Simulation of Plant-Agent Interactions in a Landscape Information Model

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Abstract: An individual based model simulation within a digital landscape information model is used to generate and evolve a planting scheme for a given site. Plants are simulated as individual agents and over time those that are more suited to their environment and the designers' goals survive, thrive and spread.

Keywords: Agent-based, digital landscape architecture, simulation, individual based model

1 Introduction

In a time of increasing pressures on our urban environment, landscape architects are uniquely positioned to use living systems to improve outcomes. Appropriate selection and distribution of plant species in constructed landscapes can help to address problems such as water scarcity, rising temperatures and urban heat island effects (LOVELL et al. 2009, WHITE et al. 2015). While they provide numerous benefits, plants are complex living organisms with their own lifecycles and needs. To design with plants our tools ought to be able to express their growth and change over time as well as interactions with each other and their environment. This paper investigates the use of ecologically-inspired computational strategies to create intelligent, performance based planting designs. A simulation using the established mem (LIM) to generate and evolve a planting scheme for a given site. Plants are simulated as individual agents and over time those that are more suited to their environment and the designers' goals survive, thrive and spread. The proposed methodology can be adapted to any performance goal given the required input layers. The creation of a data-driven tool for performative planting design that is integrated with documentation practices could help landscape architects to address future challenges.

The aim of this paper is twofold; first, to suggest improvements upon prior work in which an agent-based ecological model was developed in Grasshopper for use in planting design (WHITE et al. 2019). This paper offers extensions on this initial model by including additional individual level behaviours, input goals and constraints, and greatly improving computational efficiency. Secondly, the application of this model is demonstrated in a production BIM environment using Revit and Dynamo. A case study is then presented illustrating how the tool is used to rapidly create and visualise a high-performing planting design from given site inputs.

This work is inspired by a renewed focus on performative goals for built planting design (THOMAS et al. 2001). In landscape architecture, performative planting design may be used to create future cities that are more sustainable, use fewer resources and mitigate the effects of climate change and other environmental challenges. Our model is informed by the *Australasian Virtual Herbarium* database of digitised herbarium specimens, providing a source of data for the growth conditions and distribution of plants in a real world environment (AVH 2020).

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1.1 Landscape Information Models

As a profession, landscape architecture is rapidly moving into the digital realm, with pressure to coordinate with multidisciplinary BIM models and provide an additional layer of information rich output. Existing CAD software has been developed for use in architecture and engineering and has limited capacity to deal with ephemeral qualities of soft landscape, leading to the development of the concept of Landscape Information Models or LIMs (ZAJÍČKOVÁ et al. 2013, WALLISS et al. 2015). These models include plant-objects as a central information element. While there have been numerous successful approaches to developing generative planting tools for landscape architects (TEBANYIAN et al. 2019, BILURBINA et al. 2019, BELESKY 2016), there has been limited uptake as part of industry documentation standards. This can be improved by integration with documentation & processes to effect substantial improvements in practice.

1.2 Approaches in Computational Planting Design

Although planting design is traditionally a manual process, a number of methods have been developed to systematically distribute plants across a given site using computer systems. These methods originate from diverse fields including agriculture, forestry and ecology. Approaches that have been explored for their application within the field of landscape architecture include the use of cellular automata (BILURBINA et al. 2019), parametric systems (TEBANYIAN et al. 2019, BELESKY 2015) and agent-based approaches (AREVALO 2019).

The use of Cellular Automata (CA) to represent local plant interactions as in BILURBINA (2019) has precedent in forestry and ecology where it has been used to simulate population dynamics and interactions between individuals across large sites. This approach uses a grid system to represent space in which plant-cells interact with neighbouring cells according to a defined set of state-change rules. Site parameters are used to inform the preselection of species and their distribution on a given site (BILURBINA 2019). This method requires the analysis of experimental data to produce formal CA rules of interaction for each species combination. The addition of new behaviours or input layers requires a reevaluation of CA interaction rules. This method is well suited to the study of interactions of plants in large-scale landscapes including scaling and computational efficiency.

