swarm tectonics:
a manifesto for an emergent architecture

It can be no coincidence that commentators from a variety of disciplines are now looking to biological models to understand structures of behaviour. From hard-line scientific research to philosophical enquiry they are finding that a constructive engagement with biological models is providing new insights into all forms of natural phenomena. It is as though even the structure of the universe itself and its continuous expansion cannot be understood using static theoretical models, but need to be exposed to more dynamic models of behaviour. And it is precisely studies of the 'life-force' within nature — from cellular organisations to swarming and flocking behaviours of insect, plant and animal life — that are opening up understandings of how human beings themselves behave. Just as we have seen bio-chemistry emerge out of chemistry, bio-technology out of technology, so too we are beginning to see a form of 'bio-philosophy' taking hold within philosophical debates.[1]

Broadly put, much recent thinking in science has sought to overcome the traditional conception of nature as governed by closed, static rules, to understand that almost everything operates within a dynamic, open system. The Santa Fe Institute in New Mexico has acted as a catalyst for much innovative thinking in this field. Operating within an interdisciplinary framework, researchers there have looked to self-organising systems in nature as models for understanding other structures of behaviour. It is precisely by studying the networking operations of ant colonies, for example, that we can begin to unfathom the complex interactions in group behaviour which rely as much on the individual responding to the logics of the mass or the swarm as they do on any single initiative. And through these we can glimpse the complex nature of any form of cultural life, extending right through to social, political and even economic systems, as Kevin Kelly has argued.[2]

Much of the work at Santa Fe has been grounded in the early studies of complexity theory by Mitchell Waldrop and others.[3] Complexity theory strives to understand the processes by which complex patterns of behaviour are generated in nature. Its project is somewhat paradoxical in that, rather than accepting the unfathomable complexity of the universe, it

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[1] Keith Ansell Pearson, *Germinal Life*, London: Routledge, 1997.

[2] Kevin Kelly, *Out of Control*, Cambridge, MA: Perseus Books, 1994; *New Rules for the New Economy*, London: Fourth Estate, 1998.

[3] Mitchell Waldrop, *Complexity: The Emerging Science at the Edge of Order and Chaos*, New York and London: Simon and Schuster, 1992; John Holland, *Emergence: From Chaos to Order*, Oxford: OUP, 1998.

seeks to detect the very structuring principles that have created that apparent complexity. In other words, it attempts to show that complexity is not so complex, but borne of clear principles.

The urge to symbolise, to order and clarify within conditions of complexity lies at the heart of not just animal behaviour, but all operations. There is a tendency for phenomena in almost every field to self-organise and arrange themselves into some sort of system. This has led researchers at Santa Fe to develop an interest in 'self-organising systems'. These are systems first developed in the fields of physics and chemistry to describe 'the emergence of macroscopic patterns out of processes and interactions defined at the microscopic level', but which can be extended to social insects to show that 'complex collective behavior may emerge from interactions among individuals that exhibit simple behavior.'[4]

Moreover, the model may also extend to the operations of the computer. Research by Eric Bonabeau, Marco Dorigo, Guy Theraulaz, and others has drawn comparisons between ant behaviour and computer software programs, and recognises that both phenomena depend upon interactive vectorial forces that operate within a network and not in isolation.[5] Such thinking looks towards 'swarm intelligence' — 'the emergent collective intelligence of groups of simple agents'.[6] Nor is this limited to insect life. What is remarkable is that within any 'population' — no matter how varied its nature — certain common patterns of operation can be seen to emerge. As DeLanda points out: 'The dynamics of populations of dislocations are very closely related to the population dynamics of very different entities, such as molecules in a rhythmic chemical reaction, termites in a nest-building colony, and perhaps even human agents in a market. In other words, despite the great difference in the nature and behavior of the components, a given population of interacting entities will tend to display similar collective behavior.'[7]

One can see swarm intelligence at work with a flock of birds. The flock veers, dives, soars in a fairly uniform movement — uniform in the sense that each individual bird is more or less conforming to the overall pattern of the group. Conventional thinking might dictate that there would be a leader in the flock — one individual bird taking control of the movements of the the others. In fact what is happening is that each bird is responding individually to those

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[4]Eric Bonabeau, Marco Dorigo and Guy Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems,* New York and Oxford: Oxford University Press, 1999, p. 6.

