**Chapter Eight**

**Title:** The Benefits of Employing Stigmergic Signals in Virtual Platforms to Inform Real World Decision-making.

**Introduction**

Virtual environments are playing an ever-increasing role in helping us understand, navigate, and plan our urban worlds (Pereira et al., 2012). As we are still in the early days of smartphones and web applications, we can anticipate the creation of ever more interfaces that frame the potentialities of urban space through interactions mediated within virtual space. Accordingly, greater attention needs to be paid to the mechanisms through which virtual urban platforms are structured – how one navigates their interfaces, how decision-making is steered and how data is relayed amongst users.

In order to undertake this understanding of the structuring of the virtual, this paper turns to the realm of Complex Adaptive Systems (CAS) theory. CAS provides a framework for analyzing subject domains that involve many actors, complex interactions amongst them, and the emergence of ‘fit’ patterns of action. In many instances of CAS the nature of the actors, their goals, and the resources available to them is initially unknown; yet meaningful coordination nonetheless occurs in the absence of top-down prediction and control.

While there are many ways to center research drawn from CAS, and many ways to discuss virtual platforms, this paper will focus specifically upon the mechanisms that allow flows of information to be exchanged within virtual and CAS systems. In CAS, multiple actors or ‘agents’ operate independently: but with the presence of information these agent actions become constrained, such that energy is distributed in a more ‘fit’ or effective manner Stigmergy - a term used to refer to the ‘marking of action or work’ (Grassé, 1959) – is a key mechanism that enables CAS to relay information and coordinate complex tasks without the benefit of either top-down control or direct agent-to-agent contact, thereby solving the ‘co-ordination paradox’ (Theraulaz and Bonabeau, 1999).

This research argues that virtual interfaces, informed by a more complete understanding
of CAS dynamics - and specifically the functionality of stigmergic signals - can be designed to effectively optimize coordination dynamics, without need for top-down control. The first part of the paper provides a general overview of CAS and its relevance for virtual interface design. The second part considers the role stigmergy plays CAS, in terms of permitting information to be relayed within the system. Part three considers how stigmergy can be conceptualized as a coordination mechanism within group decision-making platforms and proposes a framework for discussing stigmergic coordination within these contexts. Finally, Part Four provides two examples that illustrate how, through a more explicit understanding of both CAS and stigmergy, it is possible to identify, disseminate, filter, and evaluate urban information into subsets, such that relevant patterns for action can emerge to the forefront. The paper concludes with observations and directions for further research.

PART 1. Overview of CAS and bottom-up co-ordination
Complex Adaptive Systems (CAS) theory provides the basis for a growing body of interdisciplinary research into the dynamics of systems. While a full outline of complexity theory lies outside of the scope of this paper, some introductory remarks are necessary to situate the remainder of the study. The interested reader can consult a substantive body of research that pertains to CAS dynamics in a variety of domains, including those specific to urban planning (Batty, 2007; Innes and Booher, 1999; Portugali, 2000).

CAS research was spearheaded initially at the Santa Fe Institute, with early influencers that included John Holland (1992), Stuart Kauffmann (1996) and Murray Gell-Mann (1994). It quickly garnered growing attention in fields as divergent as biology, physics and sociology due, in part, to CAS’s ability to analyze systems that do not obey simple linear chains of cause and effect. Some examples of the range of systems that have been analyzed through the lens of CAS include: trading patterns on the stock market and the emergence of bubbles (Arthur et al., 1997); coordination of ants in a colony and the emergence of trails (Deneubourg et al., 1990); and academic citation patterns and the emergence of ‘highly cited’ papers (Barabási, 1999).

While the systems differ, in each case the underlying dynamics engage similar processes. The systems are complex in that they are subject to non-linear feedback loops (where small scale changes to initial conditions can lead to large scale changes in
outcomes); they are *adaptive* in that they can shift over time to adopt more ‘fit’ behaviors; and they are *systems*, in that they are comprised of a wide variety of agents where the relations between the agents are of primary importance in structuring the behavioral dynamics of the system. Finally, CAS exhibit *emergent* properties. These properties are neither predictable nor self-evident, yet, they nonetheless exhibit pattern, functionality and structure (Holland, 1996; Kauffman, 1993).

Complex systems involve *resources*, *agent* and *connections* between these agents (Holland, 1996). *Resources* are the source of energy that drives the system. This energy can take many forms: it can be a currency, a food source, or an idea source (to list but a few examples). *Agents* are considered the ‘base unit’ through which this energy is steered (be it ants, stocks or academic papers). Agents become *connected* to one another through information transfers between them (such as through pheromone trails, stock prices, or citation links) such that productive protocols can be reinforced through positive feedback loops.

These feedback loops steer evolutionary outcomes that gradually determine the system’s overall global structure. This global structure may include ‘emergent’ outcomes: patterns or protocols that evolve out of the bottom-up interactions of many agents. These emergent patterns highlight and operationalize ‘fit’ dynamics (trails to food, valued companies, helpful articles). Thus, the system is able to ‘learn’: altering behaviors such that the system gravitates towards regimes that optimize energy use and minimize energy waste. This creation of ‘order’ from chaos would seem to exist in violation of the second law of thermodynamics. But order is nonetheless achieved, in part due to the fact that these systems have dissipative boundaries: allowing for inputs of energy that drive agent interaction, which in turn tend towards regimes that optimize fitness (Prigogine and Stengers, 1984).