The approaches defined by BELESKY (2015) and TEBANYIAN (2019) use a circle-packing or grid system to establish plant distribution. The development of these plant species over time is controlled by a parametric time-scale to visualise changes in growth and mortality. The primary goal of these methods is to communicate and explore these changes on a given site, rather than optimisation. The approach being proposed here uses an Individual Based Model, drawing from methods developed in the study of computational ecology. There are a number of advantages to the IBM over alternative methods. In an IBM, behaviours and interactions of individual organisms are simulated and the dynamics of the system emerge from these interactions. IBMs allow the simulation of behaviours such as growth and resource consumption of plants as they occur across space and time, leading to complex emergent outcomes (GRIMM et al. 2005, DEANGELIS et al. 1992). IBMs can be applied to a variety of scales and additional inputs and behaviours can be added to or modified from an existing model. The use of each of these techniques in a new application for the generation of planting designs raises a number of questions of validity and accuracy. The value of IBMs in representing the behaviour of real world planting communities has been addressed in ecological simulation literature (GRIMM et al. 1999). It is important to clarify that the simulation, as with all models, is not a one-to-one physical simulation of plant processes, but a tool for creating a more informed planting layout for any given site.

1.3 Individual-based Model Implementation

Individual based Ecology or IBE looks at ecological systems as an assembly of unique individuals. In an IBM, the properties of an ecological system emerge from the adaptive behaviour of individuals (GRIMM & RAILSBACK 2005). In plant communities this could include competition for local resources, allelopathy, shading of neighbours, root competition. The theories of IBE are models of individual behaviour. These models of individual behaviour are used to predict and understand the behaviour of larger systems. The developed model can then be tested against empirical observations.

Our goal is to predict the success and survival of combinations of plant species growing together under varying conditions in the built landscape. We make an assumption based on existing models that key factors for survival are access to sunlight, root competition and water availability. An individual based model is developed that simulates and analyses these factors in a given site arrangement. Predictions can be made about the success of this configuration of plants for this site. This could then be validated against empirical observations of plant survival.

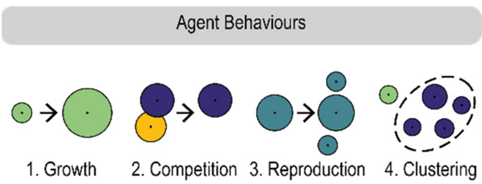

Fig. 1: Behaviours of individual plant agents that are represented in the proposed IBM simulation. These include growth, competition, reproduction and same-species clustering. A description of these simulated behaviours follows.

1) Growth – plants increase their occupied volume, colonising space to maximise their intake of solar energy, water and other resources.
2) Competition – As they encounter other specimens, Plant-agents are forced to compete both above and below ground for water, sunlight and nutrients necessary for survival.
3) Reproduction – successful Plant-agents that reach a state of maturity are able to reproduce to create more agents of the same species and colonise a larger area.
4) Clustering – Within natural plant communities there is a tendency for same species groups to compete less intensely (BENES 2004). When competing plants are of the same species, there is a greater chance of mutual survival.

In our plant community IBM, the intersection of circular Zones of Influence (ZOI) trigger competitive interactions for each plant. When these zones overlap and intersect, the resulting competitive interaction is calculated and may trigger mortality. This is a simplified model of the ecological principle of self-thinning taken from FIRBANK & WATKINSON (1985) as described in DEUSSEN (1998).

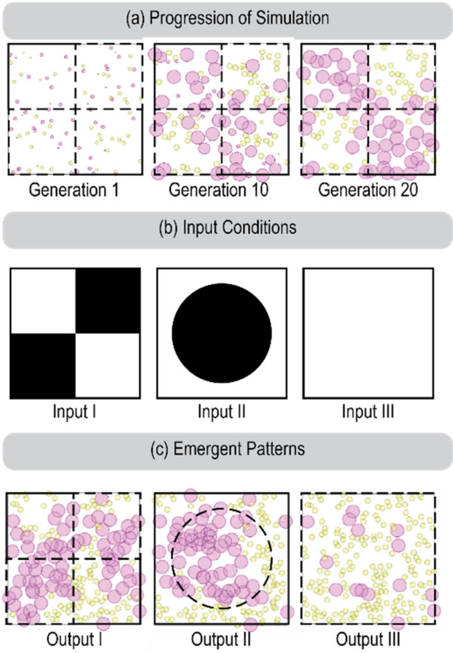

Fig. 2:
a) Progression from a randomised state to site specific planting scheme over 20 generations of IBM simulation.
b) Patterns of light values input into simulation to demonstrate the relationship between site condition inputs and the emergent outcomes from our IBM simulation.
c) Resulting emergent patterns. Species that are suited to conditions in specific areas on site will dominate. Colours indicate the shade tolerance of subject species. The final outcome is the result of multiple layers of influence on plant development that may include shade, soil depth, water availability or any other spatially expressed parameter.

