

Agent-Based Modelling Assessment 1

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1 Research Question

How does the urban morphology change when people and buildings effectively consider externalities of development on the surrounding environment, rather than simply aiming to maximise its own amenity? What is the ideal form of development that can maximise the amenity of all residents, while maintaining the required floor area within the district?

2 ODD Description

The model description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al., 2006), as updated by Grimm et al. (2020).

2.1 Purpose and Patterns

The model simulates the impact of developments on the surrounding environment, and seeks to figure out the optimal built-up form that accommodates the required floor area. Large-scale buildings are essential for an efficient and dense urban environment and may provide high amenity, but may come at the cost of lowering amenity on the surrounding environment by blocking the views and sunlight. By changing the extent to how much each building considers the externality, this model observes the change in the urban skyline depending on the 'selfishness' of the residents within the area.

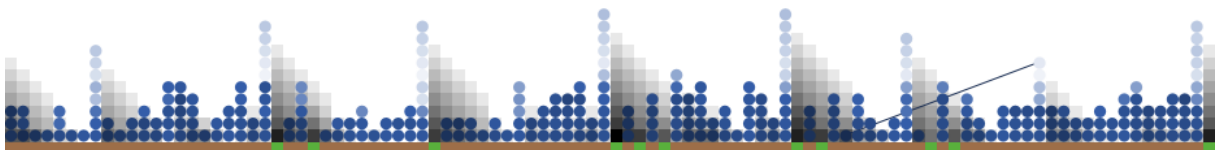


Figure 1: Screenshot of the model, showing the buildings created from stacking building blocks, the shadows cast by the buildings, and the most recent movement of a building unit.

2.2 Entities, State Variables, and Scales

The world is designed as a vertical cylinder with dimensions listed in Table 1: the x axis representing a one-dimensional location of buildings, and the y axis representing the height. One patch is equivalent to the size one building unit occupies, therefore the scale of the width of the patch is the width of one building, and the height scales to one level height. The 3-dimensional world is reduced to a vertical planar world for simplification.

Table 1: Dimensions of the world of model.

Feature	Value	Additional Information
min-pxcor	0	100 locations in total
max-pxcor	99	The world wraps horizontally to express a wider area.
min-pycor	-1	Patches on pycor = -1 are used to represent the ground.
max-pycor	30	Height of buildings not expected to surpass this value.

Assuming a northern-hemisphere context, the north is at the right of the screen, and shadows are created on the north side of the building. The patches represent the ground and the surrounding environment, with the lowermost row of patches representing the ground. Time steps do not represent actual temporal measures; in one time step one building units relocates to a different position.

Building units are represented as the turtles, which are stacked on top of each other to form multi-story buildings. They are shown as blue circles in Figure 1. They observe the surrounding environment to quantify the amenity level of the position based on the view, access to sunlight, access to open space, and the price. The position of the units are snapped to patches. The entities and the variables used in this model are shown in Table 2.

2.3 Process Overview and Scheduling

The flowchart of this model is as illustrated in Figure 2.

In each time step, the first step is to determine whether it is physically possible to have an unit on the patch without it floating. A patch is considered buildable and `is-buildable?` set to true if:

- it is located directly above the ground (`pxcor = 0`)
- it is already occupied with a building unit
- the patch directly below is occupied with a building unit

For all patches considered buildable, `amenity` and the `hate` of all current building units and patches that can be built up are calculated. These two measures are aggregated, weighted by the parameter `selfishness` to calculate the 'net amenity' of each unit. Based on this measure, the one unit with the lowest net amenity is chosen to move to a vacant patch where it can maximise the net amenity. After the new locations are confirmed, the model loops again to quantify amenity. This is repeated until the unit with the lowest net amenity can no longer find a place to increase its net amenity.

The morphology of the buildings are quantified by the distribution of building heights. The

Table 2: Agents and variables introduced in the model.

(a) Global variables used in the model.

