LORIKEET, GREENING THE CITY

Developing a data driven computational decision support tool that analyses optimal locations for vegetation on rooftops and facades

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Abstract. The potential for vegetation to be incorporated into the design of urban sites is often dismissed by the Architecture, Engineering and Construction Industry (AEC), but can be influential to the outcome of a sustainable design. Plants livability in urban environments is difficult to predict, as the success of vegetation in such an environment is dependent on a range of intertwining environmental and structural factors. This research project investigates how a data driven design (DDD) tool can enhance reliability within the design process and promote the development of urban greening. The aim of this project is to develop a tool that is capable of identifying the optimal locations for planting various types of vegetation on rooftops and facades on an urban site. This is achieved within a Grasshopper scripting environment that evaluates a series of environmental analysis and simulation results on a building mass against a database of plant types and their requirements. The result of this research project is Lorikeet, a tool that effectively matches a grid of space on a building mass with its optimal plant type counterpart. This research contributes to expanding the knowledge on how landscaping practices can be assisted using data driving computational analysis and simulation techniques.

Keywords. Digital Landscaping, Urban Heat Island, Data Driven Design, Simulation Aided Design, Decision-Making Support

1. Introduction: (Research context and motivations)

Successful green roof spaces are proven to be 1.1℃ – 4.4℃ cooler than conventional roof spaces and can reduce city-wide ambient temperatures by up to 2℃ (Sntamouris 2016, p. 682). Despite evidence that increasing vegetation in the built environment will improve air quality, alleviate the urban heat island effect, provide green spaces for human use, support biodiversity and contribute to urban agriculture and food production (Decker 2016) there is still limited design methods and resources to develop urban greening. Often the decision making of what plant type goes where is left to landscaping specialists which make judgments based on intuition. Such a decision can become increasingly complex once contextualized within the built environment as the success of a plant type is based on a multifaceted environment created through the fusion of climate and structure.

This research project investigates how such factors can be rationalized into a DDD tool that fosters reliable decision-making within the process of planting different types of vegetation in the urban environment. The aim of this project is to develop Lorikeet, a DDD tool that is built on a framework capable of identifying the optimal locations for planting various types of vegetation on rooftops and facades of an urban site.

This project adopts an action research approach that engages an industry partner in a process of planning, designing, testing, and evaluating the proposed computational tool Lorikeet. A case study involving an urban site located in Sydney's CBD and Nanmu Queensland will provide a testing ground for Lorikeet to ensure the tool is built on an adaptive framework and can provide reliable results. Lorikeet is aimed at designers and stakeholders in the early planning stage of an urban development project to encourage the incorporate vegetation into the design through reliable decision-support.

Lorikeet uses computational methods including data driven environmental simulation using LadyBug and the EnergyPlus databases, geospatial climate analysis using Bureau of Meteorology satellite data and building information processing through the population of a 3D site model with building data. To ensure wider usability and operability, Lorikeet will be built using the visual scripting software Rhino/Grasshopper, enabling it to be delivered in the future as a Grasshopper plugin or a JSON application run through an Urban Virtual Modelling Platform (UVMP) like Giraffe (2018).

Once developed, Lorikeet can lead into more specified processes like simulating the behaviors of chosen plant types on specified topological landscapes (White 2020). The research conducted will contribute to scholarship in the field of digital architecture and DDD methods. Furthermore, Lorikeet will expand the knowledge revealing the potential urban greening has for more reliable and sustainable design outcomes in the urban environment.

2. Research Aims

The overarching aim of this research project is to develop Lorikeet, a tool that processes environmental and building data to automatically estimate best suited plant types for rooftops and facades on an urban site. By doing so we aim to adapt climate data analysis techniques to accurately correlate to the environmental requirements for plants and build a system that identifies how building information effects the suitability of different plant types on rooftops and facades. As Lorikeet is aimed to be used as a DDD tool for designers the relationship between accuracy and efficiency of the tool must be judged.

Due to time constrictions, this project aims to prototype a working version of Lorikeet with focus on developing it on an adaptable framework that allows for future expansion.

3. Research Question

How can climate and building data be processed to automatically and reliably estimate best suited plant types for rooftops and facades on an urban site?

4. Methodology

“Quality assurance of an action research project is not only established by conceptual advances, but also by practical results and achievements in the field that actually solve the problem at hand (Hearn et al. 2005, p. 2)”. Design in essence is experimental and an everchanging discipline that requires action to reach a conclusion. Action research can be embodied through the investigation into real-life cases where different design processes are tested against each other to provide insight on how to address a certain design problem.

Computational design emerged into the AEC industry precisely to address complex problems that could otherwise not be solved using traditional methods of design and as a field has followed the action research methodology. This makes the methodology fitting for this research project as the purpose of developing a data driven landscape design tool is to fulfil what can-not be done reliably and efficiently by traditional methods of landscape design.

To validate the project’s aim in the context of the AEC industry we will seek the guidance from scholars in the field (UNSW) and an industry professional (Mott MacDonald) that not only can provide insight technically but also theoretically to the design problem in hand. Furthermore to ensure the outcomes of the Lorikeet are relevant and true in the context of the AEC, the tool will be tested on a 3D model of an urban site in Sydney's CBD and an identical site will be tested, only located in Nanum Northern Queensland to test for adaptiveness.

"Action research is operationalized by constant cycles of planning, acting, observing, and reflecting (Hearn et al. 2005, p. 2)". As described, the process of action research at its core is a cycle of learning from failure. To ensure this research project is insightful not only towards the subject of the project but also to the larger field of computational design the techniques used to build Lorikeet will be recorded through a case study. The analysis results of Lorikeet are evaluated against the research aims to inform changes to the analysis techniques in an iterative pursuit to establish an optimal design approach. Not only does this method direct the cycle of planning, acting, observing, and reflecting towards the established aims but will also expose flaws in the aims that can either influence change or future research.