‘Fitness’ in CAS is seen as a measure of how well the system is able to extract value from its overall capacity. CAS are not only effective at ‘discovering’ fit regimes, but also at partitioning actors and resources into groupings or ‘clusters’ that serve divergent needs. These clusters of ‘fit’ but divergent protocols can be conceptualized within a ‘fitness landscape’ (Kauffman and Johnsen, 1991; Pigliucci, 2008), that illustrates how various ‘states’ within a potential system are more viable then others. Agents exploring
state behaviors will attempt to gravitate towards fit positions or ‘peaks’ within this landscape. One can consider these peaks as analogous to ‘niches’ that can be exploited by different kinds of species, allowing differentiation of behaviors. The ‘phase space’ of the system includes all possible states, but the peaks and valleys of the fitness landscape - which is gradually ‘explored’ by agents - is conceptualized as the differential states or clusters that are more (or less) productive. As agents modify their behaviors and receive feedback, an iterative cycle ensues: this drives agents towards peaks within the landscape, such that the system is able to ‘learn’.

While there is no ‘definitive’ consensus of what constitutes a CAS system, a literature review of key definitions establishes that certain system aspects are repeatedly mentioned (see Wohl, forthcoming). These aspects point to CAS being:

- adaptive, evolutionary, and rule-based
- comprised of a diversity of agents
- described by scale free/nested mathematical hierarchies
- characterized by self-organizing and fit emergent features.
- subject to non-linear, far from equilibrium and historical processes,
- organized through flows and interactions (information),

CAS dynamics have been invoked to study a broad spectrum of urban issues - including agent based models that lead to emergent outcomes; studies into the fractal properties of urban forms and networks; and social theory that employs emergence and historically contingent assemblage theory. Each of these CAS aspects is important, but different research domains tend to center attention upon only a few themes in particular. Thus, while both computational and assemblage geographers draw from CAS theories, the former tends to focus upon the nature of ‘rules’ and the emergence of scale free hierarchies\(^\text{ii}\) (Batty, 2007) whereas the later focuses upon the non-linear and contingent processes that prompt emergent outcomes (Dittmer, 2014). Similarly, both Evolutionary Economic Geographers and Communicative Planners focus upon agent traits of CAS, but the former considers agency at the firms level (Boschma and Martin, 2010), whereas the latter focuses upon agency at the individual stakeholder level (Inness and Booher, 1999).

There is, however, a lack of research that examines how information flows are
operationalized in CAS in the absence of top-down control. This area has remained largely under-theorized in most urban and planning studies that introduce CAS. Yet such an understanding is critical: in order for CAS to learn there must be mechanisms through which information can be transmitted between agents. In some instances, this information transmission occurs directly, but in many instances (and in virtual context) agents may be part of the same system but nonetheless act independently with no direct contact between one another.

**Part Two: Stigmergy as the mechanism for organizing information flows in CAS**

Stigmergic coordination - from the Greek meaning ‘stigma’ (to mark or puncture) and ‘ergon’ (action,) - provides a mechanism through which information can be relayed within self-organizing systems. Stigmergy is the process whereby an agent in a system leaves a *trace* of its action within an intermediate medium that is shared by all agents. These traces act as *information*: differentiating the medium and directing or attracting agents to particular courses of action - which further differentiates the medium – and generates feedback cycles. This information content can take an array of forms, such as pheromone traces, stock prices, or number of academic citations. Agents both emit information signals *and* adjust their behaviors in accordance with the information they encounter.

An example of this is the indirect coordination of termites building a mound. Here, termites have neither the capacity to communicate directly with one another, nor any control structure to manage behaviors. Instead, each termite interacts with a ‘common medium’: in this case the mud deposits that have become activated with pheromones that are present in the termite saliva used to form the mound. The variations in these pheromone deposits ‘carry’ traces of prior termite activity, resulting in the fact that, as subsequent termites interact with the mud, particular actions are triggered in accordance with the nature of the trace encountered (Bonabeau et al., 1998). The medium carrying these traces serves as a form of ‘memory’ for the system as a whole - even when individual actors are no longer present to interact and convey experience.

Stigmergic coordination can be *quantitative or qualitative*. In examples of *qualitative* stigmergy, signals are ‘customized’ so as to record a specific range of actions. Here, *different* actions can be marked and serve as prompts *depending upon the unique*
nature of the trace that is left behind. In some cases an agent will be ‘primed’ to react only to specific traces. In the case of termite mounds, the signal differentiations of mud traces serve to allocate differentiated tasks – the building of walls, pillars, and royal chambers (Bonabeau et al., 1998, 2000).

Signals can also be reinforced by agents in a process referred to as quantitative stigmergy (Theraulaz and Bonabeau, 1999). Here, cumulative traces produced by many agents emit a stronger ‘prompt’ to steer behavior versus weaker emissions. Thus, an individual ant can leave a pheromone trail, but as other ants follow this trail, its scent grows stronger, attracting more ants. Quantitative stigmergic signals are either reinforced if they continue to signal effective work, or decay if they are no longer relevant.

The manner in which stigmergic signals are registered can either be ‘marker-based’ or ‘sematectonic’ (Heylighen, 2015a; Parunak, 2005). Sematectonic traces are created as part of the action or ‘work’ itself. In the example of termite building, the mud formations are both signal and work. Another example is that of the paths formed when treading over a grassy field. As subsequent walkers retrace paths that are useful, a trail emerges. Here, the crushing of grass occurs during the act or work itself (of walking) leaving a trace that is then reinforced or decays over time. Similarly, in virtual environments an action itself (buying a book on Amazon), can be recorded as a trace that steers other buyers (by generating recommendations). Alternately, in the case of marker-based stigmergy the trace is not a direct consequence of the work performed. Instead the trace is produced as an intentional act, as when ants deploy pheromones. Again, if we consider virtual platforms, users actively rating content (providing ‘stars’ or ‘thumbs up’), provides a signal to other users but the action in this case is separate from the ‘work’ of using that particular content.

