SN IFFING SPACE II

The use of artificial ant colonies to generate circulation patterns in buildings

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ABSTRACT: This model uses agents, which lay and respond to alternative pheromone trails to define circulation routes between specific locations. There is no a priori knowledge embedded in the model. The communication network generated between the colonies represents a routing structure, which is emergent and dynamic. The intended application is for building types that are specifically defined by complex circulation parameters, such as airports, hospitals and schools. Proposed here, is a generative process in which the circulation patterns between specific destinations and the spatial arrangement emerges in a process of mutual compatibility.

KEYWORDS: Agents, pheromones, circulation, building typologies, stigmergy

RÉSUMÉ: Cet exemple utilise des agents, qui agissent et réagissent à différentes pistes de phéromones définissant ainsi des itinéraires de circulations entre des lieux spécifiques. Ce modèle n’inclut aucune connaissance a priori. Le réseau de communication généré entre les colonies représente une structure de circulation à la fois émergente et dynamique. Le but est d’appliquer ces recherches à des types de bâtiments dont les paramètres de circulation sont particulièrement complexes, tels que les aéroports, les hôpitaux et les écoles. Ce qui est proposé ici, c’est un processus génératif dans lequel les modèles de circulations entre des destinations spécifiques et l’environnement spatial émergent à travers un processus de compatibilité réciproque.

MOTS-CLÉS: Agents, phéromones, circulation, typologies de bâtiments, stigmergy
1. INTRODUCTION

This paper explores the application of an agent-based system to the planning of circulation in programmatically complex buildings. The example employed here is the airport: an interesting example due to the asymmetrical parameters involving departures and arrivals.

The work consists of two themes: (1) The hypothesis that a dynamic self-organising process may be applied to generate the routing structure between specific destination points within a complex building typology; and (2) an examination of how such a process may be applied to generate spatial configuration. The latter explores a process of dynamic co-operation between both conditions that co-evolve through mutual compatibility.

First the background and theoretical approach is explained. The use of artificial ants to generate circulation patterns forms the basis of the model, and is demonstrated before explaining how the model is being extended towards generating patterns of spatial configuration relative to emergent routing structures.

The model presented is written in Netlogo version 4.0.2. Netlogo is a programmable modelling environment for simulating natural and social phenomena that is well suited for modelling complex systems (Willensky 1999).

2. BACKGROUND AND THEORETICAL APPROACH

The premises of the two themes are described individually. The first theme questions the typical methodology of optimising proximities and proposes an alternative self-organising approach. The second considers architectural space and how the East and West perceive it differently.

2.1. The problem of circulation as optimisation

General architectural principles describe the consideration of path configuration, path-space relations and the form of circulation space in designing the connectivity of a building’s “parts”. Such principles promote the building’s circulation system as a positive element that can affect our perception of the building’s form and space (Ching 1979). Such attention though is typically distracted from the start by the importance indicated in the architectural brief and its representation of circulation as servicing; being an area provided to link the parts. This promotes optimisation and the practice of trying to organise rooms in a plan in the most efficient arrangement so as to minimise circulation space, which hinders the potential articulation of that space. Perceiving circulation as little more than optimisation inherently defines space that is linear, juxtaposed and generally considered as little more than a connector between destinations, which equates to the manifestation of the corridor.
“Spatial behaviour should not be seen as static… but continuously variable, defined primarily by context, such as the rules governing the behaviour of social insects, from which local interactions global behaviour emerges” (Asquith 2006). Human beings do not walk in straight lines, as Le Corbusier (1929) proposed, they wander, hesitate, change objective, respond to context and meet. The intent here is not to simulate human behaviour but to explore the idea that patterns of circulation may be generated through simple interaction between discrete entities, and that this in turn may be a generator for spatial configuration; further that the two parameters may trade off each other in a dynamic process of mutual cohabitation.