We begin with a randomised distribution of species, and progress to a state in which regions are colonised by species most likely to thrive. The competition algorithm is a development of methods proposed for use in creating realistic natural environments in computer graphics (DEUSSEN 1992, BENES et al. 2004). The efficacy of this technique in creating intelligent planting layouts was previously demonstrated in (WHITE et al. 2019).

The IBM procedure is as follows:

1) Divide total planting area into contiguous zones
2) For each zone:
   i) Fill with plant-agents in a randomised distribution
   ii) For each agent:
      a) Evaluate species suitability against environmental parameters for a given position
      b) Check for intersection with other agents
3) When two plants intersect: the healthier, more competitive plant displaces the other.
4) Plant-agents grow according to species growth rate and maximum size parameters.
5) Successful mature plants propagate to the next generation within a local radius given by the equation below, where θ represents the angular direction of the new agent from the parent and d represents the distance in project units.

$$\theta = 360 \times rand(0,1); \quad d = \sqrt{\left(rand(0,1) \times (r_1^2 - r_2^2) + r_2^2\right)}$$

2 Integration into A BIM Environment

2.1 Simulation Methodology

This paper demonstrates the integration of the simulation model into industry-standard documentation practices, developing an interactive planting generation and evaluation tool using Dynamo and Revit. The core of the IBM is scripted in Python due to its extensive library support and compatibility with platforms including Dynamo, Grasshopper and Revit. Platform-specific tools provide user inputs and site information. A system of plant-agents is created in a live production environment and subjected to a competitive simulation. This simulation provides quantitative and spatial feedback on planting performance during the design process.

2.2 Practical Implementation

In the context of a working studio, efficiency and speed are key to the effectiveness of an integrated solution for planting design. A key constraint of IBMs is the increase of computing time in proportion to agent population. The process of agent-agent interaction can be approximated as $O(n^2)$ if each agent is required to interact with each other agent per timestep (WILENSKY et al. 2015). In this implementation, programming techniques were needed to reduce computing time on larger problems by an order of magnitude. An analysis was conducted of the correlation of program variables with performance. This analysis found that Time (t) was most strongly correlated with number of individual agents. To increase performance of the IBM two methods were investigated; replacing individual plants with an agent-proxy representing a number of plants in a cluster, or segmenting the simulation into multiple sub-areas. For this implementation it was found that individual plants would be preferable in the process of documentation and visualisation outputs and the segmentation method produced a sufficient performance increase. This is consistent with recommendations by WILENSKY et al. (2015).

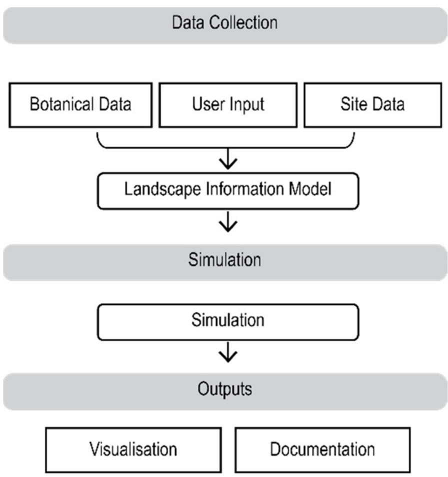

Fig. 3: The flow of data within the IBM as implemented in Revit and Dynamo. Inputs are taken directly from the Landscape Information Model as well as variable user inputs, site conditions and botanical data. The outcome of the resulting simulation is visualised and fed back into revit as documentation elements.

3 Case Study

A case study was conducted using two reference planes with contrasting planting requirements including high and low light availability. A Landscape Information Model was constructed in Revit to test the performance of the proposed simulation in providing a suitable planting solution.