**Figure 1: Kinds of Stigmergy**

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Characteristic</th>
<th>Biological Context</th>
<th>Urban Context</th>
<th>Virtual Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantitative</td>
<td>Weighted by multiple actors</td>
<td>Ants deploying pheromone trails</td>
<td>People walking across a grassy field</td>
<td>Many users rate a service</td>
</tr>
<tr>
<td>Qualitative</td>
<td>Differentiated into different aspects</td>
<td>Variations in kinds of pheromone emitted (designating different building tasks)</td>
<td>Different stores ‘signal’ what resources they offer with window displays that differentiate their niche markets(^iv)</td>
<td>Ratings designate categories or parameters; (price, cleanliness, etc.)</td>
</tr>
<tr>
<td>Sema-</td>
<td>Created as part</td>
<td>Mud deposits are</td>
<td>The act of walking across</td>
<td>Book purchased</td>
</tr>
</tbody>
</table>
Part 3: Engaging Stigmegy in the design of Virtual Urban Platforms

Whether it be the need for a pedestrian crossing, the addition of a daycare, or the desire for a neighborhood grocery store, individuals have knowledge and insights regarding particular civic resources and amenities. Many planners are interested in bringing these insights together, harnessing collective ideas to envision future urban scenarios. In recent years, a number of virtual platforms have been developed to do just that: amass public visions about the city from a broad range of stakeholders. Consultation platforms like ‘NextHamburg’ or Future Melbourne, solicit ideas from the public regarding the future of areas targeted for improvements (see Bier and Ku, 2013; Pereira et al., 2012). Other 3D interfaces, like ‘VirtuoCity Rotterdam’ (http://rotterdam.virtuocity.eu/home) or “Participatory Chinatown” (http://www.participatorychinatown.org), provide intuitive and interactive ways of visualizing future development, where participants role-play in an immersive 3D environment and their reactions to proposed developments are gathered. These kinds of platforms are gaining widespread interest because they go beyond the capacity of traditional community consultation processes, and can bring many voices and ideas together even when these are not co-located spatially or temporally.

However, in the vast majority of these platforms, the control over final decision-making ultimately relies upon top-down control. In the first examples ideas are solicited but decision-makers ultimately determine which ideas should be incorporated. In the 3D platforms, participants walk through an already established idea and then provide input. Thus, while there are a growing number of virtual participatory platforms that solicit citizen opinions about urban projects, for the most part, when citizen voices have been engaged, the data generated is analyzed and parsed from the top-down.

However, there are alternatives. If stigmergic processes were to be harnessed as a coordination device, then platforms could be developed that not only gather citizen
generated data, but also sort, prioritize and refine this data from the bottom up. Drawing inspiration from platforms that successfully crowd-source solutions (Wikipedia and Airbnb being two such examples) participatory sites could potentially use stigmergy to coordinate decision-making, in the absence of top-down control.

A growing body of research is considering such ways in which stigmergy can play this role in coordinating human activities. Francis Heylighen argues that stigmergy provides a ‘universal coordination mechanism’, enabling “complex, coordinated activity without any need for planning, control, communication, simultaneous presence, or even mutual awareness.” (2015a: 1). He identifies stigmergic processes as involving agents, actions, medium, traces, and coordination. While each of these aspects of stigmergy can be very straightforward, they nonetheless enable sophisticated coordination of complex tasks to occur without need of centralized control.

Further elaborations on the role of stigmergy have surfaced in domains as diverse as collaborative software development (Bolici et al., 2010), military coordination (Parunak, 2005), and distributed social condition (Susi and Ziemke, 2001). In this latter field, stigmergy is examined to determine the role ‘coordinating artifacts’ can play as social ‘mediators’. Here, three components, ‘agents, environments and artifacts’ are needed in order for coordination to occur (Susi and Ziemke, 2001). Dron and Anderson, (2009), in considering the development of educational software, argue that stigmergy should be considered as a foundation for applications “that employ the aggregated behaviours of individuals in a crowd to shape their environment and to provide structure and influence in that environment”. They suggest that data processing occurs in five layers, built into three cyclic phases: information gathering (selecting and capturing), information processing (aggregating and processing) and information presenting (displaying). Pertaining more specifically to virtual interfaces, Dipple et al. (2011; 2012) discuss how stigmergy helps enable collaborative knowledge generation by providing an ability to ‘sense, evaluate and actuate’ within shared virtual environments. Likewise, Zamfirescu and Filip (2010) discuss the role that stigmergy plays in Group Decision-making Platforms (GDPs) arguing that stigmergy is particularly useful in dealing with issues that are “dynamic, open and uncertain”.

While these sources concur that stigmergic mechanisms are critical for coordination,
there is a lack of consensus regarding a common framework with which to discuss these mechanisms. Dron and Anderson (2014) are perhaps the most explicit, providing numerous examples of their gathering/processing/presenting cycle, but within these examples there remain inconsistencies and ambiguities between various system aspects: such as differentiating between

Heylighen’s framework also presents ambiguities, given that certain of his key processes - agents, actions, medium, traces – can be considered mechanisms for stigmergy, while others – coordination - would seem to be outcomes of stigmergy.

