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An Information Architecture Approach to Understanding Cities.

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Abstract.

Cities are systems of information architecture. Here, "architecture" refers not to the design of buildings, but to how the components of a complex system interact. Information exchange includes visual input from the environment, personal contact and interactions, telecommunications, as well as the movement of people. Information networks provide a basis for understanding living cities and for diagnosing urban problems. This paper argues that a city works less like a commercial electronic system, and more like the human brain. As a functionally complex system, it heuristically defines its own functionality by changing connections so as to optimize how components interact. An effective city will be one with a system architecture that can respond to changing conditions. This analysis shifts the focus of understanding cities from their physical structure to the flow of information.

1. Introduction

Successful cities coordinate activities requiring a complex pattern of cooperation among large numbers of human beings. Furthermore, this must be accomplished under conditions in which the activities are changing continuously. Jane Jacobs points out the contrast between static cities such as 19th century Manchester, and dynamic cities such as Birmingham (England). Manchester was very successful in the cotton industry, but declined in the face of external competition. It has never been possible to point to one industry by which Birmingham earns its living; rather its capability has been the creation of new industries in response to changed conditions. Other roles with which successful cities are associated include assignment of resources and maintaining order across expanding empires (16th and 17th century Madrid; 18th and

19th century London) and providing exchange and port services under dynamic trade conditions (medieval Venice).

Coordinating a complex combination of changing functions drives other natural and artificial systems such as biological brains and real-time electronic systems. In the case of electronic systems, functional change occurs under explicit intellectual control. In other words, the desired functional change is decided beforehand and then specified in complete detail. This requires extensive testing before its implementation in order to avoid undesirable side effects. For cities and biological brains, on the other hand, change is to a considerable degree heuristic (i.e. learned by the system itself in response to experience).

The need to change functionality forces a complex system to be modular at many levels (Coward, 2000). Following the example of electronic systems, modules are defined as clumps of activity which have larger information exchange within the module than with other modules (Courtois, 1985; Parnas et al, 1985). In a city, a functional module at the most detailed level could identify a person with the buildings and spaces in which most of his or her time is spent. At a somewhat higher level, modules could include small groups of people who interact strongly on a daily basis with various urban nodes. At a yet higher level, modules correspond approximately with institutions, individual businesses, educational and political organizations, etc. The correspondence is only approximate, because a major city function at the highest level may be partly in a specialist module, but some elements of it may reside within other modules.

A system needs to minimize the overall cost of information exchange. Analysis of a city as a system should therefore begin by identifying groups of people who exchange more information within the group than external to the group. Groups on any level cannot be identified cognitively in advance, but only on the basis of differential information exchange. Intervention would then try to enhance city functionality by making information exchange more efficient. City modules in general do not correspond with simple city functions. Urban structure needs to be assessed by abandoning strict visual ordering based on aerial geometry, and concentrating instead on the evolving information and movement networks.

Information exchange at a detailed level includes conversation, observation, or display by individuals. At a higher level it is people or groups of people moving from one function to another. The networks of a city, the paths, roads, telecommunications, etc. are the mechanisms which support information exchange. A complex pattern of information exchange coordinates city functions, drives a city's dynamics, and determines its evolving structure. Also, the need to change heuristically results in all such information exchange being partially ambiguous. By this we mean that it recommends but cannot demand specific coordination actions. Resolution of conflicting recommendations must occur in an institutionally separate function which does not require complex coordination. Electoral and legal institutions perform this role.

2. Understanding the city as a system

An earlier paper (Salingaros, 1998) formulates urban functions in terms of relationships and movement. Nodes of human activity such as home, work, park, store, restaurant, church, etc. are connected into a network. Successful paths occur along boundaries. One way of understanding their success is that people moving along such paths for the purpose of higher level information exchange can carry out lower level information exchange with other modules (e.g. observing). The time required for higher level exchange is therefore used more effectively. A subsequent paper (Salingaros, 1999) links the use of urban space to the information field generated by surrounding surfaces, and to how easily the information can be received by pedestrians. Urban space is bounded by surfaces that present visual information. This information is functional; it can recommend behaviors to the observer.