[5]Bonabeau, Dorigo and Theraulaz, *Swarm Intelligence*. See also James Kennedy, *Swarm Intelligence*, New York: Morgan Kaufmann, 2001; Mitchel Resnick, *Turtles, Termites, and Traffic Jams*, Camb., MA: MIT Press, 1994.

[6]Bonabeau, Dorigo and Theraulaz, *Swarm Intelligence,* p. xi.

[7]Manuel DeLanda, 'Material Complexity', unpublished manuscript, delivered at *Digital Tectonics* conference, University of Bath, March 2002.

around it, obeying simple commands such as 'follow the bird in front' or 'keep a certain distance from the bird to the right', and so on. The net result of these individual responses is a logic of swarm behaviour, which is both the sum of the individual responses, but also — in some senses — more than it.

These researchers note that in a society of increasing complexity and information overload there is a need to offer 'an alternative way of designing "intelligent" systems, in which autonomy, emergence and distributed functioning replace control, preprogramming, and centralization.'[8] Thus the operations of ants building nests can be recognised as a form of 'stigmergy' — direct or indirect interaction between ants — that lies at the heart of all self-organisation. And it is the very effectiveness of ants, creatures with relatively limited cognitive skills, but with a highly advanced capacity for social co-ordination that illustrates the extraordinary potential of 'swarm logic' as a means to address social problems.

Collectively these ideas come under the heading of 'emergence', a term popularised to describe a development in scientific explanations of the universe, but one which expands to all aspects of social life. It represents a shift in understanding from 'low-level' rules to higher-level sophistication, a kind of bottom-up development of complex adaptive systems that self-regulate, in opposition to top-down overarching principles. It looks to patterns of behaviour, but not ones which freeze into one single expression, but rather ones which are premised on dynamic adaptation. Constantly mutating, emergent systems are intelligent ones, based on interaction, informational feedback loops, pattern recognition and indirect control. They challenge the traditional concept of systems as predetermined mechanisms of control, and focus instead on their self-regulating adaptive capacity.

Emergent Cities

There is an obvious parallel to be drawn between the self-organising capacity of ant or termite colonies and the 'natural' patterns of growth of human cities. Indeed some of the early thinking of the Santa Fe Institute was based on the observations of Jane Jacobs in her book, *The Death and Life of the Great American Cities*.[9] Here, in a polemical attack on wholesale urban demolition and rebuilding, Jacobs recognises the complex choreography of life in the city.[10]

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[8] Bonabeau, Dorigo and Theraulaz, *Swarm Intelligence,* p. xi.

[9] Jane Jacobs, *The Death and Life of the Great American Cities,* New York: Vintage, 1961.

[10] 'Under the seeming disorder of the old city, where the old city is working successfully, is a marvellous order for maintaining the safety with the streets and the freedom of the city. It is a complex order. Its essence is intimacy of sidewalk use, bringing with it a constant succession of eyes. This order is all composed of movement and change, and although it is life, not art, we may fancifully call it the art

But there has now been a second generation in which these ideas — as filtered through the work of the Santa Fe Institute — have been taken up and developed by figures such as Manuel DeLanda and Steven Johnson, and extended into an analysis of the very structures of our cities.[11] For cities and towns themselves must be understood as amalgams of 'processes', as spaces of vectorial flows that 'adjust' to differing inputs and impulses, like some self-regulating system. John Holland sums them up as follows: 'Cities have no central planning commissions that solve the problem of purchasing and distributing supplies. . . How do these cities avoid devastating swings between shortage and glut, year after year, decade after decade? The mystery deepens when we observe the kaleidoscopic nature of large cities. Buyers, sellers, administrations, streets, bridges, and buildings are always changing, so that a city's coherence is somehow imposed on a perpetual flux of people and structure. Like the standing wave in front of a rock in a fast-moving stream, a city is a pattern in time.'[12]

Cities are physical traces of patterns of social behaviour operating through time. As such, we must always question the need for 'master-plans', or at least recognise the potential of their authority to be determined by 'bottom-up' street level interferences. Moreover, they are governed by principles of self-organisation. As Rem Koolhaas has shown in his study of Lagos, the apparent chaos of city life can be understood as an enormously sophisticated self-organising system that sorts, orders, categorises and recycles according to quite clear economic principles. Indeed, for the most exacting model of a self-organising urban system we might perhaps look beyond Lagos and turn towards a city such as Hong Kong, which is thoroughly imbricated within a capitalist framework, and unconstrained by strong historical ties. Hong Kong, with its jungle of social interactions, can be understood not as a chaotic and confused collections of disparate activities, but as a hugely sophisticated connection of interdependent micro-systems that operate within an overall swarm intelligence.

