Reversing the process of living:
Generating ecomorphic environments

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Abstract
Space syntax has shown itself to be a useful analytic tool, but until now there has been little advance in the application of space syntax to generate environments. While there have been theoretical advances in knowledge about how urban environments come to be constructed, there has been little concentration on how we might build a constructive tool. This paper addresses this shortfall by appealing to the biological theory of autopoiesis. Autopoiesis is the process by which an organism maintains itself within the environment; we might propose autopoietic software agents that similarly maintain themselves within the artificial environment through natural movement. In response, the artificial environment may adapt to the software agent, moving services that the agents may use to more integrated or segregated locations, or by changing the relationship of the local to the global structure of the system in order to achieve intelligibility. Here, several experiments applying these ideas about the structural coupling between agent and environment are demonstrated, showing how environments may be evolved to fulfil the natural movement process of agents. That is, moving towards artificial buildings and cities that are generated as an ecomorphic response to inhabitation, in the hope to both understand better the process of occupation and urbanisation, and to look to the future of building and urban design.

1. Introduction

We should rightly be wary of any formal generative procedure that may be applied in order to construct configuration. With scant, although growing, appreciation of how space affects society, it would seem premature to argue that we are in a position to provide a method of design that might have certain, albeit basic, societal outcomes. Indeed, Soja (2001) argues that we should be careful not to exceed the limitations of spatial description; he declares that an exact explanation of social behaviour is beyond any theory due to the number of social variables in existence and the complexity of their interactions both with each other and the environment. However, this does not mean to say that there is not a set of sociospatial relationships that exist in the world, nor that they cannot be modelled or, indeed, be applied to design. This is essentially the premise of space syntax: that there is an underlying grammatical structure of space that we can access. To draw briefly on an analogy: Chomsky (1957) has famously shown that sentences can be deconstructed into grammatically correct and incorrect, even if the sentences themselves are meaningless. Likewise, it is possible to generate grammar, vast amounts of it, using Chomsky's schema of a recursive transformational (or generative) ruleset. The results are dramatic when applied to simple natural systems: Lindenmayer's (1968) L-grammars can produce wonderfully plant- and tree-like structures. While bearing in mind that Lindenmayer's plants and trees are not actually plants or trees, we can still appreciate that they are, grammatically speaking, correct plants and trees. The same is true, of course, for sociospatial systems. We can assess them by means of their grammatical structure, without recourse to their meaning. Of course, this is anathema to most architectural authors, concerned, as they are, with experience of the environment: that a tool is unable to assess the semantic quality of (the experience of) a space would seem, to them, to render it incapable of generating good architecture. At this point the argument becomes circular: Soja has already shown that a phenomenological understanding of space through a tool or spatial description is impossible, and therefore, through this argument, the automated generation of good architecture is impossible. Are we at a loss?

I would hold that we are not[1]. In order to bypass Soja, the question is, essentially: how can we quantify phenomenology? We should note that the experience of architecture is a process that inextricably involves both the experiencer and the environment, that is, it is a situated process. This is, of course, not a new idea to architecture. Norberg-Schulz (2000, p. 10) invokes the Heideggeran notion of human as Dasein, that is, as a being which only makes sense as a part of its environment, to state: "Life, then, is understood as a series of relationships, and existence is seen as a way of openly mirroring oneself in an array of different ways of being. Thus, man stops being an observer and becomes a participant...". Wheeler (1996), a cognitive scientist, goes further, to suggest that the human and environment — or, for the purposes of his paper, Rothko's art — are engaged in a hermeneutic dialogue, that is, an ongoing process of exchange of (nonlinguistic) interpretation. Importantly, he suggests that this exchange may be modelled by considering the possible interactions between human and artwork. The model is of the act of semantic appreciation, while abrogating knowledge of the semantic appreciation itself. This leads to the argument that a model of the possible interactions of the Dasein with its environment may lead to a reasonable model of the hermeneutic dialogue established between the two. In order to create the model itself, we can invoke the biological notion of autopoiesis (Maturana and Varela, 1987). The Dasein, or human, is a self-contained system which interacts with the environment through walking and (in the majority of cases) vision. Figure 1 shows Maturana and Varela's diagram of autopoiesis. The being maintains itself within and with respect to the environment, in an ongoing ecological process between the two. Within this model the visual interaction which draws the two together is provided by the psychologist Gibson's (1979) natural vision; he states:

"When no constraints are put on the visual system, we look around, walk up to something interesting and move around it so as to see it from all sides, and go from one vista to another. That is natural vision..." (Gibson, 1979: 1)

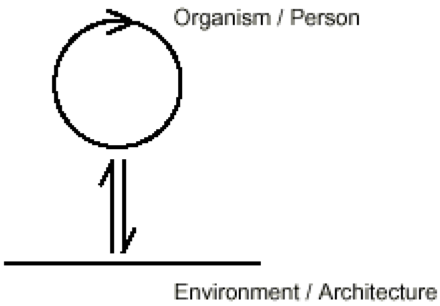

Figure 1: The autopoietic view of the person and her or his environment.

Gibson gives us two contrasting concepts in this sentence. Natural vision is composed of what we might call natural movement: "we look around / we move from one vista to another", and what we might call natural interaction "we walk up to something interesting / we move around it". In this paper, the consequences of both of these modes of natural vision will be considered. The human, encoded as a computer software agent will be drawn through the environment or the something interesting (we will use artwork to continue Wheeler's theme) by the affordances they offer her or him, and the affordances will be constructed between the human and either the environment or the artwork via the visual connections between the two. The environment, of course, offers the possibility to walk through it (for the able-bodied human). The artwork offers the possibility to walk up to it and move around it, just as Gibson states. The software agents themselves act as directly motivated by the affordances presented to them.

The agents, in following their rules, come to resemble not only observed people movement in aggregate, but also the outputs of space syntax analysis — at least, when engaged with the environment in natural movement (see Turner, 2003). As bodies propelled through configuration by affordances, they move as if space were a machine (in the words of Hillier, 1996), and they, the agents, were the cogs. Turning the cogs *in reverse* should lead to the generation of spaces which at least function in certain predictable ways. While it might be impossible to predict a specific societal usage, we can at least determine a range of possible usages based on the configuration. These solutions may in themselves be inspiring, but why stay at the level of the cogs? Space syntax has shown itself to be a useful analytic tool, which breaks space into syntactical units we might construct with: axial lines and convex spaces. However, the combination of free spaces does not lend itself easily to generative rulesets, since space syntax has come to primarily focus on the relationship of spaces to usage, despite the early grammatical formulations of Hillier and Hanson (1984) in the *Social Logic of Space*. That is to say, slight changes in the composition of spaces can radically alter the sets of convex spaces and axial lines found, and the relationships between them found in the system as a whole; therefore, a compositional strategy devised through incremental steps must either work with space in terms of axial lines and convex spaces directly, or, if it works with small changes in form, be able to cope with significant changes in spatial structure. Although working with the syntactical units directly might seem a useful start, the mapping of a graph of convex spaces or axial lines to physical space is not necessarily possible, nor can it cope with notions of scale (a perennial problem with space syntax as it stands).

Remaining at the level of the cogs allows us to compose space by means of what autopoietic theory calls *structural coupling* — the organism moulds itself to the environment and the environment moulds itself to it. Small or large mutations may be made to both the agent and the environment in order to form a perfectly attuned ecology. In this paper first the result of ecomorphic natural movement is explored through the generation of configurational forms suiting particular inhabitation patterns using agents with vision and an evolutionary algorithm to modify the environment. Second, the result of ecomorphic natural interaction is explored through the interaction of the two inhabitants of Wheeler's world — the agent and the artwork, while situated within an environment which supports the process. The artwork agent is allowed to move (!) from location to location in order to find more people agents, but to do so it must relocate its supporting wall, affecting the overall configuration of the space. Finally, a short conclusion reflects on the outcome of the experiments.