5. Background Research/Literature review

One of the most debated topics of the current AEC industry is whether certain design processes should be reconstructed to incorporate computational methods. Although the benefits to apply such methods may be obvious to more quantitative aspects of the built environment, in comparison computational assistance towards the design of vegetated landscapes has been relatively neglected because such environments are hard to define.

Despite this, pushes towards more technologically enhanced design methods of agriculture have been very fruitful as exemplified by the Netherlands, the world's second largest exporter of fruit and veg and are the "world leaders in agricultural innovation" (Vivano 2017). Unlike the Netherlands, Australia's rural climate is exceedingly unfertile, and the most prosperous climates for vegetation are concentrated around the coast, where also the built environment is. For this reason, focus towards building tools to help integrate the Australia's natural and built environment are invaluable, especially as their outcomes are "recognized to improve air quality, alleviate the urban heat island effect, provide green spaces for human use, support biodiversity and have a great potential to contribute to urban agriculture and food production." (Decker 2016, p. 604)

5.1. DATA DRIVEN DESIGN

"To improve the design process and effectively build towards a sustainable future, we need to rely on the multiplicity of data available from our existing building stock to inform future design decision-making in an Evidence-based manner." (Petrova et.al 2019) Here the argument to include intuition into the DDD process implies a designer to review the implications of the data and make an evidence-based design choice. Alternatively, if we remove intuition the data can solely drive the design outcome in what Zhao (2004, p. 749-754) describes as a DDD Optimization Methodology (DDDOM). Such a DDD method is commonly performed using machine learning techniques where a neural network striving towards a design goal uses data to optimize one or many design variables. (Sun et.al 2019, p. 1). whichever the method, a successful DDD outcome is strongly reliant not only by the availability of data but also its reliability. “Better data, and the volume and speed with which it is now becoming available, affords practitioners new possibilities to understand people and places more deeply to inform their design.” (ARUP 2018)

5.1. DATA BASED SIMULATION AND ANALYSIS

There are three main methods of simulation assisted design, and the way they use data through the design process determines their design outcomes. A compliance approach requires a design to be delivered, and then tested by a simulation to determine whether the design complies with its criteria. A preventative approach introduces the simulation into the earlier phases of the design process as “Iterating between modelling and simulation can improve the quality of the system design early, reducing the number of errors found later in the design process.” (Carone 2014) Lastly an entangled approach, defined by Pěchouček (2010, p. 1) is a “methodology tightly integrating simulations of the target system into the MAS application development process.”

Computational tools focusing on landscaping have mainly been centred around simulation assisted design, where a simulation replicating real environments gives insight to inform design decisions. Climate data can be analysed using tools like Ladybug (2012). Although not focused towards digital landscaping such tools can use climate data to simulate base environmental conditions to drive and optimize certain aspects of the design. This exact process is what Tablada (2018, p. 124-131) studies, where a tropical environment is simulated through a Multi-Agent system to optimize the design of a façade in accordance with a solar farming and interior comfort. He quotes, “Computational optimization through parametric analysis is needed when multiple conflicting criteria intervene during the process of façade design”.

Groundhog (2020) is a landscape analysis tool developed by Philip Belesky that simulates and evaluates landform in relation to terrain, water flows and vegetation. In Belesky’s (2020, p. 235-241) paper he discusses the importance of analogue and computational methods in relation to landscape architecture as “it enables a circular process of experimentation that brings the designer into a ‘conversation’ with a particular medium”. In his case a sandbox is used to create a real time landscape environment, which then can be computationally analysed through data assisted simulation. furthermore, the results of the simulation can be projected back onto the sandbox, enabling a constant feedback loop to the design, resembling Pěchouček’s multi-agent approach to simulation where a design outcome may be directly derived from its dynamic inputs. Similarly, White (2020, p. 188-196) explores the tendencies of different plants when simulated to grow in a "digital landscape information model", which defines a sites environment. This type of simulation approach uses a multi-agent system not only to display results and give feedback to the designer but also to automatically generate an optimized design outcome mirroring Zhao's methodology of DDD. "A simulation using the established mem (LIM) to generate and evolve a planting scheme for a given site." (White 2020, p. 188)

Geographical Information Systems (GIS) can process and visualize data containing location properties, highlighting the data's relationship with spatial context (National Geographic). Although typically GIS are integrated within the design process using Petrova's evidence-based method of DDD such a system can also drive Zhao's method where the geospatial data directs the design outcome. The AEC industry currently uses GIS software's like QGIS (2009) and ArcGIS (1999) as digital environments to perform DDD, but GIS defines a framework that can be translated into most 2D and 3D software's.

5.2. URBAN VIRTUAL MODELS

Simulation tools like Ladybug and Groundhog can be applied to a wide range of environments, which is preferable to those who seek to simulate a base environment but are not tailored for the urban environment. Discussed in Kawagishi's (2020, p. 31-40) paper is "Urban Virtual Models" which using geospatial data can twin an urban environment at a Level of detail 100. Kawagishi through a comparative study evaluates the success of current UVMPs and clearly determines for such a platform to be deemed successful it should enable "Simulation-based Design". This paper praises the success of Giraffe (2018), a UVMP that not only enables built-in environmental simulations like solar and wind but also allows the user to define their own simulations. Although UVMPs have been used to map vegetation as existing context for an urban environment (Wee Chen 2020, p. 227-233) there is still room to use UVMPs as to integrate data assisted simulations to plan urban greening.

5.2. NICHE

Currently in Australia there are numerous projects involving urban greening, (Yerrabingin 2018), (One Central Park 2008-14), (Biofilta 2017). These projects are all located in dense urban environments but show no sign of environmental simulation or data analysis inform landscaping decision. Using such methods to inform design decisions like where to plant why type of plant could be a driving influence towards a reliable and optimised urban green area.