Information and communications technologies need to be incorporated into traditional city functions (Drewe, 1999; 2000). The dynamics of the rapidly evolving electronic city are as yet little understood, while the twentieth-century model of a city based on simplistic geometrical ordering is irrelevant for modeling a communications network. Blocks of functionally segregated buildings strictly aligned to a rectangular grid do not reveal the various overlapping networks that actually drive a city to function (Dupuy, 1991; 1995). As a complex system whose output is commercial wealth and culture, a city has a functional architecture based on information exchange. Information and communications technologies should fit neatly into the hierarchy of information exchange functions at different levels of scale.

Our work may be considered as part of recent attempts to understand cities as complex systems. The most comprehensive of these are by Peter Allen (1997) and Juval Portugali (2000), and their collaborators. The work of Michael Batty and Paul Longley (1994) and Pierre Frankhauser (1994) is concerned with structure and urban growth on different levels of scale, although it focuses on fractal forms rather than networks. To this must be added the results of the Space Syntax group, ably summarized in the book by Bill Hillier (1996). There is overwhelming evidence that cities are complex systems, and this opens the door to studying them in more realistic ways than the simplistic geometry of the CIAM model. We are not aware, however, of previous studies that attempt to find the system architecture of cities, and so we feel that our own contribution is a useful addition to this general effort.

Christopher Alexander pioneered the understanding of complex city structure. In roughly eleven-year intervals, he and his colleagues have published seminal statements about how a city grows and repairs itself (Alexander, 1965; 2000; Alexander et al, 1975; 1987). Most important have been the pointed comparisons between the processes whereby a living city develops, and a dead city decays. That body of work goes to the heart of the matter: it includes specific guidelines on how to build a living city; what legislation is needed to do so; the distribution of money in urban projects; the specific urban design process to follow; etc. The authors see the present paper as a prelude to Alexander's work. Once our theoretical results are accepted, practicing urbanists will need to implement practical strategies to heal decaying cities, and generate new, living cities. Those details are already contained in Alexander's work.

Information architecture implies that city form is dynamic, and it evolves heuristically. This conclusion invalidates much of current planning practice. What is required instead is a process of diagnosis and repair of the urban fabric, much as biological tissue calls upon mechanisms to repair itself. Such a process of urban design is precisely what Alexander and his colleagues have been insisting upon all along. Clearly, the fact that those proposals represent the opposite of the post-war CIAM approach to planning has discouraged their implementation up until now. Our original aim in writing this paper was unrelated to Alexander; we wanted to understand a living city's system architecture in an abstract, theoretical manner. Perhaps our conclusions will now give a needed boost to work we believe to be both correct and prescient.

3. Cities optimize information exchange

Optimization means that a maximum of information is exchanged with a minimum of effort. In a city, many people need to change location in order to coordinate two functions. An information activity could be made more efficient by generating other information exchanges than just the primary one (e.g. via observation during a move from one location to another). Walking to an appointment in a European capital can be more pleasant than a drive to achieve the same end in an American metropolitan area. One sees other people, some of whom one might wish to talk to; observing others provides education in how to dress and behave; information may provide clues on social currents; and window displays provide information on available products and services. Of course, we are discounting negative factors which interfere with effective information exchange such as inclement weather, crime, overcrowding, etc.

The cost of information exchange in most urban activities is woefully underestimated. A half hour trip has a cost and a value. How much valuable information exchange occurs? Do you see a wide range of behaviors? Are you exposed to people you want to influence? Would a city be more effective if people saw more directly what was going on? Note the trade-off with television: while "walking around" you are doing the selection, but may get lots of irrelevant information; with television, you can focus the relevance of the information but someone else is doing the selection. Shopping malls minimize information exchange for one cognitively defined function (shopping) but result in excessive information exchange requirements for many other functions.

Imposing a naive high level separation, such as separating shopping areas from business areas and housing areas, creates several problems. First, any information exchange between these functions will be high cost. Second, there is little scope for components with necessary functions but no physical structure/location to contain them (in contrast to the restaurant example). Informational networks do not possess a compact geometry, hence do not fit into a geometrical node. They will always be at odds with a city that is restricted to a simplistic visual plan. It will almost certainly be impractical to design the informational networks of a major city in advance, and in any case, as the functions of the city evolve, it is vital that the city have the capability to evolve heuristically. No leadership will be able to anticipate and manage this at all levels of detail.