2. Generating configuration through natural movement

There is empirical evidence that computer software agents programmed with very simple rules can successfully reproduce observed human behaviour at the aggregate level. Turner and Penn (2002) demonstrate a correlation of $R^2 = 0.76$ between agent and human through room movement counts in the Tate Britain Gallery on Millbank. The agents are programmed with a simple movement rule: to select a destination (any possible destination) from their field of view (~170°), then walk three steps, and choose another destination, and so on. In this way they progress through the environment until removed from the system (Figure 2). Outside the constraints of an art gallery correlations are seen to be worse, but still reasonable, for example $R^2 = 0.67$ when released from specific zones in the City of London (Turner, 2003).

Both such experiments demonstrate the effect of the environment on the being (the upward arrow in Figure 1 — the internal process in the being itself cannot be accessed, which is what the circular loop shows: a closed system). In order to create an effect on the environment (the downward arrow), the environment must respond in some way to the being. For the purposes of this paper, the response will be driven by a genetic algorithm.

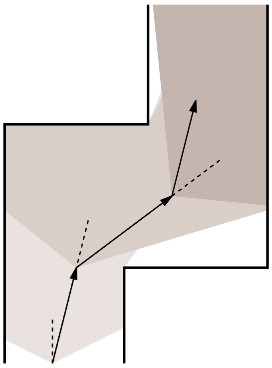

Figure 2: Natural movement drives an agent through a configuration due to the ecological affordances for further movement that the environment embodies.

A simple test configuration was designed comprising a 5 x 5 grid, with columns separating notional rooms, and a single entrance (Figure 3a). As can be seen from figure 3b, if agents are released from the entrance into the system, they tend to coalesce at the centre. The question, then, to be addressed, is: is there a configuration that will lead to equally distributed movement throughout the system of 25 rooms defined by the columns? The question was attacked by using a genetic algorithm to specify and modify the position of internal walls within the system. A genotype of length 40 was used to represent each of the possible internal walls in the system (Figure 3c) with a binary 0 or 1 to indicate if a wall does not or does exist in the system. A population of 30 such genotypes was constructed, and the corresponding phenotypes evaluated by releasing agents into the system. The agents had standard properties from Turner and Penn (2002): a walking pace of about 1.5ms-1, three steps to decision and a field of view of ~170°. The agents were released at regular intervals and allowed to circulate the system for 11/2 minutes before being removed, so that about 25 agents were present at any one time. Each evaluation was run for a simulated time of 30 minutes. At the end of this time, the standard deviation of the numbers of agents passing through each room was taken as a score of how broadly the agents had been distributed by the system. In addition, not visiting rooms at all was penalised (to avoid premature convergence to the result of a single room being available to the agents, which has a relatively low standard deviation, but is a bad solution to our problem). The system was evolved to minimise the penalty using rank selection and uniform crossover over 300 generations in order to produce a result (see Goldberg, 1989, for details of genetic algorithm operators). Figure 4 shows the evolution, from an initial random solution, through the situation after about 150 generations, to the final result.

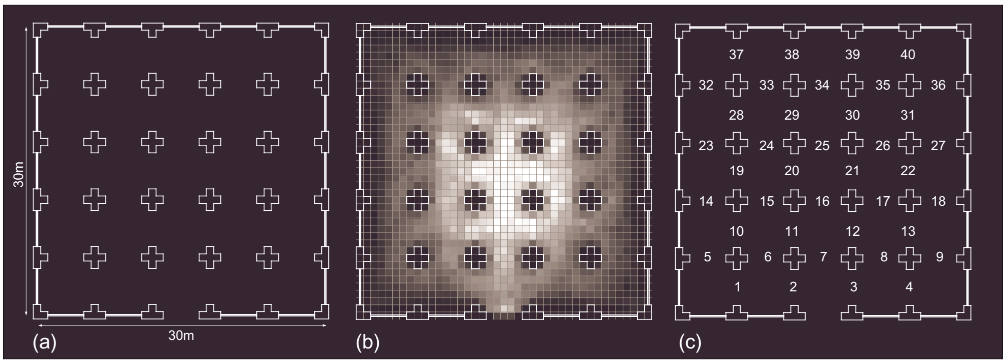

Figure 3: (a) The 5 x 5 environment used for the experiments. (b) Visitor movement patterns without internal configuration. (c) The set of possible locations to place internal walls in the system.

