CONCEPTUALIZING THE PRINCIPLES OF EMERGENT URBANISM

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Abstract

This article is the product of reflections on the consequences of the latest discoveries in complexity science upon the practice of urban design. Its intent is to establish a foundation for a new debate in urban design, which is trapped in production processes inherited from a failed ideology, modernism, but has had no scientific alternative until the last decade. It will not argue over the superiority of one urban design morphology over another, the debate that many urban designers are engaged in, but make the counter-intuitive claim that urban design morphology is an unimportant determinant of the life and sustainability of a city, and that the relevant determinant is the process through which the city is grown. From the starting point that spontaneous city growth is absolutely necessary for sustainability, techniques to produce large-scale geometric order are reintroduced that respect this condition and produce order out of the random actions of large numbers of individuals, a phenomenon known as emergence. With this insight, urban design is explained as the selection of urban growth processes that emerge desirable patterns.

Keywords

Complexity; emergence, morphology, fractals; sustainability.

Introduction

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The Journey to Emergence

Of the different domains of design, urban design is an oddity. While the design of a machine can be traced to a definite, deliberate act of invention, and even the design of buildings (architecture) is rooted in known production processes, the design of cities was never seriously attempted until well after cities had become a normal, ordinary aspect of civilized living, and while the design of machines and buildings was a conscious effort to solve a particular problem or set of problems, cities appeared in the landscape spontaneously and without conscious effort. This casts doubt over the efficacy of urban design. The designers of machines and buildings know fully how the processes that realize their design operate, and this knowledge allows them to predictably conceive the form they are designing. Urban designers do not enjoy such a certainty.

How is it possible for what is obviously a human artifact to arise as if by an act of nature? The theory of a spontaneous order provides an explanation. According to Friedrich A. von Hayek (Hayek, 1973) a spontaneous order arises when multiple actors spontaneously adopt a set of actions that provides them with a competitive advantage, and this behavior creates a pattern that is self-sustaining, attracting more actors and growing the pattern. This takes place without any of the actors being conscious of the creation of this pattern at an individual level. The spontaneous order is a by-product of individuals acting in pursuit of some other end.

In this way cities appear as agglomerations of individually initiated buildings along natural paths of movement, which originally do not require any act of production as dirt paths suffice. As the construction of individual buildings continues the most intensely used natural paths of movement acquire an importance that makes them unbuildable and these paths eventually form the familiar “organic” pattern of streets seen in medieval cities. This process still takes place today in areas where government is weak or dysfunctional, notably in Africa where urban planning often consists of catching up to spontaneous settlement, and in the infamous squatter slums that have proliferated in the 20th century. Figure 1 shows a transect of the spontaneous urbanization process in the exurbs of Mexico City.

As urbanization becomes denser, the increasing proximity of concurrent, competing individual interests causes conflicts between the inhabitants of the emerging town. Individuals build out their properties in such a way that it interferes with others, for example by blocking paths or views. These acts threaten the sustainability of the spontaneous order, and to resolve this situation the parties involved appeal to the same judges that rule on matters of justice. These judges, again according to Hayek, are required to restore and preserve the spontaneous order with their rulings. These rulings provide the first building regulations and, when government authority becomes powerful enough to do so, are compiled into comprehensive building codes to be applied wherever the force of that government extends. (Hakim, 2001).

Figure 1: A transect of the city of Tultepec in Mexico provides a snapshot of the different phases of spontaneous urban growth. (Google Earth image).

The compiled building codes are later brought by colonists to create new settlements, reproducing the morphology across multiple towns but each time in a pattern that is adapted to the local context, physical and social. Early town planning efforts are attempts at regularizing the building codes in order to plan for long-term organization of cities, but maintain the spontaneous production process. Most notably the rapid urbanization of New York City was accomplished by very simple rules on the size of blocks laid out in the 1811 Commissioners Plan for New York. Unlike the experience of urbanization in previous centuries, where urban growth was slow and often stagnant, the urbanization of New York took place in a time of rapid social and economic changes, and the city government had to invent building codes involving issues that never could arise in a pre-capitalist society: first the tenement, then the skyscraper, and ultimately, the automobile.