Global Variables	Explanation
floor-area-percentage	The ratio of building units to the number of patches
num-units	The number of building units (turtles) in the world
sun-height	Solar altitude in degrees, used to calculate shadow
selfishness	Dictates the ratio of amenity and hate when calculating net-amenity
open-range	The maximum distance turtles consider when calculating view-north and view-south
max-view	The maximum distance turtles consider when calculating view-north and view-south
light-weight view-weight open-weight price-weight	Weight of each variable when calculating patch-amenity
visualise-net-amenity	When turned on, the net-amenity of each building unit is visualised

(b) Patch (environment) variables in this model. Variables are only assigned to cells above ground unless otherwise stated in the explanation column.

Patch Variable	Explanation
area-type	Assigned to ground: classifies if location is an open area or a building exists
building-height	Assigned to ground: the height of building on the x position
num-neighbours	Assigned to both ground and above ground: the number of building units within open-range
price	The property price of building unit at patch. Assumed to be linear with height, calculated as $price = building-height \times price-weight$
shadow	The strength of shadow cast by tall buildings on the south. Shadows are simulated as a percentage of the sun's height
view-north	Cells between self to the nearest building unit on the north at the same level, calculated as $view-north = \frac{num-neighbours}{2}$
view-south	Cells between self to the nearest building unit on the south at the same level, calculated as $view-south = \frac{num-neighbours}{2}$
open-space	The number of open space the building unit has access to. A unit has access to open space if it is on a patch with area-type set to 'open'
patch-amenity	The total benefit the building unit at the patch achieves from the view and open space
patch-hate	The total amount of amenity the other building units are losing (or will lose) as a result of the building unit's presence
patch-net-amenity	The net amenity the building has on the whole world, calculating the amenity minus hate

(c) Turtle (building unit) variables used in the model. Note that amenity-related values are actually calculated on the patch level and extracted.

Turtle Variable	Explanation
amenity	The total amount of amenity of building unit. Equal to patch-amenity of the patch the unit is on
hate	The total amount of amenity the unit is decreasing from all other patches. Equal to patch-hate of the patch the unit is on
net-amenity	The net amenity the building has on the world considering selfishness . Equal to patch-net-amenity of the patch the unit is on
is-top?	A boolean variable storing whether the building unit is the tallest building in the world

