

Interacting unities: an agent-based system

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Abstract

Recently architects have been inspired by Thompson's Cartesian deformations and Waddington's flexible topological surface to work within a dynamic field characterized by forces. In this more active space of interactions, movement is the medium through which form evolves. This paper explores the interaction between pedestrians and their environment by regarding it as a process occurring between the two. It is hypothesized that the recurrent interaction between pedestrians and environment can lead to a structural coupling between those elements. Every time a change occurs in each one of them, as an expression of its own structural dynamics, it triggers changes to the other one. An agent-based system has been developed in order to explore that interaction, where the two interacting elements, agents (pedestrians) and environment, are autonomous units with a set of internal rules. The result is a landscape where each agent locally modifies its environment that in turn affects its movement, while the other agents respond to the new environment at a later time, indicating that the phenomenon of stigmergy is possible to take place among interactions with human analogy. It is found that it is the environment's internal rules that determine the nature and extent of change.

1. Introduction

The emergence of computation and digital technologies that have given rise to new ideas, have affected the architectural process, so the classical models of pure static, timeless form and structure are no longer adequate to describe contemporary architecture. Architecture is evolving, re-establishing its boundaries to adjust to a new medium, between the organic and the Euclidean that is considered supple. Zellner writes: "*Architecture is re-casting itself, becoming in part an experimental investigation of topological geometries [...] and partly a generative, kinematic sculpting of space*" [1]. There is a shift from a very deterministic view of the architectural object to a more dynamic one. This is evident in the work of Greg Lynn,

where the object controls the whole process of form production. He describes the process as follows: “an *object defined as a vector whose trajectory is related to other objects, forces, fields and flows, defines forms within an active space of force and motion*”[2].

With the introduction of dynamism, space and architecture are related to the notion of time. The connection between space and time establishes the idea of movement. In order for an architect to work with movement and form, it is essential to develop techniques that can relate gradient fields of influence with flexible forms of organisation. This implies a shift from a passive neutral space to an active space of interactions. Architecture can be conceptualised and modelled within a field that is understood as dynamic and characterised by forces that can be crystallised into forms. To an architect, questions of the surroundings are often questions that contribute to form. As Iain Borden poses it “*architecture [...] is not made just once, but it is made and remade over and over again each time it is represented through another medium, each time its surroundings change, each time different people experience it*” [3].

By regarding pedestrian movement as an external force acting on the environment, this study attempts to explore the interaction between pedestrians and their environment, aiming to generate a form dynamically responsive to its surroundings, fully embodied within the context in which it exists. It intends to explore that interaction through an agent-based system, where two interacting elements can be identified: agents representing pedestrians and environment. It is demonstrated that the recurrent interaction between agents and environment can lead to a structural coupling between those two elements: every time a change occurs in each one of them as an expression of its own structural dynamics, it triggers changes to the other one.

The next section investigates issues from the field of architecture and biology, establishing the theoretical background upon which the research is based. Against this background, the basis of our exploration, the agent-based system is introduced and described along with the results of experimentation. We conclude with a discussion of the outcome of the whole process.

2. Literature review

In this section we look at movement and its effect on form generation in the field of architecture along with the relation of time to form, since in the interaction between pedestrians and environment we explore, movement is considered the medium through which the system evolves and the interaction is realized in time. We also refer to autopoietic and stigmergic theory from the field of biology that defines the relation between a unity and its environment in an attempt to find a mechanism of explaining that interaction, providing the theoretical backup of our hypothesis.

2.1 Architecture and animation

With the shift of architecture from a passive space to a more active, dynamic one and the advent of the computer in studios, animation has emerged in architectural practice as a design tool at conceptual level. It has enabled architects like Greg Lynn, Mark Goulthorpe of DECOI, Lars Spuybroek of NOX or Marcos Novak to develop dynamic and evolving design techniques. The use of animation has introduced duration and motion into static forms, so

architecture is no longer based on the inert material properties. Design is viewed as a highly flexible and plastic medium in which architectural form constantly evolves through motion and transformation. According to Greg Lynn “*while motion implies movement and action, animation implies the evolution of form and its shaping forces; it suggests animalism, animism, growth, actuation, vitality and virtuality*” [4]. Simple parameters like scale, volume and dimension are no longer adequate to define forms; multivalent and external or invisible forces such as pedestrian and automotive movement, environmental forces like wind and sun, urban views and alignments, intensities of views and occupation in time affect form of a dynamically conceived architecture.