Modernism: The Replacement of the Spontaneous Order

Architects and urban planners of the early 20th century, confident in the techniques of engineering and industrial production, believed that the spontaneous city had become irrational and had to be replaced with a new design fully integrating new industrial technology. The Swiss architect Le Corbusier is famous for designing a complete city around the automobile and building models of his design, as shown in figure 2. In so doing he adopted a process of urbanization that was completely planned hierarchically, applying the processes familiar to architects at the scale of an entire city. He also ridiculed the morphology of spontaneous cities as being the product of donkey-paths.

Although the architectural program of high-rise living of Le Corbusier was discovered to be a colossal failure, the modernist process of development replaced spontaneous urbanization in the industrialized world. The housing subdivision substituted adequately for the high-rise tower block, providing affordable housing in large numbers to a war-impoverished society. This production process is still in force today, separating cities into three distinct zones: residential subdivisions, industrial and office clusters, and commercial strips.

Modern city planning has been successful at its stated objective, producing a city designed specifically around automobile use, yet it was immediately and has been perpetually the target of criticisms. Most significantly the vocabulary of these criticisms had to be invented in order to spell out the critics' thoughts because the type of deficiency they were observing had never been seen. Words like placeless or cookie-cutter were invoked but fell on the deaf ears of urban planners who were trained in

Cartesian processes and industrial production techniques.

Figure 2: This scale model of Le Corbusier's Plan Voisin marks the turning point where city plans as constraints on individual initiative are replaced with architectural design at the scale of millions of inhabitants. (Le Corbusier, 1964).

The most devastating criticism of modernist urban planning came in the form of a sociological study and personal defense of the spontaneous city, the book Death and Life of Great American Cities by Jane Jacobs. (Jacobs, 1961) In it she described in great details how the functions of a spontaneous city related and supported each other. Her concluding chapter, the kind of problem a city is, is still the most relevant. In it she attacks the scientific foundations of urban planning at a paradigmatic level, and claims that the methodology of the life sciences, at the time undergoing the revolution created by the discovery of DNA, is the correct approach to producing cities.

Death and Life of Great American Cities has been adopted by contemporary urban planners as a textbook for urbanity. Its descriptions of the characteristics of a city are now the models upon which new developments are planned. The old urban development of housing subdivisions and office parks is being substituted for the new urban development that has streets, short blocks, and mixed uses, just as Jacobs had described to be characteristic of life in the city. A major difference between Jane Jacobs' preferred city and the new urban plans remains. The layout of mixed uses is organized and planned in the same process as Le Corbusier planned his city designs. The scientific suggestions of Jacobs have been ignored.

The Discovery of Emergence and Complexity Science

Since Jacobs published her attack on planning science molecular biology has made great technological achievements and provided countless insights into the morphology of life. In parallel the computer revolution has transformed the technology of every human activity, including that of design. But the computer revolution brought along some paradigm-altering discoveries along with its powerful technology. In geometry, the sudden abundance of computing power made it possible for Benoit Mandelbrot to investigate recursive functions and his discovery, fractal geometry, generated a universe of patterns that occurred in many aspects of the physical universe as well as living organisms. (Mandelbrot, 1986).

Some thinkers saw that the life sciences were part of a much more general scientific domain. They formed the Santa Fe Institute and under the label complexity studied not only organisms but also groups of organisms, weather systems, abstract computational systems and social systems. This research formed a body of theory called complexity science that has resulted in the creation of similar research institutes in many other places, including some centers dedicated specifically to urban complexity.

Their scientific revolution culminated in two major treatises within the last decade, both from physicists practicing in a field of complexity. The first was A New Kind of Science by computer scientist and mathematician Stephen Wolfram (Wolfram, 2002), where he presents an alternative scientific method necessary to explore the type of processes that traditional science has failed to explain, elaborating a theory of the universe as a computational rule system instead of a mathematical system. The second was The Nature of Order (Alexander, 2004) by architect Christopher Alexander, where he presents a theory of morphogenesis for both natural physical phenomena and human productions.

