EMERGENT SPACE DIAGRAMS
The application of swarm intelligence to the problem of automatic plan generation

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ABSTRACT: This work investigates how diagrams of architectural space might self-organize relative to specific associational parameters to generate diagrams of spatial organization. The premise is that buildings are systems of spatial relations defined by the dynamic interactions of various autonomous spatially discrete entities. Looking to swarm intelligence, the focus here is on the problem of circulation and explicit spatial arrangement. The paper reports an investigation of emergent route formation and spatial connectivity based on simple agent and pheromone interaction. An array of ant colonies defines the system. A colony’s nest represents a specific space. Space-agents transmit information throughout the space-colony population, defining an emergent communication network.

KEYWORDS: Agents, pheromones, ant colonies, spatial configuration, emergence

RÉSUMÉ : Ce travail étudie la façon dont les espaces architecturaux peuvent s’auto-organiser en fonction de paramètres spécifiques associés, afin de générer des schémas d’organisation spatiale. Le postulat de départ est que les bâtiments sont des systèmes de relations spatiales, définis par la dynamique des interactions d’entités variées, autonomes et spatialement distinctes. Appliqué à l’intelligence des essaims, l’accent est ici mis sur le problème des circulations et des aménagements spatiaux clairement définis. L’article fait état d’une enquête sur l’émergence de la formation de routes et de connectivité spatiale, basée sur un seul agent et sur l’échange de phéromone. Un ensemble de colonies de fourmis définit le système. Un nid de colonie fourmilière représente un espace spécifique. Les agents spatiaux transmettent les informations à la population à travers tout l’espace de la colonie, définissant ainsi l’émergence d’un véritable réseau émergent de communication.

MOTS-CLÉS : Agents, phéromones, colonies de fourmis, configuration spatiale, émergence

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1. INTRODUCTION

This research looks into the problem of spatial arrangement, the well-trodden field of the automatic generation of architectural plans (March & Steadman 1979; Steadman 1983; Flemming 1986; Grason 1970; Mitchell, Steadman & Liggett 1976; Elezkurtaj & Franck [n.d.]; Rosenberg & Gero 2006). Space, here, is perceived as a complex adaptive system. The test model described is an abstract theoretical framework for the final modelling tool outlined in section 6. This model 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). Translation of the test model into a more flexible object oriented platform will facilitate integration of geometric features, potential zoning or interlinking of specific spatial networks and the implementation of extended parameters (agent types, specific behaviours, etc). The platform being used for this is Processing; version 1.0.1.

Decomposing typical hierarchies of architectural space we look to the use of agents to generate architectonic form in a process of distributed representation. The focus here is the problem of circulation and explicit spatial arrangement. The work presented looks to swarm intelligence and established computer methods based on the way-finding means of social insects (Bonabeau, Dorigo, Theraulaz 1999; Dorigo, 2004). Ant foraging algorithms are used generally for optimisation and tend to rely on a priori knowledge of the environment (Resnick 1994). Outlined here is an investigation of emergent route formation and spatial connectivity based on simple agent and pheromone interaction. This is a stigmergic process which defines arrangements for which optimisation is not the key, but rather emergent connectivity through blind local communication.

Deconstructing rooms into their constituent parts identifies an array of activities, which will inherently own some measure of association with each other, but these associations may be asymmetric, may have associations to activities typically located in other rooms or relative to a specific routine of habitation (in relation to the problem of dwelling), and may have varied and ambiguous associations. The premise is that the dynamic association of these associational parameters may develop spatial topographies previously obstructed by the traditional hierarchical definition of rooms in plan arrangement.

The model incorporates two systems of agents working in parallel: the space-colonies and the space-agents (being equivalent to the artificial ants nest and ants in other models described in the references). The space-colonies represent the specific spaces or activities. Space-colonies have associational parameters with each other, like those within a brief between different rooms. Space-agents, whose birthplace is a particular space-colony, transmit information throughout the space-colony population, whilst defining an emergent...
communication network that defines circulation trails. See Figures 1a and b below.