The issue of involvement of outside forces in the development of form is not new. The morphologist D’Arcy Thompson is perhaps the first person who attempted to describe the transformations of natural form in response to environmental forces [5]. He associated bodies and measures in such a way that specific dissymmetries and disproportions were maintained as events within a supple geometric system of deformations. In those deformations, particular information influences and transforms a general grid, so geometry becomes a more fluid and dynamic system to describe changing bodies through their appearances at singular moments. Additionally, another model that has been developed to describe the relationship between an evolving form within its environment is Conrad Waddington’s concept of the epigenetic landscape. Kwinter writes: “*The epigenetic landscape is an undulating topological surface whose multiplicity of valleys corresponds to the possible trajectories (shapes) of any body evolving on it*” [6]. Any point change in that is distributed smoothly across the surface so that its influence is not locally related to any point. The introduction of any exogenous forces at any time will perturb the evolving on the landscape body from its determined trajectory and cause it to evolve a unique and original form.

For Greg Lynn “*this possibility of an animate field opens up a more intricate relationship of form and field that has not been possible before*” [7], so the form becomes the site for the calculation of multiple forces. In combination with time, topology and parameters it establishes the model that Lynn has developed to design in an animate space. A characteristic example of his work is Port Authority Gateway project, where the site was modelled using forces that simulate the movement of cars and buses, pedestrians and vehicles, underground and overground, land and water, each with varying speed and velocities. On the other hand, for Mark Goulthorpe of DECOI [8], animation is an emerging cultural phenomenon in which movement is implicit, while virtual dynamism is the essence of it. An example of his dynamic architecture is Aegis Hyposurface that actualises the idea of dynamic and responsive architecture capable of responding physically to stimuli from its surrounding environment. The surface deforms by capturing stimuli from the theatre environment and dissolving them into movements, supple fluidity or complex patterning.

The notion of dynamism relates space and architecture to time, making it amenable to human manipulation. Architects no longer limit themselves to the three dimensions of Euclid, but incorporate time in their design as the fourth dimension. Kwinter suggests that time functioning as a form of pure information “*is what makes the emergence and evolution of form possible by providing a communicative middle term –a metastability- affording exchanges and absorbing and transmitting tensions across the many and various systems of influence. Thus time is not just a novel or superadded variable; it is that agency which multiplies all variables by themselves*” [9].

2.2 Structural coupling and stigmergy

Autopoietic theory, developed by the Chilean biologists Humberto Maturana and Francisco Varela [10] concerns the theory that an organism, or unity, maintains itself within the environment through an internal delimited process. One of the key concepts of autopoietic theory is *structural coupling*, which defines the relation between a unity with either its environment or another unity. In a structurally determined dynamic system, since the structure is in ongoing change, its structural domains will also change, although they will be specified at every moment by their present structure. Provided that the unity does not enter into a destructive interaction with its environment, there will be compatibility between the structure of the environment and that of the unity. As long as this compatibility exists, environment and unity act as mutual sources of perturbation, triggering changes of state [11]. This ongoing process is called structural coupling. In Maturana and Varela's words "*we speak of structural coupling whenever there is a history of recurrent interactions leading to the structural congruence between two (or more) systems*" [12].

We can think of the unity's effect on the environment in terms of the notion of 'stigmergy' [13]. Stigmergy is an indirect interaction among social insects that results to the emergence of self-organization in them. When two individuals interact indirectly, one of them modifies the environment and the other responds to the new environment at a latter time; therefore individual behaviour modifies the environment, which in turn modifies the behaviour of other individuals. Grasse originally introduced stigmergy to explain task coordination and regulation in the context of nest reconstruction in *Macrotermes* termites.

3. Method

In this section we examine the action of pedestrians within an environment. Firstly, the agent-based system is introduced and described. Secondly, we explore the nature and extent of interaction between pedestrians and their environment through a series of experiments. Thirdly, the outcome of the whole process is discussed.