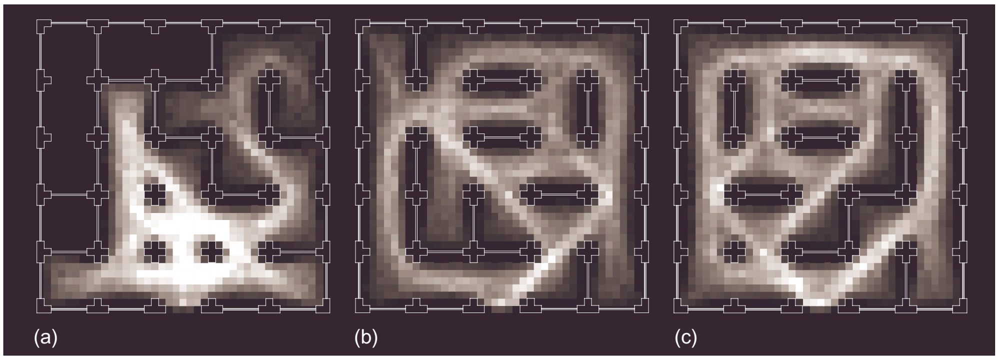

Figure 4: Initial, 150 generation and 300 generation patterns of ecomorphic evolution for 1 1/2 minute visit duration.

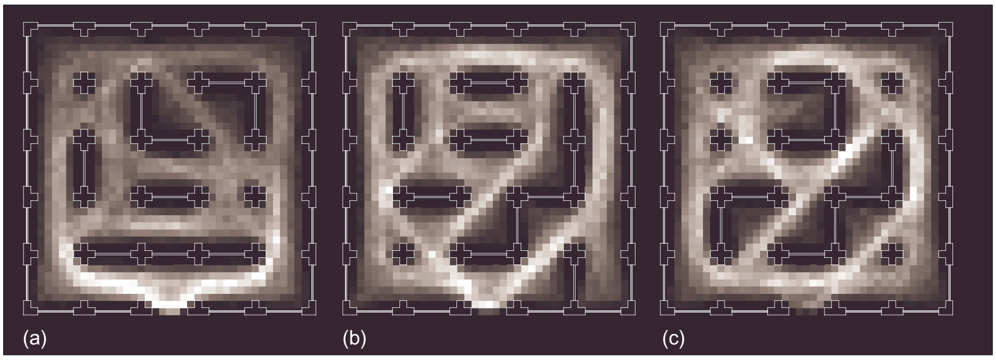

Figure 5: The effect of 1/2 minute, 1 1/2 minute and 3 minute visit duration on the evolved ecomorphic environment

The solution found channels movement to either side of the entrance, and then around the system. Interestingly, a range of solutions seem to have been attempted simultaneously. There is a long diagonal, a shorter diagonal and several smaller circulation zones. This perhaps is a factor of the time involved: a period of 11/2 minutes is just enough for an agent to visit every room in the system from centre to centre, but no more. Thus, the entrance rate is important, but so is some degree of circulation. It is interesting to compare the strategy chosen for 11/2 minutes with that for just 1/2 minute, and that for a full 3 minutes. The results are shown in figure

5. The 3 minute solution appears to extend the 11/2 minute solution, giving a more rounded overall circulation pattern, with more pronounced diagonals: in other words, providing as many long and straight routes as possible. The 1/2 minute solution, by contrast, selects a bar across the bottom of the configuration in order to split movement outwards as quickly as possible, leaving vague short circulation routes behind the bar. Before moving onto movement generated through natural interaction, it is worth noting that these patterns are produced when the agents are simply removed from the system: there is no notion that they should be able to find the exit again. Although the agents are making brief visits in the 1/2 minute solution, it is likely that any real life inhabitants would quickly become frustrated by their inability to find the exit once in the open configuration behind the bar.