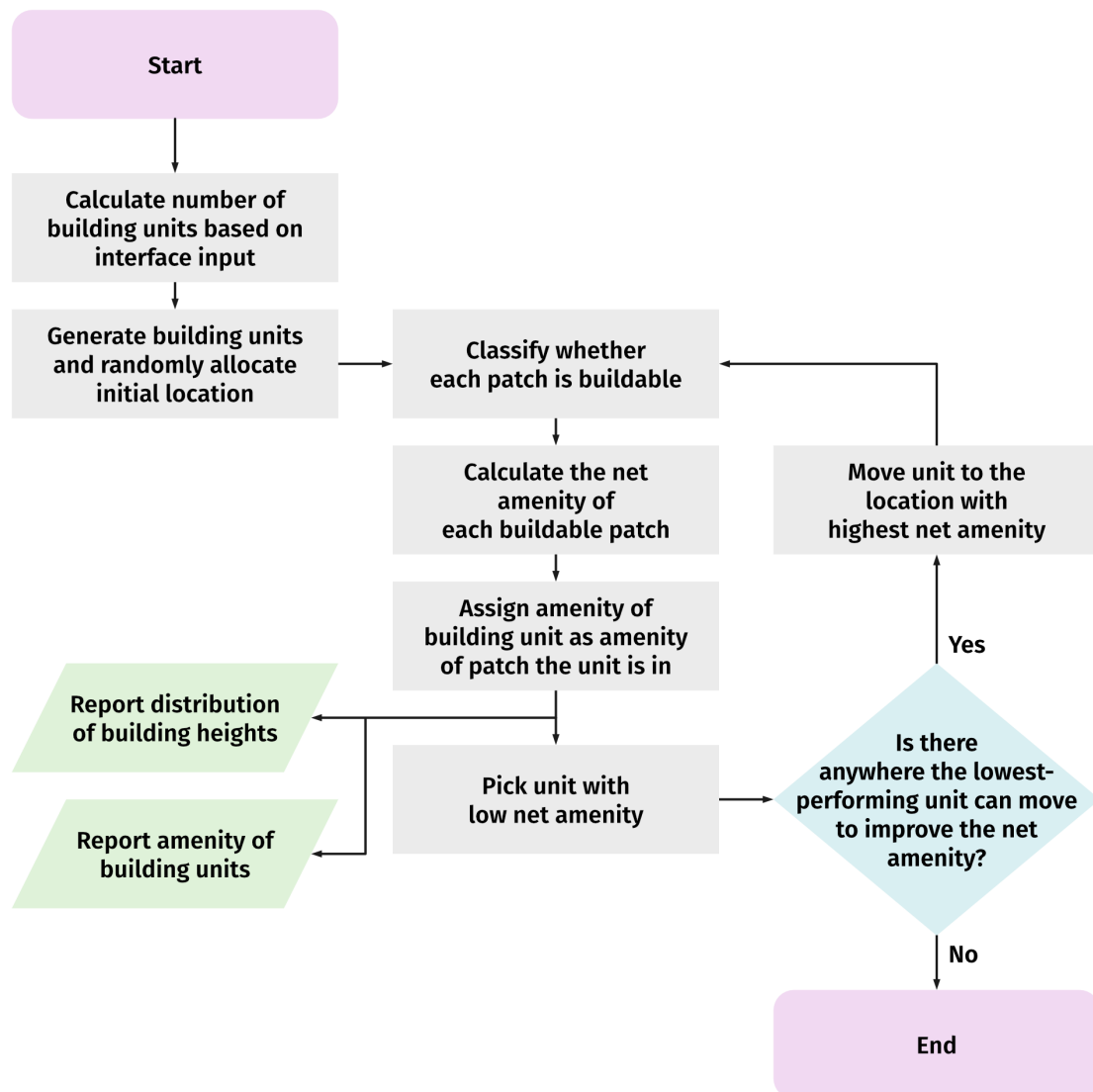


Figure 2: Overview of the model process.

performance is measured using the average **amenity** of all building units. These measures are reported every time step at the interface.

2.4 Design Concepts

Of the components of the design concepts in the ODD protocol, this report covers the basic principles, objectives and observation.

2.4.1 Basic Principles

Large scale developments, equipped with great views and plenty of sunlight, may provide new functions and amenity to its users, but they have a large impact on the surrounding environment, blocking views and sunlight from their neighbours. The significance of these externalities are highlighted through regulations aiming to maintain access to these benefits implemented in some areas (Tavernor and Gassner, 2010; Li et al., 2019) and lawsuits occurring between large-scale environment-disrupting developments and surrounding residents (Sorensen, 2011). Another attempt to internalise the externalities is by environmental impact assessments but without success (Arts, Tomlinson and Voogd, 2005; Glasson and Therivel, 2013). This model aims to explore the optimal placement of development by proposing a methodology that explicitly quantifies externalities and embed into the maximising factor to directly address this issue.

2.4.2 Objectives

The objective measure each turtle seek to maximise is the **net-amenity** measure. This is the weighted aggregation of the amenity of itself and the negative impact to others, the weight being dictated by the global variable **selfishness**. With maximum selfishness units only consider their own amenity, and units will only consider impact mitigation on others when set to 0. The details of the calculation is explained in Section 2.7.1. Agents aim to optimise the outcome of a 'good balance' between own satisfaction and its impact on the surrounding.

2.4.3 Observation

The two main factors of observation are the distribution of building heights and the amenity of each building unit.

The distribution of building heights are summarised as a histogram in the interface, accompanied by the standard deviation. The standard deviation shows the variance of building heights; a high value indicates high variance - indicating the existence of high-rise buildings and open spaces, while a low value indicates buildings are around the same height. Since the number of units are dictated by the floor-area ratio and remain unchanged, the mean of the building will always be **floor-area-percentage** / 100.

The **amenity** of each unit is observed from the perspectives of temporal change and distribution. For the temporal change, the mean amenity for all building units are shown in a plot, along with the current value shown as an output. The distribution is shown using a histogram of the amenity, as well as being shown on the graphical output by the colouring of the turtle. In the model interface, the temporal change of **hate** is displayed as well.

We must note that it is not possible to compare between scenarios with different weights for each amenity component.