3.1 Description of the system

In an attempt to investigate the role of movement as an external force in an active space of interactions, we look at pedestrians' action within an environment. It was decided that agent modelling should be used as human movement can be successfully generated by applying simple rules that describe the behaviour of individual agents [14]. These simple rules result in a complex overall behaviour. Each agent is autonomous and seeks to modify its environment in a constant interaction with it. Taking into consideration our hypothesis that refers to structural coupling, it was indicated that the environment had to be constituted of components in order for us to be able to identify changes in structure. This led us to the use of a grid, since it is easily transformable both locally and as a whole. Agents and environment are regarded as a system –we refer to it as an agent-based system- since they constitute a complex whole, where two autonomous unities with internal rules interact together to achieve a certain goal: influence each other.

The choices already made for using agents and a grid to represent the environment determined the nature of interaction. The agents move independently on a two-dimensional grid consisted of blocks. By using an array of elements, a simple surface is created based on a geometrical simple form: a block. The agents modify their environment by translating each block they are standing on at the time, along with their height. The “identity” of the block –its position on the grid- can be established by rounding agent’s location (x and z coordinates) to the nearest integer.

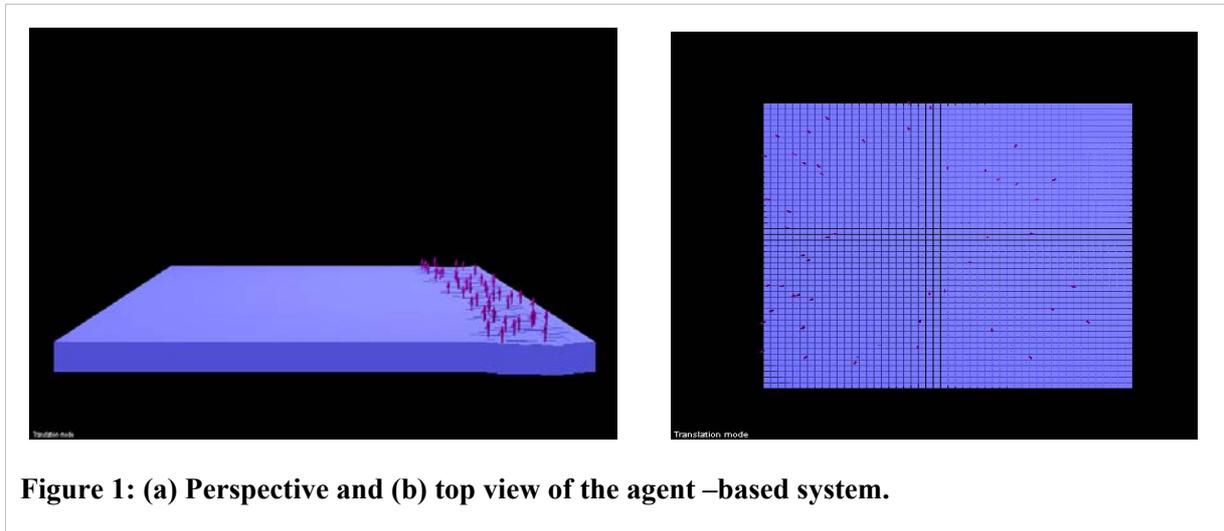


Figure 1: (a) Perspective and (b) top view of the agent –based system.

In pseudocode, the following simple process defines the interaction between agents and environment:

Loop

Find the grid reference of the block you are standing on by rounding your current location to the nearest integer.

Move a little bit.

Find the new block you are standing on by rounding your location to the nearest integer.

If the new block is different from the first then

Find this block’s height.

Translate the new block you have stepped onto

Translate your height along with that block.

End if



End loop

In this way the agents have knowledge of their environment, while the structuring of the environment caused by agents’ activities influences in turn their movement.

The interaction between the agents and their environment is explored through a series of experiments, the most interesting results of which will be presented in the following section. Those experiments focus on movement (random movement and movement based on vision) and its effect on the whole process, and on the extent of interaction agents-environment along with the result of this interaction. For the purpose of producing an experimental model, variables are established that can be manipulated to produce different conditions for

comparison. Through using a set of parameters that define the relation between features of agents and features of the environment, the extent of interaction is determined and the initial environment is modified in each individual case creating a different visual effect. Those parameters are: speed and initial position of agents, height difference between blocks [15], sink height of a block each time an agent steps onto and maximum depth the block can reach.