2.1.1. Rethinking circulation

The field of automatic plan generation incorporates the problem of circulation; an obvious component since the rectilinear configuration of plan arrangements is defined by the problem of circulation. Tabor (1976) investigated plan arrangements, and the economy of different plan forms in relation to their communication structures; being the mean sum of travel distances between individual rooms/user locations. Willoughby (1975) approached the problem as optimisation. Considering the problem of multiple organisations occupying the same building he approached the problem by allocating organisational communication patterns to a variety of geometric plan forms to evaluate circulation efficiency. Concluding “There is a basic mismatch between the geometry of the building and the circulation pattern”; that typically circulation is a compromise in the efficiency of the desired communications pattern. Packing (of typical rectangular arrangements) increases the problem, and any exercise to ‘tune’ a building to a specific communication pattern will be impaired further to a change in the organisational arrangement set. Clearly there is a strong case for the transaction between mean communication values and generalised geometric forms (Tabor 1976; Steadman 2006).

The combinatorial problem of configuring rectangular plan arrangements dictated optimisation, prompting efficiency in circulation. The calculation of shortest paths connecting the individual rectangular arrangements had direct similarity with the combinatorial optimisation of wiring diagrams in engineering, being a well-defined problem for computer application. Although the majority of our buildings are rectangular configurations navigated through a framework of corridors and optimised to fit within total floor area requirements the consideration here is that architecture is not merely optimisation. Market constraints on practice promote optimisation, and our manual capacity to surpass this is constrained, but the capacity of the computer applied in a bottom-up approach of distributed representation may provide a facility to question the standard practical approach.
2.1.2. Emergent trail networks

Helbing et al. (1997) recognised that the emergent trail formations where people had formed routes across open space, did not ‘efficiently’ connect the actual destination points. Investigating this he developed his peploid model, later extended to the active walker model (Helbing, Molnar, Farkas and Bolay 2001). Demonstrating the self-organising capacity of pedestrian movement their results determined that people’s movement in such instances is defined by where people want to go and where others have gone. Helbing’s peploid model was an ontological approach in which the trails emerged as a result of many autonomous agents’ behaviour. Although the global outcome of the agents’ behaviour was an emergent system of trails the behaviour of the agents was as discrete entities interacting with their immediate context. It was the system feedback between the individual elements that defined the trail network not the programming of behaviour to generate the trails. This stigmergic relation between agent and its environment is the basis for the intelligent behaviour of social insects that provides the computational basis of this model. Helbing et al’s research focused on the problem of human trail formation in open space and the behavioural force of pedestrian motion. The focus here is architectural and generative configuration.

The spatial agents, applied to interpret the interior space of Tate Britain gallery, London, (Turner and Penn 2002) used ‘visibly’ responsive agents. The populations’ accumulated behavioural response to the spatial structure generated patterns relative to human navigation. This was an analytical study; the interest here is generative. Turner and Penn’s results were successful in demonstrating the use of agents to generate circulation patterns, which reflect human behaviour, but their focus was on defined spatial parameters: the finished building and the circulation pattern generated thereby.

This research is concerned with the generation of architectonic form, at the stage in which the fundamental spatial configuration and the utilitarian parameters are defined: organizational diagrams and plan layouts. The criteria engaged here are specifically connectivity, the sequence of events, potential behavioural routines between specific destinations and the combined emergence of spatial configuration qualified to a pattern of circulation.

2.2. Constructing the ephemeral: alternative approaches to architectural space

The parameters of the problem are spatial and as such are complex. Space itself is an undefined entity; the ephemeral (void) commonly defined by the tangible (solid). The object (solid) defines the western perception of space; it is bounded, constructed. The antithesis to this is the eastern perspective of the space in-between (void). Typified by the jug, Lao Tzu postulated that a jug’s significance is derived from its void, that the void defines its form and affords its ability to
function as (Lau 1982). Heidegger (1951), (possibly) taking cue from Lao Tzu, proposed that the void was the generator of the jug's form defining its capacity to function as a jug, and that the jug's utilitarian significance (embedded in human experience) defined it not as an object, which is abstract and detached from daily experience, but as a “thing” (Sharr 2007).