6. Case Study (Lorikeet)

The ongoing development of Lorikeet will be used as a case study for this research project as we seek to develop a design outcome that meets the research aims. A 3D model of an urban site located in Sydney's CBD and Nanum Queensland will be the testing grounds for Lorikeet to ensure the design methods and results are reliable and relevant in the context of the AEC Industry. This case study is guided in collaboration with computational design scholars from UNSW and an industry professional from Mott MacDonald to validate both technical and scholarly relevance. To ensure wider usability and operability, Lorikeet will be constructed using the visual scripting software Rhino/Grasshopper, enabling it to be delivered in the future as a Grasshopper plugin or as a JSON application run through an UVMP like Giraffe.

6.1. DATA DRIVEN WORKFLOW

Lorikeet is built on a simple input to output workflow, where a set of data inputs are processed using data driven analysis techniques, producing an output that meets the aims of the research project. To grow successfully, plants have a set of requirements. Although most plants generally have the same type of requirements, the amount of each requirement can vary from plant to plant. These requirements include but are not limited to an amount of sunlight exposure, water, soil, space, temperature, humidity, and wind. Estimating the success of a plant type based on these requirements becomes increasingly complex when introduced into the context of an urban site as the environment the plant grows in is influenced by the site and its surroundings. Thus, the data input and the techniques employed to analyse the data must be able to integrate the 3D context of the site. Here is a matrix matching a specific plant requirement with a corresponding data input and analysis technique that can be scripted in Grasshopper/Rhino.

TABLE 1. Matching Plant Requirements with Data Inputs and Analysis Techniques

Plant Requirement	Data Input	Data Type	Analysis Technique	Achievable in Project Time Frame
Sunlight Exposure	Energy Pluse Weather Data	EPW File	Ladybug Sunlight Analysis	Yes
Soil Depth	Grasshopper Façade and Rooftop Load Bearing Capacity Population	Floating Number (kg/m2)	Native Grasshopper Script	Yes
Space	Grasshopper Façade and Rooftop Usable Space Population	Curve/Polyline Geometry	Native Grasshopper Script	Yes
Water	Bureau of Meteorology Climate Map	PNG / Vecor PDF	Image Sampling	Yes
Temperature	Bureau of Meteorology Climate Map	PNG / Vecor PDF	Image Sampling	Yes
Humidity	Bureau of Meteorology Climate Map	PNG / Vecor PDF	Image Sampling	Yes
Wind	Energy Pluse Weather Data	EPW File	Dragonfly Wind Load Analysis	No

Once the plant requirements, data inputs and, analysis techniques that Lorikeet will use are established, we can order them into a sequential workflow diagram. This will give a visual pseudo representation of how the Grasshopper/Rhino script will be constructed.

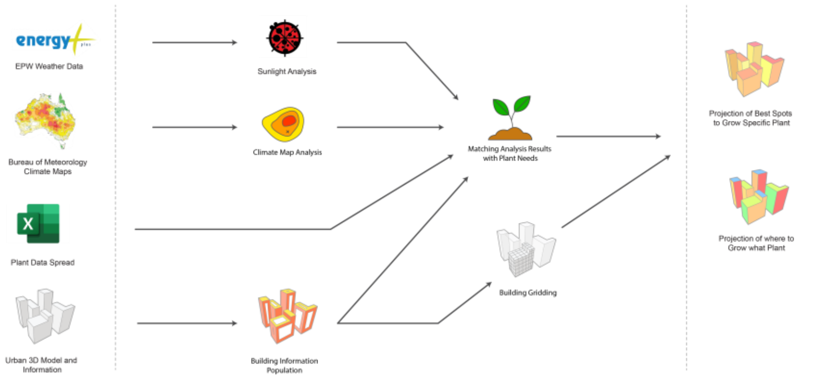

FIGURE 1. Lorikeet Workflow Diagram

6.2. ENVIRONMENTAL AND BUILDING ANALYSIS

After outlining possible analysis solutions in relation to plant requirements we can isolate each and apply the cyclical principles of action research in pursuit to establish an analysis solution that optimally addresses the aim of the research project.

6.2.1. 3D Site Model

To begin analysis, Lorikeet first needs a 3D site as a testing ground. A 3D model containing a segment of Sydney's CBD was chosen not only because Mott MacDonald has this model readily available but also because such a site is relevant to the to the types of sites Lorikeet aims to develop in the AEC industry.

The 3D model Mott MacDonald provided is a detailed and irregular mesh (most likely the type of input geometry Lorikeet would potential receive in the AEC industry). Grasshopper, UVMPs and most climate analysis plugins best work with simplified NurbsGeometry which instead of defined by a cloud of vertices is defined by mathematical vectors. Thus, to ensure Lorikeet is built using an adaptable framework that allows for future expansion a cleaning script is employed which simplifies the curves defining the rooftops of the buildings and extrudes them to the ground, creating a building mass. Furthermore, the 3D model provided contains a large portion of Sydney's CBD and is not realistic to the potential sites that Lorikeet aims to deal with. With this in mind, a smaller section the 3D model can be selected as the analysis geometry and the neighbouring buildings can be selected as the site's context.

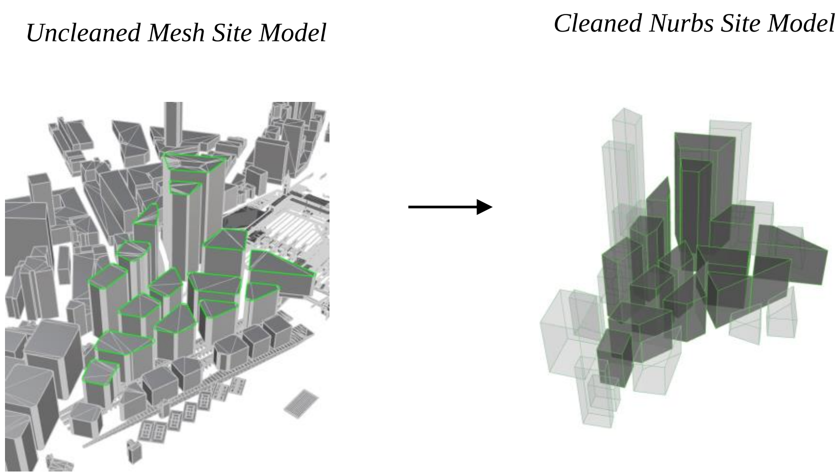

FIGURE 2. 3D Site Model Cleaning and Analysis/Contextual Geometry Selection

Different analysis techniques output their results in different formats. To create a common ground for these results the 3D site model is subdivided into even square grid cells. This way each grid cell contains a result from each type of analysis that can be later evaluated against the corresponding requirements each plant type. Once evaluated each grid cell will be matched with its optimal plant type counterpart.