In the absence of any consistent and agreed upon framework for discussing stigmergic coordination, this article proposes the following five mechanisms to portray the dynamics of stigmergic processes as they steer evolution within virtual space. These include: TAGGING (differentiating both agent attributes and evaluation criteria for those attributes); FILTERING (determining which evaluation criteria are meaningful, and which range of attributes are significant); EVALUATING (assigning ‘credit’ to attributes that respond to fitness criteria and to fitness criteria that matter); RANKING (aggregating independently sourced credits to foreground emergent patterns of fit protocols) and ITERATING (repeating this process in order to allow agents to mutate towards more refined or ‘fit’ configurations) [see figure 1]. Whether discussing urban participatory platforms or other virtual interfaces that employ crowd-sourcing dynamics (kickstarter, airbnb, etc.), this system is proposed as a generic framework with which to discuss stigmergic dynamics within crowd-sourced environments.

**Figure 2: Stigmergic Mechanisms:**

**Part 4: Illustrative Examples**
Turning specifically to applications within the urban context, this next section considers two illustrative examples of how such platforms could operate. Each is depicted with specific sites in mind, but both have been conceptualized much more broadly, geared to be suitable in any context. The first, example “Tempelhof 2020”, was conceived in 2015 as part of an academic exercise produced by one of the author’s graduate students. This ‘thought experiment’ proposed the design of a digital platform that would employ principles of CAS to engage bottom-up design decision-making. Tempelhof was envisioned as a virtual platform explicitly conceived so as to incorporate CAS and stigmergic mechanisms. The platform would enable distributed users to discover optimal synergies and groupings of distinct urban features in the absence of face-to-face contact, deliberative consensus, or top-down control. The Tempelhof site (originally a central airfield in Berlin, closed in 2008) was a particularly germane site for this exploration, as it has been ‘appropriated’ by the citizens of Berlin, who have resisted any sort of top-down control over the site’s long-term development (Burgess, 2014). The second, example, “Wikitecture”, was developed as part of a 2007 competition submission prepared by the author and her colleagues for Europan 9. The submission for a development site in The Netherlands, vii proposed the creation of a ‘Wikipedia-type’ interface that would allow planning and design decisions about the site to be managed almost in their entirety from the bottom-up.

In both proposed interfaces, users are invited to suggest ideas for a site, and propose evaluation metrics for those ideas (both their own and other’s). Here, both the proposed solutions, and the evaluation parameters for the solutions are ‘refined’ through an iterative process, ‘evolving’ as the result of feedback that harnesses ‘the wisdom of crowds’ (Surowiecki, 2005). The state of the solution at any given moment in time is visualized within the interface (see figure 3), and individuals are encouraged to modify this solution space by adding input or information signals. The prominence of various ideas is gradually filtered through the use of crowd-sourced parameters, as well as according to surveys (in the Tempelhofer example) or discussion forums (in the Wikitecture example). Both platforms have mechanisms to encourage greater participation in the forum (thereby adding information fidelity). In Tempelhof ‘points’ or ‘credits’ are assigned to users who bring in more users, whereas in Wikitecture there is a group of ‘trusted contributors’ (those who gain crowd-sourced credits) and ‘site stewards’, the latter whom are responsible for promoting site use, and encouraging both layman and expert
The Tempelhof platform aims to create general planning consensus in terms of project types and locations. Wikitecture, by contrast, is more ambitious in terms of aiming to achieve full designs. In Wikitecture, users are encouraged to upload design ideas into the virtual platform and then debate the merits of various ideas in discussion forums. Simultaneously, various quantitative aspects of the solutions (square footage, parking spaces, etc.) are automatically tracked with monitoring tools so as to provide comparative data. The operating platform is partitioned into nested hierarchies, such that both experts and amateurs can participate in the creation of solutions, and ‘stubs’ can be created to mark where more input is required.

Both platforms ‘learn’ from the bottom-up. Tempelhof largely relies upon marker-based stigmergy, as users ‘rate’ various inputs, (similar to Airbnb) whereas Wikitecture, proposes a more sema-tectonic stigmergic environment, (similar to Wikipedia), where the ‘work’ of modifying solutions within a shared platform creates implicit consensus around an issue. Site stewards also occasionally intervene, but their role is minimized so as to maintain overall bottom-up steering of solutions. Both platforms, and their relationship to the framework above, are outlined in what follows.

1. Tagging
In both Tempelhof and Wikitecture, users are prompted to propose both design ideas - or ‘resources’ that might be built - and evaluation parameters for these ideas. Users can propose amenities such as shops, schools, fitness centers, transportation hubs, green energy initiatives, etc. But unlike in typical participatory platforms, the individual projects proposals within Wikitecture and Tempelhof, are not simply seen as ‘data’ to be parsed and evaluated from the top down. Instead, each proposal is considered as an ‘agent’ within the complex system. These agents, in turn, seek to ‘survive’ through a competitive process with other agents: gathering energy or “approval” ratings from users (their form of ‘food’). So the proposal ‘local market’, is an agent, ‘seeking’ energy and approval from stakeholders interacting within the virtual platform; an empty land parcel is also an agent ‘seeking’ a function or idea (such as a school), that best utilizes its particular locative dynamics.
Concurrently, in both Wikitecture and Tempelhof, users have the capacity to determine criteria with which a project will be evaluated. Users propose parameters that they deem to be relevant for evaluating a project’s ‘fitness’. These parameters act as another kind of agent within the system, also competing with one another for relevancy. So the evaluation parameter ‘provides ample green space’, might compete with the parameter ‘provides ample parking’ for approval. Once again, fitness parameters gather ratings and try to ‘outperform’ one another. In this way ‘niches’ are established.