Consider, for example, the process by which decisions are made to invest in a new business. Such decisions require coordination between future technology directions, market needs, financial resources, and business resources. This knowledge will be distributed across many city modules. A city with efficient information exchange of the required type will be more effective in creating new business than one without.

However, creation of new business is not the only city function requiring a complex pattern of information exchange, and so there is a conflict between the information exchange needs of different functions. Ideally, the result will be a compromise which allows all functions to operate effectively. There must also exist mechanisms for adjusting this compromise as functional needs change.

The functional role of an intermediate level module such as a restaurant could be: (i) Producing things (i.e. preparing meals from raw food); (ii) Distributing things (prepared food, but maybe offering candy and souvenirs for sale); (iii) Education/Learning (people watching other people for ideas on how to dress or behave); and (iv) Information exchange (meetings between people to discuss business or politics). Some restaurants become focal points for information exchange in a city -- often identified with a particular business in a large metropolitan area, or the restaurant is an important node in a small town's social and government networks. Lots of other functions could be imagined for a restaurant. The parking arrangements, footpaths, and proximity to other locations all affect the ease of and effectiveness of information exchange.

Information exchange in the area in which you live occurs through walking in the neighborhood -- learning how neighbors manage their environment. Information is exchanged through discussions with neighbors and meetings for local planning. This creates an informational network, which is the social "glue" holding a neighborhood together. Just as the electricity, water, and road networks define connectivity for the region in a functional sense, so the informational network defines a neighborhood rather than a cluster of isolated buildings. As pointed out in (Salingaros, 1998), today's suburbia consists of isolated house nodes, and is thus devoid of the older information exchange network among neighbors. The appearance of one's house is a display to influence others; an event that assumes particular meaning during holidays such as Christmas when people decorate their houses' exteriors. The size of a house's façade makes a statement about the owner's income level and social aspirations.

Environmental information is an important part of maintaining order. Litter in the street implies that more serious crimes are tolerated there, whereas clean subways give the message that someone is watching. Peer pressure and public demonstrations help establish social order. Observing how others behave is very important, and getting what you want in a particular situation depends partially on how you behave. The loss of social cohesion in a region -- and on a larger level, the loss of community in urban society -- starts by eliminating information exchange between neighboring residences. Urbanists pushed house fronts too far back for effective personal communication between neighbors. Other physical components of interpersonal neighborhood information exchange like the front porch and the wide, walkable sidewalk were suppressed. For millennia, the hustle and bustle of urban street life generated commercial interactions that created wealth for nations.

4. Different types of complexity

A wide range of systems are called complex, and it is important to recognize major differences between different types of complexity. We identify two broad types of complexity: *physical*, and *functional*. Cities are functionally complex, and analogies based on physical complexity (like chaos theory) can be misleading. Thinking of a city as merely physically complex leads some authors mistakenly to think that cleaning up physical complexity will solve urban problems. In fact, since that idea is based on a serious misunderstanding of system architecture, it almost inevitably leads to disaster.

In a physically complex system there is in general a small number of component types, and all components of one type are identical. The interaction between two components depends primarily on the types of the components and the distance between them. Complexity in this case derives from the very large number of many similar connections among components. On the other hand, while in a functionally complex system there could still be a small number of component types, different components of the same type are similar but not always identical. The interaction between any pair of components is in general unique to that particular pair. We thus have a very large number of connections, each one distinct.

Different types of complexity imply drastically different system properties and behavior. In a physically complex system, very slightly different starting states can give rise to radically different end points. This chaotic behavior is a key reason for the difficulty of weather prediction. In a functionally complex system, however, slightly different starting points will tend to give rise to similar end points (i.e. similar input conditions should generate similar behaviors). Partial insensitivity to input variability guarantees stability or homeostasis in living systems. Convergence on appropriate end points is achieved by controlling the available variability at the system level.

5. Systems and modular decomposition

Complex systems are coherent working wholes that cannot be completely separated into fully independent modules. A structure that can easily be separated into non-interacting constituents is not a complex system, but rather an aggregation of units; it is called a "heap" in systems theory. However, separation into modules with some degree of interaction is widely used both for the design of artificial systems, and for the understanding of natural systems. As pointed out earlier, modules are defined as clumps of activity which interact more strongly within the module than external to it. Herbert Simon (1962) has argued that there could be a small number of inequivalent separations of a system into components, all of which might make some sense because they identify different subsystems. This means that there is no consistent mapping between top level functionality and the functionality of submodules.