**FIGURES 1A AND B.** *(a) EMERGENT TRAILS BETWEEN TWO SPACE-COLONIES. INVESTIGATION OF SPACE-AGENTS ALONG A TRAIL HIGHLIGHTS THAT EACH TRAIL MAY BE SPECIFIC TO EITHER COLONY. (b) EMERGENT NETWORK GENERATED BY SPACE-AGENT AND PHEROMONE INTERACTION.*

2. RETHINKING SPACE AND PLANNING METHODOLOGY

The premise of this paper is that the plan is embedded in the process of architectural production and that space is vicissitudinous; meaning that it is in constant flux. This is not the visible object space of the built environment, but the space of user movement, activity, habitation and interaction. This is in a condition of constant change, a natural process of mutability. The Euclidean practice (commanding form; of mapping a perception from above) of organising space and defining architectonic form is therefore contrived and a perverted representational methodology to define the intrinsic substance of space; being the plastic qualities of the *thing* produced through the act of bodily movement and the behavioural practices of social interfaces. Buildings are systems of spatial relations, defined by the dynamic interactions of various autonomous spatially discrete entities (Hillier and Hanson 1984). The basis of any building is the relationship between solid and void, the void being the theatre of activities that take place in the building (March and Steadman 1979).

The typical practice of plan generation is a Euclidean methodology, which uses an abstract representation of space, founded in the classical understanding of the world. Pickering (2002) proposed that the historical concept of the world, defined by classical science was representational, being the exercise of mapping the world to produce articulated knowledge of it. He proposed that such studies were epistemological and in contrast proposed an ontological approach: studies of causation and how things come to be. The architect Frederick Kiesler opposed the deterministic approach, recognising the opposition
between historical representation and the creation of architectonic form, writing “If God had created a man from a plan, a monster all heels and toes would have emerged not man” (Bognar 2001). Given that the plan is embedded in architectural production the judgment here is that the approach towards its manifestation needs to be reassessed. Thus, taking inspiration from Pickering’s favouring of an ontological approach the process of organising space is reconsidered.

2.1. Representation

Organizing the functional parameters of a building brief is traditionally defined through the development of a plan. The problem with traditional planning methodology is that it abstracts the dynamic event of user habitation into a two dimensional Euclidean exercise. Here we move to an earlier stage lying somewhere between bubble diagrams and plan formation termed, for clarity, the practice of generating space diagrams. This is a broad-brush approach considering two aspects of spatial organisation; circulation and the arrangement of individual/activity spaces. The LOOS program (Flemming 1986) specifically focused on individual spaces, and on their arrangement, primarily describing the crucial spatial relations. LOOS generated diagrams of loosely packed arrangements of rectangles; a broad-brush approach which was generative and exhibited emergence. By contrast the model described here does not represent any plan geometry. It is specifically a model of associational parameters, although there is a geometry which is an emergent property of the system, defined through the interaction of space-agents with the emerging pheromone trails, by which a trail system connecting the individual space-colonies is generated. See figure 1b.

3. USING AGENTS TO GENERATE SPACE DIAGRAMS.

The test model derives from the ants model (Resnick 1994) but differs in that it has an array of colonies and the space-agents lay two different pheromone trails depending on whether they are searching or returning home (Panait and Luke 2004). Basically, the typical relationship between nest and food is revised so that each nest is another colony’s food. This works to create a communication network based on each colony seeking the other colonies with which it shares associations. In effect, this is an automation of the justified access graph (Hillier and Hanson 1984), extending the analytical illustration of the heterogeneous qualities of a spatial configuration towards a generative system.
3.1. Model mechanics

A space-colony has associations to other space-colonies. Therefore each space-colony has an identity, which is held in a list by those other space-colonies which are associated to it. The space-agents born to a particular space-colony hold the identity of that colony. Therefore, the space-colonies visited can check whether they are associated to the visiting space-agent’s home colony, and if so follow it on their return journey (see Section 5).