Operationalizing this classification and differentiation of both agents and evaluation parameters is accomplished through the mechanism of ‘tagging’. Tags - also referred to as stubs, traits, facets, building blocks or set attributes – are the “labels, banners, or identifiers” (Holland, 1993) that assist in coordinating interactions amongst CAS components. Tag ‘clouds’ permit similar attributes or ideas to cluster and then be considered as a group. Tags offer a dynamic way of classifying information without relying upon static and hierarchical taxonomies. In most traditional classification systems, when the medium for carrying this information is static – such as in a library, data table, or printed book - taxonomies are necessary for sorting information. But this requirement for hierarchical taxonomies is removed within virtual platforms, where there is a capacity to dynamically sort and resort information according to flexible groupings of attributes. This flexibility allows individuals to customize attributes to suit their needs. Thus, “everyone can tag (his or whoever’s content) and the tags are also chosen personally and not from a pre-defined set of values” (Levy, 2009).

Tags are used not only to differentiate design ideas, but also to differentiate the various attributes of these ideas. So the general tag ‘housing proposal’ might have various attributes: ‘single family’, ‘located near a view’, ‘low income’, ‘mid-rise’, etc. These attributes are suggested by users and, similar to the projects themselves, compete for approval according to how strongly their import is rated.

There are no restrictions placed on the number of tags/agents generated within either Wikitecture or Tempelhof. Rather, the greater the variety of tags the more options can be explored within the virtual environment. Unpopular tags will simply fade to the background. Tags can be considered as a marker-based, qualitative signal, left within
the virtual environment that the various users encounter. The initial marker helps coordinate subsequent user activity

**Figure 3: Wikitecture Interface showing Tags (stubs)**

Illustration of a sample user interface screen in ‘Wikitecture’. Users are able to add fitness parameters, modify proposals, enter into a discussion forum, track recent changes, add monitoring tools, and propose new projects to be explored (Tags or Stubs). Users can also add fitness parameters. Various quantifiable statistical properties of the solutions proposed (square footage, program distribution, green space, parking spots, etc.) are continuously auto-updated using algorithms. However, these monitoring devices are there for information purposes only, and do not impart value upon any given solution. Site stewards manage (but don’t control) the site - tagging areas that are of priority or that require particular expertise (as in Wikipedia).

2. Filtering

While many tags can be created, not all tags are relevant. Filtering determines which of the various tagged parameters and solution attributes provide meaningful *information* about fitness. Users rate the relevance of tagged attributes that, in turn, establishes the kinds of attributes that are relevant in determining agent ‘fitness’. Similar to web sites that filter results for searches according to multiple parameters (airbnb will rank findings based upon price, location, cleanliness, etc.), users can individually rate the relative import of these criteria as they see fit. This filtering occurs through *marker-based, quantitative stigmergic* processes: a variety of distinct parameters and attributes may be meaningful, but the extent to which they are meaningful depends, quantitatively, upon how many users attribute ‘fitness’ to these tags. The relative import of various evaluation
criteria is aggregated based upon individual user input or ‘ratings’ of criteria merit. In both platforms, only those agents that successfully target those fitness criteria deemed to be most relevant through the filters will have a chance to ‘survive’ through generations of design iterations. In Tempelhof fitness criteria largely pertain to locational, functional, and scale attributes, whereas in Wikitecture multiple, divergent criteria can be proposed, including those that are aesthetic.

In Tempelhof, determining viable attributes for design solutions is operationalized through the use of parameter bars. Parameters might pertain to the sizes of things, or their relative distances between amenities, etc. Users are surveyed to determine personal viable thresholds for various solution attributes, such as: “how far are you willing to travel from your home to get to X?”; “how close does it need to be to function Y?”; or “how many times per week would you expect to visit?”. If citizens favor a new school and are all willing to drive up to fifteen minutes to get there, the acceptable threshold for location would situate the school's potential sites. These actionable ranges are not individually determined, but are crowd-sourced. So, the resource ‘housing development’, might be deemed to hold an actionable scale of ‘50 to 100 units’. Through a combination of rating the relative import of the various proposed attributes, and those deemed to hold actionable attributes impractical design solutions can be filtered out of the system (see Figure 4).

In Wikitecture, determining viable attributes is achieved through fitness parameter bars, discussion forums, and a series of ‘monitoring tools’ that track whether or not solutions are responding to various fitness criteria. Some of these monitoring tools track non-subjective quantitative data attributes and are pre-embedded in the system, whereas others are user submitted. However, in all cases the relative import of various monitoring tools vis-a-vis particular design solutions is crowd-sourced.

The ability to tag new traits over time (by creating either parameter bars, monitoring tools, or discussion posts on a design topic), and to modify actionable thresholds for a particular criteria, mean that the choice of these most salient traits can constantly be refined according to user needs. At the same time, variants in traits might form quite distinct niches. So, a food market might exist on different sites within the development
but cater to different users, offering different stocks of foods. Distinct niches can therefore emerge within the fitness landscape.

Figure 4. Example user interface across platforms: Actionable parameters are established (Image by Jeff Givens).