The size of the cells if packaged as a Grasshopper plugin or a UVMP application can be determined by the user, the compromise being the smaller the cell the more accurate the analysis but the longer the computation time. Currently the cell size is proportional to the site size which maintains a uniform resolution across any site.

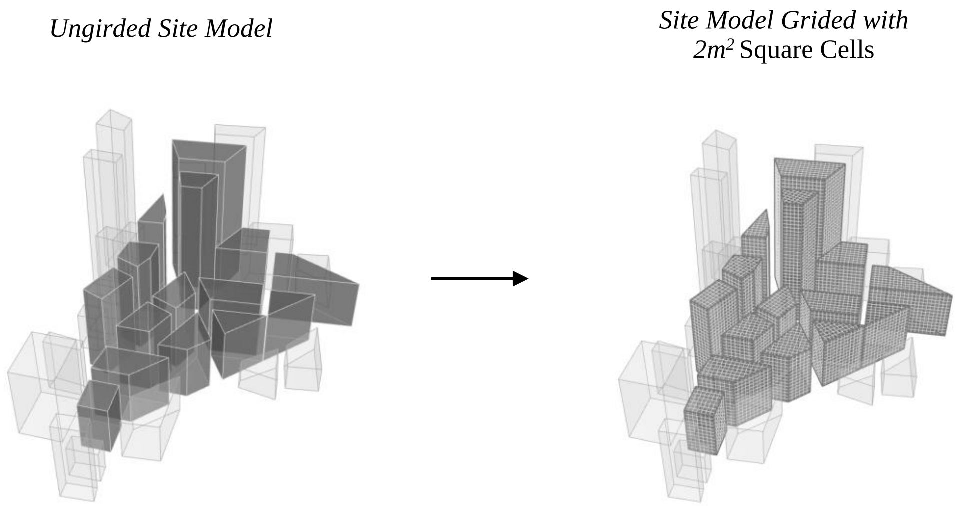

FIGURE 2. 3D Site Model Gridding

6.2.2. Sunlight Analysis

"The tremendous importance of photosynthesis for development and maintenance of life upon the earth can hardly be overemphasised (Blum. 1937)". Arguably the most essential need of a plant is sunlight, some plant types require more than others. In a complex 3D environment like an urban site, using traditional landscaping techniques to calculate how much sun exposure spaces on rooftops and facades receive on average can be inaccurate and time consuming.

Energy Pulse (2001) is an organisation that specialises in climate data and package a yearly collation of climate data for locations across the world into Energy Plus Weather Files (EPW's). LadyBug is a grasshopper plugin that can process EPW's and project climate data onto 3D analysis geometry based on contextual geometry. LadyBug uses a ray tracing 3D analysis technique to calculate sunlight exposure for spaces on a 3D surfaces which computes the amount of sun rays clashing with an area of geometry for a specified period of time. The key variables for this analysis technique all have compromises between accuracy and computation time:

TABLE 2. LadyBug Sunlight Analysis Accuracy vs Computation Time

Variable	Longer Computation Time (More Accurate Results)	Shorter Computation Time (Less Accurate Results)
Contextual and Analysis Geometry	More / Highly Detailed Geometry	Less / Low Detailed Geometry
Testing Grid Size	Smaller Gride Size	Larger Grid Size
Analysis Time Period	Longer Analysis Period	Shorter Analysis Period

The aim of Lorikeet is to analyses only rooftops and facades. Thus, to stay consistent throughout the project the contextual and analysis geometry remained as building masses defined only as planar rooftops and facades. This means that the computation time for this variable is optimized.

The testing grid size is already established universally throughout the project as proportional to the site size. Despite this, LadyBug project results onto a distorted set of mesh faces. To ensure the resolution of the analysis remains true universally the LadyBug testing grid size is half of the universal grid size to account for any mesh distortion.

At first to save computational time the Analysis period was run on the Australian summer and winter solstice and then averaged in aim to replace an computationally heavy analysis period of an entire year. This may seem like an efficient solution but proved to be inaccurate for Sydney because the two solstices are in different day light saving periods. Alternatively, the Ladybug analysis period was set to the entire year which took 185 times longer (0.5sec vs 92.5sec) to run but guaranteed in a more accurate result.

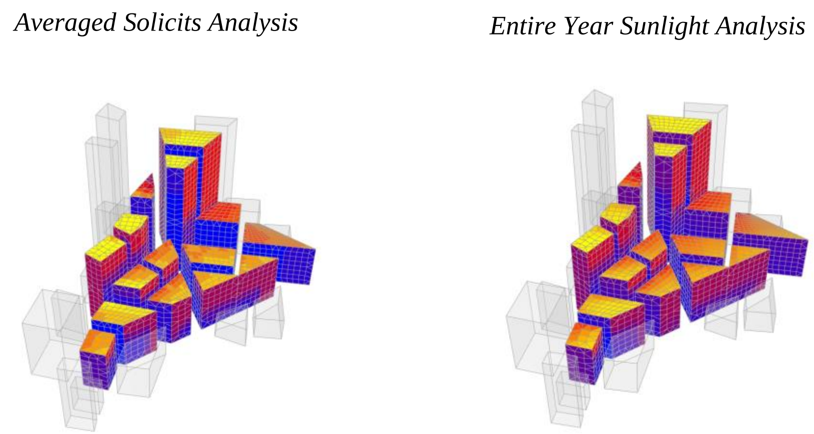

FIGURE 4. Averaged Solicits vs Entire Year Sunlight Analysis Period

To check that the Ladybug sunlight analysis is providing reliable results an analysis performed on both the Sydney and Nanum site was compared. Because Nanum is closer to the equator, intuitively we can prove accuracy if the analysis results indicate that Nanum has more sunlight exposure than Sydney.