3.1 Botanical Data Inputs

Real-world data used to inform our IBM parameters was sourced from the Australasian Virtual Herbarium (AVH). This database contains millions of digitised records of herbarium specimens, provides insights into distribution and environmental requirements of these species. Species were selected from two ecological communities: Eastern Suburbs Banksia Scrub and Robertson Rainforest in the Sydney Basin. From these communities, 8 plants were selected for commercial stock availability and to form a representative cross-section of plant forms. In this case we used mean Leaf Area Index (LAI) as a proxy for shade tolerance of species. In the future as discussed below further experimental testing of individual species would provide greater accuracy for this parameter.

Table 1: Plant parameter values generated from Australasian Virtual Herbarium data (AVH 2019)

Species	**Soil depth min. (m)**	**Precipitation annual min. (mm)**	**Leaf Area Index (LAI) mean**
Actinotus helianthi	38.40.6	753	2.0
Asplenium australasicum	1	959	2.2
Banksia integrifolia	0.6	745	1.8
Blechnum nudum	0.9	753	2.4
Cyathea australis	0.9	849	2.4
Lomandra longifolia	0.6	753	2.0
Viola hederacea	0.6	745	2.5
Xanthorrhoea arborea	1	959	2.1

The Mean Leaf Area Index (LAI) of plant species is calculated using data from Australasian Virtual Herbarium (AVH 2019). LAI is a measure of the total single-sided leaf area as a proportion of ground area in a given plant community. Although a true experimental measure of 'shade tolerance' for the selected species was not available, a mean LAI value of >3.0 was found to have a high correlation with understorey plants identified as 'shade tolerant' in horticultural practice.