3. Evaluating:
As new tags for urban offerings are proposed they gain credits, depending upon how effectively a proposal fulfils the tagged parameter or attribute. Similar to the way an Airbnb offering can receive many stars for cleanliness but few stars for location, a project can be highly credited for beauty, but receive few credits for cost-effectiveness. These credits provide a marker-based stigmergic signal: a ‘thumbs up’ that can be likened to a strong pheromone trail. Users independently determine how many credits to award each proposal and each evaluation metric. This is important, in order to avoid situations where users are steered to award credits based upon previous input: if users are somewhat ‘blind’ to previous user decisions, the system as a whole is more likely to ‘discover’ a broad range of fit clusters of agent attributes (Surowiecki, 2005). Regardless of format (thumbs up, stars, ranks on a scales of 1 – 10, etc.) independently sourced ratings provide a performance indicator of a particular product, action, agent, tag, or parameter. Supplying high ratings can be likened to ‘feeding’ a particular attribute or parameter with energy that helps ensure its survival.

In Wikitecture the merits of various schemes are also inferred through sema-tectonic means. Projects that attract attention, modification, and discussion by users are
displayed more prominently within the interface. Ideas that fail to gain traction become dormant and fade to the background. This is similar to Wikipedia, where users may propose 'stubs' for articles, but if these stubs are not deemed to be of sufficient interest, they tend to remain unfilled. However, as in Wikipedia, Wikitecture does provide mechanisms whereby the both project stewards and individual contributors who have gained ‘trusted’ ratings can use editorial discretion to ‘flag’ projects that are deemed critical (marker-based stigmergy). While this implies some top-down control, this is minimized particularly when those granted ‘editorial discretion’ are iteratively selected from the bottom-up as they gain ‘trust’ for previous performance.

4. Ranking:
The reliability of individual evaluations gains \textit{quantitative} depth when corroborated repeatedly by other agents. This is similar to the formation of ant trails in a colony: viable pathways emerge due to the overlaying of pheromone signals on pathways that lead to reliable food sources. Overall \textit{rankings} of parameters and attributes are the outcome of an \textit{aggregate} of evaluations, which summarizes top ranked traits or tags. There are also some traits where rankings can automatically be generated without need for agent input, provided that the categories of performance are non-subjective. The ‘price’ of an offering or resource is one such example of a ‘non-subjective’ performance parameter that remains stable irrespective of quantitative depth.

Rankings direct our attention and provide a hierarchy for the information that is available in a peer-to-peer platform. In both Tempelhof and Wikitecture, independently sourced evaluations are aggregated such that each of the proposed ideas is conceived as an individual attractor point, gaining strength in accordance with the amount of support it garners (quantitative stigmergy). Once the relevant fitness criteria have been filtered, those agents that are associated with gaining credits from those parameters that are strongly weighted are visualized to appear at the top of a ranking list. These agents are seen as ‘thriving’ within the fitness landscape.

The difference between platforms like airbnb and Tempelhof/ Wikitecture, is that highly ranked results for an airbnb search will be based upon fitness criteria that are \textit{personally considered} important: an individual may only wish to consider accommodation in particular neighborhoods, or only places that permit pets. In both Tempelhof/Wikitecture
it is instead the aggregate output of crowd-sourced fitness criteria that determines the fitness of any proposed project or project attribute.

Many virtual environments assign a dominantly ranked offering to a position of higher visibility with the web platform. Most commonly this is manifested as the positioning of an offering at the top of a list. Thus, when a restaurant receives a variety of evaluations, these are then categorized into ranked lists according to attribute tags: price, location, quality, etc. The ‘top’ items on the list are the ones users ‘sense’ most strongly in the virtual environment. Other options are possible, such as relative size (used on the ‘TED Talks site’ to communicate relative popularity, for example). This reinforced ‘information scent’ of tags helps steer navigation within virtual contexts (Cress et al., 2013). Strong weightings result in a tag emitting a stronger stigmergic signal: suggesting fitness and drawing further attention in a reinforcing feedback loop (Barabási, 1999).

In Tempelhof, ranking is operationalized through algorithms that survey rankings of attributes, then automatically generate a ‘fitness landscape’ to visualize this differentiated terrain of weighted possibilities. Here, ‘peaks’ in the landscape indicate project proposals that have been deemed as high-functioning. Unpopular and unsupported ideas fade into obscurity as favored options gain dominance within the fitness landscape. It is anticipated that the levels of support for various kinds of ideas will follow the dynamics of power law distributions. Multiple ideas will co-exist as unique niches within the solution terrain. The location of these potential niches is assessed according to parameter attributes of the various proposals – a certain threshold range of functional terrains is determined for each of the project ideas. The virtual fitness landscape of design ideas is thereby overlaid upon the physical landscape of the site, shifting and evolving over time as ideas are added, parameters are refined, and evaluation ratings are tallied (see Figures 5+6).

In Wikitecture, the fitness landscape is not auto-generated, but instead evolves iteratively as users modify the visualization terrain of the project. Much like a Wikipedia article that changes in real time, but is still the subject of discussion, changes to the visualization can be accepted or rejected by users based upon how the system state at any given moment responds to the various monitoring and fitness criteria. Managing this assessment occurs within discussion forums and is assisted by the monitoring tools that
have been flagged by ‘trusted contributors’ (who are also rated) as being important for the project under discussion.

Both instances parallel how the senses operate in the biological realm – where the pheromone trails that are the strongest attract the attention of the greatest number of agents. This does not mean that all agents will follow the same pathways: CAS become less effective if agents do not maintain the capacity to explore multiple trajectories. On occasion, perturbations may be introduced into CAS in order to shake it out of entrenched patterns of behavior that have become overly reinforced (‘lock-in’) such that new options can be explored. In the case of Wikitectecture, site stewards can potentially introduce such perturbations. However, to a large extent lock-in is avoided by encouraging a broad range of participation to continually add input to the process. Thus, in sites like Airbnb, where new offerings are continuously uploaded, new ‘fit’ patterns can emerge.