6.2.3. Climate Map Sampling

Images displayed on monitors are defined by red, green, and blue dots (or channels). Each triplet of dots creates one pixel, and the brightness of each channel determines the Red Blue Green (RGB) colour (Zhu et al. 2010). This encodes each pixel of an image with an RGB properties that we can use identify the RGB of a specific point on an image.

The Bureau of Meteorology stores a library of Australia climate maps that display weather data in the format of image, where different RGB values correlate to different climate values. Lorikeet uses the average annual temperature, rainfall, and humidity maps to analyse temperature, rainfall, and humidity plant requirements for the urban site.

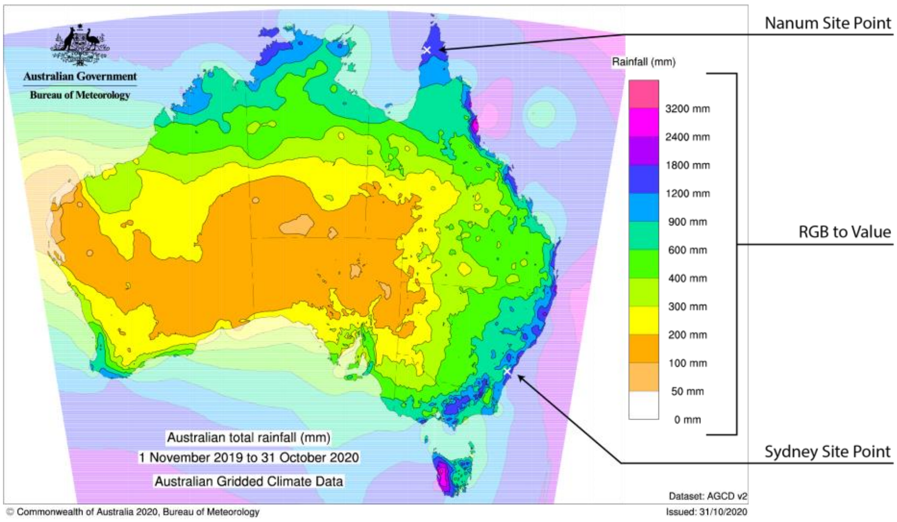

FIGURE 5. BOM Rainfall Climate Map Example

There are two potential GIS techniques that can be used to identify the RGB value of a site point on these climate maps.

- First a Grasshopper image sampling technique that uses a pixel-based format of the map. This technique creates a point for each pixel on the image and finds the closest point / pixel to the specified site point to obtain the site point / pixel’s RGB value. This technique is advantageous because it can sample any pixel-based image but is disadvantageous because it uses a closest point method that is inaccurate. The only way to make this method more accurate is to increase the resolution of the image which exponentially increases computation time.

- Second, a point in curve technique that uses a vector format of the map. This technique uses the vector curves bounding the different RGB areas on the map and finds which curve the site point is in, obtaining the curve’s corresponding RGB value. This technique is advantageous because it finds what vector curve the site point is directly in, making it more accurate and less computationally heavy than the pixel-based method. This method is disadvantageous because only vector formats of the climate maps can be used and requires the maps to be manually converted into vector curves.

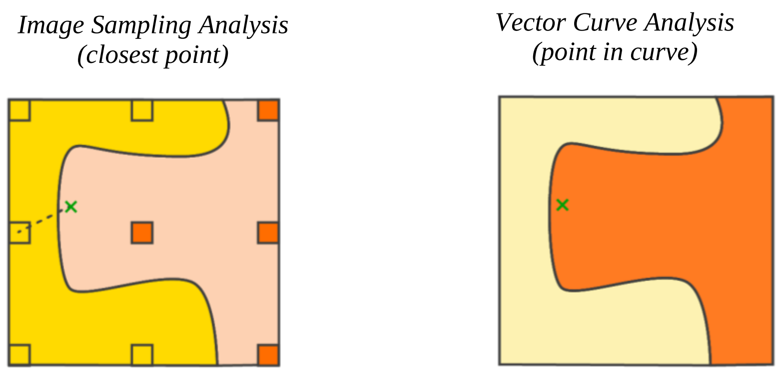

FIGURE 6. Image Sampling Analysis (closest point) vs Vector Curve Analysis (point in curve)

Weighing both these options against the aim of the project, the second option provides more accurate results and is computationally faster.

Now that we have a temperature, rainfall, and humidity value for a site location in Australia we can use this value as a basis to perform an analysis that considers the site's context. To test the robustness and accuracy of the script both the Sydney and Nanum site are analysed and compared.

The temperature of a specific grid cell on a façade or rooftop is determined by the value acquired from the Climate Map (CM), the amount of Sun it is Exposed (SE) and the height it is from the ground (H). "Temperature decreases higher in the atmosphere" (Brooks, et al. 2016, p. 1).

$$Cell\ Temp = CM + (SE * x) + (H * y)$$

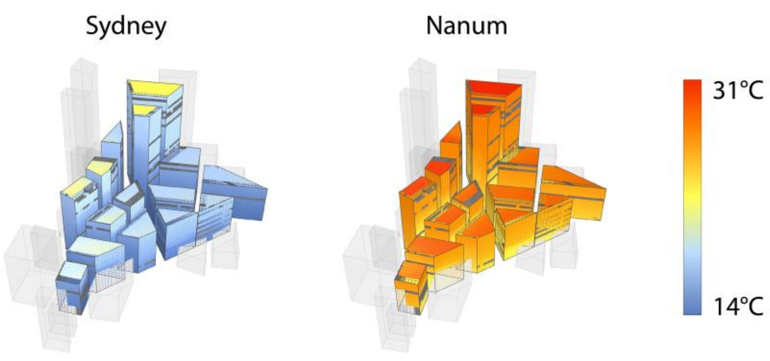

FIGURE 7. Temperature for Rooftop and Façade Cells (Degrees Celsius)

The rainfall a specific cell receives is determined by the value acquired from the CM and the angular relationship between the cell’s plane and the downwards Z axis (P) (this is currently inaccurate because it assumes that rain will always fall directly downwards but can be more accurately determined by wind direction analysis in the future.)