3.2 Theoretical set of experiments

Movement is the medium through which the system evolves and the interaction is realized in time. In this section we will review experiments with random movement. The agents move independently on the environment. Each one moves forward and changes direction of movement gradually every 10 steps it takes.

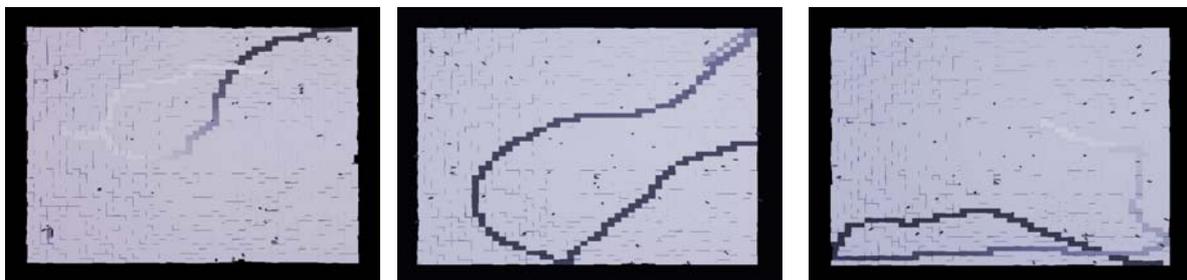


Figure 2: Each agent starts its movement from a different initial position. The blocks have been coloured lighter the more recently the agent has moved through them.

The following process determines each agent's movement, where *turn step* is a variable that defines the number of steps the agent takes while turning:

Loop

If the *turn steps* counter is 0 and the *movement steps* counter is 10 then

set *turn step* counter to 1

set the *turn angle* to between -0.1 to 0.1 radians

Otherwise, if the *turn step* counter is greater than 0, then

increment the *turn steps* counter by 1

turn by the *turn angle*

If the *turn steps* counter is more than 5, then

set the *turn steps* counter to 0

set the *turn angle* to 0.

End if

End if

Move forward with random speed.

Increment the *movement steps* counter by 1

End loop

Movement is restricted within the grid. Every time an agent reaches the edges, it turns left or right quite rapidly according to the previous direction of movement. This process results to agents' interaction with different parts of the environment each time. This is demonstrated in figure 2, which shows the path of three different agents as it was recorded during our experimentation.

If the parameters "height difference" and "maximum depth" are given small values, then the environments' final form is uniformly shaped. At this point we should clarify the term *form*. It refers to the environment's shape at different points in time, while *final form* is the environment's shape at the end of the interaction agents-environment. This interaction terminates when the height difference between blocks prohibits agents' movement towards any direction. In our experimentation with small values given to previously mentioned parameters, we observe that the agents interact with all the blocks of the environment and not with specific parts of it that would result to the generation of an environment with peaks and valleys. The evenly shaped final form can be attributed to the local character of the interaction: each agent locally modifies the environment by translating one block every time while the other agents respond to the new environment at a later time.

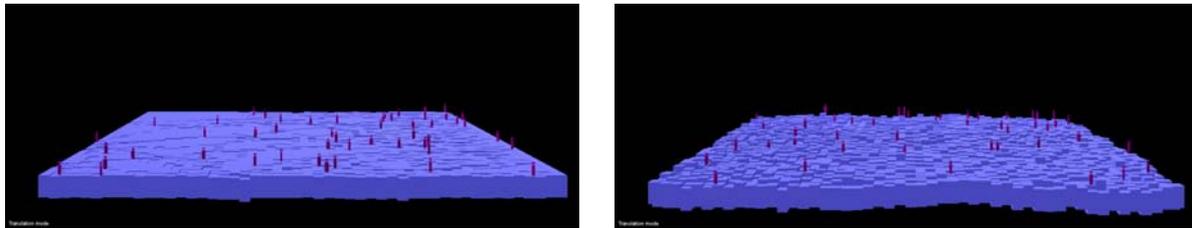


Figure 3: The environment's modification after X time steps. Two states of the environment at different points in time.

Taken it a step further, we expand agents' interaction to a neighbourhood of blocks instead of only one. This results to a smoother, plastic form of the environment (figure 4). Although the interaction can still be considered local because changes affect only one part of the environment and not the whole, it is indicated that its form can be manipulated and by extending the interaction the whole environment can be affected by one agent's action.