A space-agent will leave its space-colony laying pheromone marking its way back home, whilst in search of those space-colonies with which its home colony shares an association. Upon finding a colony held in its association list it marks its discovery and returns home laying an alternative pheromone marking a trail leading to its find, in search of home or a trail leading it home. A space-agent will continue on this tour-of-duty until it has visited all the space-colonies with which its home colony is associated (see Figure 2 below). Upon completing its tour-of-duty it dies. A space-colony continues to produce space-agents until it is in the company of all those space-colonies with which it is associated.

**Figure 2.** A space-agent’s ‘tour of duty’ generates the associational structure of its specific space-colony. This globally generates the associational structure of the system.

A space-agent sniffs the eight patches surrounding it. Patches are the individual squares in the grid, which are a type of agent. They can be assigned values and change state but do not move. A space-agent hill-climbs the scent value of the trail. In motion an agent ‘wiggles’ forward, therefore those patches in front are checked first for any trail scent. If none exists the two patches immediate left and right are checked, moving backwards until finally the patch lying immediately to the rear is checked. This ensures that the agent maintains a predominantly forward motion. If no scent is found to exist in any of the patches the agent moves forward in a random direction.
The pheromones laid by a space-agent attract other space-agents, which in turn reinforce the trail. Diffusion of the pheromone attracts further space-agents and if a trail successfully connects space-colonies, this will help to reinforce the trail, defining an emergent network of trails linking each space-colony to others: see Figures 1a and 1b. The pheromone laid by a space-agent is specific to its colony; hence space-agents only search for pheromone and follow the trails laid by fellow space-agents. An emergent result of this is that particular trails can develop between colonies in which only space-agents from the same colony are travelling a particular route: see figure 1a. Negative feedback, through evaporation of pheromone, ensures that trails leading to ‘nowhere’ are not reinforced and that successful trails maintain a level of equilibrium.

3.2. Using the model

A number of slider bars allow easy manipulation of an array of variables:

- **diffusion-rate**: amount of pheromone passed onto neighbouring patches
- **evaporation-rate**: amount of pheromone each patch loses at each time step
- **splodge-rate-at-destination**: amount of pheromone dropped by an agent when it leaves a space-colony
- **amount-of-pheromone**: how much pheromone a space-agent carries
- **splodge-trail**: how much pheromone a space-agent deposits on a patch
- **max-smellyness-of-trail**: limit on how much pheromone a patch may hold
The space-agent population can either grow from 0 or an initial population may be specified. Reproduction of space-agents may be turned on and off. The number of variables within the model, which are available for easy manipulation (noted above) together with those within the code, result in a sensitive system.

A plot window illustrates the space-agent population and shows whether the system is reaching a stable state. The organization will come to an end when each space-colony’s associations are satisfied. A space-colony is satisfied when all those with which it is associated are within its company (defined as within a particular radius). Alternatively only those colonies which have not settled their associational parameters are still producing; in this case no further reorganization of the structure will occur since space-colonies only respond to space-agents of a system with which they are associated, not their own agents. (The user interface is illustrated in Figure 5 below.)

**FIGURE 5. MODEL INTERFACE.**

![User Interface Diagram](image)

An essential assumption of such work is that it is not people’s behaviour being modelled, or that ants in any way represent the behaviour of human beings, but that the application of autonomous agents can be used to simulate natural systems¹ and systems modelling can help to understand and define an alternative approach to problems which are complex and dynamic.

4. EMERGING PATTERNS OF CIRCULATION

During the model’s operation the trails generated will emerge and fluctuate. These trails may materialise and expire, fuse together, join in part, move closer together or separate. The ‘behaviour’ of the model is similar in effect to the

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observed behaviour of biological systems and is interesting from a systems perspective due to the emergent quality and fluctuating behaviour produced through the self-organising properties of the space-agents. From an architectural perspective the results illustrate a dynamic methodology towards generating circulation routes.