2.5 Initialisation

The model space is initialised as an abstract physical space, where the area is required to accommodate the floor area ratio determined by the input from interface. The initialisation procedure is as follows:

1. Patches are set up, with the bottom row (`pycor = -1`) as the ground.
2. The number of building units are calculated from the floor-area ratio and the width of world.
3. The building units are allocated random x-coordinates, and are stacked on top of each other to create initial state of buildings. Since the locations are assigned randomly, the model is initialised differently every time it is executed.
4. The views (`view-north` and `view-south`), `open-space`, `price`, and `shadow` are calculated and aggregated as the amenity of each building unit.

2.6 Input Data

The model does not use input data to represent time-varying processes.

2.7 Submodels

In this section, we will briefly cover the determination of amenity and hate for each patch created, and the relocation process.

2.7.1 Calculation of amenity

The amenity is calculated from four components: the view from the position, access to open space, the accessibility to light, and the price, as illustrated in Figure 3. The methodology for quantification of each component is summarised in Table 3.

Table 3: The methodology to calculate each component in the model. The variables in the notation column are used in Equation 1, Equation 2, and Equation 3.

Component	Notation	Methodology	Range
View	$v(k)$	Number of columns between the nearest building unit with the same height on each side, implemented in the model as <code>view-north</code> and <code>view-south</code> respectively. Each side capped at the global variable <code>max-view</code>	0 - <code>max-view</code> for each side
Open Space	$o(k)$	Number of open spaces (ground with no building units) within the horizontal distance of <code>open-range</code> from the unit.	0 - <code>open-range</code> $\times 2$

Component	Notation	Methodology	Range
Sunlight	$l(k)$	Determined by the shadows cast by other building units, calculated as follows: For each unit, the area of shadow made by itself and all units below are considered to be the triangular area north of the building, at an angle equal to the height of the sun. A shadow level of 1 is added to patches within this area, and iterated for all building units. Overlap of shadows calculated by units on the same building automatically create a more intense shadow at the bottom: one cell down, one level increase in shadow intensity, as observable as the gray-to-black gradation visible in Figure 1. Patches with multiple high-rise buildings on its south, and considerably lower than the adjacent buildings' heights are simulated to have a more intense shadow, replicating the cumulative impacts in real life.	-
Price	$p(k)$	Determined solely by the height of the building unit as $\text{pycor} + 1$.	$1 - \text{max-pycor} + 1$

For each building unit at patch k , the amenity $a(k)$ is calculated from the raw values from Equation 1, by adding the amenity gained from the view and the open area, and subtracting the price and the shadows cast on the unit, each weighted by the parameters (denoted below as α) set by the interface.

$$a(k) = \alpha_v v(k) + \alpha_o o(k) - \alpha_l l(k) - \alpha_p p(k) \quad (1)$$

The hate is the amount of amenity that was lost as a result of the building unit existing, or will be lost if a building unit was to be built at patch k ; blocking the view, casting shadows, and consuming potential open space. This is calculated as Equation 2 by comparing the current environment and a scenario without the one unit, making the building one unit lower - equivalent to removing the top unit. The change in the views and the distance are considered, as well as the production / reduction of open space - if the building was one unit tall.

$$h(k) = \sum_j \Delta_k a(j) = \sum_j (a_k(j) - a_{\bar{k}}(j)) \quad (2)$$

- $h(k)$: the hate calculated for patch k
- j : all other patches influenced by patch k
- $a_k(j)$: the amenity of patch j if a building unit exists in patch k
- $a_{\bar{k}}(j)$: the amenity of patch j if a building unit does not exist in patch k

