# The Architecture of Flows

## INTEGRATED INFRASTRUCTURES AND THE 'METASYSTEM' OF URBAN METABOLISM

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The traditional approach to urban design studies has been based on what can be described as a generalised anatomical model, e.g., functional zoning coupled to metaphors such as green areas serving as the 'lungs' of cities. Despite the frequent use of biological metaphors, urban design has generally proceeded from an understanding of cities as static arrays of buildings and infrastructures that exist in, but are distinct from, stable environments. But this approach does not reflect the dynamic systems of cities throughout history, nor their close coupling to the dynamics of their local environment, climate and ecology, and now the global dynamics of culture and economy. The limitations of this approach, in which cities are treated as discrete artefacts, rather than nodes interconnected by multiple networks, are compounded by the legal and regulatory boundary of the city usually being defined as an older core, so that cities are regarded as something quite separate from their surrounding territory. All cities have administrative boundaries, but cities are very rarely either physically or energetically contained within those administrative boundaries. In the past, cities gathered most of the energy and materials they needed from their immediate local territory, and trade linked systems of cities across whole regions. The growth and vitality of many cities are no longer dependent on the spatial relationship with their immediate environs but on the regional and global flows of resources. The flow of materials, information and energy through cities comes from far outside their physical and regulatory (municipal) boundaries. Cities now extend their metabolic systems over very great distances, so that the extended territory of the urban metabolism of a city and its geographical 'place' are often completely decoupled.

Cities exist within the dynamic processes of the natural world, and they have had, and will continue to have, a profound effect upon it. There are no ecological systems on the surface of the earth that have not been modified in some way by the effects of the extended metabolisms of human societies. Cities operate and are maintained by a complex series of exchanges with their environments, and the dynamics that characterise the complex relations of city forms to the ecological and climatic systems within which they exist are turbulent. Extended conurbations are now common right across the world, consisting of several overlapping city territories that extend urban fabric across a range of scales, often coterminous with agriculture, industrial and energy generation territories. The complexity of the relations of cities to ecologies is accordingly accelerated, and the sensitivity of each to changes in the other is increased.

### Infrastructure and Metabolism

Cities are the largest and most complex artefacts constructed by humans; dynamic spatial and material systems that display phenomena characteristic of complex systems:power scaling, self-similarity across a range of scales and 'far-from-equilibrium' dynamics. All cities have an 'architecture', an arrangement of material in space that changes over time as they are continuously repaired and rebuilt. They collapse and expand in uneven episodes of growth and decay, and their infrastructural systems are changed accordingly. From this perspective, cities are dynamic nodes on extended multiple networks through which food, energy, people, water, materials, and information flow.

Infrastructure is traditionally defined as the physical array of systems that provide the 'public services' of transportation, water, energy, communications, and waste collection and disposal. In contemporary usage two other significant systems have had a profound effect on urban physics: the green spaces such as open woodlands or nature reserves, parks, gardens and other public recreational spaces, and the public spaces of the built environment. The hypothesis of this paper is that the architecture of the integrated 'metasystem' of urban metabolism is comprised of the 7 interacting subsidiary systems named above. Integrated and intelligent infrastructural systems will be a critical component in the adaptation of expanded human societies to impending climatic and ecological changes.

The study and design of infrastructures are conventionally focused on the separate physical artefacts of the networks, and in recent times there has been strong focus on the architectural renewal and implementation of stations, bridges and terminals but much less on the topology and physical architecture of the network systems themselves or on the interdependencies between differing infrastructural systems, and even less on their integration. It is now clear that developing strategies for the adaptation of existing urban settlements to the accelerating changes of climate and population requires integrated system analysis.[1] There are, as yet, very few studies that have focused on the performative parameters for integrated urban infrastructures of urban metasystems, nor on the design criteria for their adaptation to climatic and ecological changes. The 'state of the art' studies of adaptation of cities all tend to be focused on singular systems, such as green infrastructure[2] or the development of adapted patches and microclimatic oases that are aimed at helping to regenerate the urban tissue from within. Large-scale studies that integrate the analysis of urban morphologies to the flows and capacities of their 'metabolic' systems are vanishingly rare.