Any functionally complex system, whether natural or artificial, is forced into a hierarchy of functional modules for two reasons (Coward, 2000; 2001). The first reason is that there are always advantages in minimizing the volume of information (design or genetic) required to build the system. As a result, such systems tend to contain a relatively small number of fundamentally different types of components. The system will be constructed from large numbers of these basic types, with relatively slight variations within one type.

The second reason is that any system needs to fix problems, and make functional changes which do not disrupt existing functionality. Knowledge of a problem to be fixed, or a functional change to be made generally exists at a fairly high level (e.g. a feature does not work properly; an area of a city is declining). The necessary actions, however, must be taken on a much more detailed level (e.g. replace a specific group of transistors; implement investment and regulatory actions). One has to find and follow logical paths which link high level conditions with detailed actions. The existence of such paths requires a modular hierarchy in which the highest level functionality of the system is separated into modules, these modules into submodules, and so on through a series of levels to the primary components.

All modules on one level must be roughly equal in terms of the number of primary component operations each module contains. The information exchange needed to coordinate module functionality must be minimized as far as possible. If one module were much larger than the others, then most logical paths would pass through that one module and little discrimination would result. Very large information exchange between two modules precludes their effective separation for the purpose of tracing logical paths. The requirement that modules be separated so that information exchange be minimized corresponds with Courtois' (1985) point that the join between modules will be successful if it occurs along a region that is weaker than any module's internal connections.

Designing extremely complex electronic systems begins with an experimental separation of functionality into roughly equal modules, followed by performing functional scenarios to determine information exchange. If this exchange is excessive, functionality is shifted between modules (i.e. the partition into modules is re-defined) until a compromise between module equality and minimized information exchange is reached. This process is then repeated with the modules at the next smaller level of detail, and so on. Defining modules by this process of finding compromise means that such modules may have a very complex relationship with high level system features, with one module contributing to many such features.

Re-usability of modules is a central concept in design, but it gives urbanists a false impression of systems. "Plug and play" strategies in modular design offer the possibility of replacing a module that fails, or which is superseded by an improved module. This also allows a module to be added to a system without rearranging the entire system. Conversely, a module can be removed when not needed, without requiring a complete re-organization. Plug-in complex modules became popular during World War II in military hardware. Savings in time from the ability to quickly service a complex mechanism -- usually with no specialized training -- overrode the higher cost of replacing a module instead of fixing one of the module's internal components. The same mentality has been inherited by the computer industry, with throwaway modules as today's hardware standard. All of this depends on an interface that permits modules to connect easily to the system. This plug and play capability has been achieved by functionally simplifying the hardware, and moving most of the functional complexity into software. It is extremely difficult to achieve "plug and play" with software modules in a complex real time system, unless the functions performed by different modules have very little interaction (Garlan et al, 1995).

If we had to find a city analogy for the hardware/software separation in computers, the obvious choice would be to identify hardware with buildings, spaces, and infrastructure; whereas software would correspond with people exchanging information through communication and movement. We know that early twentieth century urbanists adopted mass-production techniques from manufacturing, and applied them to cities. One of these was the extreme simplification of city hardware, in the misguided attempt to implement the idea of reusable modules. One should not be surprised, therefore, at the system consequences of this action: separation and segregation of modules, and overburdening people's daily movement with all the functional complexity removed from the city's built structure.

The need of a city to recover from problems and modify functionality is shared by natural systems such as biological brains. Such systems are also forced to adopt a hierarchy of modules, with the appropriate compromise between module equality and the need to minimize information exchange. Absence of such an architecture will in the case of brains result in a brain which has difficulty in recovering from physical damage, or in learning without disrupting earlier learning. A species with such a brain is likely to become extinct. In the case of a city, absence of such an architecture will reveal itself in the inability of finding solutions to urban problems, or responding to changing conditions.

Segregating urban functions (the paradigm for modernist planning) creates aggregates of high level separations which increases the cost of information exchange between aggregates (Salingaros, 1998; 2001). The need for communication at many other levels in addition to within the selected urban functions will create excessive information exchange at an expensive level (e.g. traffic jams), inefficient information exchange (e.g. unproductive time wasted in commuter journeys), the inability of the city as a whole to adjust to changing conditions (e.g. urban decline), or most likely all three.