Within this research, architectural space is considered a complex adaptive system (CAS). Relative to the user its organisational properties are dynamic. A user inhabits architectural space, which is created (further to shelter and protection) towards some function. Function being defined by activity, which is three-dimensional, defined by the act of bodily movement, and human behaviour. Hillier (1998) noted a relation between space and behaviour (that space affects behaviour and behaviour affects space). As such, user, behaviour and the unquantifiable notion of space define a CAS. The intention of this research is the development of a tool that bridges our understanding of space as a thing, and the practise of architectural production.

“Form is… expressive because it images space”… [In that walls] “bring space into being through their mutual neighbourhood. Wall and space are indissolubly bound to each other; together they form the single dyad solid-void” (Van der Laan 1983). This is a reflection of built space; objectified space. The fundamental architectural task is to interpret the spatial configuration of a particular set of parameters specific to function and human behaviour, to generate a building. The western approach is calculative, concentrating on the interstices of spatial configuration; it segments or adjoins, focusing on object qualities. Fundamentally, architectural design is a dialectical problem of the interchange between solid and void, considered alternatively by the east and west. “[The] fundamental difference between western and Japanese consciousness lies in the fact that the western mind is schooled towards a dichotomy of consciousness into ‘self’ and ‘other’. “I’ see the ‘rock’”. The native Japanese way of being in the garden would not distinguish between the self and the elements of the garden in such a way. The focus of consciousness would be on the unity of the components, where rock and human constitute a fused consciousness” (Van Tonder 2006).

Analysing the structure of Japanese rock gardens using medial axis transform (Van Tonder and Lyons 2005) revealed a structure of empty spaces; a global branching structure in the apparent unordered, ambiguous design of Ryoanji. The model illustrated does not generate the medial axis transform but may be perceived as generating a structural connectivity diagram between specific destination points, which forms a framework for generating spatial arrangements; the reverse diagram of ‘empty’ space generating ‘occupied’ space.

1. Speaking from personal experience, through the study and practice of architecture.
In adopting, simultaneously, an emergent process of both circulation and spatial arrangement the interchange between each emerging organisation will cause a dynamic architectonic cohesion of circulation and spatial configuration.

3. THE MODEL: EMPLOYING ARTIFICIAL ANTS TO GENERATE CIRCULATION PATTERNS AND CONFIGURATIONS OF SPACE

Research on how social insects (specifically ants) communicate and form circulation routes has illustrated that they are adaptive and resourceful in their ability to form routes and define communication networks. They are self-organising, hence robust and flexible. Search algorithms based on swarm intelligence have shown that paths to solutions are emergent rather than pre-defined which leads to better utilisation of resources and gives a dynamic character to the solution finding process (Bonabeau et al. 1999).

3.1. Sniffing space: ant pheromone routing

No a priori knowledge is provided in the model, in which artificial ants generate circulation routes between specific destination points. See Figure 1.

Agents leave one pheromone trail in search mode and an alternative one when returning to the home nest (Panait and Luke 2004). Whilst in search mode they seek the home of their colleagues. Upon a discovery they change state and follow the trail of other agents (from the same colony) and return home. Figure 1 illustrates the ant colonies as specific destination points, in which the ants from other colonies are all in search of each other’s homes. This generates a circulation network defined by the simple interaction between agent...
and pheromone, reinforced by a continuous loop of reinforcement, by agents depositing pheromone along successful trails, which attracts further agents.

Figure 2 illustrates the same model with an alternative arrangement in which one colony is separated from the others. The problem of the agents’ assignment to generate a network of connectivity is augmented, due to the asymmetrical arrangement. The increased proximity of spaces (a colony nest represents a destination, which refers to a space) along the upper half of the screen should equate to a greater probability of their discovery by agents, whilst the single space at the lower half is obscured. The result remains a network connecting all spaces in which little distinction can be made between trail successes defined by proximity.

**FIGURE 2. EMERGING CONNECTIVITY PATTERN BETWEEN ASYMMETRICALLY ARRANGED COLONIES.**

During the emergence of trails interesting dynamic routings appear, as the agents traverse the environment and interact with the pheromones of kindred agents; see Figure 3. The fluctuating and shifting behaviour of the emerging trails indicates an interesting application for the problem of spatial configuration; in that the mutual augmentation of both the problem of circulation between specific points of departure (such as check-in and departure gates in airports) and the ambiguous arrangement of intervening leisure and entertainment facilities, in a dynamic process of feedback, might illustrate configurations typically unconsidered through manual exercises.

