VIRTUAL COMFORT

Using a persona and gaming environments to communicate thermal comfort experience to support urban design decision-making.

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Abstract. The portrayal of outdoor thermal comfort data in design is simple but challenging to communicate to others due to its lack of quantitative results and human subjectivity. Outdoor thermal comfort decisions on urban masterplans are based on thermal data charts and assessments, but these design impacts are difficult to evaluate in a humanistic sense. Designers can only introduce human thermal comfort evaluation after the masterplan is built and be assessed over time for results to be quantifiable. This creates a dilemma of testing human thermal comfort without the participation and assessment of actual humans, instead forming reason relying on static data and formed imaginations. By gamifying the experience from an observed environmental ecosystem with overlayed thermal information, users can visualise themselves on a platform presentable to others, increasing empathy towards the understanding of comfort as an issue embedded in spatial, material, social and environmental phenomena. This research aims to develop a workflow that can display thermal comfort data in a semi-realistic virtual build of a masterplan while delivering a first-person experience, tracking the effects of thermal comfort strategies on human comfort. This will be achieved by conducting a thermal analysis and evaluation on an 3D urban masterplan model of Blackwattle Bay. The thermal analysis will be simulated through Honeybee (Ladybug tools), utilising EPW weather file data in Grasshopper/Rhino. Both Honeybee results and the model will be then imported into the Unreal Engine 4 to be configured into a semi-realistic, real-time, self-testing, interactive first-person virtual gaming environment. By creating a workflow, this research aims to provide the designer with a virtually simulated first-person experience of thermal comfort data but may in the only term influence improved urban liveability outcomes and usability of urban environments.

1. Introduction:

The *"case of a performative artefact that works to align multiple, discontinuous social worlds. Like any technology, the prototype does not work on its own, but as part of a dynamic assemblage of interests, fantasies, and practical actions, out of which new socio-material arrangements arise."* (Suchman et al., 2002). Like Suchman's statement, technology evolves to accommodate for new social trends and needs to remain relevant. This emphasizes the need of human intervention, where individuals possess "interests, fantasies and practical actions" (Suchman et al., 2002) influencing how design is shaped. Hassle Studios, the industry partner of this research, asks how thermal data can be analyzed and communicated to allow for greater understanding and be translated to formulate decision-making. In the professional design world, architects and designers working the in the public urban sphere understand the relevance and necessity of outdoor thermal data in considering comfort in the ever-changing world climate conditions but despite its heavy influence, it only presented as a non-quantifiable data chart and 2D colour heat-map , ignoring how individuals may actually interact with the public realm. In turn, this generates a dilemma of result communication, data interpretation and design requiring multi-stage discourse to understand.

   Poor communication could be the result of a lack of a singular platform in the design industry for combining simulated thermal information with the stipulated interests of individuals. Digital gaming a as extraordinary phenomena risen since the 1970's providing arcade classics of Pong to Space Invaders, have evolved into highly realistic virtual environments, mirroring the possible physical world. RPG's or role-playing games are a genre of games, where the user controls a player to perform actions to play the game for example, Call of Duty, being a staple of first-person shooter games. In these games, environments are built to strikingly similar (re)imaginations of a world which represents the context and stipulate actions which are appropriate for the individual to survive in that world. But to resolve such a world, gaming engines are built to combine various data aspects of a game, ranging from game environments to user interfaces providing the user with information on the environment upon request. Subsequently, within the environment, player choice in actions and consequences of these actions can also be simulated, creating a more realistic approach of action and consequence unlike in modelling software where only design consequences are considered. This provides the opportunity for objects to bring "culturally and historically reiterated fields of possibility, which afford the familiar

ground of everyday experience" (Suchman et al., 2002) as users can recognise actors and react to according to their interests.

This paper seeks to address a possible method to communicate outdoor human thermal comfort through the lenses of a first-person, RPG like game, displaying various sources of information regarding outdoor human thermal comfort outputted from design software while showcasing significance of action and effect and how it supports designers in decision-making.

By utilising an action research methodology, challenges that arise during an iterative design process are approached via feedback, received both from the prototype itself through testing and industry professionals ensure outcomes remain relevant and tailored to practice and scope. The development of a prototype workflow allows the research to contribute to bridging communication gaps through the usage of different mediums and platforms by introducing game-like methods. This project seeks to increase the importance of cross-platform communication, the necessity of human factor integration and potentially introducing gamification as a encouraged method for decision-making.

2. Research Aims

The key aim of this project is to explore a potential method of communicating thermal data to inform and support decision-making. More specifically, developing a workflow that encourages visual data communication and user participation, by presenting consequences. This take shape as a prototype workflow that uses a Grasshopper script to extract weather information and conduct thermal analysis on a 3D urban masterplan model of Blackwattle Bay during Summer solstice, Winter solstice and Equinox. Subsequently, develop user interface functions, and game level calculations used to translate thermal data into quantifiable information will in the Unreal Engine 4. This project takes inspiration from previous work and research in how RPG's (Role-playing game) can be used as a tool for decision-making and how urban thermal analysis for thermal comfort is becoming increasing important due to rapid urbanisation. It is proven both can work independent of each other, but this project attempts to seek the possibility of bridging the two together to give not only designer, but potentially others a chance of being informed and understand the importance of how design can impact thermal comfort from a human view.

3. Research Question(s)

Can the creation of an interactive virtual game environment allow designers to experience and communicate human thermal comfort data of urban design from the public realm?