This thinking comes close to the account of the city offered by Deleuze and Guattari. In their terms, the city becomes a complex *machinic phylum* that adjusts, self-regulates, and that becomes the very space of deterritorialisation.[13] The city, as a smooth space of networks

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form of the city and liken it to the dance — not to a simple-minded precision dance with everyone kicking up at the same time, twirling in unison and bowing off en masse, but to an intricate ballet in which the individual dancers and ensembles all have distinctive parts which miraculously reinforce each other and compose an orderly whole.'Jacobs, *The Death and Life of the Great American Cities,* as quoted in Steven Johnson, *Emergence: The Connected Lives of Ants, Brains, Cities and Software*, London: Penguin, 2001.

[11] Manuel DeLanda, *A Thousand Years of Nonlinear History*, New York: Zone Books, Swerve Editions, 1997; Steven Johnson, *Emergence: The Connected Lives of Ants, Brains, Cities and Software*, London: Penguin, 2001.

[12] John Holland, as quoted in Steven Johnson, *Emergence*, New York, Schribner, 2002, p. 27..

[13] 'The town exists only as a function of circulation and of circuits; it is a singular point on the circuits which create it and which it creates. It is defined by entries and exits: something must enter it and exit

and flows, can therefore be contrasted to the state, as a striated space of hierarchies and order. The state, in other words, seeks to impose a certain form on everything. The city, on the other hand, is predominantly a result of a process — it is a *formation*.[14]

Emergent Architecture

DeLanda's book, *A Thousand Years of Non-Linear History*, is effectively a rewriting of the past millennium of urban development according to a broadly Deleuzian framework. It is an approach that focuses on process rather than representation, on formation rather than form. This approach could equally be applied at the level of architecture itself. Indeed one could imagine a volume, parallel to DeLanda's, that attempts to rewrite the history of the last thousand years of architecture on similar principles.

The key to this approach is already to be found in Deleuze and Guattari's own brief references to architecture. It is as though the whole history of architecture can be divided into two contrasting, yet dialectically related, outlooks. One would be a broadly aesthetic outlook that tends to 'impose' form on building materials, according to some pre-ordained 'template'. (And here one immediately thinks of the role of 'proportions' and other systems of visual ordering.) The other would be a broadly structural outlook that tends to allow forms to 'emerge' according to certain programmatic requirements.

The first is described by Deleuze and Guattari as the 'Romanesque'. The term seems somewhat limiting, in that the principle covers a range of approaches which broadly come under the umbrella of the Classical. This would include not only the Classical as such — the Roman and Greek derived style which mutated through successive generation through the

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from it. It imposes a frequency. It effects a polarization of matter, inert, living or human; it causes the phylum, the flow, to pass through specific places, along horizontal lines. It is a phenomenon of transconsistency, a network, because it is fundamentally in contact with other towns. It represents a threshold of deterritorialization because whatever the material involved, it must be deterritorialized enough to enter the network, to submit to the polaralization, to follow the circuit of urban and road recoding.'Deleuze and Guattari, 'City/State' in Neil Leach (ed.), *Rethinking Architecture*, London: Routledge, 1997, p. 313.

[14]The city is therefore contrasted to the state, as the space of deterritorialisation. And yet, as with deterritorialisation itself, which will always be prone to fold into its opposite — territorialisation — so too the city threatens to become stratified and to fold into the condition of the state. It is not that we can ever avoid such processes of reciprocal presupposition — they remain an inherent part of the model that Deleuze and Guattari offer — and yet, crucially, they would always wish to commend one over the other. These should not be seen as 'opposites' within a condition of binary opposition — for Deleuze and Guattari seek to overcome such polarisation, seeking to invest their attention in the notion of process — the oscillation or movement between two extreme conditions, rather than the conditions themselves. The 'tendency' towards multiplicity, fluidity and process that the city embodies would therefore be preferable to the 'tendency' towards unicity, stasis and representation, that the states embodies.

Romanesque, and into the Renaissance, Mannerism, Baroque, and Neo-Classical — but also any outlook which focuses on appearance over performance. In this sense the Neo-Gothic could almost be included in this group, but so too Modern or indeed Postmodern architecture, and even the excessively *formal*, scenographic work of architects such as Frank Gehry.