Architectural space is not homogenous (Hillier and Hanson 1984) and as such the facility to navigate boundaries and confined ‘geometries’ is a necessity, in any simulation or process applying agents to the problem of generating architectural space; see Figure 4. The spatial agents of Turner and Penn (2002) demonstrate a potential technique towards implementing agents with behavioural traits, but they require an article to provide visual stimulation. The article in Turner and Penn’s model being the building fabric; walls and openings in plan form. However, in this model there is no article. An amorphous approach requires that stimulation be generated through the agent’s inherent behaviour. As such the ant model presents the technique for a generative process defining the amorphous through the simple behavioural model of interaction between ant and pheromone.
3.1.1. Sequencing events

Sequencing is introduced into the model, to facilitate specific programmable routing between specific destination points. Each agent has an agenda, which it must complete. This allows direction to be introduced into the model, effectively representing people’s movement between points within a building programme, such as the distinction between airport arrivals and departures. Figure 5 illustrates the sequence of a population of agents navigating the same specific points tested in figure 2. Agents belonging to the orange space all navigate between their home and each of the other three spaces. The only aim of the agents belonging to the other three spaces is to find the orange space below. By incorporating sequence the communication network is entirely adjusted, and the emergent pattern concludes with a pattern reflecting the problem, practically.

By incorporating a further space into the sequencing, the problem is altered to differentiate a central space. This is an arrangement evocative of a hub model, to which everything flows to and from. In this scenario, illustrated in Figure 6, below, agents from the central ‘hub’ search for all other spaces, whilst agents from the other spaces all search for the hub; defining an asymmetrical flow diagram. Here the problem is tackled in both directions simultaneously.
Alterning the sequence so that the behaviour of the agents reflects the behaviour of either departure or arrivals only means that the agents’ journey from many points to one and vice-versa. In Figure 7 the agents traverse the diagram moving north; the agents of the orange colony seek the central cyan, which in turn search for the remaining three. This reflects the departure sequence.

Switching the direction to arrivals, the agents travel south from the north points to the central cyan colony. Agents from here seek the bottom orange colony, reflecting the movement of multi departure points to a single destination.

The emerging diagrams conclude reflecting similar patterns, but the latter sequence (arrivals) results in a more distinct network; the execution is much quicker and generates a population far smaller than that generated during the departures routine. Clearly, the agents’ task is far reduced in the arrivals routine as they only seek one destination, leading to exclusive trails which specific colonies traverse.

It is clear the scenario results reflect one another once the systems settle into a stable state. Considering the test in which this asymmetrical sequence
is processed simultaneously (Figure 8) the result reflects a similar stable network; the trail network emerging towards this appear to be an amalgamation of the agents' behaviour in both the arrivals and departure routine.

In extending the model towards spatial configuration agents are programmed with behavioural parameters relative to the typology typical to arrival and departure sequencing. This is to be tested again separately and simultaneously, (on-going) in order to determine whether flow makes a significant difference to the problem of generating spatial configurations relative to individual routines between specific destination points, or not.

3.2. Extending the ant routing model to generate arrangements of space

The sequencing demonstrated above was between points of final destination. In the airport scenario this equates, for departures, to check-in, then security/immigration, then departure gate and for arrivals, arrival gate, then immigration, then customs. (Note: baggage has not been included, as this is a similar procession as the move from security to departure gate and not stipulated as it is not an obligation in the case of passengers with hand luggage only.) The sequence is specific but in actuality passengers do not generally run this sequence in practice; they will visit leisure facilities in the departure lounge and conversely navigate the baggage reclaim area between immigration and security.

Agents are therefore given behavioural qualities, which will signify exemplar journeys within the traditional airport model. Agents will navigate between specific destination points, as demonstrated in Section 3.1.1, but will also respond to other agents sharing like qualities. Hillier and Hanson (1984) suggest that “Encountering, congregating, avoiding, interacting, dwelling, are not attributes of individuals, but patterns or configurations, formed by groups or collections of people” and that the “relation between space and the act of living lies in the relations between configurations of people and configurations of space”.