This is broken down into the following sub question which must be addressed:

1. *How is human thermal comfort calculated and what will be used to calculate it?*
2. *How will human thermal comfort be experienced and communicated; what are its parameters?*

4. Methodology

Action research is an approach that introduces change (variables) into the process, and its effects is the evaluated (Cole el at 2005), allowing people to negotiate generate discourse and place emphasis on the problematics as much as the successes (Foth 2006). When interacting with tools which require pre-existing knowledge to be used, consistent iterative design, user-testing and feedback become a necessity for learning progress. As such, this research project will be developed using a cynical staged process of 'plan', 'action', 'observe' and 'reflect' to improve outcome though meaningful assessment (Kemmis 2009). Incorporating both test result self-feedback, and the feedback form industry professionals who are familiar and more aware of the challenges which may lie ahead, a realistic application and direction can be erected, while recognizing the potential shortfalls of the given workflow and the technology used. By working together with Hassell, the research outcome becomes increasingly more transparent and relevant to the research context and scope. (insert cycle image)

The practical-based methodology is split into two focuses: analysis and communication. Analysis focuses on producing thermal results on the 3D masterplan model that is being analysed. In using an iterative approach, conducting tests on small and larger scale models, different design proposals can be analysed and produce the fundamental outdoor thermal data results which can be later used for evaluative purposes. During this, software capabilities and limitations in Grasshopper/Rhino and Ladybug tools can be identified and evaluated. Communication focuses on forming site evaluations by incorporating the human experience into the thermal results by testing for comfort levels on human after integrating data outputted during from analysis. For this, the capabilities of the Unreal Engine 4 are used to design a game level, creating a situation where the user can view thermal information, virtually experience heat conditions and develop a strategy which best matches the game conditions which are to accumulate the most optimal overall comfort score.

An action research approach is the optimal for the project also due to its participatory nature. As the final outcome is a game, it does not require a specific understanding of a software program or a trained imagination to

place the user themselves into the environment, it allows users to participate and discuss why certain designs are "good or bad" since it is subjective in nature. In addition to data charts and tables, designers/users can more visualise the data and make more informed decisions. After this human-centric testing is completed, and if results are not satisfactory, the design can be altered, and the whole cycle restarts, linking the two focuses analysis and communication together. Due to limitations of resources, the original Rhino 3dm model of Blackwattle Bay was not accessible, therefore a new model had to be recreated for this research.

5. Background Research/Literature review

5.1 URBAN ENVIRONMENT AND OUTDOOR THERMAL COMFORT

The outdoor thermal comfort in an urban environment in a city plays a vital role in managing the livability of its citizens that dwell within it. Human subjectivity in thermal studies is relative to the test location and the characteristics of the general populous in heat preferences. This presents a challenge for designers trying to consider livability or suitability on outdoor thermal analysis on design concepts as it is difficult to mimic characteristics with many variables. Studies in microclimate management and people's behaviour when interacting with it have shown that certain factors will contribute to outdoor comfort, influencing human behaviour, while others may not generate any comfort even if designed for comfort. Again, highlighting the subjective nature of human sensed or perceived comfort.

5.1.1. Social context and human subjectivity

Globally, around "54 % of the world's population resides in urban areas, and in 2050, this ratio is projected to increase to 66%" (Mutani 2016), meaning that more people are moving to cities. Urbanisation will increase population density, directly impacting the city's social, cultural, and economic factors. For example, the "lifestyle among urban dwellers, especially in medium- and high-income groups, who nowadays tend to spend more time indoors" (Ahmed 2003) may tend to higher energy use, particularly from indoor air-conditioning and overall electricity use, producing a cycle of demand of energy, energy production, the release of greenhouse gases and its subsequent implications.

Human subjectivity plays a significant role in thermal comfort studies as it forms the climate context of the area and thus accepted social norms regarding outdoor comfort. Shooshtarian (2019) argues that participants must have long-term exposure or familiarity with the studied environment to rule out outlying variables from individuals such as tourists for a more accurate thermal test result. A finding by Chen et al. (2015) when conducting meteorological measurements, questionnaire surveys, and

observations in Shanghai, China, found that the duration of human exposure and familiarity combined with local thermal expectations affected the acceptable range of thermal comfort. In relation, Lin (2009) conducted physical measurements, observations, and interviews to investigate outdoor thermal perception and adaptation in Taichung City, Taiwan. It was found that in the humid city, people generally accepted ranges compared to the European accepted range, indicating that people living in different climate regions will have different preferences. Similarly, Lu et al. (2019) investigated the outdoor thermal sensation in Harbin, China, and the correlation between actual thermal sensation and microclimate parameters. It was found that people living in extremely cold climates are more physically better adapted to their environments.

5.1.2. Human behaviour and attitude in outdoor spaces.

Depending on the urban space context, they will be differing behaviour and attitudes from the individual. Public space usage under the influence of its local microclimate and the objects placed within those spaces may or may not encourage higher use levels. A study on public spaces done by Zacharias et al. (2004) shows the differing attitudes of public space users on an outdoor project, before and after reconstruction. During this study, it was found that although designs may offer more seating but had little influence on increasing use. Instead, the most influential factors when judging whether space will be used or not were climate conditions, wind shelter, and shade from direction sunlight radiation.

5.1.3. Material impacts

A study done by Canan et al. (2019) in Konya (Turkey) in Summer showed how outdoor material configuration might impact outdoor thermal comfort. The results from the field survey taken from random participants indicated a very unfavorable condition in an area covered with the stone-covered ground and solar reflection from it. This highlights the importance of material and design, which may influence physical, thermal, and perceived comfort. However, this test had limitations as the majority surveyed were youth, and the lack of climate background consideration may impact research results. But it presents insight into how materials can affect thermal analysis results.