Figure 5: Fitness Landscape showing emergent configuration for various projects: the height of the peak pertains to how strongly both project idea and location are ranked; Figure 6. Possible locations of citizen-proposed projects, based on feedback: The range of locations pertains to threshold limits: Image by Jeff Givens.
5. Iterating:
In both Wikitecture and Tempelhof, neither the proposals themselves nor the fitness parameters remain static. Each ‘evolve’ over time, according to the modifications generated by multiple iterations of users. While a given user might initially propose a loosely defined urban agent, they, or subsequent users, can then go on to modify or mutate that agent such that it attracts more support or approval. These mutations will be informed by feedback signals provided in the environment: the awareness of which parameters are, at any given moment, considered as most viable or relevant. In this case the virtual urban agent is co-mingled with a human agent that is advocating for and enhancing its ‘survival’ capacity.

Concurrently, the fitness parameters themselves also go through stages of evolution. As more users enter the system and observe the ‘state of the visualization’ they can make critical adjustments. The collective refinements generated by this kind of input/output feedback cycle operate whether the system is being driven by many individuals, or simply by one individual repeatedly interacting with the system. An example of this is the Internet radio station Pandora, where a user initially loosely ‘seeds’ a station with particular artists whose music they enjoy (thereby defining a list of general traits that they consider consistent with their listening tastes). But then as they hear specific music
associated with the artists they can provide ‘thumbs up’ or thumbs down’, gradually filtering out music ‘solutions’ that are do not operate within the thresholds of their preferences.

It should be noted that the solutions produced are highly contingent and, like any complex system, subject to non-linear historical bifurcations: a particular project located at a given site may, due to random fluctuations, gain a slight advantage over another equally viable option. Due to the dynamics of reinforcing feedback, this will eventually become the ‘preferred’ outcome. Thus, the complex system does not converge towards a singular ‘perfect’ outcome, but has the potential to diverge into multiple trajectories, each of which are viable ‘satisficing’ solutions.

In both Wikitecture and Tempelhof, the fitness of the final solutions relies upon the quality and diversity of the ‘creative fuel’ driving the system. This fuel is in the form of the collective creativity of the users. Without engaged, ambitious, and creative users, the system will not have the input energy it requires to drive the best outcomes. The platform would prove no more useful in engaging the public than a town hall style meeting, where few voices (and often only the loudest) are heard. Thus, incentivizing participation is key. Both platforms have mechanisms to incentivize participation, such as offering ‘bonus’ votes to users who refer others to sign up, or for those who consistently propose high ranked solutions - thereby garnering trust (through sematectonic signals). These users will gain ‘credit’ within the system – more input or voting. There is therefore an incentive to propose high quality ideas in order to garner more influence within the system. Stewards within Wikitecture might encourage contractors or suppliers to contribute, hoping that these will ultimately receive financial gain by contributing to the knowledge base.

Ultimately the goal of these, or other, incentives are to increase the amount of input from the user population, thereby enhancing the number of iterations or mutations that can be generated within the platform. This speeds evolutionary outcomes, and is expected to correlate with higher degrees of fitness amongst the favored project proposals. Again, this parallels the way ant trails are formed. As more ants respond to the signal of the path, they in turn leave their own signal, reinforcing the signal strength. Through this cycling of iterations: input -> output -> input the system is able to learn without top down
control. Both parameter traits and agent attributes learn as they are modified by increasing numbers of iterations, enhancing both the qualitative and quantitative depth of the stigmergic signals – and, in the turn, the number of viable outcomes. The signals are refined - differentiated, clustered, classified - and prioritized, such that information - in the form of useful actions - is extracted from the platform: places to go, services to use, ideas to develop.

Discussion/Conclusion:

“ The Internet can play the role of a highly intelligent mediator, which coordinates all the actions needed to tackle challenges, in such a way that problems are resolved and opportunities are exploited in the most efficient manner… This avoids such sources of friction as queries that do not find an answer, offers that are not taken up because no one knows about them, effort needlessly spent in searching for things that are readily available, poor matches where what you get is not really what you want and pointless delays where agents suffer while waiting for something that has not yet reached them.” (Heylighen, 2015b: 8)

While many virtual urban platforms do, in fact, incorporate stigmergic, aspects within their contexts, to date this has not been theorized in an explicit manner, nor has any relationship to CAS dynamics been highlighted. Thus, while complexity is increasingly brought to bear in planning discussions, the means through which learning occurs is often buried within agent-based rules, or within discussions about collaborative outcomes (which are perhaps more about consensus then self-organization). This lack of explicit understanding means that stigmergic aspects that could otherwise be operationalized to spur learning are instead deployed in a haphazard manner. As a result, at some point expert input is required in order to ‘manage’ the outcomes.