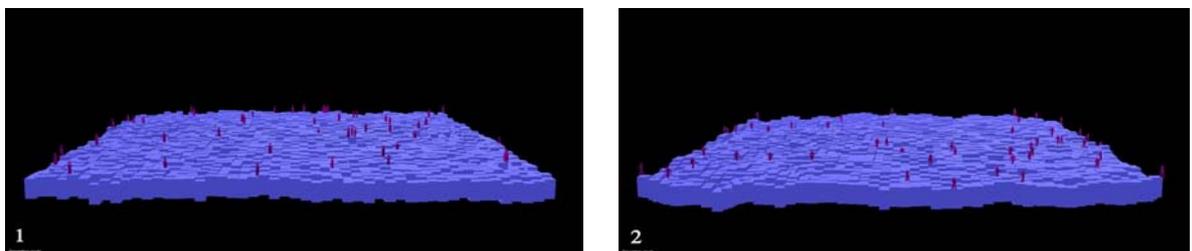


Figure 4: Experimenting with plasticity: (a) one block moved as the agent walks over it, (b) blocks within the neighbourhood are deformed as the agent moves near them.

In the above experiments, when the interaction agents-environment terminates an interesting behavioural pattern rises: the agents get trapped in a continuous circular movement on a block either as individuals or in groups, as shown in figure 5. When they form a group, they create holes made by more than one sunken blocks.

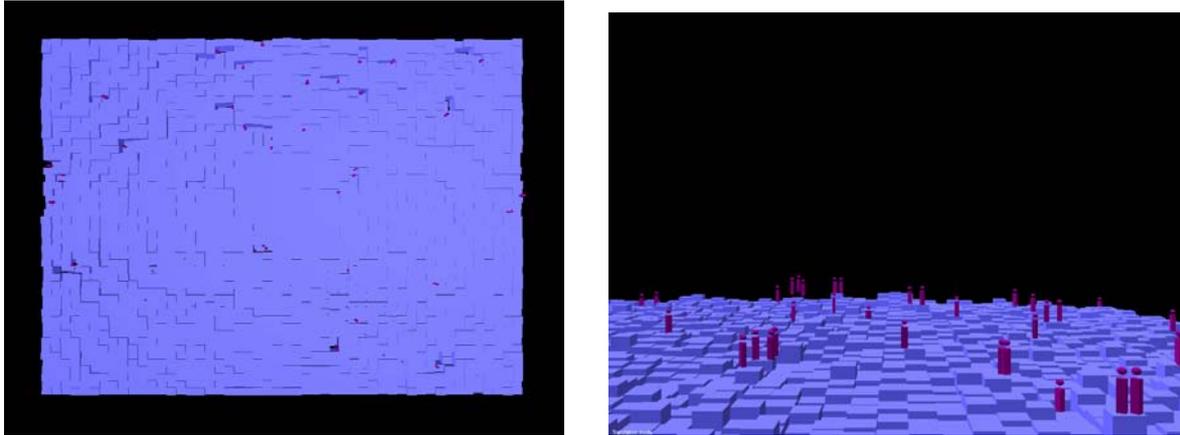


Figure 5: (a) Top view and (b) perspective view of the system when agents become trapped due to block height differences.

When large values are given to the parameters “height difference” and “maximum depth”, the agents are able to interact continuously with the environment and move towards any direction without limitations. We can consider the interaction non-constrained, since it can be infinite. This constant unlimited interaction gives rise to a curved form. This form is the outcome of agents’ movement towards the edges and corners of the grid and interaction with these parts at bigger extent than the rest of the environment. The agents’ movement in the environment is forward but limited within the grid, meaning that all agents have to turn when they reach the marginal blocks. Each agent does not necessarily interact with all the blocks of the environment. Since the number of the marginal blocks is less than that of the blocks that constitute the rest of the environment and given that more agents pass through them, they modify the marginal blocks more times than the central ones.

