Data Influenced Infrastructure Generation

Combining holistic urban datasets through a digital Slime Mold algorithm for cycle path generation

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Existing infrastructure in cities has become increasingly incapable of operating at its designed efficiency. This demand has been created by the growth in population generating a larger demand and strain on the existing infrastructure. This paper explores how user-generated data could be utilised to create transport infrastructure, more specifically bicycle pathways. Through a series of ‘four sprints’, a pathway generation system has been adapted from the behaviour of Slime Molds (Physarum Polycephalum), in particular, its ability to define shortest paths on a terrain. The first sprint outlines the design of a Slime Mold algorithm between user-specified points, the second utilises the algorithm for pathway generation in a macro and micro urban scale (acknowledging both the existing infrastructure and cadastral), the third defines weight or effort limits for the pathways in order to suite realistic user-profiles (fitness level of cyclist groups), and the last sprint creates the start and end points for the pathway generation from user-generated data, applying the Slime Mold system to a ‘real world’ context. Through the four sprints, a design tool has been created that can be used to not only create and analyse cycle pathways, but tweaked for various other forms of tangible transport infrastructure.

Keywords: urban planning, agent based modelling, optimisation and decision support, transport planning

INTRODUCTION AND AIMS

Urban infrastructure and population growth are challenges faced by metropolitan cities around the world. The suburban sprawl and increase in population outwards from the metropolitan centre has created issues in linking people to and from suburbia (Trubka, Newman and Bilsborough 2010). However, the inherent problem does not necessarily lie with the rate of housing growth, rather, the decline in efficiency of transport links or with complexities involved when proposing and developing new or complementary transport routes. Here the paper argues that the generation of transport links are closely related and interlinked (Cervero and Duncan 2003) with (a) topog-
raphy; (b) existing use of cadastral [being occupied
by existing infrastructure]; (c) existing infrastructure
[roads, paths, rails, etc.]; and (d) existing or projected
use of infrastructure. The research team acknowledges that economic, political, social, and various
other external factors undoubtedly influence the pro-
cess of infrastructure planning, but will ignore these
factors for the sake of this research and the presented
paper due to their transient qualities which are con-
stantly changing.

In order to achieve meaningful infrastructure
planning that is directly associated with the current
conditions of cities, the research team introduced
Slime Molds (Physarum Polycephalum) as the behav-
ioral framework for the infrastructure gener-
ation. Slime Molds are single-cell non-intelligent or-
ganisms which colonate with a community of other
Slime Molds connecting themselves with their food
sources with the most optimised pathway. Hence,
designing and using an algorithm to digitally imitate
the behaviour of a Slime Mold became the outlin-
ing objective. Furthermore, in giving the Slime Mold
algorithm a meaningful generation purpose, the in-
frastrucure generation was targeted and tweaked
towards cycle pathways. This purpose was to address
a cultural change towards the perception of cycling
as a mode of transport rather than a cardiovascular
exercise (Zander et al, 2013).

This paper reports on how a non-intelligent or-
ganic system can be used to generate cycle infra-
structure with predetermined criterion set by the user,
in detail the items listed above on (a) - (d). Design-
ing process systems that complement and responds
to nature in a meaningful and reasonable way is the
core philosophy of the research presented in this pa-
er. Hence we argue for the use of Slime Molds
over other agent-based approaches due to the inher-
ent intelligence of Slime Molds and their ability to
create the most optimal path between itself and its
food source relative to the environment surrounding
it (Beekman and Latty 2015). The Slime Mold does
not create the shortest straight-line path to the food
source, however it negotiates the topography to op-
timise the effort required to reach the food. Taking
this conceptual idea and applying it to infrastructure
planning may improve accessibility and minimise ef-
fort from one point to another (Adamantzky 2014).

Therefore the research aim is to design a cycle
pathway generating algorithm which simulates the
natural behaviour of Slime Molds to produce a tool
which can be applied to workflows involving cycle
pathway planning. Further to this point, the research
aims to address the plausibility of designing infras-
tructure using organic behaviour within a paramet-
ric framework whilst optimising for specific purpose
or effort criterion. Ultimately, the research sets out to
create a new understanding of infrastructure master
planning which responds to and is inspired by nature.