3. Generating configuration through natural interaction

So far we have concentrated on the natural movement component of natural vision. Let us turn to the natural interaction with objects. There are two modes in which natural interaction might occur. The first is simply through the configuration of an object. A sculpture, for example, might invite us in through the spatial possibilities it affords us rather than, or in addition to, its aesthetic appeal (if we assume that the object fulfils separately Vitruvius's *utilitas* and *venustas*). Paintings, however, must draw us in through aesthetic appeal alone, since they afford us no enhanced spatial possibility. In order to cope with this facet, a slight modification is necessary to our model. Mottram et al. (1999) introduce the idea of *taste vectors*. Each agent is provided with a taste vector — for simplicity, a 2D dimensional direction, see figure 6 — the taste vector is drawn inside the circular closed loop to indicate that it is an internal function of the agent to which we cannot gain access. If the two taste vectors are aligned, then the agents are drawn to one another, if they are opposite then the agents are repelled. As agents that are attracted meet each other, their taste vectors are modified, and eventually they go on their way. It is important to understand that artwork itself is both an agent and has a modifiable taste vector. The taste vector of the artwork essentially represents the cultural perception through time of the artwork. As society views the artwork, so the meaning it embodies is modified (see Wheeler, 1996, once more).

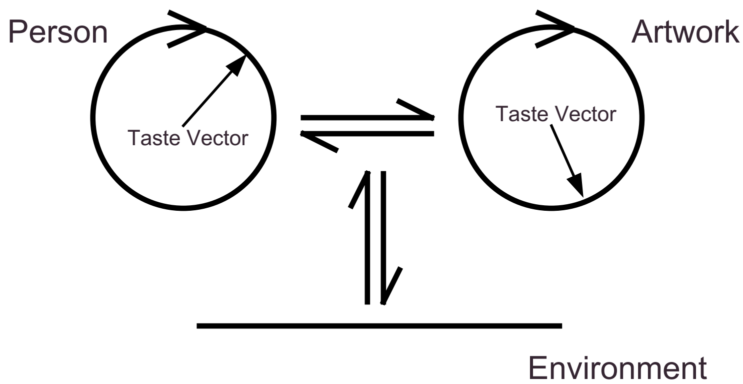

Figure 6: Autopoietic diagram of person / artwork / environment relationship

The problem at this stage is how to provide an ecomorphic environment around the interaction of people agents and artwork agents. I suggest that we view the artwork agents not only as static objects with taste vectors, but take a mental leap and allow them to move like people agents. The artwork can ‘set up shop’ in any location, provided it builds a wall behind itself. Depending on how many visitors view the artwork it might choose to move, picking up its wall and move to a new, more popular location (Figure 7). The idea for this artwork movement was originally developed as an ongoing architectural process (Turner, 2002), but it seems sensible to cogitate on the social implications of such a system. For this experiment, the same 5 x 5 grid as was used for the natural movement experiments was utilised. People agents were similarly released into the environment and allowed to peruse the artworks. When they catch sight of an artwork that they have not visited before, people agents check their taste vector match with the artwork agent. If the angle between them is less than 15° they are attracted, and move towards the artwork and visit it. The taste vectors gradually change as the person agent and artwork are engaged in their hermeneutic dialogue, and when there is no longer a 15° match, they move on to find another artwork. As for the artwork agents, fifteen are initially randomly distributed around the system just in front of a possible wall location (see Figure 7 again). Behind each a wall is constructed. At the end every simulated minute of the run, all are evaluated for the number of visitors they have received. The artwork agent with fewest visitors is allowed to release itself from its location, and if it has an unshared internal wall, the wall is removed. It moves using standard natural movement rules through three rooms, and selects the one with highest visitor through movement to locate itself. As it locates itself, a wall is placed behind it once more. The experiment is run for as long as desired.