A Definition of Emergence

To define what is meant by emergence we will use the abstract computational system upon which Wolfram bases his theories, the cellular automaton. Each cell in a row is an actor, making a decision on its next action based on its state and the states of its direct neighbors. All cells share the same rule set to determine how to do this, that is to say all cells will act the same way with the same context. In this way each row is the product of the actions of the cells in a previous row, forming a feedback loop. The patterns of these rows are not in themselves interesting, but when collected in a sequence and displayed as a two-dimensional matrix, they develop complex structures in this dimension, as shown in figure 3.

The same general principle underlies all other emergent processes. In a biological organism a single cell multiplies into exponentially greater numbers of cells that share the same DNA rules. These cells create structures in a higher dimension, tissues and organs, which form the entire organism. In the insect world complex nests such as termite colonies emerge from the instinctual behavior of individual termites. And in urbanization, buildings form into shopping streets, industrial quarters and residential neighborhoods, each of which forming a gradient with no obvious boundaries and overlapping into one another as a single whole system, the city.

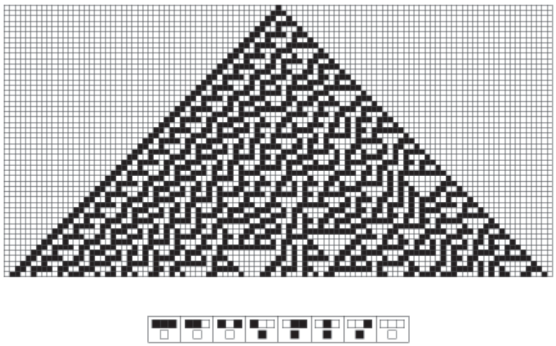

Figure 3: The 30th rule of all possible rules of one-dimensional cellular automata produces a chaotic fractal when displayed as a two-dimensional matrix, but most other rules do not create complex two-dimensional structures. The first line of the matrix is a single cell that multiplies into three cells in the second line in accordance with the transformation rules pictured below the matrix. This process is reiterated for the change from the second to the third line, and so on. All the information necessary to create structures of this complexity is contained within the rules and the matrix-generating process. (Wolfram, 2002).

The Qualities of an Emergent City

The adoption of mass-production processes, or development, in substitution for spontaneous urban growth in the mid-20th century created for the first time a phenomenon of alienation between the inhabitants and their environment. While the physical features of spontaneous cities could be traced to complex histories of families, businesses, and organizations, the physical features of planned cities owe their origin only to the act of planning and speculation. This has severe consequences towards the sustainability of place as there will not grow any particular attachment by the residents, their presence there being only a temporary economic necessity and not the outcome of their life's growth. Mass-production of the environment left people as nothing more than consumers of cities where they used to be their creators. A building culture was replaced with a development industry, leaving the landscape culture-less and with no particular sense of identity. This took place despite the evidence that a building which has a unique history and has been fitted to someone's life, as opposed to speculatively produced, generates market value for that property. (Alexander, 1975) This is why, although the demolition of so-called "slums" to replace them with modern housing projects created a great deal of opposition against urban renewal programs, the demolition of the housing projects later on did not lead to a popular preservationist opposition. They were not the physical expression of any culture.

In addition to cultural patterns, spontaneous settlements also have a peculiar morphology that has not successfully been imitated by modern growth processes. Spontaneous settlement processes give individuals full freedom to determine the boundaries of their properties. Spontaneous settlement is one where total randomness in building configuration is allowed, with no pre-determined property lines acting as artificial boundaries. Buildings and building lots as such acquire general configurations comparable to cell structure in living tissues, unique sizes and boundaries that are purely adapted to the context in which they were defined. In the absence of abstract property boundaries, property rights are bounded by real physical limits such as a neighbor's wall. (Hakim, 2007).

Very attractive spontaneous cities, sometimes labeled "historic" cities, feature a specific pattern of the urban tissue to complement the previous two qualities. It consists of similar vernacular buildings that appear very simple when considered individually, but produce a visually fascinating landscape when considered as a whole. This is a form of fractal geometry. In mathematics a fractal is a geometric object of infinite scale that is defined recursively, as an equation or computation that feeds back on itself. For example the Sierpinski triangle is defined by three triangles taking the place of one triangle as in figure 4.

In addition to its remarkable similarity to natural phenomena, this form of geometric order informs us of a very important law in geometry: a feedback loop that is fed through the same function will produce an ordered but unpredictable geometric pattern out of any random input.