**RESEARCH OBJECTIVES**

The research investigation addresses the following
objectives which are met by the cycle path generat-
ing process (algorithm) as a series of rules that are
executed as calculations or problem-solving opera-
tions:

- Each path should connect two points (start
  of cycling / end of cycling) with the most op-
timised (according to user parameters) path,
  primarily based on the objectives below.
- Using effort as a criteria for the generation, the
  user may specify different effort weights to
  generate a more customised cycle path, i.e at
  a later stage statistical data such as age, popu-
  lations health could play a role to define the
  specific effort.
- Argued that cycling is not necessarily a car-
diovascular exercise, but a mode of trans-
port, generated paths should be developed
so they respond to the topography of the cho-
en area, as investing effort in cycling is mainly
defined by cycling up-hill.
- Yet, as the tool is becoming capable of func-
tioning in already built-up areas (brownfield
vs. greenfield sites), the generated path
should fundamentally respect the existing
context conditions such as roads (road hier-
archy; as one may not desire or is able of cy-
cling on a highway but can cycle on residen-
tial streets), housing (occupied cadastral one
can not build on), and (at a later stage) other
urban factors (specific to a particular site).
• Further, in order to reduce the cost of build-
ing new cycle paths, the tool should be able
to retrofit existing roads. The generated path
should primarily make use of the existing in-
frastucture (roads, cycle paths) and use the
hierarchy of these networks as a parameter in
which users can specify the generation on.
• Lastly, start and endpoint of generated paths
should reflect usage patterns from user data
(data from cycling uptake apps) - generate
paths only where evidence of concentrated
cycling activity exists (Hotspots) and direct
them to other ‘hotspots’, thus generating a
network based on existing demand.

METHODOLOGY
The research applied a dual methodology. Firstly, in
order to gain knowledge in the three main research
domains, a literature review in three fields of inquiry;
Slime Molds, environmental datasets for computa-
tional design, and cycling culture was conducted.
For the project development, as a second method-
ology, the research argues that an agile methodol-
yogy would be the most appropriate due to its flex-
ibility when developing a software package. Ag-
ile software methodologies is a commonly used ap-
proach for software development under which re-
quirements and solutions evolve through the collab-
orative effort of self-organising and cross-functional
teams. Given that the software has to respond to very
distinct requirements (Slime Molds, environmental
datasets for computational design, and cycling cul-
ture) an agile methodology allows for adaptive plan-
ning, evolutionary development, and continual im-
provement, as it is flexible to change. Consequently,
the research in its one and a half year duration could
respond to the change in the different stages of re-
search (four sprints), therefore allowing much more
leniency to produce or finish stages of the research
itself. This methodology applied to all four sprints of
the research where each sprint lead into the follow-
ing sprint, allowing for a continuation of progress and
logical understanding.

PROJECT DEVELOPMENT
In considering the aims and objectives of the re-
search, the development of the Slime Mold infra-
structure generation tool was spread across four
‘sprints’. Each sprint succeeded the previous sprint,
using and developing further the functions and
methods used. This iterative design process focuses
on different aspects of cycle pathway generation, all
adding and complementing to the overall goal of the
research.

Sprint 1 - Slime Mold algorithm
The initial design of the Slime Mold algorithm was
derived from studying the behaviour of the Slime
Molds. This algorithmic approach into understand-
ing how Slime Mold’s behave allows a certain de-
gree of imitation through programming within a dig-
ital environment. Once the Slime Mold has estab-
lished a connection with its food source, the most
optimized connection is chosen, which does not nec-
essarily mean the shortest straight path from a two-
dimensional plane, but a path in which is the shortest
from a three-dimensional plane (Tero, Kobayashi and
Nakagaki, 2007). The algorithmic testing was done
through a scaled model based on a real-world site in
Sydney’s western region. A 3d printed topography
was overlaid by agar and a Slime Mold grew from the
center of the landscape.