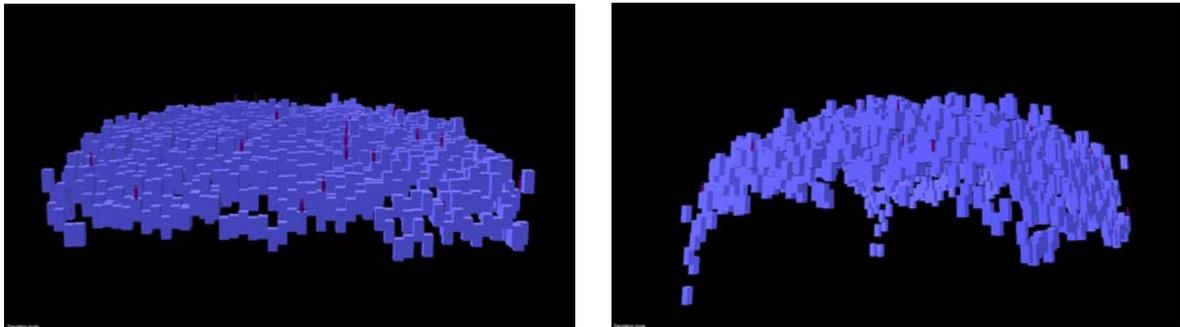


Figure 6: Curved form: two states of the environment in a different moment in time, when large values are given to the parameters “height difference” and “maximum depth”.

Our experimentation with the system showed that the height difference between the blocks and the maximum depth a block can reach are mainly the parameters –part of environment’s internal rules- that determine the extent of interaction and its duration. The agents select the direction of their movement, but it is the environment that either allows or prevents this movement that in turn brings about the changes that will occur in it. The bigger the height difference the longer the agents interact with the environment and manipulate it, resulting to more interesting forms.

3.3 Experimenting with vision

So far we have concentrated on the interaction between agents and their environment based on random movement generated by a few simple rules. Considering that our agents represent pedestrians and their movement is based on vision, in this section we present our experimentation with vision and its effect on agents' interaction with the environment.

Taking into consideration Hillier's theory of natural movement [16], we apply agents that decide on which direction to go based on the length of line of sight from their current position. They have the ability to select one out of three possible directions of movement, while their field of view is 170° . Initially, the agents select three different probable directions of movement within this field. They add the lengths of the three lines of sight of each direction and select randomly a number within that range (from 0 to sum). According to that number's fluctuation, the agents take three steps towards  corresponding direction. When the agents come too close to an obstacle or another agent, since they have the ability to see it, they turn rapidly to avoid it and select a different direction of movement.

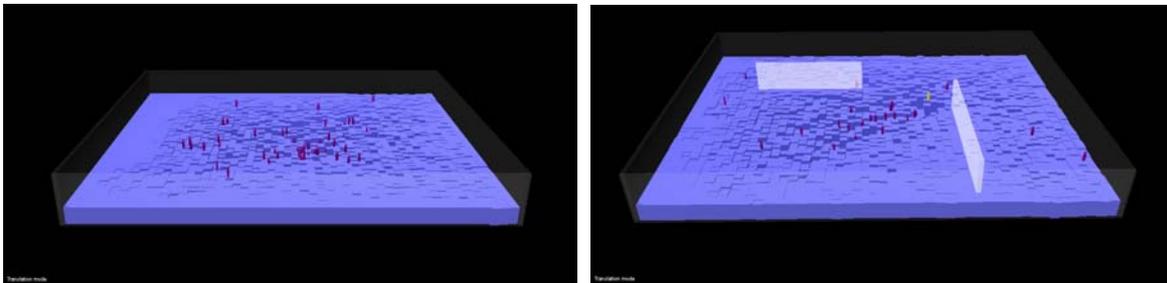


Figure 7: The longest line of sight leads agents to the central part of the environment, while the centrality is determined by configuration and availability of free space.

The agents with vision mainly move in central areas of the environment and interact with that particular part of it, because this is where the longest line of sight leads them. The centrality of an area in the environment is determined by configuration and availability of free space. For instance, if there are no obstacles in the environment, all agents concentrate exactly in the middle of the environment, while in a model with two internal walls they concentrate on the centre of the area demarcated by those two obstacles. This observation is supported by figure 7. The agents' constant interaction with the same part of the environment results to the modification of that part, giving rise to a curved form, a whirl that is shown in the following figure.