*Cell Rainfall = CM + (P * x)*

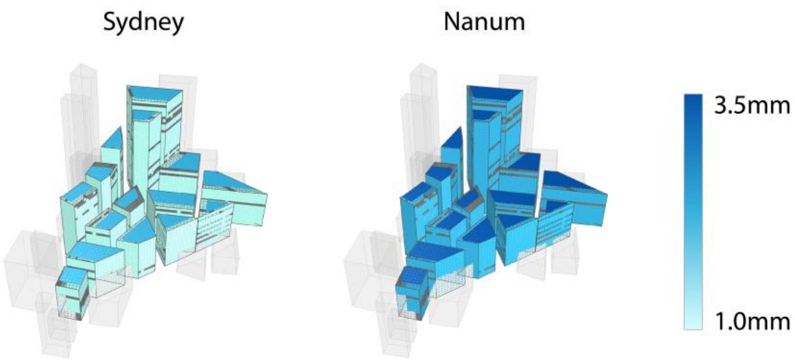

FIGURE 8. Rainfall for Rooftop and Façade Cells (mm per day)

The humidity a specific cell receives is determined by the value acquired from the CM and the height it is from the ground (H). "Cooler air can hold less water than warmer air" (Brooks, et al. 2016, p. 1).

*Cell Humidity = CM + (H * x)*

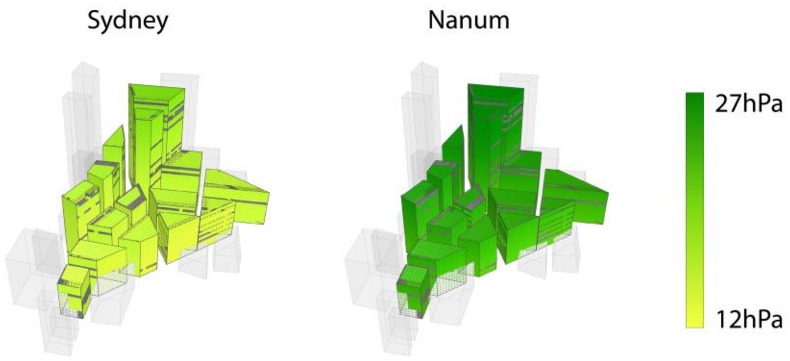

FIGURE 9. Humidity for Rooftop and Façade Cells (Hectopascals)

The x and y values in all these formulas are currently estimations of how much the preceding value should be weighted in the equation. With the help of a climate expert these values can be accurately determined in the future.

6.2.4. Building Information population

On an urban site there are restrictions to what can be planted on rooftops and facades. The two restrictions Lorikeet currently accounts for is Surface Load Baring Capacity (LBC) and unusable spaces.

Consulting with Mott MacDonald, an average LBC for an existing multi-level building rooftop is 400kg per m^2 and 60kg per m^2 for a façade. Soil weight is approximately 1800kg per m^3. With this in mind, LBCs are populated onto the rooftops and facades of the site model to disallow any plant types with soil requirement that aced these values.

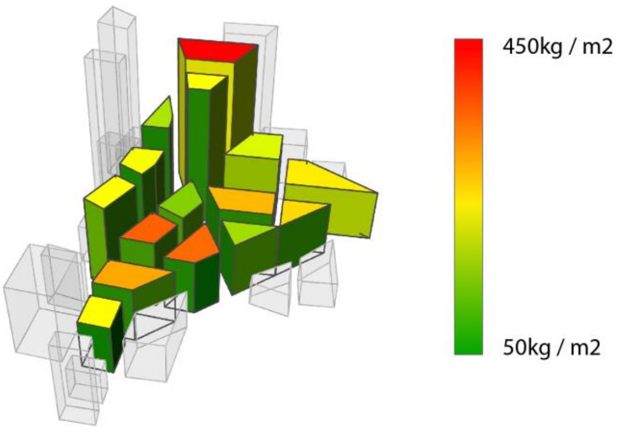

FIGURE 10. Rooftop and Façade LBC Population

Unusable spaces on facades can include windows and signage and unusable space for rooftops can include satellite areas and recreational areas. A randomly seeded script populates the rooftops and facades with unusable spaces in attempts to replicate such spaces in the context of an urban site. In these spaces the script disallows plants types to be estimated.

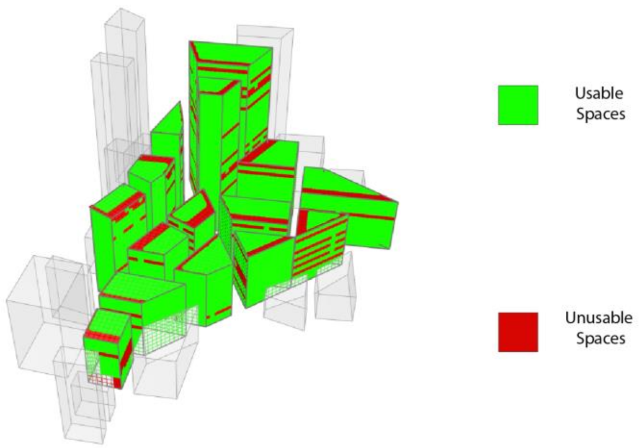

FIGURE 11. Unusable Space Population

A floating value defines the LBC, and a curve / polyline defines the unusable for space for the rooftops and facades on the site model. Such a framework is robust in the case that Lorikeet is packaged as a Grasshopper plugin or a UVMP application as these data inputs instead of being populated can be easily provided by the user.