6. The nature of functional modules in a city

Suppose that city functionality at the highest level were experimentally defined in terms of modules. One of these might be "research", which would include all activities for gaining knowledge about the future. A significant proportion of the activity making up this module would occur within universities, colleges, and schools, but there would also be activity in businesses, government, specialist organizations, etc. Even trying to define this module brings out the key issue. High level functions are in fact physically and institutionally distributed across any living city. To act in a coordinated and effective manner, individuals and groups of people are required to interact in a pattern which will not neatly correspond with the defined functions. In general, it will not be possible for functional modules to be given neat cognitive labels.

For example, a geographical area such as an office park demonstrates this. Typically, there will be much less interaction between different offices in the park than between each individual office and its headquarters, branch locations, customers, suppliers, bankers, etc. Such an area is therefore not a city module. For similar reasons a suburban cluster of houses is not a module (Salingaros, 2001). Creating office parks and suburban clusters makes all genuine functional exchange high cost. This is the system force behind Jane Jacobs' (1961) observation that successful city neighborhoods are always mixed usage.

If information exchange within a city module occurs mainly via direct personal interaction between people, then physical proximity is necessary. This will minimize the travel required. On every level, modules associated with physical areas will perform activities which require the exchange of information, but relate in a very complex fashion to city functions. Only the most simplistic functions (i.e. those which require minimal interaction with any other functions) can be physically separated without loss of city effectiveness. The information exchange needs of different modules will compete, and thus it may be physically impossible to satisfy all the modules' needs for physical proximity to other modules. A compromise definition of modules which minimizes overall information exchange is therefore inevitable.

Consider now some of the obstacles which may be encountered in establishing effective information exchange. If a business or other group discovers the need for intensive personal interaction with groups of people in a different area of the city, the solution is to move. If no suitable premises are available (e.g. because of planning restrictions) then city functionality will suffer. In a different scenario, if there is a need for informal information exchange in a casual environment between a number of groups in an area, but there is no location (e.g. a coffee house) available, again city functionality will suffer.

Creating city "modules" naively by separating identifiable city functions will in general result in an inefficient pattern of information exchange. That, in turn, leads to city dysfunctionality. How can/does a city achieve an effective modular structure and the corresponding networks to support the required information exchange? Given the complexity of real cities, an individual or group of individuals will not have the intellectual capacity or the necessary information to identify the detailed changes needed to improve city effectiveness. Even in an electronic system made up of transistors rather that people, it is extremely difficult to identify the changes needed to implement a desired change without undesirable side effects. Typically, provisional changes are identified, and extensive testing of all system functionality is performed to verify that the new function works as desired, and no undesirable side effects occur. This type of testing is not an option for a city.

The solution is for a city to define its own modules and networks in a distributed fashion. In other words, partitioning into modules has to evolve, with existing modules on every level contributing to functional changes. This change management may in fact be the most complex function performed by a city. It requires that a city adopt some of the forms of the recommendation architecture visible in human brains, to address issues such as context for information exchange between modules, and resolution of conflicting behavioral recommendations from different modules. The effectiveness of different cities can then be compared in terms of the relative effectiveness of their module hierarchies. We are devoting the remainder of this paper to explain these issues in detail.

7. A city works like a brain, not a computer

It is necessary to look into differences in the system architectures of complex systems that work differently, as for example a digital computer versus a mammalian brain. In order to do this, we require some minimal technical background. Even though at first this discussion might appear more suited to a computer science journal, it is nevertheless highly relevant for our conclusions.

Information exchanged between two modules must have some meaning to the recipient module in terms of its own functionality. In electronic systems the context is always completely unambiguous. This means that modules can use their input information to generate outputs that are commands for the system. Thus the functionality of an electronic system is expressed in software as a series of commands. The use of unambiguous contexts results in the familiar memory/processing separation of the von Neumann system architecture upon which most computers are based (Coward, 2000). *Memory* is required to provide a reference copy of unambiguous information available to all modules, and because two modules cannot change the same information at the same time (since that would make it ambiguous) there is a need for a common *processor* which executes instructions sequentially.