The second could be broadly defined as the Gothic, which is configured not as a style, as it was in the nineteenth century, but as a method. It is a way of designing that privileges 'process' over appearance. Architecture becomes the result of competing forces. It is a programmatic architecture that registers the impulses of human habitation, and adapts to those impulses. Deleuze and Guattari analyse the distinction between the Gothic spirit and the Romanesque as a 'qualitative' distinction, between a static and a dynamic model of understanding architecture.[15]

Emergent form 'evolves' over time, much as the gothic vault 'evolved', becoming ever more refined in its structural efficiency, until it reached its glorious culmination in the fan vaulting of the English perpendicular style. The task for designers, then, would be to 'fast forward' this process, and to imagine how forms would have evolved so as to be totally adapted to their patterns of colonisation. It is an architecture, then, of the 'future perfect' tense, trying to predict through exhaustive analyses the activities that will have happened, so as to facilitate those processes, by enabling connectivities and so on. In its most advanced form it would be an architecture that was open to those processes themselves, an adaptive, responsive environment, that did not crystallise into a single, inflexible form, but was able to reconfigure itself over time, and adjust to the multiple permutations of programmatic use that might be expected of it.

Rather than describing these two different outlooks in terms of style, Deleuze and Guattari refer to them in terms of different 'sciences'. One is a science of intensive thinking that understands the world in terms of forces, flows and process.[16] The other is a science of

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[15] 'Gothic architecture is indeed inseparable from a will to build churches longer and taller than the Romanesque churches. Ever further, ever higher. . . But this difference is not simply quantitative; it marks a qualitative change: the static relation, form-matter, tends to fade into the background in favor of a dynamic relation, material-forces. It is the cutting of stone that turns it into material capable of holding and coordinating forces of thrust, and of constructing ever higher and longer vaults. The vault is no longer a form but the line of continuous variation of the stones. It is as if Gothic conquered a smooth space, while Romanesque remained partially within a striated space (in which the vault depends on the juxtaposition of parallel pillars).' Gilles Deleuze and Félix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia*, trans. Brian Massumi, Minneapolis: University of Minnesota Press, 1987, p. 364.

[16] 'One does not represent, one engenders and traverses. This science is characterized less by the absence of equations than by the very different role they play: instead of being good forms absolutely that organize matter, they are "generated" as "forces of thrust" (*poussées*) by the material, in a qualitative calculus of the optimum.' Deleuze and Guattari, *A Thousand Plateaus*, p. 364.

extensive thinking, that seeks to understand the world in terms of laws, fixity and representation. In other words, the one is a smooth science, and the other striated. Deleuze and Guattari also describe this opposition as being between a nomad, war machine science and a royal, state science. The latter is a science of fixed rules and given forms, a hierarchical system imposed from above.[17] By contrast, the nomad war machine science is a bottom-up model that responds in each individual instance to the particularities of the moment.[18]

There is a genealogy to this Gothic outlook. It is articulated clearly within the Gothic tradition, but so too within a certain approach to structures, such as bridges.[19] Yet, the principle of designing according to efficiency and minimal use of materials lies behind all good engineering practice. More recently, one might find certain incarnations of this Gothic science in the work of Antonio Gaudi at the beginning of the twentieth century, and Frei Otto towards the end. At the beginning of the twenty-first century, we might recognise within the work of Foreign Office Architects, Reiser and Umemoto, Mark Burry, Mark Goulthorpe, Lars Spuybroek and U N Studio, traces of a re-articulation of this spirit. The work of this group shares a common goal, a sympathetic engagement with the principles of structural engineering, that embraces structural concerns not as some practical afterthought, but as a vital component folded into the whole conceptual process of designing. This work has been described as 'post-Gaudian *praxis*'. Importantly, it relies heavily upon computational methodology.

Digital Tectonics

But how might these operations be facilitated by the digital domain? At first sight there is little to suggest that the question of structure and structuration has much to do with operations of the computer, in that one remains a decidedly material domain, and the other an immaterial one. Yet, once we reinterpret the computer, not as a monadic machine, but as a 'population' of smaller, nomadic components operating within the logic of swarm

17'Royal, or State, science only tolerates and appropriates stone cutting by means of *templates* (the opposite of squaring), under conditions that restore the primacy of the fixed model of form, mathematical figures, and measurement.' Deleuze and Guattari, *A Thousand Plateaus*, p. 365.