5.2. GAMIFICATION AS A TOOL FOR COMMUNICATION AND DECISION-MAKING

The communication of thermal analysis for designers is becoming increasingly crucial as design tools become increasingly intelligent and translate weather data into more presentable graphical or mapped information. However, an investigation into the use of climate knowledge in

urban planning by Eliasson (2000) argues that there lacks a valid design evaluation framework that can facilitate quantitative and qualitative parameters (local microclimate, human adaptation, and other variables). As such, this research explores the possibilities of gamification and a platform for facilitation.

Gamification can be defined as "A process of enhancing a service with (motivational) affordances for gameful experiences to support the user's overall value creation" (Huotari and Hamari 2012). The use of gamification as a method to communicate and aid in the decision-making process as a tool in an urban planning context is "gaining momentum more and more as a research method in recent years" (Peinaru 2018). Traditionally, a game can be thought of as something that is played by someone to enjoy and pass the time, whether it be physical in a park such as a soccer game or virtually such as Animal Crossing, but what is interesting is the fact that all games are played under the pre-established rules and what shall the player do to clear/play the game under this establishment. A game itself can be defined as "Free, no material interest, voluntary, uncertain, governed by rules, interesting choices, mastery, flow" (Huizinga 1955), to create an experience whereby the player strategises in movement and flow to master the game. Gamification inherently, having the qualities of a game, attempts to support and enhance a system's value through the human experience.

For games to perform as a decision-making tool, the human player needs to be to rationalise the circumstances given the rules of the game and be concluded or, in other words, make a choice. An RPG (Role-playing game) can be used ", which follows a particular storyline, require players to make decisions that change the course of the story resulting in individual and unique endings for each player" (Lo et al. 2017). This game model only requires the user to make choices that will impact the result of the story. In Lo et al.'s (2017)'s housing design case study, this form of decision-making allows "a framework mapping out every decision towards the number of outcomes they would want" (Lo et al., 2017) to be presented. If the user is not satisfied with the result, they can retrace and rearrange the design while also providing a reason or argument as to why certain moves were made and its consequences. This subsequently establishes the direction of this research by attempting to integrate the value of the human experience into the design process and offers a platform that performs under a set framework providing quantitative and qualitative data.

5.3. VIRTUAL SIMUALTION AS A LEANING PLATFORM

For a game strategy to be taught, learned, and mastered, conditions or game objectives must be created, so the user understands their performance will affect the outcome; therefore, the user interface plays a role in the learning

process. Certain behaviours from the users will be encouraged from a game, such as physical movement in a game like "Wii Fit" or "Ring Fit" from Nintendo, and are incentivised by showing the users of their progress and setting up goals for improvement. By providing a steady string of feedback to the users, can it ensure the user stays within the bounds of rules and make an adjustment to their strategy as it enables the user to connect "action and cause, thus enhancing the educational process" and "at the same time suggesting ways for self-improvement" (Cohen el at. 2013).

Providing designers or users with the opportunity to simulate real-life conditions to form a basis of understanding will aid greatly in the design process. As suggested by (Pak el at. 2012), virtual simulation provides designers the opportunity of seeing "virtual worlds as sustainable mirror media for increasing the quality of life in the real world" (Pak el at. 2012) by collecting different project and have an interactive discussion about the project and have a better understanding of its impacts. In a project by Pak et al. (2010) looking at ecosystem management in Colombia, the team utilised an RPG as a tool for education and decision-making. The game provided players information on property management, decision conditions, and the consequences to the land from development and social relations among fellow actors. This system establishes itself as a singular entity but calculates multiple different factors together, allowing for a greater understanding of the targeted context as a whole and a model of the decision-making process. By showcasing these effects, new potential data can be observed from the participants, offering discussion opportunities.

A project in TU aimed at simulating Berlin's population increase, housing placement, and school commuting distance attempted to create a tool using GIS data and Grasshopper which displays "correlating data on geometrical, numerical and text-level, directly inside its environment, to allow for real-time responsiveness and thus fast understanding of otherwise abstract information" (Schulz 2018). Data visualisations and live feedback would allow users to compare different urban planning decisions and adjust their strategy. Emergent virtual strategies as tools for challenging and redefining the existing conventions" (Pak et al. 2012) can allow designers to teach and learn about the effects of the design strategy and hence allow for more participation from others.

From the discussed past studies, this research aims to mitigate post-construction outdoor comfort problems by simulating similar real-world circumstances to reduce inertia and communication barriers from designers to others via showcasing and learning the action and consequences of planned design strategies.

6. Case Study

In this case study, two primary developments will be addressed: Analysis and Communication. A Grasshopper plugin suite called Ladybug tools, primarily Honeybee and Ladybug, will be used for analytical purposes in conducting thermal studies on a target environment. The Unreal Engine 4 (UE4) will serve as a platform for communication and data integration from Grasshopper. In consulting with Hassell, an iterative approach was used when testing software to form a more foundational understanding before engaging in advanced studies. Grasshopper and Ladybug tools were used as a widely known and accepted plugin to the industry, and UE4 was also a commonly known platform for game development. In practice, this workflow should be appliable to all projects, given the right inputs, but for this project, a case study script and manual setup in UE4 were used for testing and proof of concept.