Maintaining unambiguous contexts is impractical in a complex system such as a city, however, which has to heuristically modify its own functionality, or learn. In a system which learns, modules must heuristically determine their own inputs and outputs. Nevertheless, if a module changes its outputs, it is difficult for modules which have previously received inputs from that module to readjust. The receiving modules cannot assign a completely unambiguous meaning to the new output. Exchanged information must be meaningful to all recipients, now in a partially ambiguous context. Outputs from modules can only change gradually, in ways that minimize the loss of meaning to other modules. In a city, this means that replacing an entire city area by redevelopment destroys meaningful information exchanged within the replaced area, as well as between the replaced area and other areas. The result is city dysfunction until enough time has passed to rebuild information contexts.

In a complex system which heuristically defines its own functionality there is a major architectural separation between *clustering* and *competition*. A hierarchy of modules (called clustering) coordinates system functionality via information exchange, and a function (called competition) uses module outputs and consequence feedback to determine appropriate system behavior. A competition subsystem interprets the outputs of clustering as a range of alternative behaviors, and quickly selects one of the alternatives. Continuous competition cannot support a complex pattern of information exchange because context could not be maintained.

There are thus two possible information architectures for a complex system. One is the von Neumann architecture with a memory/processing separation supporting unambiguous information exchange, in which functionality is under explicit intellectual control. The other is the recommendation architecture with a clustering/competition separation supporting partially ambiguous information exchange, in which functionality is defined heuristically. A similar idea is behind what is known as a "Darwin architecture" (Calvin, 1987; 1990) where pieces of information compete with each other, and the majority wins out. Thus, a recommendation architecture is based on the repetition of information, and the competition between different pieces of information. Information exchange is ambiguous on its most fundamental level and thus low-level reliability is abandoned. Clustering and competition lead to a recommendation. Such systems achieve overall reliability via stable superstructures (Calvin, 1987).

When it is necessary for functionality to change heuristically, or without central direction, a system adopts the recommendation architecture. Biological brains have evolved a recommendation architecture (Coward, 1990; 2000; 2001). In the mammalian brain the clustering/competition separation corresponds with the anatomical separation between cortex and subcortical structures (Coward, 2000). Commercial electronic systems, on the other hand, invariably use the von Neumann architecture. In the most complex electronic systems it is extremely difficult to evolve functionality in a controlled fashion. When a change is made, extensive testing and error correction is required, with the testing covering not just the modified functionality, but examples of all different system functions.

In many cases functional evolution leads to specialization, resulting in the loss of adaptability. The recommendation architecture uses more resources that the von Neumann architecture to perform the same functionality, so if there is no need for functional change, operational forces push the system towards the von Neumann architecture. Information exchange tends to become unambiguous because the action required in every condition is well understood. However, if conditions begin to change, such a system will find it very hard to adapt. The system can no longer find an effective compromise between module equality and information exchange, which reveals itself in a steadily decreasing ability to make changes. The failure of 19th century Manchester is one example. The city became extremely efficient for the cotton industry, but could not adapt when circumstances changed.

There are interesting similarities between the competitive subsystem as defined here, and legal and political mechanisms. In a physiological brain the competitive function will in general choose one or another option rather than try to find a compromise, because it is impossible to know whether a compromise will not make things worse. Thus the legal and government regulation process for resolving conflict in general selects a winner amongst alternatives rather than generating novel behavior.

8. Ambiguous information recommends actions

An effective pedestrian space is one which provides useful information that helps to determine our behavior and movement (Salingaros, 1999). It should answer questions like: How should I behave in this area; What can I learn in this area; Who can I meet in this area; What can I do in this area; Which way do I go to get to the function I am looking for? The provided information is not a command, but a recommendation which has to be integrated with other recommendations and the needs of the observer to generate a high integrity behavior. Functional information cannot be replaced by geometrical information. In courtyards and amphitheaters, for example, it is not so much the geometry as the human meaning which is attached to the geometry that determines their effectiveness as spatial structures.

How another person behaves in a particular location is information that constitutes a recommendation. A walk in a city area provides observations that are partially ambiguous from the point of view of how to behave there. Information exchange also includes conversations and visits. A visit is an attempt by one function to gain information and to influence (by providing information to) another function. In some cases exchanging information may lead to a physical transaction such as the purchase of a product. Different information is communicated by sending the head of an organization than by sending someone at working level. Either way, the information exchange is partially ambiguous because a range of different subsequent behaviors of the two functions may be consistent with the information exchanged during the visit.