The qualities given to an agent will reflect the behavioural patterns of passengers; in that one departing passenger may grab a coffee and a last minute present in duty-free, whilst another may buy a book in a newsagent, enjoy a meal at a restaurant and might further relax with a drink at the champagne bar or sit waiting the boarding announcement. The possible journey configurations are vast but the points visited common. Therefore agents are given, from a common list, various random ports of call to visit during their journey between a particular set of destinations. In effect they each carry a cargo of assorted spaces. As illustrated in Figure 9, agents respond to other agents they ‘meet’ along their journey between specific destinations, carrying cargo that corresponds to their own.
FIGURE 9. SCHEMATIC REPRESENTATION OF SPATIAL AGGLOMERATION.

1(a) Agent leaves home in search of associates leaving a trail

1(b) Having found associate agent returns home following scent and leaving alternative trail

2(a) During journey agents carry a cargo of activity spaces

2(b) Agents deposit cargo item upon meeting other agents with equal item; creating an area of activity space

2(c) Spaces with less than ‘\text{x}’ neighbours are collected

Spatial agglomeration is a result of agents encountering, congregating and interaction with environment
When an agent comes into contact with another agent holding cargo of which a part is equal to their own they will each drop that part of their cargo. This piece of cargo represents an activity, being an activity along their journey between specific destination points. The displacement of their cargo defines the location of an activity, thereby creating an area of space. An agent will continue to travel between their specific destination points, reinforcing the paths generated or defining new ones whilst they still carry a cargo. Alternatively an agent that comes across an area of space that represents an activity equal to a part of its own will drop that part of their cargo, adding to the already accumulated area of space.

If an agent has surrendered all of its cargo it will return to its home colony, where it will expire or if it encounters an area of activity/space that has few equal neighbouring spaces it will recover that portion of space and continue with its journey.

In this way specific activity space accumulates in relation to the encountering and congregating behaviour of the agents. An area of space must have $x$ neighbours (a variable, which may be altered by the user) of self-type, in order to prevent it being picked up by a passing agent. This prevents scatterings of space and encourages the arrangement of space in relation to activity, context, behaviour and routing (see Figure 10). This is similar to the termite model (Resnick 1994) inspired by the behaviour of termites gathering wood chips into piles.

**FIGURE 10. SPATIAL ARRANGEMENT AND ROUTING BETWEEN DESTINATION POINTS EMERGING.***

4. CONCLUSION AND FURTHER WORK

The practice of configuring of space is more complex than illustrated here, through the dynamic interaction of autonomous agents. The use of agents in generating routing and the arrangement of ‘activity’ space between specific
destination points does illustrate a process in which the results to the two problems are demonstrated to emerge through mutual collaboration. But this has illustrated a particular user type, the visitor. In the case of the airport example this is the passenger, on his/her journey through the airport. Buildings are configurations of spatial domains defined by permeability and control (Hillier and Hanson 1984; Hanson 1998). “… every building is a domain of knowledge, in the sense that it is a spatial ordering of categories and at the same time a domain of control, in that it is a certain ordering of boundaries, which together constitute a social interface between inhabitants and visitors. This abstract structure is common to all buildings” (Hanson 1998).

The sequencing illustrated in Section 3.1.1 needs to be developed. Extension of the model to incorporate specific categories is required for practical consideration of the proposal as a potential tool: whether for application or study. Of course actual extension may not be the only course, as the existing model may be developed for use to generate individual patterns, which a user may be expected to formulate. The model could be used as an investigative tool for routing diagrams in relation to spatial organisation, requiring further expression by traditional manual skills. In this way the model may be comprehended as a tool that might be used by an architect/designer to visualise specific combinatorial problems (i.e. departments or zones) within an overall particular building typologies configuration, to analyse and inform ‘pieces of the puzzle’. Alternatively explicit categories may be implemented within the model, in which the emerging ‘pieces of the puzzle’ evolve in relation to threshold parameters, in a manner comparable to the mutual collaboration of circulation and spatial arrangement demonstrated here.

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