6.1 CHOOSING A CASE STUDY: BLACKWATTLE BAY

Before being able to analysis for outdoor thermal comfort, a model precinct was necessary for this research. After consultation with Hassell, the Blackwattle Bay precinct was decided as the test location. This choice was made as Hassell has knowledge of the development plans for the redevelopment of the area, and there is public state government documentation outlining proposed designs and their potential deliverables. For this research, several small-scale models and Plan A (Figure 1.1) were used initially to test the Honeybee/Grasshopper workflow, and eventually, Plan C (Figure 2.1) was decided with Hassell as the final testing ground. By recreating proposed design plans in 3D using Rhino/Grasshopper, it allows for a better visualization of the model masterplan and sets the foundations for the model inputs, later to be used for analysis. It was also discussed with Hassell that the most relevant period for analysis were Equinox, Summer Solstice, and Winter Solstice, and the most looked at times were 9 A.M, 12 P.M, and 3 P.M.
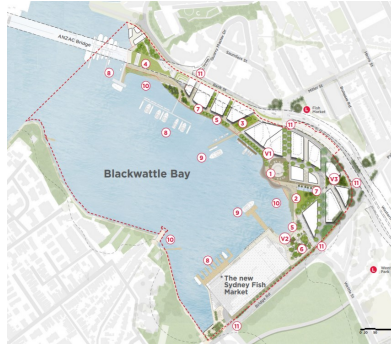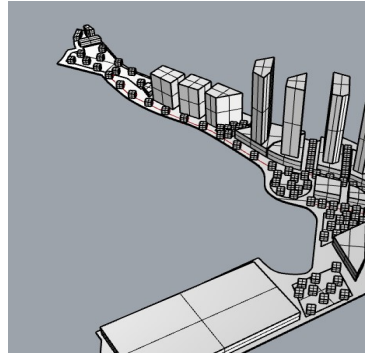
Figure 1.1 Plan A (NSW Planning)

Figure 1.2 Rhino Model (1:1 scale)
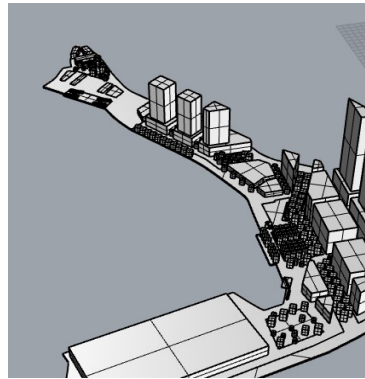

Figure 2.1 Plan C (NSW Planning)

Figure 2.2 Rhino Model (1:1 scale)

6.2 GRASSHOPPER WORKFLOW AND THERMAL ANALYSIS

6.2.1 Honeybee Workflow

Prior to engaging with the 1:1 scale Plan C Model (Figure 2.2), a deeper understanding of Grasshopper Plugin, Honeybee is necessary before thermal analysis can be conducted. Iterative models were developed to create a testing environment to gain insight into Honeybee capabilities and limitations, drawing what is possible during the project's duration. Honeybee requires zone definitions to determine which geometry will be calculated for outdoor thermal comfort and contextual geometry (geometry that indirectly affects the area). During this, material properties (EP zone materials) can be added to surfaces for thermal testing.
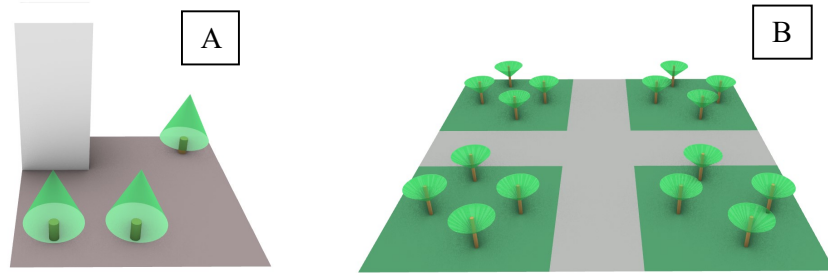
Figure 3. Iteration of Models

Tree transmittance indicates trees' ability to allow light to pass through, as seen in Figure 3 (Model A). Figure 3 (Model B) shows one iteration containing various elements, such as trees, grass, and concrete. Model B was created to expand the analysis area from model A to observe the calculation time necessary for thermal analysis. Trees in model B were more preferred than model A to suit Blackwattle Bay. Material properties will impact outdoor thermal comfort, where grey represents concrete and green indicates grass.