The Mandelbrot Set is a much more interesting fractal that is defined as a simple recursive

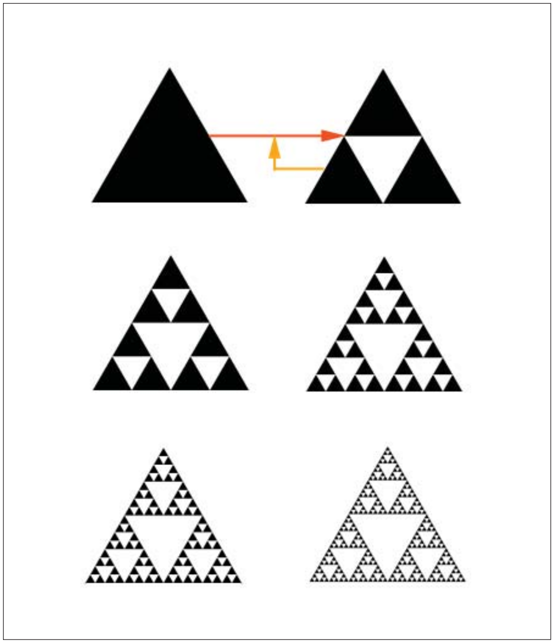

Figure 4: A triangle triggers a feedback function that produces three triangles, which themselves trigger the feedback function to produce nine triangles, and so on. This process can unfold as long as computational resources can be invested to increase the complexity of the object. (Source:Author).

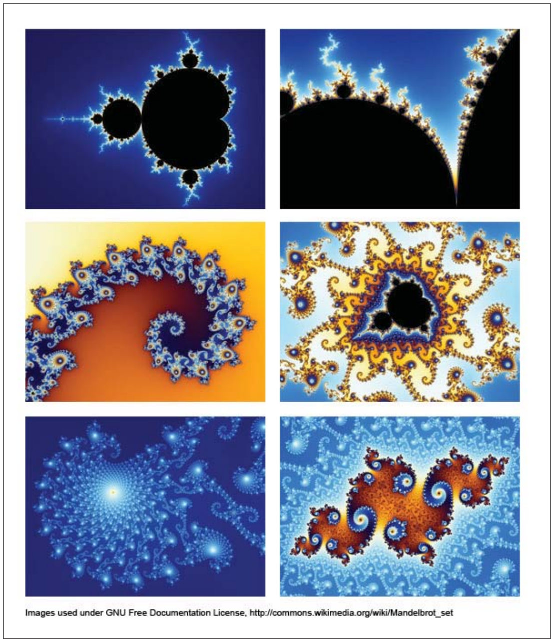

Figure 5: The image on the right is a deeper magnification of the image on the left, produced with a narrower range of coordinates as the input of the Mandelbrot set's feedback function (Source:Author).

mathematical equation, yet requires a computation to visualize in its full complexity. When computing how many cycles of feedback it takes for the equation to escape to infinity for specific coordinates, figure 5 is the outcome.

This tells us why cities of vernacular buildings have such appealing geometric properties at the large scale, despite being often shabby and improvised at the scale of individual buildings. Shanties made of scrap metal and tarp look rough at the scale of the material, but because multiple shanties share their construction process despite originating from random conditions they form an ordered geometric pattern with its specific “texture”. The same law applies at other scales of feedback, for example the production of a door. Whether the input for one door is larger, taller, wider than another door, if the same production process is employed the two doors will contribute to the overall fractal order of the urban space. This law has been employed not only in traditional and spontaneous cities, but also for modern urban planning initiatives.

In the New York City neighborhood of Times Square the structure of billboard advertisements is defined by a building code that determines their configuration in relation to the configuration of the building. The outcome is a unique tissue of advertisement billboards that has become more characteristic of the neighborhood than the buildings themselves, which are not produced by a shared feedback function.