CAS mechanisms – and stigmergic processes in particular – provide an alternative. Here, differentiated, corroborated and iterated stigmergic markings replace the need for established hierarchies or pre-determined ideas, allowing the system to learn in the absence of top-down control. While the Internet allows many users to upload content, and to easily search through that content, stigmergy provides a means to sort, filter, and learn which content matters. It is this capacity for stigmergy to organize information content that allows the virtual phase space of limitless possibilities to be shaped into a highly differentiated landscape of fit niches.
Today, there is a growing awareness that planning issues are too complex to be tackled by single visions. As such, there is a sustained effort to involve the public to a greater extent in decision-making. But this is difficult. Individuals have varying levels of expertise, time, and commitment. In the context of assigning ratings to various ideas and parameters, individuals need not take the time and cognitive effort to consider the needs of others: in fact the system as a whole performs better if they simply rate attributes according to their personal preferences, and then allow the stigmergic sign they leave to either be corroborated or decay. In the platforms outlined, information never dies: stigmergic ‘marks’ remain in place long after contributors have left the forum, always present to be discovered, to emerge to the forefront through feedback mechanisms. How different is this from traditional consultation meetings, where a quietly uttered small insight is lost in the shuffle as a contentious issue takes the floor, and where negotiations between bottom-up actors places a huge cognitive demand on participants? By contrast, participatory virtual platforms informed by stigmergic processes “lower the ‘costs’ of contribution by reducing the need to become acquainted with other participants and to maintain relationships and negotiate contributions with them as they are made” … “This streamlines the creative process, freeing up time and energy that participants would otherwise use in negotiation” (Elliott, 2016).

The examples presented in this paper are thought experiments only. While the projects illustrate what bottom-up participatory platforms might look like, more critically they attempt to formulate how they need to be conceptualized: with mechanisms that allow for signals to be introduced (tagged), filtered, rated, evaluated, and then reiterated such that the evolving network would learn. Here CAS principles of evolution, mutations, and feedback are critical components of the process. It is stigmergy that supplies the information to drive this evolution: both of the design agents themselves and the performative criteria they must fulfill.

Clearly there is more work to be done in developing real world examples of these kinds of project. Our own research is taking steps in this direction, by developing a simple app that will allow for the crowd-sourced creation of design graphics. The platform will employ the stigmergic mechanisms proposed here, including the introduction of both tagged design elements and tagged evaluation parameters that compete for survival – with ratings being the stigmergic signal that ‘marks’ success. While there are many steps
to go between an application for graphics and an application for urban development, the advantage of developing web interfaces is that code developed in one context can be modified and co-opted in another. Further, once functional protocols are developed, there is almost infinite capacity to scale. Thus, rather then becoming more burdensome with additional input, these kinds of systems tend to become more robust. They are less subject to hacking, content becomes more sophisticated with more users, and bugs within the system are discovered sooner and can be resolved.

It should be clear such projects would not be a panacea for all the problems that currently exist in planning exercises. Much depends upon the quality of information that the platforms are able to gather, and there are inherent dangers beyond those of vandalism or hacking: it is possible that crowd-sourced emergence might lead to outcomes perceived as negative by planning professionals (what if the crowd only cares about ample parking?). Alternately, the system will fail if there is a lack of participation, or if participation is co-opted by a group to serve a particular agenda. That said, there are numerous examples of real-world projects that suggest that many of these problems can be mitigated. While no system is perfect, and the systems presented would certainly have their own problems with dangers of runaway feedback loops, we can take some hope from the efficacy of collaboratively generated offerings such as the Linux operating system, or the general information fidelity of platforms like Wikipedia.

What is clear is that city planning issues are growing increasingly complex, and that our faith in individual planners to be able to oversee and manage this complexity has been strained in light of the many planning failures experienced in cities around the world. Further, Internet technology presents incredible opportunities to coordinate vast amounts of users, insights and data: the possibilities of which are only beginning to come to the forefront. The web has been evolving: from presenting content, to having users generate content, to having the crowd parse and filter content. Notions such as ‘the collaborative commons’ (Rifkin, 2014) hint at new forms of economic and production and creative systems that can operate without the need for a central hierarchy exerting control.

Finally, while this article has focused on ways in which stigmergy help us to refine and improve our understanding and operation of urban offerings within the virtual world, parallel research by the author is considering ways in which these mechanisms might be
manifested in the physical world (Wohl, 2015, 2016). How might we design urban functions such that they too can carry stigmergic signals? Can the urban environment, as a physical entity, itself process information and ‘learn’ as it captures the traces of previous interactions? These questions demand further research, but what remains clear is that our ability to understand and engage urban systems is enriched by a deeper appreciation of the dynamics of complex systems.

Citations:


Heylighen F (2015b) *Towards an Intelligent Network for Matching Offer and Demand : from the sharing economy to the Global Brain*.


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1 It should be noted that the state of the landscape is not static, but shifts over time in co-evolution with the agents themselves: this is the way new niches are created.
2 A case in point: another study of the Tempelhof site in Berlin employed CAS to propose a plan, but used fractal (scale-free) theories to develop a methodology. (see Yamu and Frankhauser, 2015)
3 Such as when birds flock, altering their trajectories vis a vis their neighbor;
4 This phenomena is discussed in (Wohl, 2015).
5 A third thought experiment, ‘Crowd-Sourced Moscow 2012’ (Goncharov, 2011) is not part of the author’s work but follows a similar logic.
6 The project was born out of research done in the first half of 2015 during an academic course delivered by the Author on CAS systems and architecture. The work was initially presented as an academic poster at The Design, Social Media and Technology to Foster Civic Self-Organisation Conference in Hasselt, Belgium in May 2015. It was then developed into a full paper presented in Porto, Portugal as part of Aesop’s “Public Spaces and Urban Cultures” meeting (Givens and Wohl, 2015).
7 ‘Wikitecture’ by Ackerman (Wohl), Radulovic, and Hurme, Europan 9, 2007
8 In CAS agents need not be cognitive: Here the ‘agent’ in CAS is not seen as a cognitive agent, but rather an urban construct – parklet, street, office tower – that can be considered more or less viable.