Figure 4.1. Material Properties

Material	Asphalt	Brick	Concrete	Wood
Thickness (m)	0.1	0.05	0.1	0.1
Conductivity (W/m-k)	2.9	0.7	1.1	0.4
Density (kg/m^3)	2243	1700	2000	650
Heat Capacity(J/kg)	900	800	1000	1200

```
            Material:RoofVegetation,
        greenroof,                      !- Name
        0.1,                            !- Height of Plants
    2,                                  !- Leaf Area Index {dimer
    0.22,                               !- Leaf Reflectivity {dime
            0.95,                       !- Leaf Emissivit
    180,                                !- Minimum Stomatal Resist
        Green Roof Soil,                !- Soil Layer Nan
          MediumRough,                  !- Roughness
            1,                          !- Thickness {m}
        0.6,                            !- Conductivity of Dry Soi
      1100,                             !- Density of Dry Soil
    1200,                               !- Specific Heat of Dry So
          0.6,                          !- Thermal Absorpta
          0.6,                          !- Solar Absorptar
          0.6,                          !- Visible Absorpta
        0.5,                            !- Saturation Volumetric Moi
                of the Soil Layer
        0.01,                           !- Residual Volumetric Mois
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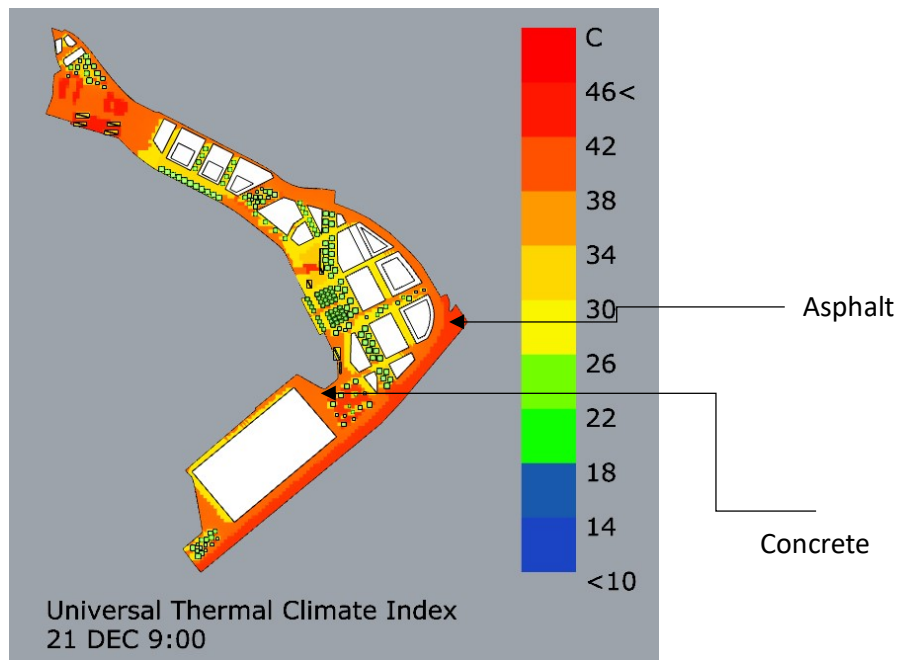*Figure 4.2 Vegetation (Ladybug Hydra Example)*

Figure 5. UTCI Result Plan C (Equinox 9 A.M)

Material properties are important when considering outdoor thermal comfort. As listed in Figures 4.1 and 4.2, each material has its own characteristics and will react differently when used in public spaces. After materials definitions have been added, Honeybee then produces a thermal analysis in the form of a mesh. Processing times took up to 15-30 minutes but is highly dependent on the complexity and number of zones allocated in the area. To demonstrate the difference in the temperature, Figure 5 showcases the difference between asphalt and concrete. Areas with concrete will generally feel hotter, as indicated by the bright red, and regions with concrete will generally feel slightly cooler than asphalt. As seen in Figure 4.1, the heat capacity of concrete is at 1000 J/kg, while the heat capacity of asphalt is 900 J/kg.

6.2.2 Understanding Thermal Comfort and Parameters

One of the core aims of this project is for the user to understand outdoor thermal comfort; hence it is necessary to define how thermal analysis should be understood within this research context. Thermal result mapping generated by default in Honeybee is in the range of the potential lowest and highest values (Temperature) and is not uniform as the analysis period changes. The colour mapping represents the temperature value, where dark blue defaults to extreme cold and bright red means extreme heat. If a value range is unique to Sydney, it can act as a catalyst for both quantitative and qualitative data, whereby a uniform colour range is set to represent temperature value. But it can also be used as a reference for allocating comfort points when building the game in UE4; hence a legend has been developed for this (Figure 6.1). For the industry, a more advanced representation, a psychrometric chart (Figure 6.2), has been created using Honeybee to map out Sydney's comfort range. From using the component, it was found that on average, Sydney is approximately 20% comfortable without any built environment context, and the most comfortable temperatures ranged from 18-26 degrees Celsius. The colour mapping on the chart was allocated based on Figure 6.1 to give a clearer indication of how the two charts relate. These charts are later used for indicative purposes in the User Interface development in UE4.
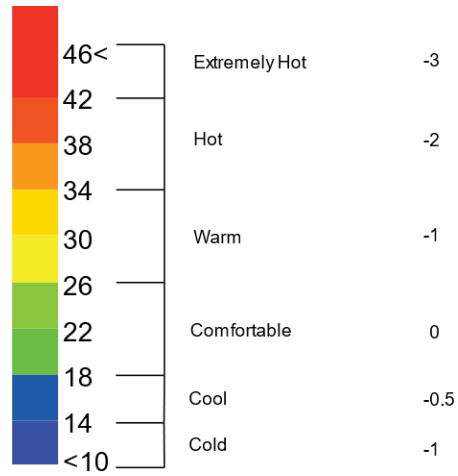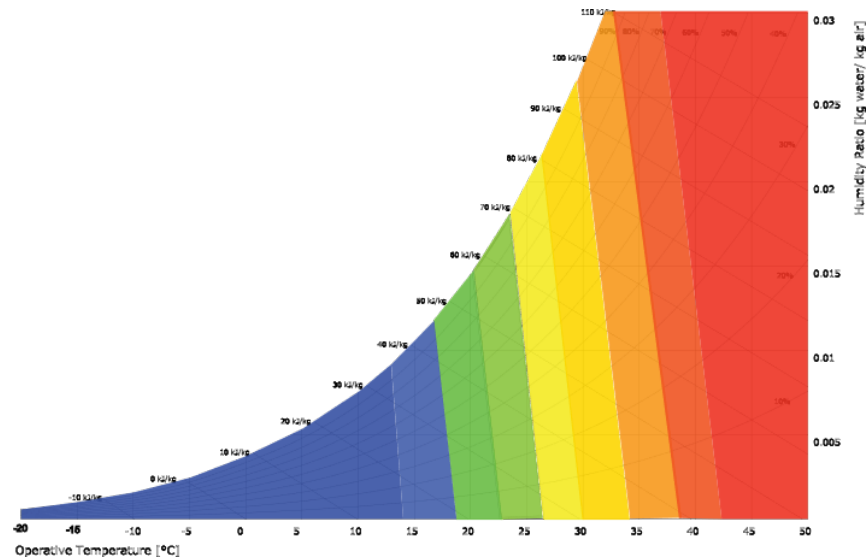
Figure 6.1. Temperature Legend

Figure 6.2. Coloured coded Psychrometric Chart

6.3 THE BRIDGE BETWEEN GRASSHOPPER AND UE4

There are limited channels for Grasshopper colour mesh results to be transferred to the UE4 correctly. If the coloured meshes were imported into UE4 without further conversion by additional tools, it would render the mesh a uniform default white colour. Hence, finding a solution to this problem and Ladybug tools provided a solution in using one of its components (Ladybug Texture Maker). For meshes to be used in UE4, it would be first converted to a PNG file and saved, next select a layer in Rhino and select the PNG as a custom material, finally rebake the mesh on that same layer (Figure 7). This can be later imported all at once when working in the UE4 environment.