Learning the meaning of visual information is a major attraction for visits to European cities which have only changed gradually over hundreds of years. Undirected wandering in such cities allows the visitor to accept recommendations offered by different visual environments and to discover the results of such acceptance. It is thus possible to learn the "visual language" of the new city. For example, one may learn how to find places by observing and following trends in the visual environment. This is true to a much lesser degree in North American cities, where in many cases rapid redevelopment has destroyed the context for visual information over wide areas.

9. The role of telecommunications

As has been well documented (Droege, 1997; Graham and Marvin, 1996), the advent of telecommunications ever since the introduction of the telephone dramatically altered urban systems. Information exchange intensified to a degree that was previously unimaginable. Telecommunications is low cost in the sense that it requires very little physical movement of people. One of the principal reasons for the initial aggregation of people into cities was in order to communicate with each other at low cost, and this is still the driving force behind, say, the Diamond districts of New York and Antwerp. It could be argued that the need for persons in the same trade to cluster is in part replaced by telecommunications. However, this is only true if the type of information exchanged by telecommunications is exactly the same as that exchanged by personal contact.

Some authors predicted that telecommunications would replace commuting. The reasons this prediction failed are not hard to see when analyzed from the informational architecture perspective. Information exchange through personal contact and people movement has a much richer content, including information derived from a combination of voice tone, expression, and body language. In addition, a visit allows the visitor to observe the quality of office, style of working, and coworker relationships of the visited person, and allows the visited person to observe the reaction of the visitor to these conditions. The multiplicity of sources of environmental information cannot be duplicated by a restricted number of communications channels.

Large corporations have generally found that introducing new communications mechanisms (such as e-mail or videoconferencing) does not in fact reduce the amount of physical travel. The effect of the new communication capability is to increase the complexity of projects which can be undertaken, rather than to replace existing communications. The exception is that if a new communication mechanism results in the same information exchange at lower cost in resources or time, the new one will replace the old. Examples are the replacement of telegraph by fax, and replacement in North America of intercity train travel by air travel.

Telecommunications fits into the hierarchy of different channels of movement and information exchange in a city (Drewe, 1999; 2000). Working from home via an electronic link is now feasible, and there are several instances of successful applications. First, the mother with small children at home, and the handicapped or elderly individual can now link to informational nodes that would otherwise be too costly (in terms of time and arrangements) to interact with physically. Second, powerful and wealthy individuals set up residence in some fancy resort, and conduct their business via electronic links. This is made possible because their financial resources enable them to have all necessary information available, and any personal level of information exchange is taken care of by a quick trip. The module here is an informationally stimulating environment for those who can afford it.

An office worker can in principle work from home to perform a task that requires only a narrow information link. Someone stuck in an informationally starved environment may not be altogether happy to work exclusively from home, however. He or she normally prefers to fight rush-hour traffic because that at least gives some informational stimulation, and enables face-to-face information exchange with coworkers. Suburbanites spend hours on the telephone and in front of the television for this very reason, and still feel informationally deprived. The workplace has for many people replaced the home as the primary social node. People don't just want to eliminate the ordeal of a lengthy daily commute by car, bus, or train; they want to get their daily information exchange with a lesser inconvenience. Today we pay an inordinately high price in automobile traffic for very little meaningful information.

10. Networks and evolving city form

Unless adequate meaning can be conveyed by telecommunications, information exchange will involve the movement of people. The time required for people movement is an overhead cost on any information exchange other than telecommunications. This overhead cost is lowest for an exchange which can be carried out by a short neighborhood walk, and greater if it requires a longer journey by mechanical transport. The effective overhead cost is reduced if the journey time can be used for some other functional purpose, such as a necessary information exchange with functions at intermediate locations.

An effective transportation network will allow a high proportion of required information exchange to take place via short neighborhood walks (say < 10 minutes each way) with secondary information exchange; an intermediate proportion to take place by moderate overhead mechanical transport (say < 30 minutes each way); and only a small proportion requiring high overhead mechanical transport (say from 30 minutes to 1 hour each way). Journeys which occupy in total much of a working day or more will in general be ruled out. The distribution of both pathlengths and journey times should follow an inverse-power scaling law favoring the small scale: the number of paths is inversely proportional to their length (and the same for journey times) (Salingaros, 2001).