There is a remarkable similarity between the mathematics of biological metabolism and of urban metabolism, and in both, the operation of metabolic systems occurs through surfaces and networks.[3] The pattern of energy flow through living forms, and through all the forms of cities, is subject to many fluctuations and perturbations. The flow is modified by 'feedbacks', but occasionally there is such an amplification or inhibition that the system must change, must reorganise or collapse. A new order emerges from the turbulence of the system that has collapsed. The reorganisation often creates a more complex structure, with a higher flow of energy through it, and is in turn more susceptible to fluctuations and subsequent collapse or change through reorganisation – a tendency of living systems and of cultural systems to ever increasing complexity.[4]

Complexity theory formalises the mathematical structure of the process of systems within which hierarchical organisation arises. The complex is heterogeneous, with many varied parts that have multiple connections between them, and the different parts behave differently, although they are not independent. Complexity increases when the variety and dependency of parts increase. The process of increasing variety is called differentiation and the process of increasing the number or strength of connections is called integration. In biological systems and cultural systems both differentiation and integration are produced at many 'scales' or levels. Each level interacts with other levels, and hierarchical orders are to be found within all complex systems, from the anatomical form and metabolism of an individual organism, to the distribution of species and ecological systems, to the pattern of settlements and cities distributed across a region. Some, if not all, of these characteristics are amenable to being modelled mathematically. Networks for information, energy and material distribution exhibit many similar parameters to the hierarchical branching metabolic networks of living forms, and a great variety of other culturally produced networks also exhibit comparable 'scale free' power law characteristics.[5]

Scaling is an invariant property of a dynamic system in general, most likely to be produced by the way in which the systems grow. It is evident that both biological and cultural networks grow by the addition of new nodes or hubs, but these new nodes preferentially attach to nodes that are already well connected. In consequence, the topology of the whole network has only a few nodes with a high number of connections that link to all of the other nodes that have progressively smaller numbers of connections. Flow patterns are dominated by the highly connected nodes, through which the maximum volume and velocity of energy, information or material flow.[6] It is also clear that the robustness or vulnerability of scale-free networks to the random failure of any single node or link is high, as the greater majority of nodes have few links, but if a node with a high number of connections fails (a hub) then the scale-free characteristics of the entire network will be affected, and it may fail altogether.[7]

## Integration of the Architecture of Flows – A Research Agenda

There is an emerging consensus, widespread but by no means universal, that the design of the new cities needed for an expanding world population can be founded on intelligent and inhabited infrastructural systems that harvest and distribute energy, water and materials, that intimately connect people and open urban green spaces, and that unite rather than divide urban and ecological systems.

The questions arises 'can the dynamics of cities be computationally simulated, and if so, can computational models of new cities be generated for a world in which climate, ecology, cultural and economic systems are transiting through critical thresholds of stability?' The scale of such an undertaking is daunting, but it is possible to delineate the outlines of a research agenda that will provide the substrate from which answers to this question could emerge. It may commence with the computational simulations of expansion and development of cities over time that integrates growth, density and morphology. It is clear that the search for defined parameters that can be quantified mathematically as the basis for this computation will need to be abstracted from a substantial database of the known and calibrated data from existing evolved and planned cities in differing climatic zones. There are significant difficulties in incorporating the full morphology of cities and conurbations into computational simulations, even where it is accepted that city forms display self-similar or fractal properties across all scales. Recent studies suggest that an interdisciplinary quantitative synthesis of organizational and dynamical aspects of cities could be collated from existing data sets and the various outputs of current researchers, although it would require collaborations from across the world.

In parallel, the identification of general scaling patterns in urban infrastructure and their relation to the dynamics of urban morphology and energy flows have been theorised and data collected, but not yet calibrated for existing cities. There is recent work too on the relation of urban morphology to macro and micro climates, based on consideration of the physicality of the city as a porous and folded material surface coupled to the topology and physical architecture of networks and the volume and velocities of flows through those networks.[8] By coupling the analysis of urban morphologies to the flows and capacities of their metabolic systems in differing climatic zones, performance criteria for the physical geometries and engineering of material of new 'flow' architectures could be derived.

## Notes

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