However, although this is a valid solution, it was manually done during this project, and the time needed (30mins) to calibrate the many layers generated was more than optimal as each layer had been independently created. In addition, the rebaked mesh layers had to be kept after baking. Therefore, it was necessary to lock and toggle the layers' visibility to avoid selecting the wrong layer for conversion.

Figure 7. Steps for Conversion (Winter Solstice Example)

6.4 UNREAL ENGINE 4 AND GAME CREATION FOR COMMUNICATION

6.4.1 Importing Geometry

To import geometry into UE4, two methods have been attempted: FBX file format and via Datasmith (In-built plugin). This test was conducted to investigate the most suitable platform to import geometry into UE4, as both contained advantages and disadvantages. For the user, the platform must be both fast and efficient. FBX offers the user, Static Mesh collision (Physics), Material and is generally more stable upon import, but import time is very dependent on the level of design and can take up to one hour or more. Datasmith being in its experimental Beta phase, has occasional import errors but is much faster and can take local Rhino 3dm. files directly. However, Datasmith does not automatically assign physics. Hence the user must manually set it, and like FBX files, materials are automatically imported. For this research, Datasmith has been used. It is simply faster and more efficient for users in the long run. It is essential to know the constraints and potentials for these platforms, as this research project and its target audience necessitate it.

*6.4.2 Blueprints and Level Communication*

Communication forms the second primary aim of this project. To achieve this, a first-person RPG game was developed to attempt to address this. Level programming via Blueprint (UE4 Visual Scripting) is necessary after successfully importing geometry into UE4 for a game to be developed. There are two focus points when working in the UE4 environment to achieve the primary goal of communication: User interaction and Background Level Programming.

User interaction focuses on creating widgets and input commands for the user to be able to toggle through different layers of information and add the human experience factor. Creating widgets (Figure 8.1.1) allows the user to toggle and select a specific analysis period and time to be viewed. As three different types of thermal analysis layer results be can be generated (UTCI, Radiance, and Air), it may be in the interests of users to be able to see these layers in the game level to gain an understanding as to why the character is being affected when entering a zone. Inputs commands are programmed using Blueprints and are keys that the user can input to access and view information and change game level properties. As indicated in Figure 9.2.2, the key commands can be used to view the layer after selecting the indicated period (Figure 8.1.2). In addition, Figures 6.1 and 6.2 are included in the

user interface for the user to interpret the thermal information more easily without having to bring up another platform. Both widgets and user input commands work together to allow information to be viewed on one platform upon user request and aim to communicate information visually while still presenting a virtual environment where the user can roam without its constant obstruction and only serve as a guide.
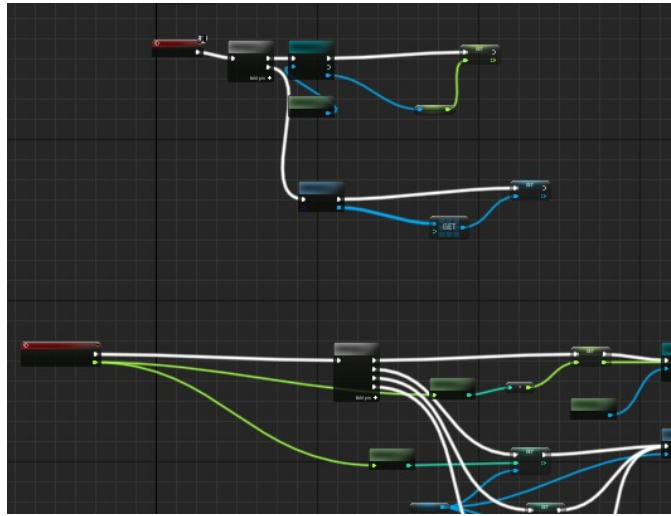
Figure 8.1.1. Blueprint Scripting (Summer Solstice)
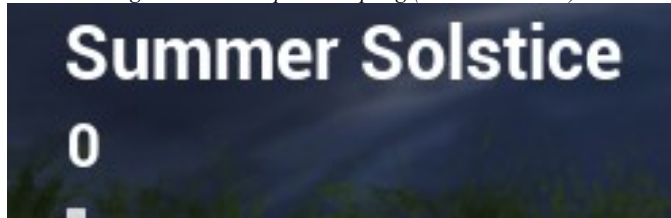
Figure 8.1.2. Period Selection Widget (Summer Solstice)
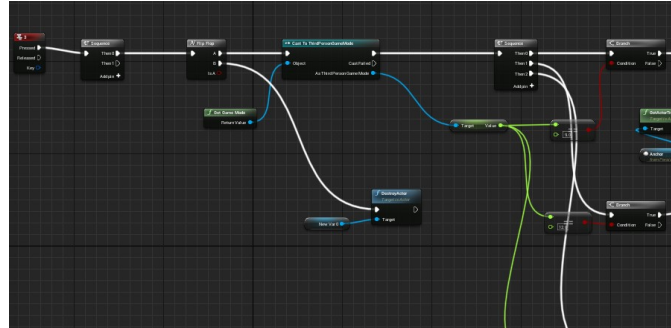
Figure 9.2.1. Blueprint Scripting (Summer Solstice)

Figure 9.2.2. Command Keys

Background Level programming focuses on using the thermal analysis results as the base for zoning and adding consequences to the player persona when entering those zones. For the project to provide a quantitative and qualitative result, a scoring system has been devised, calculating the current level of comfort when entering a zone and an accumulated overall comfort level taken during the entire playthrough of the game. The scoring system was developed in referral to Figure (6.1), according to the level of comfort which is estimated. However there are some rules embedded into the game when the system is at play; comfort levels will never drop below 20 (refer to 6.2.2), the highest being 100, and the amount of points taken its dependent on the zone the persona enters (refer to Figure).