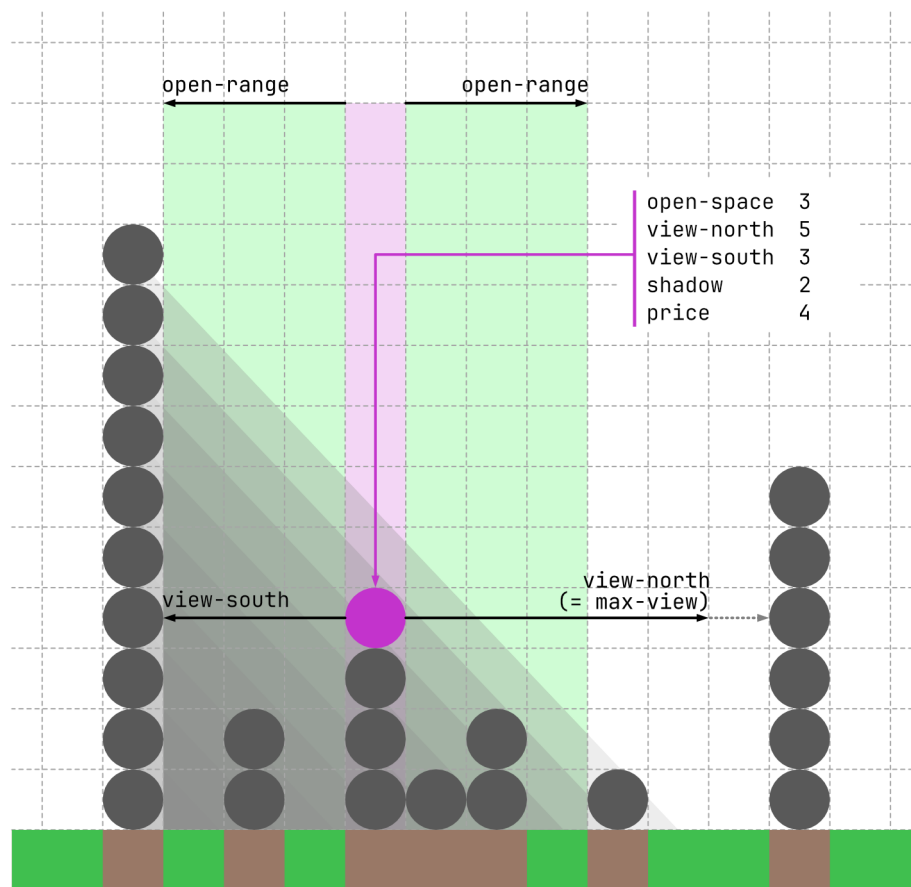


Figure 3: Illustration of each component for amenity.

Table 4: Variables and measurements to vary and observe in the BehaviorSpace experiment.

(a) Varying variables in the BehaviorSpace experiment		
Variable	Range	Increments
floor-area-percentage	100 - 500	100
selfishness	0 - 100	10
(b) Observing measurements in the BehaviorSpace experiment		
Measurement	Explanation	
mean amenity of building units	Measurement to maximise	
standard deviation of building-height	To gain insights on the morphology	

The **net-amenity** A_k is calculated by weighting the **amenity** and the **hate** for each patch by the weighting parameter **selfishness** (denoted σ (%)), as shown in Equation 3.

$$A_k = \frac{\sigma a(k) - (100 - \sigma)h(k)}{100} \quad (3)$$

The **amenity**, **hate**, and **net-amenity** of turtles are equal to the corresponding values of the patch the unit exists in.

2.7.2 Relocation of units

One unit within the 5 lowest **net-amenity** is chosen for relocation. The reason that the single lowest one is not directly chosen is to avoid loops and to make the model potentially be able to escape local maxima. The possible destinations are patches that are buildable (**is-buildable** = **true**) and are not already occupied with a building unit: this means an unit can relocate itself to the top of an existing building or to an open space. It will move to the patch where it can maximise the **net-amenity**; thus maximising the amount of **amenity** it can achieve while minimising the negative externalities to the surrounding environment, weighted by the **selfishness** variable.

3 Brief Methodology

The aim of the research is to explore the relationship between the **selfishness**, the characteristics of the built environment, and the **amenity**, to find out the most optimal form of the urban environment for different density levels. We will use the BehaviorSpace function to iterate over different conditions in the density and **selfishness**, dictated in the model by **floor-area-percentage** and **selfishness** respectively, to maximise the mean **amenity** of turtles. The variables and measurements are organised in Table 4. Each condition is repeated 10 times.

The observation of measurement variables will be conducted under the usual state, assumed as **ticks** = **floor-area-percentage**.

For each density condition, we will determine the **selfishness** value that can achieve the maximum **amenity** among units, and the variance of the building height under this condition. This

will allow us to gain insights on the ideal urban environment that can maximise the amenity for the residents as a whole.

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