3.2 Results

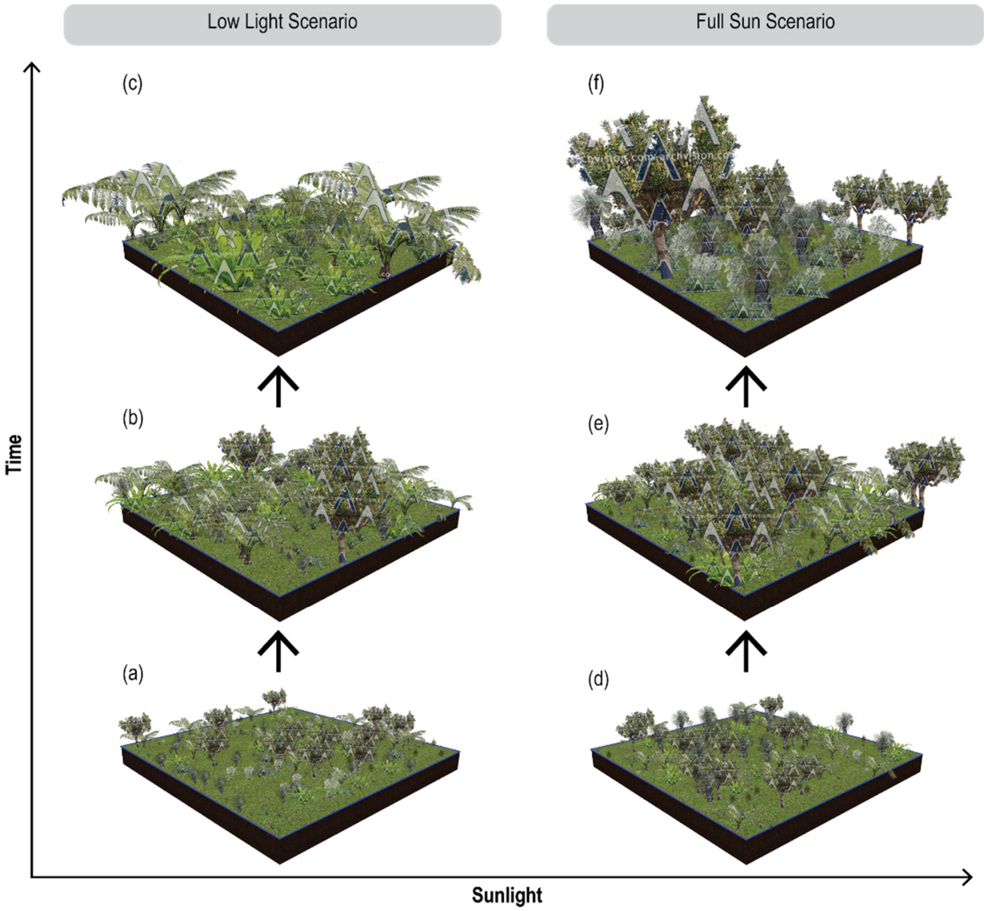

Fig. 4: The IBM methodology was used to generate a planting scheme for a sample area. The visualisation and documentation outputs provided including an annotated planting plan and predicted performance graph. Effective visualisation of planting schemes is vital in communicating outcomes to clients and stakeholders, while the performative graph helps designers identify issues with species selected for the site. Visualisations were produced using Archvision RPC within Revit. In the final generation of the low-light scenario (c), dominant species visible are *Cyathea australi*s and *Asplenium australasicum*. The full-sun scenario is dominated by *Banksia integrifolia* and *Lomandra longifolia*.

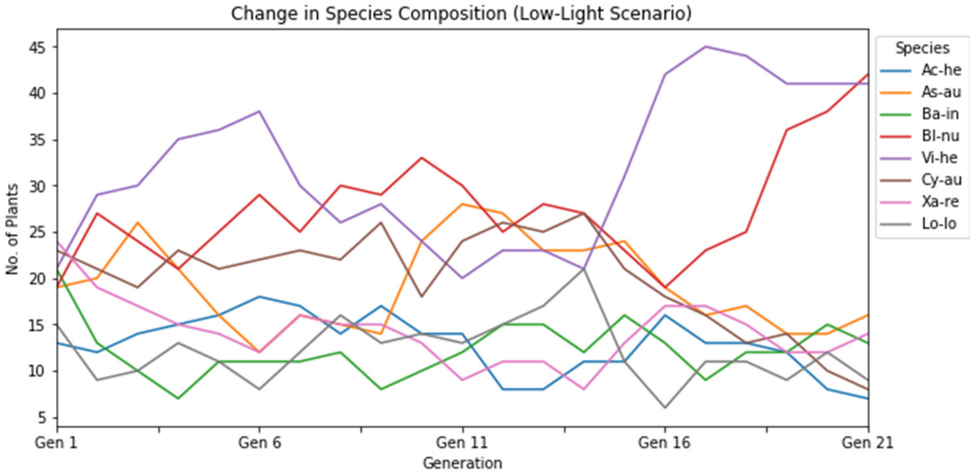

Fig. 5: As the simulation progresses, plants that are suited to their overall environment increase in number, displacing those that are less suited. From generation 12 onwards, a clear divergence is visible between the two most suitable species – Blechnum nudum and Viola hederacea, and species with a lower tolerance for shade.

4 Conclusion

The proposed method of IBM simulation for planting design produces an output in which the position of plant species is intelligently adapted to site conditions. When implemented, this may lead to reduced resource inputs, water usage and plant failures. Building upon previous work it demonstrates the potential of data-driven approaches to planting design to improve performance and elevate landscape designs (White et al. 2019, Bilurbina et al. 2019, Belesky 2015, Arevalo 2019). With advanced computational tools, it will be possible to use more rigorous approaches to landscape design with an account for performance. Key to this development will be improvements in methods of collecting and utilising data of living systems and adapting them into design schemes. To this end, there is a need for a model of landscape planting performance, and a collection of accurate and validated data to inform this model.

The model being proposed serves to this direction, and it will be much more efficient as it is further developed in sophistication of user inputs and design goals. Performative planting design will assist to create future cities that are more sustainable, use fewer resources and mitigate the effects of climate change and the urban heat island effect.

There is a growing trend of increased data availability that may inform such a simulation. The Which Plant Where research project is currently undertaking a series of physical experiments to determine growth characteristics of native Australian vegetation and exotic species in common use. This experimental data, when released will assist in the validation of digital models. Further, the current trend of digitisation of herbarium assets will provide a supplementary source of data for species performance (AVH 2019). Further development is required to take advantage of the data available from the LIM including sunlight, soil depth and water availability at each plant location. Our future goal is the addition of a more complex mechanistic model including raycasting to calculate light interruption and local competition for available water and nutrients. Future outcomes will include the publication of a Revit plugin for performance based planting design.

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