This part contains two other areas of focus, which influence the calculation of thermal comfort level. Firstly, is persona characteristics; by defining how much or additional 'damage' will the persona take when entering a collision zone. Figure 10 shows the Blueprint scripting of when the persona enters an extreme hot zone take will take 30 points of damage in current comfort level and 3 points in overall comfort level. Figure 11.2.1 shows the Blueprint of the collision zone and its boundaries, telling the game to impose damage on the persona when it enters the zone and end upon exit.

In relation Figure 11.2.2 displays what how zoning is placed in the game background.
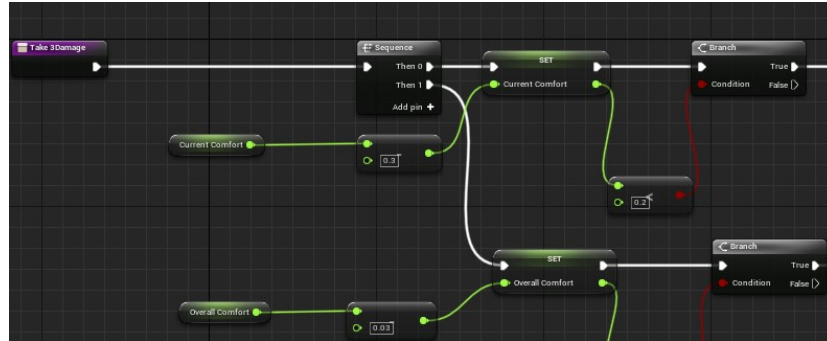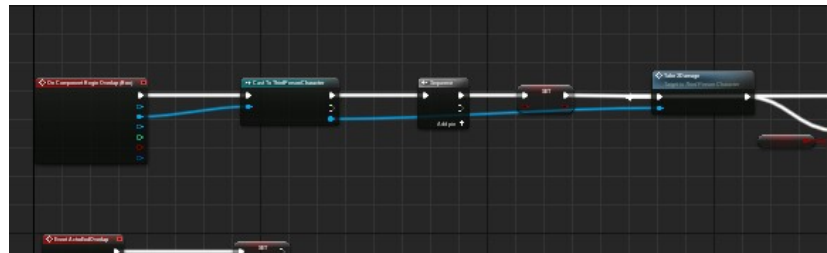

Figure 10 Persona Characteristics

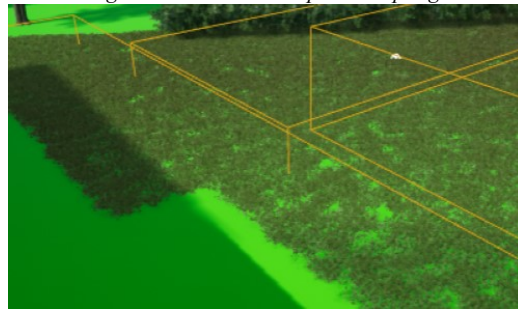*Figure 11.2.1 Zone Blueprint Scripting*

Figure 11.2.2 Zoning boundaries and placement (Extreme Hot)

In practice, when both the user interface and background level programming work together, it will attempt to address the research questions and propose an answer. It should use the foundational knowledge from Honeybee's thermal analysis and transform it into a communicable virtual world, where consequences are accountable. Designers can get an informed glimpse of the whole design picture before engaging in actual physical planning and construction.

6.5 Results

Figure 12.1 Unreal Visualisation 9A.M Equinox- Normal View Area 1
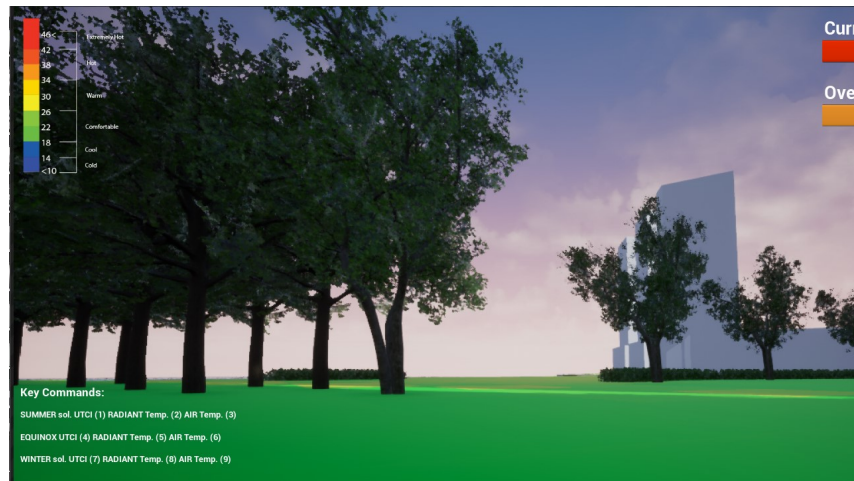

Figure 12.2 Unreal Visualisation 9A.M Equinox- Heat Map Area 1

Upon starting the game, Figure 12.1 represents the normal view at 9 A.M, Equinox. This view presents the user with a visualisation of the Blackwattle Bay model and the Unreal Engine user interface. Figure 12.2 shows the heat-map for the model at 9 A.M, Equinox. After the heat-map is toggled, the user can refer to the legend on the top left of Figure 12.2 to determine the current temperature the persona is standing on. A green colour indicates that

the temperature is between 18-26 degrees Celsius, meaning that the persona is within a comfortable zone. This explains the reason why both current and overall comfort levels do not decrease. Since temperature is within the comfortable green zone and humidity during this time at is 0.01386, the user can determine which position of the psychrometric chart they are currently in.

Figure 13.1 Unreal Visualisation 9A.M Equinox- Normal View Area 2

Figure 13.2 Unreal Visualisation 9A.M Equinox- Heat Map Area 2

Figure 13.1 displays the normal view for Area 2 at Equinox 9 A.M; as shown in the top right-hand corner of the user interface, the current comfort

level has dropped from 100 to 90, and the overall comfort level has dropped from 100 to 99. The yellow zone indicates an increase in the temperature, as seen in Figure 13.2, representing the zone to be warm. The decrease by 10 in current comfort and 1 in overall comfort value is explained in section 6.4.2. There is no change in humidity from Figure 12.2 to Figure 13.2 due to the simulation being in the same time period. However, the position of comfort in the psychrometric chart changes due to a shift from the green to the yellow zone.

7. Discussion

After a series of iterative tests, the research has produced a workflow that bridges Honeybee/Ladybug tools to Unreal Engine 4. This project demonstrates the ability of transforming thermal data generated from Honeybee into information that possess meaning by forming consequences in UE4 adding a layer of human experience complexity in design. The outcome of the project has more specifically produced an environment which allow the user to roam, view thermal information with the ability toggle between different layers of thermal information (UTCI, Radiance and air) and time periods giving the user qualitative data. Design information on how material properties can impact the overall outdoor thermal comfort can also be observed during the analysis stage. For communication, by using a first-person RPG style of game, it allows the user to view and experience data from a human perspective, giving it a human touch. The game in addition to layers which can be toggled, also possesses a working scoring system which can give quantifiable data in terms of both current and overall thermal comfort as well as providing the user with an interactable user-interface. Overall, this meets the original objects of this research by combining both model analysis and data communication onto one platform, giving designers a space to discourse and form ideas, providing support for decision-making