6.3. RESULTS

To achieve the aim of automatically estimating best suited plant types for rooftops and facades on an urban site we can evaluate the environmental and building analysis results against the requirements of different plant types.

Due to time limitations, an estimated mock-up dataset of 15 plant types and their requirements is used for this case study. With more time this can be replaced with an accurate plant requirements dataset. However, the framework integrating the dataset into the script can remain the same.

Type	SoilDepth	Sunlight	Temprature	Rainfall	Humidity
Bush Ranger	200	6.5	22	700	10
Better John	130	5.5	23	600	9
Casuarina Glauca	40	3	20	1100	8
Blue Bird	60	4	17	900	9
Olea Europaea	430	8	25	1100	13
Jade Vine	30	2.5	18	800	16
Tecomanthe Dendrophylla	35	4.5	19	700	14
Basil	50	5	22	500	10
Strawberry	55	7	23	650	12
Carrot	140	3	17	250	9
Tomato	400	8	25	900	14
Hoya Imbricata	25	3	27	1000	15
Lemon	420	7.5	23	760	11
Platycerium	5	1.5	25	600	15

FIGURE 12. Plant Type and Requirements Mock-up Dataset

6.3.1. Suiting Plants with Spaces

For each grid cell there is an analysis result for sunlight exposure, LBC, temperature, rainfall, and humidity, corresponding to its plant requirement counterpart. The requirement values for each plant type are subtracted from their corresponding analysis result. These results are then reparametrized across all requirements and added to each other to give each plant type a score for each grid cell. The plant with the lowest score is best suited for specified grid cell, the plant with the second lowest score is second best suited for the grid cell etc.

The reparameterization step of this process can be a method of user management and is dependent on the domain defining the reparameterization. For example, a user that is able to water their own plants can set the domain of the rainfall result lower than the rest of the results, weighting this result less than the others in the final plant scores. Moreover, a user that is constructing a new site can design the rooftops and facades in a way where they can have a larger LBC. In this instance they can set the domain of the LBC result lower than the rest weighting this element less than the others in the final plant scores.

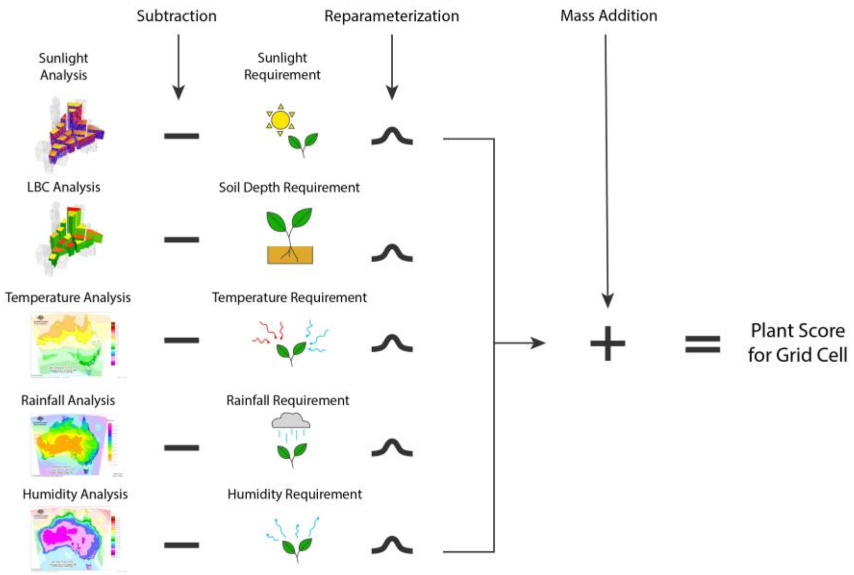

FIGURE 13. Calculating Best Plant Type for Grid Cell

This method of suiting plant types with spaces is built on an adaptive framework that allows new analysis / requirements to be added in the future.

6.3.2. Visualising Results

There are two main approaches to visualise the results of Lorikeet. Both involve a user specifying the certain rooftops and facades of the site they want to grow vegetation on.

The first approach uses the entire dataset of plant types and colours each grid cell according to its best suited plant type. The user can scroll through the best suited plant types for each grid cell, the second best suited, third best suited etc. Here, the robustness and reliability of the Lorikeet can be tested by running the script on both the site located in Sydney and Nanum and then comparing the results. In the example bellow all rooftops and facades on the site are tested for vegetation.

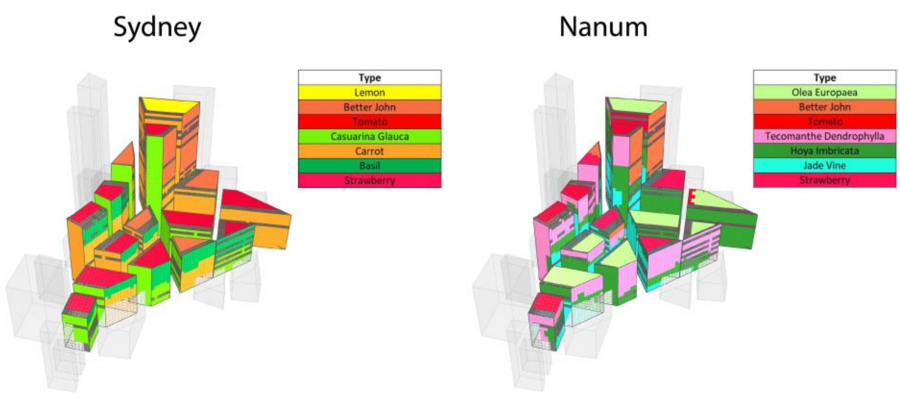

FIGURE 14. Best Plant Type for Grid Cell Visualization

Based on the results, we can make observations.