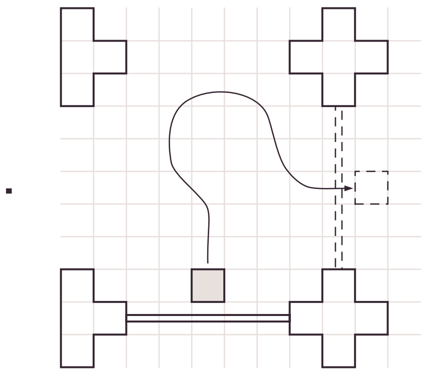

Figure 7: An ecomorphic wall is moved to a new position due to the change of location of an artwork agent.

Figure 8 shows the results through time as the artworks move to better locations. The background colour scale shows the aggregate movement over all time of the people agents. The results, though obvious, have interesting economic implications. As can be seen, the agents move gradually to the centre of the system and towards the entrance (where most visitors will be captured). If run to its logical conclusion, three agents will position themselves around the entrance room, leaving the other agents starved of visitors. Of course, in an art gallery, curators will be aiming to distribute paintings, probably working on the principles of the natural movement experiments.

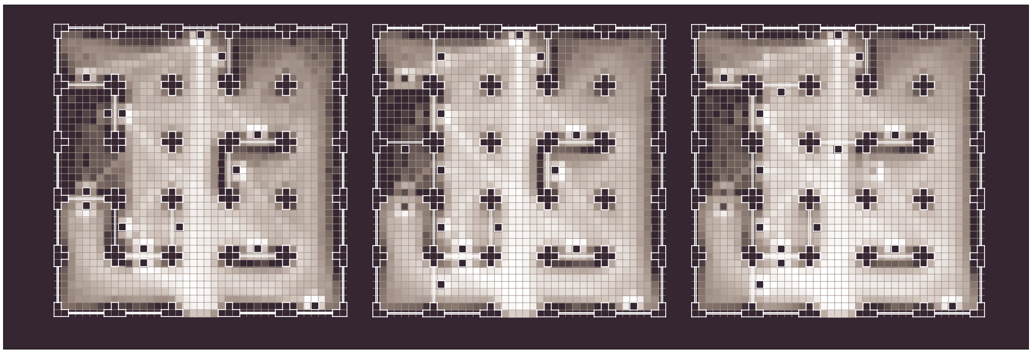

Figure 8: The development of the ecomorphic system after 5, 10 and 15 artwork agent moves. The scale shows the total aggregate movement for the lifetime of the system.

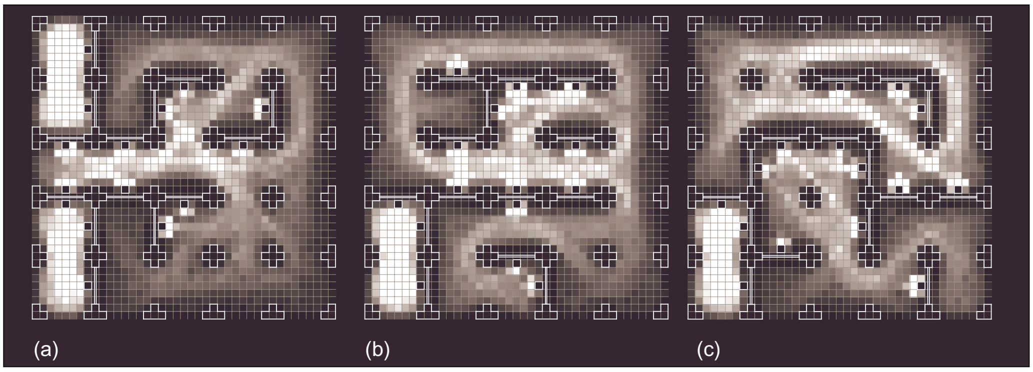

Figure 9: The development of the open access ecomorphic system after 5, 25 and 50 moves. The scale shows the aggregate movement for the current run. Note that presence of larger densely visited areas is not necessarily good for the artworks: what counts is their visitor numbers, not that there is strong overall movement in the area.