However, this project contains limitations which are unable to be addressed during the time given for this research. Currently the model is manually intensive, especially during model visualisation in the Unreal Engine. Technical difficulties in programming for level flexibility in switching and aligning between information layers and collision zones correctly is the primary issue. Given more time the results from the other time periods (Summer and Winter Solstice) could have been available. Another issue is the limitation of analysis and communication. This project is currently unable to cater for all aspects of a specific individual, therefore can only be built under generic assumptions. Model analysis particularly trees is given an assumption of transmittance level of 0.2 as it would be difficult to know the types of trees used and the thickness of the materials

used during the analysis. The shape of the trees was also simplified in cube geometries as during model iterations, as if shapes were complex or rounded, it would take significantly more time for Honeybee to calculate. It would take up to approximately 3-5 hrs of processing time (depending on the model), if the shape were complex. From this, the scoring system and psychrometric chart is also given an estimation from the designer's interpretation of the UTCI threshold levels and existing weather data on Sydney.

Regardless of constraints on time and resources, this research has implications for the future of virtual simulation and design decision-making support. More user interactive elements within the level can be implemented for user to access more information for a more personalised experience. There is potential for a further exploration into how the humans experience can aid in forming designs and decision-making by adding in agents (simulated pedestrians) and other pre-existing thermal conditions, such as a more accurate gauge of trees or a closer evaluation of wind. Overall, for the built environment, it presents an opportunity for further research into methods of virtually recreating masterplan designs and simulate real world conditions, such as the complexity of variables in the humans.

8. Conclusion

By gamifying the human experience, an observed environmental ecosystem with overlayed thermal information, can allow users to visualise themselves on a platform presentable to others. This can increase empathy towards the understanding of comfort as an issue embedded in spatial, material, social and environmental phenomena. There also exists a lack of both quantifiable and qualitative outcomes when conducting outdoor thermal analysis on a target environment. The study explored the possibilities in developing a workflow that can display thermal comfort data in a semi-realistic virtual build of a masterplan while delivering a first-person experience, tracking the effects of thermal comfort strategies on human comfort. This system serves to address the friction of wanting to evaluate thermal comfort design decision during the design phase based of the human experience to the reality of being only able to after the construction of the masterplan is completed and qualitative data is collected. Honeybee has formed the fundamental base of simulated thermal knowledge and outcomes allowing for an observable outcome but remains simulated from the perspective of a computer only translating data into an understandable form. The Unreal Engine builds a first-person RPG, incorporating the results from Honeybee. This presents the user with a singular platform which allows for a simulation of the human experience, while having access to different layers of thermal information from Honeybee through its user interface. The Unreal Engine is

used as a platform to interpret static thermal data into a form which projects an action and consequence from the user persona. The interaction between the data and the persona, provides an opportunity for the quantification and gathering of a qualitative result from an end-game outcome. This paper contributes towards a step into further simulating the complex nature of the human experience and how it can aid in communicating thermal knowledge and support decision-making. The project presents an opportunity to empower designers with a guide for decision-making in designing and planning for outdoor thermal comfort in a simulated real-world environment. Therefore, potentially bridge the communication barriers between multiple software and harbour new design possibilities where design meets life.

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