4.1. Tour-of-duty routine

The performance of the tour-of-duty routine within the program produces very different behaviour within the system. An example of five different space-colonies set up in a structured arrangement illustrates the disparity between the two systems. In the tour-of-duty example each space bears an association to each of the other four spaces; therefore each space-agent has the task of searching for each one in turn, returning to its home after each discovery. Upon completing its tour, it dies. To illustrate the results, the behavioural routine of the space-colonies in prohibited, in order that the circulatory sequence is illustrated in isolation.

Alternatively, in the other system the agents do not make a tour of associations, they only search for another space-colony, which is not their home colony. The emergent diagram results in a connectivity network of all possible routes, illustrated in Figure 6 below.

**FIGURE 6. CONNECTIVITY NETWORK EMERGING OF ALL POSSIBLE CONNECTIONS.**

The causes are the limited behavioural facility of the space-agents, the number of agents and the fact that initially they search randomly; consequently they become distributed throughout the ‘world’. As trails begin to emerge they eventually meet other trails or other spaces. A space-agent is only searching for another space, therefore upon discovering a space or a trail leading to it, a space-agent will reinforce this trail; it may be attracted to another trail with a higher pheromone value but it is likely that another agent either in the alternative state or from a different context will take its place.
FIGURE 7. ALTERNATING CIRCULATION PATTERNS.

By implementing a tour for the same space-colony arrangement, the results change significantly. The fluctuating pattern of connectivity is a result of agents travelling to each destination held in their tour itinerary. Their mission has no set routine; only that they visit each colony held in their association list. The order in which the tour is completed is completely due to chance. The alternating routings are thus the combined result of the number of agents following a particular trail, and thus of the level of pheromone reinforcement, the success rate of agents completing their tours and the birth rate of further space-agents relative to the existing population. Successful agents die and therefore specific routings may not be reinforced. Although each colony is not plainly connected
to each other colony, as in the final sequence of Figure 7 (found above), the network still maintains full connectivity. Therefore each colony maintains connectivity with all others, via fluctuating routes between them.

5. SELF-ORGANISING SPACE

The space-agents' behaviour generates a circulation network between the colonies. The space-colonies will move along these trails towards those space-colonies with which they share an association. A space-colony’s behaviour is defined by these associational parameters. These associations define the organisation of the spatial arrangement, in that the structural relations of each space define the ‘social’ arrangement of the overall spatial configuration. In essence this is an automated arrangement of the immediate permeability ‘layer’ of a justified access graph (Hillier and Hanson 1984). Further, from the dynamic interaction of colonies through the emergent circulation network, additional levels of association may emerge as a result of the dynamic feedback within the system, meaning that in effect associational parameters may be generated through the system rather than specified.

5.1. Configuration assembly

A space-colony interrogates the identity of each visiting space-agent, to check whether it shares any association with its home colony. If it does it will follow the space-agent on its return journey, taking a step in the direction that the space-agent moves. A space-colony’s movement is restricted, in that its length of step is less than that of a space-agent. Therefore a space-colony’s journey is a cumulative progression of following an array of visiting space-agents, progressing along a trail until it meets the associated space-colony. This staggered journey is necessary to prevent a space-colony ‘blindly’ following a particular space-agent; as the agent may not have successfully found a trail leading home. (Self-organising systems are robust in that tasks are completed even if some individuals fail.) This behaviour means that the colony’s journey only really begins once a circulation network starts to emerge, in that it requires a significant number of space-agents to pull a space-colony in the direction of home. This act is analogous to creating a gravitational force between the colonies.

The spatial configuration is defined by the self-organising topology of the space-colonies. A space-colony checks its context to determine whether it is in the company of those space-colonies it is associated. Its satisfaction is defined as “are all my associates within radius ‘x’?” As the associations between colonies

2. See work at Centre for evolutionary design and computing (CECA), University of East London, and Christian Derix in Dust, Plates and Blobs noted in bibliography.
may be asymmetrical, any specific conclusion may appear to take considerable
time during which space-agents will continue to be produced. In such circum-
stance a trail will emerge between the unsatisfied space-colony and the space-
colonies that the unsatisfied colony is in search of. This indicates that a group
of space-agents belonging to the unsatisfied colony are still travelling between
the two; architecturally this is conclusive as it suggests that the individual spaces
have generated distinct spatial groups (zones or areas) which are individual
yet have some connectivity: see Figure 8.