18A further way to distinguish these two models of operation is the distinction Deleuze and Guattari make between 'minor' and 'major' sciences: 'the tendency of the broken line to become a curve, a whole operative geometry of the trait and movement, as pragmatic science of placings-in-variation that operates in a different manner than the royal or major science of Euclid's invariants and travels a long history of suspicion and even repression.' Deleuze and Guattari, *A Thousand Plateaus*, p. 109.

19Deleuze and Guattari cite the example of the C18th bridge designer, Perronet, who attempted to reduce the mass of a bridge and to design it to perform as efficiently as possible: 'To the heaviness of the bridge, to the striated space of thick and regular piles, he opposed a thinning and discontinuity of the piles, surbase, and vault, a lightness and continuous variation of the whole.' Deleuze and Guattari, *A Thousand Plateaus*, p. 365. Bridges are not always designed this way, and, as Deleuze and Guattari observe, and Perronet himself soon found his experimentation obstructed by the state.

intelligence, the possibility becomes more evident. Here we might recognise that structures themselves operate in a highly complex manner. Never as discrete and self-contained as they first appear, structures operate parametrically as ‘self-organising systems’. It would be better to think of their operations in terms of networks or even meshworks.

Research has already demonstrated the theoretical links between ant behaviour, computer networks and structural forms, and this principle has been further corroborated by programs being devised to understand structural behaviour.[20] For some time architects and engineers have used computer programs to test the structural stability of their designs. But programs are now being developed for actually generating novel structural forms. These go beyond the already very sophisticated use of Genetic Algorithms championed by Karl Chu and others, to produce forms which have their own structural integrity.

One such example is the eifForm program, devised by Kristina Shea, that generates forms in a stochastic, non-monotonic method using a process of structural shape annealing.[21] The ‘designer’ merely establishes certain defining coordinates, and then unleashes the program which eventually ‘crystallizes’ and resolves itself into a certain configuration. Each configuration is a structural form which will support itself against gravity and other prescribed loadings, and yet each configuration thrown up by the program is different. Such is the logic of a bottom-up, stochastic method.

It is through programs such as eifForm, that we recognise the potential for the computer to simulate structural operations, precisely because it is based on populational behaviour. But the possibilities go further. What we encounter with such programs is the potential to view the whole design operation as a process. What applies to structure, could equally well apply to other aspects of the building process — to acoustic or environmental concerns, to constructional or programmatic issues. The computer provides an efficient search-engine that is premised on the notion of efficiency. Hence the real potential of such operations does not lie as an indulgent designer toy of the affluent West, but also as a social tool optimizing resources within less privileged regions of the world.

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[20] See Bonabeau, Dorigo and Theraulaz, *Swarm Intelligence,* esp. Ch. 6, ‘Nest Building and Self-Assembling’, pp. 205-251.

[21] Annealing refers to the method of heating and cooling metals. The eifForm program simulates this process, so that the eventual form ‘crystallises’. The process is stochastic because it contains a random element to the search process, which is controlled to allow for exploration of concepts that are initially worse than the current design. It is therefore also non-monotonic, in that it is constantly under revision, often negating previous developments. For a discussion of the eifForm program see Kristina Shea, ‘Creating Synthesis Partners’ in *Architectural Design*, no. 72, pp. 42-45.

But this also has a significant impact on the very nature of design. The computer is being used not as a tool of representation, but as a generative instrument that is part of the design process itself. In other words, at a most radical level, the computer has redefined the role of the architect. No longer is the architect the demiurgic form-maker of the past. The architect has been recast as the controller of processes, who oversees the 'formation' of architecture. With the development of new computational techniques, we find ourselves on the threshold of a new paradigm for architecture — a paradigm in which 'swarm tectonics' plays a crucial role.

This article is illustrated with the first ever full scale model of a structure generated by the eifForm program. It was constructed at the Academie van Bouwkunst, Amsterdam in June 2002, out of timber struts, held together with pin-joint connections using standard steel hooks and bolts. The structure is clad with plastic panelling by Rodeca Systems, who sponsored the project..

Design: Neil Leach, Kristina Shea, Spela Videcnik, Jeroen van Mechelen.
Construction: students of the Academie van Bouwkunst, Dessau Institute of Architecture and the University of Bath.

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