat loss inside the building, reflecting that design possibilities in the future when taking onboard this data can result in a more thermally comfortable building.

7. Significance of Research

The significants of this research more or less is a starting point of understanding the possibilities of how far BIM can take buildings while static and under sustainable development. This research shows that in all results combined, It can not be determined through one set of research to defining the ultimate software, as perhaps a case study on a real building should be conducted in the future, and compare the BIM results to the Greenstar approved results.

8. Evaluation of research project

BIM applications are the key tools needed to heighten then efficiency and functionality of passive design in the built commercial world. Using analysis on digitally fabricated models enables the designer to have the ability to change and reconfigure design outcomes pre- construction. Thus, the designer can identify how much energy wastage the building will use, why the building wastes the energy, and how the buildings energy wastage can be reduced significantly. Between the three BIM applications used to conduct this report, overall Grasshopper is the most accurate, the most flexible and the best platform for cross application transactions. The range of plug-ins available across Grasshopper allows designers to test specific sections of the design. In this reports case, Honeybee and Ladybug where used to address the buildings solar, thermal and material analysis'. With the location and weather files on Honeybee being applied from Energy Plus and DAYSIM, the data inputs can be identified with on par accuracy. In terms of being able to enhance the buildings passive design, Grasshoppers parametric sliders and range of input choice means the redesign was quick, as in some cases (for example, thickening a wall) only needed a slide of the curser. What makes the analysis of the building even more suitable for the time constraints of a design is the fact that the buildings energy analysis is in present motion with the design itself. As the designer change the building, the analysis will automatically run just as the design changes. In contrast to this, Revit Insight gives a message once you apply the analysis saying it could take up to an hour. The range of material property inputs grasshopper plug ins allow you to apply also gives designers a helpful hand of understanding the importance of material in passive design. As architect Agustí-Juan stated, element function, structural capacity, material type, hybridised functions and complexity of materials are all quintessential in the buildings GWP reports (Agusti-Juan et al 2017). The progression of Grasshopper as an efficient BIM application for environmental analysis can be expanded though because of the extremely wide and broad nature of the platform itself. Because the range of plug- ins is ongoing, there are numerous ways to evaluate a buildings design. Thus, solar, thermal and material evaluation discussed in this report is only the begins of understanding the potential of using these BIM applications to its maximum. Therefore, with further research, each of these platforms could have higher or greater analysis in specific sections, leading to understanding how designers can inhibit all these tools to the maximum to get an edge on the buildings passive design.

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Grasshopper
Honeybee
Ladybug
Revit
Insight
Design Builder

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