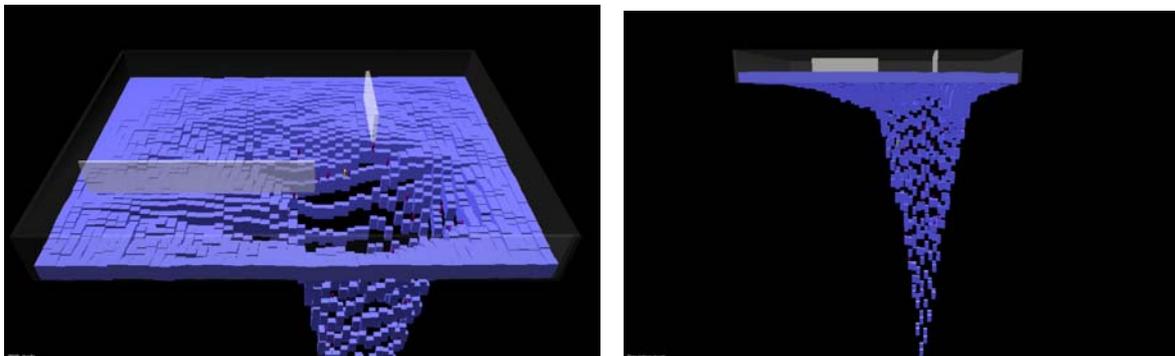


Figure 8: The result of infinite interaction between visual agents and environment.

This experiment indicates that vision and configuration can affect environments' form. Thinking of pedestrians and their actions in combination with configuration, a few questions arise: how would the environments' form be affected if the system were embodied in an actual environment? Can surroundings contribute to form? In order to explore those possibilities, we apply the system in an actual built environment, shown in figure 9. A site, Armada Way, in the city of Plymouth was selected. This choice is due to the fact that the site is at the heart of the commercial city centre and constitutes a junction of pedestrians' movement.

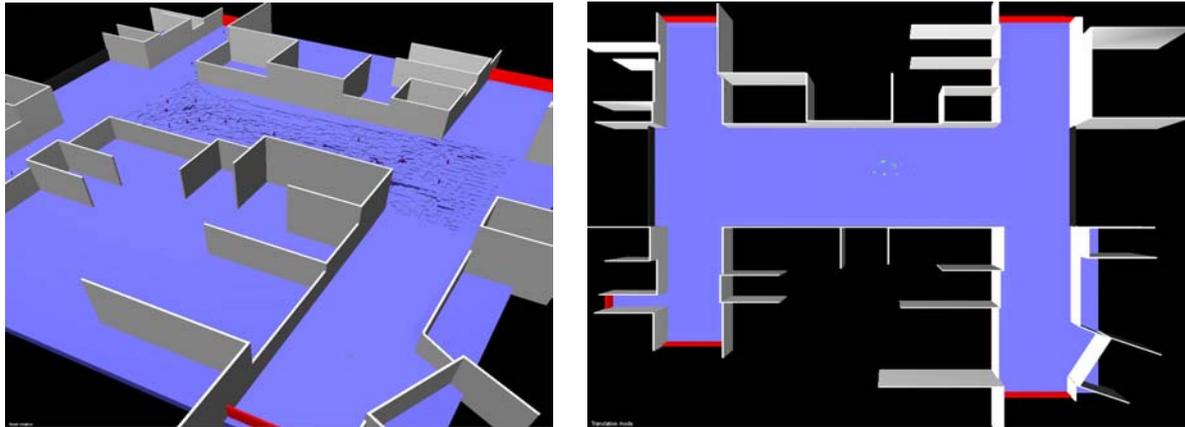


Figure 9: The agent-based system embodied in a real built environment. (a) Initially the grid was covering the whole site. (b) For simplicity, it was decided to limit it to the central rectangular area.

Although initially the agents move throughout the site, they end up in the centre of it and mainly interact with that part of the environment resulting to a conical form. They exhibit behaviour similar to the one in the previous experiment with vision, before the model was applied to the real site. In both cases, the result of this behaviour is a curved, conical shape. Since it is repeated we can talk of a pattern, the whirl pattern.

The system's application to the real site shows that there is an indirect correlation between the surroundings and the environment's form: what the agents can see guides their movement that in turn affects the interaction –since movement is the medium through which interaction is realized in time- resulting to a particular form. That form emerged because of specific conditions and interactions that took place at the particular moment the whole process occurred.