However, the results show the conclusion of running a free market in a closed environment. If the artworks were considered as shops or market stalls, the entrance ways are taken over by the shops or market stalls most able to afford the business. Even competitive pricing for location will still lead to the same result as the best performing shops taking over the prime spot. In a closed environment, the only way to distribute services is through planning. That the situation in arise in an open environment (where visitors may enter via any edge) is not clear. Hence, the ecomorphic system was run with open sides, and the results through a selection of generations are shown in figure 9. Artwork agents in this system may place themselves against any internal walls, but not block the external walls. As can be seen an interesting phenomenon occurs: at first it appears that the agents will simply place themselves around the edges of the system to get best viewing, and indeed a set of three maintain their position. However, others relocate themselves into small enclosed clusters, in order (applying an anthropomorphism: presumably), to catch as many visitors as possible between them. That is, apparent *cooperation* evolves, although according to the rules of the system, no agent is actually cooperating with any other: the complexity of the system allows this behaviour to manifest itself as what we would designate cooperation.

4. Conclusion

This paper has proposed that we examine the social process within architecture in order to advance a generative procedure to construct configurational solutions. It took as its starting point the combination of people and environment in a single ecological process, to affirm that a model can be fabricated of what Wheeler (1996) calls a hermeneutic dialogue between a human being and her or his environment. Autopoiesis was invoked in order to examine the construction of the model, and the link between person and environment was offered through Gibson's (1979) direct perception, where the environment affords movement to an individual due to the possibilities of movement that it provides him or her. Such models are heavily constrained: direct perception does not allow for higher level representational structures, so that, for example, a cognitive map might be used to retrace steps to an entrance, or suggest a direction for further exploratory movement. However, the models have been shown to correlate with aggregate movement patterns of real movement (Penn and Turner, 2002; Turner and Penn, 2002).

Based on the autopoietic direct perception model, two aspects of Gibson's natural vision were examined as precursors for evolved ecomorphic (or perhaps more correctly, ecoconfigurational) environments. The aim was to create structurally coupled environments, that is, environments whose form is coupled directly to the usage that occurs within them. Natural movement, the mode of a person moving from vista to vista within an environment, was applied to create a system of walls that distributed agent-based movement evenly within a 5 x 5 grid of rooms defined by columns. Using a genetic algorithm, internal walls were constructed and reconfigured in order to most effectly disperse movement aroundthe rooms of the overall configuration. The results showed two distinctive mechanisms: for short visitor times, the movement was directed away from the entrance as quickly as possible, before being left in a relatively free space to circulate; for long visitor times the movement was directed along circulation routes at two scales — long vertical, horizontal and diagonals lines to effectively distribute the movement over the space and smaller subregions of open circulation.

A more complex model was used for natural interaction, the mode of a person moving up to and around something that attracts his or her attention. The model was constructed as the situated interplay between notional visitors and artworks within the 5 x 5 grid. Both the people and artwork agents were given taste vectors, which, when matched, would cause the people agents to visit the artwork. The artwork agents themselves were allowed to use natural movement every so often in order to find areas of higher movement density, but in doing so they would change the configuration as a whole through the construction of a supporting wall behind them, creating a game within a structurally couple environment. With a single entrance to the 5 x 5 grid, a relatively facile procedure took place, whereby the artworks descended on the entrance and the corresponding higher visitor numbers around it. However, when the system was opened up so that visitors approached from any direction, rather than locating themselves around the edges as might be expected, many of the artworks formed small clustered zones where many of them could be visited in a short space of time. The result is interesting not just architecturally, but also socially as it implies the evolution of economic cooperation through an extremely simple ruleset. Viewing the artworks as market stalls or shops, it suggests that in a constrained environment their activities must be regulated in order to distribute them effectively, however, in an open system, they can be left to place themselves to produce varied and socially dynamic systems. This, I suggest, is a key to understanding urban morphology. It lends credence to Hillier's (1996) theory of the movement economy, and indicates that it will create configurational patterns every bit as complex and varied as the cities we see around us.

Acknowledgements

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Notes

[1.] What follows is based on the argument I develop in far more detail in Turner (2003).

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