Fundamentals of Urban Complexity

Christopher Alexander showed in A City is not a Tree (Alexander, 1965) that social and economic networks formed complex semi-lattice patterns, but that people who observed them limited their descriptions to a simple mathematical tree of segregated parts and sub-parts, eliminating connections in the process. (Figure 6 compares the structure of a tree and semi-lattice.) In attempting to plan for urban structure, a single human mind, without a supporting computational process, falls back on tree structures to maintain conceptual control of the plan, thus computing below spontaneous urban complexity, a phenomenon that is consistent with Wolfram's theory of computational irreducibility of complex systems. (Computational irreducibility states that the only accurate description of a complex system is the system itself and that no abstraction or reduction to a simpler process is possible.) Nikos A. Salingaros later detailed the laws of urban networks in Theory of the Urban Web. (Salingaros, 1998) Network connections form between nodes that are complementary, and therefore the complexity of networks depends on an increasing diversity of nodes. Salingaros describes the urban web as a system that is perpetually moving and growing, and in order to do this the urban tissue has to grow and move with it. Consider for example the smallest social network, the family. Debate over accessory units or "granny flats" has intensified as normal aging has forced the elderly out of their neighborhoods and into retirement complexes, while at the other end of the network young adults entering higher education or the labor market vanish from a subdivision, leaving a large homogeneous group of empty-nesters occupying what was once an area full of children, and often forcing school closures (a clear instance of unsustainability).

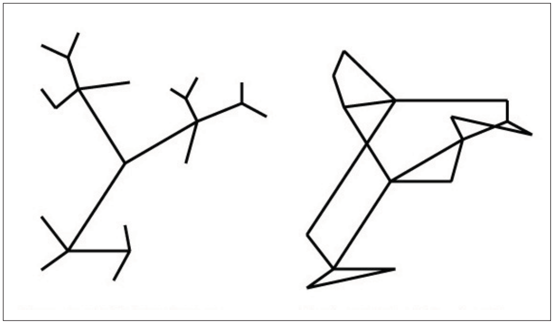

Figure 6: A comparison of a tree pattern on the left and a semi-lattice pattern on the right. The tree structure is made of groups and sub-groups that can be manipulated separately from others. The semi-lattice pattern is purely random without distinct sub-parts. (Source:Author).

These social networks grow more complex with increasing building density, but a forced increased in density does not force social networks to grow more complex. For instance the spontaneous settlements of slums in the developing world show remarkable resilience that authorities have had difficulty acknowledging. Because of squalid living conditions authorities have conducted campaigns to trade property in the slum for modern apartments with adequate sanitary conditions. To the authorities' befuddlement some of the residents later returned to live in the slum in order to once again enjoy the rich social networks that had not factored in the design of the modern apartments and neighborhoods, demonstrating that the modern neighborhoods were less socially sustainable than the slums.

In commercial networks, space syntax research (Hillier, 1996), using a method for ranking nodes of semi-lattice networks, has shown that shops spontaneously organize around the multiple scales of centrality of the urban grid at its whole, creating not only commercial centers but a hierarchy of commercial centers that starts with sporadic local shops along neighborhood centers and goes all the way to a central business district located in the global center of the spatial network. The distribution of shops is therefore a probabilistic function of centrality in the urban grid. Because the information necessary to know one's place in the hierarchy of large urban grids exceeds what is available at the design stage, and because any act of extension or transformation of the grid changes the optimal paths between any two random points of the city, it is only possible to create a distribution of use through a feedback process that begins with the grid's real traffic and unfolds in time.

The Built Equilibrium

Although they may appear to be random, new buildings and developments do not arise randomly. They are programmed when the individuals who inhabit a particular place determine that the current building set no longer provides an acceptable solution to environmental conditions, some resulting from external events but some being the outcome of the process of urban growth itself. It is these contextual conditions that fluctuate randomly and throw the equilibrium of the building set out of balance. In order to restore this equilibrium there will be movement of the urban tissue by the addition or subtraction of a building or other structure. In this way an urban tissue is a system that fluctuates chaotically, but it does so in response to random events in order to restore its equilibrium.