**FIGURE 8. SPATIAL ASSOCIATIONS GENERATING GROUPS OR ZONES.**

![Figure 8](image)

**FIGURE 9. ASYMMETRICAL SPATIAL ORGANISATION.**

![Figure 9](image)

This non-linearity expressed through the organisational patterns of the
space colonies in relation to the circulatory patterns is attractive and revealing
of explicit spatial configuration and secondary associations, which may be
translated into defined circulation routes between associated groups: see Fig-
ures 8 and 9.
6. CONCLUSION

This paper has detailed the development of a test model investigating the idea of how diagrams of space might self-organise relative to specific associational parameters, to generate diagrams of spatial organisation. This notion is based on the premise that buildings are shells to house a host of activities which a variety of individuals will perform. Encountering, congregating, avoiding, interacting, dwelling, are not attributes of individuals, but patterns or configurations, formed by groups or collections of people. The relation between space and the act of living lies in the relations between configurations of people and configurations of space (Hillier and Hanson 1984).

Although this test model to date is based on abstract spatial relations it does successfully demonstrate the system’s implementation. This has been achieved (as shown in Figure 10) with up to thirteen colonies; further colonies may be added but the performance of the model is then impaired. However this relates to software/hardware capacity not the model’s potential. It does nevertheless affect the model’s capacity to compute the necessary spatial configuration of a practical model. The model is therefore being translated for application into an alternative platform, to facilitate further testing and development (see Section 7).

**FIGURE 10. THE AGGLOMERATION OF 13 COLONIES’ SPATIAL CONFIGURATION.**

![Image of 13 colonies' spatial configuration]

The results of assessing the model’s performance with and without the tour routine illustrates the potential for extending the model by implementing different species of agents with alternative behaviours. This will be investigated in the translated model.

The possibility of hidden parameters being exposed has yet to occur, but this is a conceivable outcome given further development. Such a result is not realisable given the restricted agent form. The geometry of the model is an emergent property of the system, but the model needs extension to incorporate geometry representative of built-form to promote potential exposure of any
hidden parameters. It is also a matter of architectural perspective as to how the relationship of entities is perceived in the definition of spatial organisation: a potentially moot detail. The model needs to incorporate architectural geometry in order to demonstrate the philosophical and methodological approach towards development of a tool for generating models of architectural space.

This test model concludes the initial stage of this research, and summarises the early development of a work investigating the notion of self-organizing spatial configurations to generate architectural plan layouts.

7. FURTHER WORK

Translating the model into an object-orientated platform will extend the colony capacity. It will also facilitate integration of geometric features, and allow potential zoning or interlinking of specific spatial networks. Implementation of extended parameters (agent types, specific behaviours, etc.) and as noted above, of incorporating space-agent species that have alternative tasks, will enhance the model towards a practical tool. The platform used for this is Processing, version 1.0.1.

Having translated the model the initial extension will be to incorporate geometry. Geometry will render the model more practical, in that specific spaces will have the capacity to be allocated dimensional and area parameters. This will make the model reflective of real life problems in terms of configuration and packing scenarios. The current space-colony satisfaction of “are all my associated space-colonies within radius ‘x’?” will be translated to each space-colony having the requirement to maintain a variable of minimum-maximum area, which is defined by variable minimum and maximum x and y values. This forcefield behaviour may also be elaborated to define different levels of association/attraction between activities, thereby creating a more realistic relational structure (Ireland & Derix 2003).

The current model may also be extended to 3D. This is the intention, but whether the current methodology is extended (being the application of artificial ant colonies) or an alternative technique is used is under consideration.

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