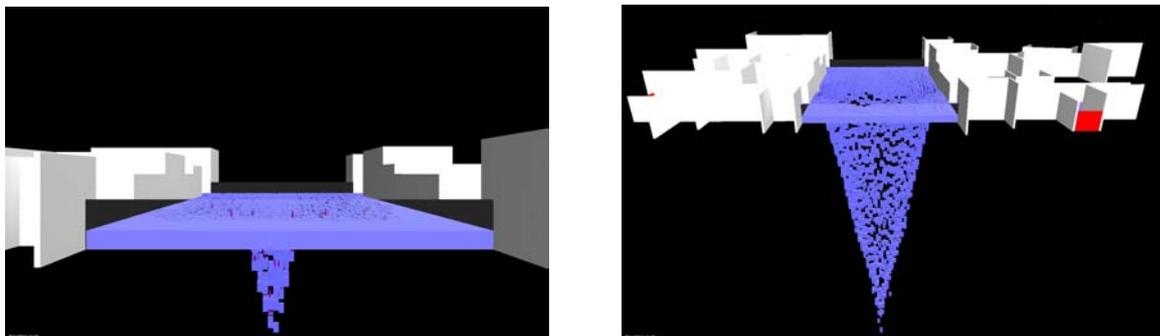


Figure 10: Whirl pattern as the outcome of agents' behaviour based on vision.

4. Conclusions

So far we have concentrated on the interaction between agents –representing pedestrians– and their environment experimenting with parameters that affect that interaction and ignored the subject matter that lies behind. Looking at the process and the outcome from that perspective, we can say that the environment evolves in time through movement. Movement is the external force acting on the environment that constitutes the medium through which the interaction is realized. Referring to the result of that interaction, we could use the landscape metaphor to characterise the environment’s final form. Looking back to the experiments and emerging forms, in most cases despite randomness or diversity in values given to parameters, the result is an evenly shaped form, a uniform landscape using the above metaphor. Taking into consideration Waddington’s epigenetic landscape we should attribute this outcome to local character of interaction. Any change in the environment caused by agents’ movement is not distributed smoothly in the whole surface, but its influence is locally related to a block. A change evenly distributed across the environment would result to an undulating form, as it was indicated by the experiment shown in figure 4. In a way this interaction could still be considered local because changes affect only a part of the environment not the whole, however it indicates the difference in the outcome.

Looking back to the nature of interaction between agents and their environment, we see that because of movement the environment’s shape changes at every point in time: each agent locally modifies the environment giving rise to a particular form, while the other agents respond to the new environment and transform it at a later time. It is an environment that constantly evolves along with its form. As far as agents are concerned there is an indirect interaction between them, indicating that the phenomenon of stigmergy is possible to take place among interactions with human analogy. It becomes obvious that this is a process totally connected to time and cannot be realized otherwise.

Taking into consideration the evolving environment and the changes that occur to it as structural changes lead us to our hypothesis. It has been hypothesised that the recurrent interaction between agents and environment can lead to a structural coupling between those elements. It means that every time a change occurs in each one of them, as an expression of its own structural dynamics, it triggers changes to the other one. Our results so far imply that it is possible for the agent-based system to evolve structural coupling but in its current state we cannot argue that the hypothesis is fully verified. The agents’ movement on the environment brings about the changes that occur on it, but it is the environment’s internal rules that determine the nature and extent of change. Given that the agent-based system has succeeded on that we can speculate that it is possible for the system to be developed to verify its hypothesis, as long as the interactions between agents are developed to result to adaptive behaviour.

In our attempt to explore the interaction between pedestrians and their environment and the implied idea of external forces’ involvement in the generation of form, we followed a process of combining ideas and theories from diverse fields of knowledge: architecture and biology. Considering the process and the outcome along with each field’s contribution, we could say that if biology has something to teach us it is that processes of temporal formation produce organisations of a far higher complexity and sophistication than instantaneous ideas. It provides us mechanisms that explain phenomena, emergent or not, and not a formalised manner of how these phenomena might occur.

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- [15] The agent checks the height difference between the block it is standing on at the time and the block it intends to step onto the next moment. If the height difference is smaller than the given value the agent continues moving towards that direction, otherwise it turns gradually to select another direction of movement that the height difference allows it to follow.

[16] That theory shows that the majority of the human pedestrian movement occurs along lines of sight. It considers the axial line as the guiding mechanism of human pedestrian behaviour. Turner and Penn, op. cit. p.476