This explains why spontaneous cities achieve a natural, "organic" morphology that art historians have had so much difficulty to describe. Every step in the movement of a spontaneous city is a local adaptation in space and time that is proportional to the length of the feedback loops and the scale of the disequilibrium. For spontaneous cities in societies that experience little change the feedback loops are short and the scale of disequilibrium small, and so the urban tissue will grow by adding sometimes as little as one room at a time to a building. Societies experiencing rapid change will produce very large additions to the urban tissue. For example, the skyscraper index correlates the construction of very tall buildings with economic boom-times, and their completion with economic busts. The physical presence of a skyscraper is thus the representation of a major disequilibrium that had to be resolved. (Thornton, 2005) The morphology of this change is fractal in a similar way that the movement of a stock market is, a pattern that Mandelbrot has studied, the result of a process that changes in proportion to its scale. In general we can describe the property of a city to adapt to change as a form of time-complexity, where the problems to be solved by the system at one point in time are different from those to be solved at a later point in time. The shorter the time-span between urban tissue transformations, meaning the shorter the feedback loops of urban growth, the closer to equilibrium the urban tissue will be at any particular point in time.

Modern urban plans do not include a dimension of time, and so cannot enable the creation of new networks either internally or externally. They determine an end-state whose objective is to restore a built equilibrium through a large, often highly speculative single effort. They accomplish this by creating a large-scale node on existing networks. In order for such a plan to be attempted the state of disequilibrium in the built environment must have grown large enough to justify the immense expense of the new plan. This is why development will concentrate very large numbers of the same building program in one place, whether it is a cluster of 1000 identical single-family homes or a regional shopping mall, just like the skyscraper concentrates multiple identical floors in one place. Demand for these buildings has become so urgent that they can find a buyer despite the absence of local networks, the standardized building plan, or the monotonous setting. This is not as problematic for large cities for which a single subdivision is only a small share of the total urban fabric, but for smaller towns the same project can double the size of the urban fabric and overshoot the built equilibrium into an opposite and severe disequilibrium.

The mixed-used real estate development has attempted to recreate the sustainable features of the spontaneous city by imitating the morphology of sustainable local economic networks. It has not reintroduced the time dimension in economic network growth. Often this has resulted in a commercial sector that serves not the local neighborhood but the larger region first, consistent with the commercial sector being a product of large-scale economic network disequilibrium. In other developments the commercial sectors have struggled and been kept alive through subsidies from residential development, another instance of unsustainability.

The sustainability of any natural system is its ability to renew itself for changing circumstances, restoring its equilibrium with the environment. An emergent city possesses this ability through a very responsive urban tissue that can restructure itself whenever necessary (much like cell growth in multicellular organisms). Modern planning has interfered with this process insidiously, sometimes going as far as banning urban tissue change after the initial design for fear that change would cause the system to break down, while in reality change is what keeps the system stable. This contradiction has been the principal cause of failure in modern cities.

How Emergent Urbanism Works

In a traditional spontaneous city, 100% of the surface is initially a network structure, open land. From this surface the best paths are selected to fit the networks that are emerging, and the leftover space is progressively built upon. Starting with a completely open, fully-connected land structure, the city's design can consist of a purely negative process by placing constraints on construction over important paths. In this way the street structure and hierarchy becomes an evolved structure that matches the history of its

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networks, and the placement of buildings and uses is also an evolved structure that matches the flows of movement. Over time these paths are paved and upgraded, and important junctions of paths become the central open space of the city. The central square of a spontaneous town can be explained as the remainder of a fractal process of subtraction, with the most underused part of the spatial network being removed at each additional step of feedback until no further network subtractions are possible. With the circulation of people optimized, the remaining space is augmented with street furniture specifically designed for crowds, such as benches, transit stops, billboards, kiosks and so on.

An emergent city similarly begins with a network structure, although one that is much more sophisticated than open land. In modern design the typical asphalt street produces a network that is suited particularly to automobile networks, but also has the unfortunate side-effect of cutting pedestrian networks that normally enjoy the entire surface in a spontaneous city. As a remedy these streets are equipped with sidewalks that are often narrow and unpleasant (if not dangerous) to walk, an effort at translating strict traffic control methods to the pedestrian. It is not surprising that pedestrians are so rare in modern cities, but some efforts have shown that pedestrian networks can emerge from modern design. One example is the three-story deck of the La Défense business city in Paris (shown in figure 7), which contains parking but also regional rail and subway links, as well as being an open pedestrian surface. At the ends of this network structure a generative process of spontaneous development creates the actual networks of the city. As evidenced by the crowds present on that surface and the abundance of neighborhood shops the pedestrian networks function quite well. What is more surprising is that the automobile networks are underused and some parking structures empty, despite the neighborhood having been conceived for the automobile.