Creating an effective network depends on the functional partitioning of the city, and will always require a compromise. The decision to reduce the overhead for one type of trip may increase the overhead for another type of trip. For example, widening a road and increasing vehicular traffic may make many pedestrian trips across the new road much longer, or make them altogether impractical, thus destroying a functional module. It is therefore essential to investigate whether an apparent demand for a new high level network connection such as a major road could be addressed by a different module partitioning, which might reduce the need for trips in the direction of the proposed road.

A city's connectivity at different levels down to capillarity is responsible for its life. Dead zones are a result of loss of network connectivity. Spatial nodes and their network are interdependent, and their mutual causality reveals the dynamic evolution of city form. Networks follow the functional reorganization of a city as it tries to make itself more connected on all levels. Automobiles and pedestrians connect at the pedestrian system level, but the car works entirely on a distinct, higher system level. Gabriel Dupuy has initiated a clearer understanding of these problems (Dupuy, 1995; 1999). The systems approach clears away decades of misunderstandings that led to such acts of violence to urban systems as cutting expressways through historical city cores. The automobile network must adapt itself into -- rather than disrupt or replace -- the network of information exchange that powers a compact, living city.

Change in a city is ubiquitous. The goal of urbanism is to help a city evolve and re-define its modules so they can modify their functionality. It is not easy to determine the appropriate module and network changes so as to respond to changes in the city's needs and environment. Urban change must be a natural built-in function of the system, driven by a complex pattern of information exchange. As discussed earlier, centrally directed changes typically introduce large numbers of unanticipated and undesirable side effects. Any attempt at total central direction of modules and networks on every level will result in steadily increasing dysfunctionality. Planning now focuses on large-scale interventions, and does not tolerate spontaneous evolution driven by input at different levels.

Different modules on every level will need to generate alternative recommendations for module and network change. A simple competitive process must select the most appropriate change. Consequence feedback then has to adjust the competitive subsystem to evolve its selections towards those that optimize the network. Knowledge relevant to one change may exist on a number of levels. There must therefore be mechanisms by which modules at many different levels of detail recommend change, which can then be received, interpreted, and integrated into a decision that optimizes overall city effectiveness.

Changes must also be constrained by the need to maintain the context for information exchange; again an issue most likely to be understood at a more detailed level. A learning process in the physiological sense is associated with the definition of information conditions which repeat in the experienced environment. In cities there will be a process of trial and error by which module conditions on various levels gain or lose influence on changes of different types to city modules and networks. Less successful cities can copy explicitly from more successful cities, provided that the functional relationships are copied, and not just physical structures and individual institutions.

An example of this process in action can be found in Jane Jacobs (1961). A city planner (Robert Moses) wanted to widen a road through a neighborhood at the expense of neighborhood sidewalks. The reduction in sidewalks was resisted by the neighborhood, which managed to gain enough political support through alliances with other neighborhoods to not only prevent the sidewalk reduction, but in fact to get sidewalk widening. It turned out that the traffic on the affected road was reduced (presumably it was carrying longer range traffic rather than local pedestrian traffic), but there was no sign of increased traffic on other roads in the area. The implication is that many of the car journeys on the target road were replaced by shorter (presumably somewhat less effective) journeys. For example, rather than going to a specialist shop far away, a local shop with fewer choices could replace the need for a journey. The result is that overall city effectiveness improved.

11. Conclusion

We identified the system architecture of cities by comparing them to complex information systems such as computers, biological organisms, and the human brain. A city works according to an information architecture that recommends, but does not demand an action. Functionality on all levels of scale is driven by the need to optimize information exchange, from a face-to-face meeting between two persons, to the movement of individuals, up to the daily movement of many people between nodes. Functional modules should develop in a way such that more information is exchanged within a module than between different modules. Cities, like human brains but unlike electronic systems, must modify their functionality without explicit intellectual control over every detail of the change. Our model allows us to help a living city repair itself much as a living organism does, and to guide its evolution under changing conditions. Rather than using models based on visually regular aerial geometries, this approach makes it possible to evaluate changes to city plans, zoning codes, transportation, and communication networks in terms of their impact on overall city effectiveness.

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