Along with other tests of specific conditions in-
cluding three-dimensional petri dishes lined with
agar, the general behaviour of Slime Molds were
translated into the digital environment using visual
programming tools. During this translation of be-
avour, it was observed that the Slime Mold could
not be predicted to a ‘fine-grain’ resolution from the
comparison of the real experiment and the digital
counterpart. An error which has been deduced to
multiple variables such as temperature, light, humidity, size of the slime mold, and more importantly the age of the Slime Mold. However, this validation error did not drastically change the overall shape of the Slime Mold as it still reached the food source with an optimised path dependant on user input variables.

The next user-defined parameter was the generation points for the Slime Mold algorithm, the start and end points, or the Slime Mold and its food source. Growing from the start point, the digital Slime Mold grows similarly to the organic counterpart, expanding in every direction of the culled topographic surface finding and connecting itself with the food sources or end points. A ‘stop’ function was developed for the algorithm which determined the termination of the Slime growth once all end points had been connected to the start point, this function stopped the Slime growing endlessly bouncing back and forth from the site constraints (Yu et al, 2017).

An optimised pathway is determined by user-defined variables (length, slope sizing) calculating the connections between the start point and end point, using an evolutionary solver, a minimum value is produced which averages all parameters creating the final pathway infrastructure. The infrastructure generated in this sprint was at a large macro scale, similar to the real-life tests comparing national transport infrastructure and the Slime Mold growth (Tero et al, 2010). However, to address the research objectives, the digital Slime Mold infrastructure generation must be performed at a micro suburban scale, which is address in Sprint 2.

**Sprint 2 - Pathway generation using the Slime Mold algorithm**
At a micro-suburban scale, the aim of the sprint was to generate infrastructure links between suburbs. Due to the significantly smaller area of the urban sites compared to the sites in Sprint 1, the topography analysis also had to be adapted to be compatible at a higher resolution, requiring a more detailed analysis of the landscape. A new method of topography analysis was defined in order to suit the aim of the Sprint (Fig.5), allowing the same usable culled cell system to be implemented, whilst using a pseudo-gravity func-
In the previous Sprint, the algorithm was not defined to recognise existing infrastructure, allowing the Slime growth to traverse over built property and transport networks. This Sprint addresses this issue by defining rules for the algorithm which states whether the growth is allowed to traverse over existing cadastral.

Road hierarchy; primary, secondary, and tertiary roads, have also been defined as input variables for the algorithm, with an attraction percentages set by the user to pull the growth towards the specified road hierarchy. The digital Slime Mold algorithm therefore had also been adapted to better suit the conditions of the Sprint, now growing on existing roads and avoiding existing cadastral (Fig.4).

The purpose of this Sprint was to develop the algorithm to be more versatile in negotiating the urban landscape. The road hierarchy was used in relation to defined the slope gradients (Yu et al, 2018).

Similar to the road hierarchy attraction percentage introduced in Sprint 2, the effort weighting is also a user-defined percentage between 1-100%, with 100% effort the ability to travel in a straight line over any gradient. This effort percentage is scaled and evaluated as the gradient values, used to signify human cardiovascular energy. The percentage itself is a calculation variable to allow the Slime Mold growth to evaluate the topography surrounding each point in the cycleway generation process. This is similar to the original Slime Mold growth described in Sprint 1, however, at this stage, the algorithm also predicts the entire route from each succeeding point grown to the end point, evaluating the validity of the effort criteria before growing a new point.

The effort weighting can be used in conjunction to the previously defined road hierarchy allowing for a more robust approach in creating user profiles that initiates the growth of the Slime algorithm. During the investigation of creating user profiles that reflected novice cyclists, the effort and road hierarchy percentages caused the Slime growth to traverse back and forth within a short distance. This caused an incompletion of the cycleway generation from the start point to the end point. This was caused when the input variables defined by the user were too low, constraining the algorithm to grow on a topography that did not have the low specified gradient or road...
Figure 4
Cycle pathway generation for different road hierarchy; site context (top left), 90% Primary Roads (top right), 90% Secondary Roads (bottom left), and 90% Tertiary (bottom right).
hierarchy. It also suggests that a certain amount of cardiovascular energy is needed in order for a cyclist to traverse between the start and finish points of the selected site.