- Both the Sydney and Nanum site share similar amounts of plant type diversity.
- Both site's share plant types Better John, Tomatoes and Strawberries.
- Plant types that require larger amounts of soil strictly remain suited only for rooftops.

The second approach requires a user to specify a plant type they want to grow on their site. The plant type is then evaluated against every cell on the site model and visualised as a heat map based on the plant's score. The warmer cells are where the plant is better suited. The grey cells are where the plant is not allowed to grow either because it is an unusable area, or the plant type exceeds the facades / rooftops' LBC.

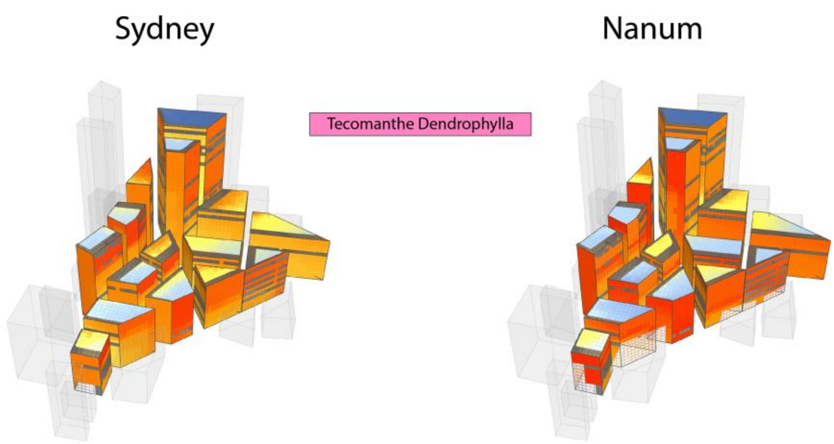

FIGURE 15. Tecomanthe Dendrophylla Suitability Heat Map

Based on the results, we can make observations.

- Nanum's site is generally more suited for Tecomanthe Dendrophylla than Sydney's Site.
- Tecomanthe Dendrophylla is better suited for facades than rooftops.
- On Sydney's facades Tecomanthe Dendrophylla is better suited for the higher altitudes whilst on Nanum's Facades Tecomanthe Dendrophylla is suited dispersing.

7. Discussion (evaluation and significance)

This research project has produced a working prototype of Lorikeet, a tool that processes climate and building data to estimate optimal places to grow different plant types on rooftops and façades. The results of Lorikeet can be integrated within the design process of urban greening either to "inform future design decision-making in an Evidence-based manner" (Petrova et.al 2019) or to directly determine the design outcome. (Zhao 2004, p. 749-754)

7.1. Evaluating Research Outcomes Against Research Question and Aims

Lorikeet is currently built on a framework that allows it to achieve the research aims and question of the project, but due to time limitations only some of the aims are achieved.

Lorikeet successfully can estimate best suited plant types for areas on rooftops and façades based on Energy plus sunlight data, Bureau of Meteorology rainfall, heat and humidity climate maps and building information including unusable surfaces and LBC's. Lorikeet is successfully built on framework that allows for further environmental and building analysis like wind load / direction and building topology, but due to time constraints these have been left as future opportunities.

Furthermore, Lorikeet fails as a fully autonomous tool as inputs like site location data and plant requirement data is still required be inputted using a manual process. With more time we can investigate how such inputs can built on an automatic framework with exploration into GeoJSON as an automatic site location deliverer and data libraries to automatically sore plant requirement data into Lorikeet.

The underlying equations that define the temperature, rainfall and humidity analysis currently contain several estimated variables that may detriment the overall accuracy of Lorikeet's results. With the help of a meteorologist and botanist these variables can be accurately defined, and the reliability of Lorikeet's results can generally be improved.

7.2. Research Contributions to the Field of Computational Design

The research Lorikeet is developed from builds into more specified work in the field of digital landscaping. Lorikeet can be used as a foundation to tools developed by Groundhog, where optimal plants types for rooftops and façades are estimated with Lorikeet and then are simulated to grow and interact with each other over time on a specified typological site.

Vector image sampling techniques although specifically used for climate map analysis in Lorikeet can be implicated into many fields using graphic processing and GIS.

At its core, Lorikeet's is built on a framework that estimates an optimally suited type based on a series of condition. Such a framework can be applied to solve a range of problems that require an optimal type to be estimated based on a series of conditions.

7.3. Future Research and Development

With more time Lorikeet can implement analysis that compares the range and distribution of the environmental and plant requirement data. In this way plant types that require specific environmental conditions are suited to more stable environments and plant types that can grow in a wide range of environmental conditions are suited to environments that vary.

Furthermore, an important environmental factor that can affect the suitability of plants is wind force and direction. With more time wind analysis can be investigated with Grasshopper plugins like Dragonfly or Eddy 3D.

Currently Lorikeet is built on a semi-automatic framework, where a user is required to input location data and plant requirement data before usage. Future research could involve investigation on how site location data can be parsed and stored automatically using GeoJSON and how a plant requirement library can evolve open source through multiple usage of Lorikeet.

8. Conclusion

The development of a DDD tool that estimates plants liveability on rooftops and facades can enhance reliability in the design process and promote the development of urban greening.

The potential for vegetation to be incorporated into the design of an urban site is often dismissed by the AEC industry, but can be influential to a sustainable design outcome. Often the decision making of what plant type goes where is left to landscaping specialists which make a judgment based on intuition. Demonstrated through an action design case study involving an urban site located in Sydney’s CBD and Nanum Quesnland, such a decision can become increasingly complex once contextualized within a building site as the success of the plant is based on a multifaceted environment created through the fusion of climate and structure. Alternatively, the case study suggests how this decision can be better informed using a DDD tool that processes climate and building data to estimate optimal places to grow different plant types on rooftops and façades.

With the help of computation, designers are increasingly influential, and it is important that such power is directed to solve complex real-world problems. This research projects outlines a computationally driven framework for matching plant types to rooftops and façades and is an advance in the designer’s quest to promote urban greening.

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