**Figure 5**
Topography analysis using grid points and pseudo gravity - creating cells that match the gradient criteria.

**Figure 6**
Cyclepath generation only using effort weightings; 100% (top), 80% (middle), and 50% (bottom).

**Sprint 4 - Using Cycling uptake data to define start and end points of paths**
In this Sprint, data was used from RiderLog’s mobile app where cyclist were able to log their trips each time they cycled[1]. The app collected the geographic coordinates of the cyclist at short time intervals creating a shapefile which displayed the route of each journey. In aligning to the research objective of designing a responsive tool that generated a cycleway due to existing demand, this Sprint analyses real user data to create the start and end points used in the Slime Mold algorithm.

In previous Sprints, the user operating the tool was required to manually input the points for the generation. This denoted that there was no affiliation with the actual built environment as the user could place points at random. It was probable that points of interest such as transport hubs, schools, etc., could be points that the user could input into the algorithm, but there was no evidence that cyclists traversed to these points of interest. The cycle data was used to show the practicality of the tool in conjunction with evidence-based research development.

To create the points for the Slime Mold algorithm, an evolutionary solver was used to determine the number of routes that started and finished within a certain area of the site, producing a point in which captures the maximum number of points within a specified radius. The routes that start or finish from these areas are also analysed, where the algorithm searches for the maximum amount of intersections between each route, displaying the paths that are most commonly used by the cyclists that start or end in the previous criteria.

The intersecting route points are used to help determine existing pathways that may be suitable to be used in the algorithm, creating not only a path between the start and end points, but also points along the route that have become ‘points of interest’. It may also identify from an analysis perspective, lacking infrastructure between start and end points if cyclists are ‘forced’ to use the routes they take.
Figure 7
User-generated cycle data, with all cycle paths (red), and the cycle paths that were selected from the most start (green) and end (orange) points in a selected area (blue).

Figure 8
Cycle pathway generation using different user-profiles; 55% Effort – 80% Primary Road Hierarch (Red), 20% Effort – 80% Secondary Road Hierarch (Blue), 45% Effort – 80% Secondary Road Hierarch (Purple), and 65% Effort – 80% Secondary Road Hierarch (Green).
PROJECT EVALUATION

In understanding the behaviour of Slime Molds, and cycling culture, an algorithmic tool was developed over four iterative phases or sprints that could generate cycling infrastructure using custom user-profiles. Through each Sprint’s tests and experiments, validity and plausibility of the algorithm could be demonstrated. As the algorithm was developed without being fixed to a location (the location in Sydney functioned just as a test study) one can apply the developed algorithm for any location as long as all input variables are present.

The tool that has been developed capable of generating a network of cycle paths autonomously with user-generated data and with certain criteria variables set by the user (road hierarchy, effort weighting, maximum points to capture, intersections). Although it may not be possible to digitally replicate the exact behaviour of the Slime Mold, this research has demonstrated that the inherent conditions of the Slime Mold can be translated and adapted to be relative in an urban development context, and especially a human context with effort as the final catalyst function.

SIGNIFICANCE AND CONCLUSION

Through the development of the four interlinked sprints, the research has demonstrated and produced a working model for infrastructure design using a Slime Mold algorithm. The algorithm imitates the behaviour of the organic Slime Mold which is tweaked with human variables for practicality. Ideologically, the algorithm bridges not only the organic and digital, but different research disciplines from computational design to urban master planning. The case studies developed and tested demonstrate that the design method is essentially plausible to be integrated within current design practices, not to redevelop the current process itself, but to aid and extend it. Consequently, we argue that the research has created a multi-purpose digital tool that could not only be used for the analysis of existing, but also the designer of future cycle infrastructure, which also presents new knowledge areas into computational design applications. Furthermore, the background framework could also be adapted from cycling to other modes of transport such as car or rail, and further research could create new parameters and variables that can be utilised in the tool. Finally, the paper contributes to the discussion of biomimicry, and the reasonable appropriations behind the relationships developed from studying nature in a computational age.

REFERENCES


Daley, M, Rissel, C and Lloyd, B 2007, ‘All dressed up and nowhere to go? A qualitative research study of the barriers and enablers to cycling in inner Sydney’, *Road and Transport Research*, 16(4), pp. 42-52