Figure 7: The "pedestrian slab" style of design was blamed for the failure of modernist urban planning projects, but at La Défense the slab is a working structure. The developer adopted spontaneous building development instead of applying the complete architectural plan, enabling the formation of a dense local economy. (Source:Author).

Because of the high costs and other complexities involved in producing networks for modern transportation systems it is not possible to practice a purely negative and subtractive process of street formation. However the network structure must still be an evolved structure that is produced with feedback from lot development instead of building an entire grid before it has been decided what size of lot is needed. Most importantly all forms of movement must be in balance in

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the street design so that one type of network structure does not cut another and prevent the network formation process. (Salingaros, 1998).

The Cultivation of a Spontaneous City

Once a network structure is in place the process of network formation can begin.

Wiki systems have shown that the simple freedom to create does not necessarily produce networks unless there also exists a simple interface to this network. The World Wide Web provided a system of linked websites that could spontaneously produce an encyclopedia for many years before the Wikipedia system catalyzed the distributed knowledge of millions of people into an exponentially growing and internally coherent system. The creation of crowd-catalyzing systems has since been named "crowdsourcing." Translating crowdsourcing principles to planning processes, Alexander described in The Oregon Experiment how an institution could directly support the spontaneous development of its city by providing designers and managers to assist individuals and realize the program that the individual users have in mind. (Alexander, 1975).

With the initiative for developing new building programs left deliberately undefined and in the hands of the individuals and organizations that develop the socio-economic networks of the city, there remains the issue of producing a geometrically coherent landscape that is harmonious and distinctive. This is accomplished with shared generative processes, (Alexander, 2004) and particularly the nesting of generative processes into one another (also known as a shape grammar or form language), as shown in figure 8. No matter what configurations of space are required by any individual building program, if this configuration is realized physically by the same building process as for any other random configuration then the two realized buildings will share symmetric properties and the result will be a harmonious geometric order. This has been employed in many instances by the regulation of construction materials, which creates a geometric order at the scale of texture, but it also applies for any other scale of geometry, as

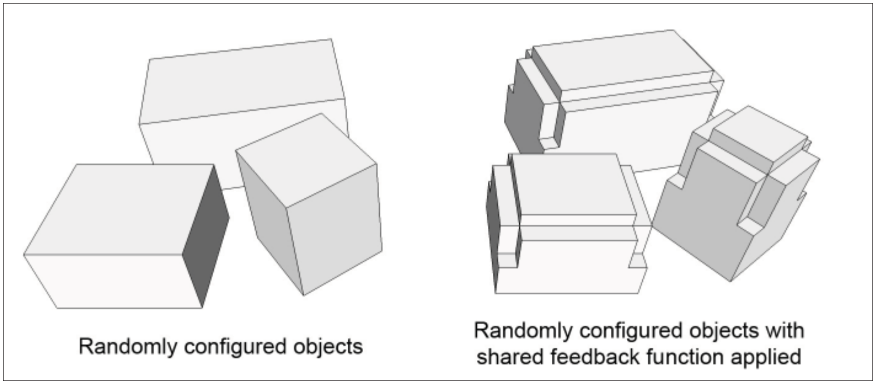

Figure 8. Three volumes are randomly defined in space without relation to each other. When a shared feedback function is applied to transform these volumes the volumes become related by these transformations. The function in this case is: 1 – Cut out the top corners to half the volume's height, 2 – Raise the center of the roof. (Source:Author).

evidenced by the geometric order created by the advertisements in Times Square.

By defining construction processes instead of fixed building designs it is possible to plan for future growth without eliminating spontaneous growth and feedback. A developer that is initiating a program of emergent urbanism can therefore prepare for construction in advance of any projects having been determined. Building high-technology structures is a complex art that requires significant expertise and a skilled workforce. The developer that creates adaptive building processes that can be used to generate and realize building plans easily and rapidly will provide the same spontaneity as squatter settlements achieve.

As evidenced by the popularity of historic towns of Europe and particularly the Mediterranean as tourist destinations there is enormous demand for and profit to be made from cities that adopt the geometry of emergent cities. For this to work however the development and banking industries must be persuaded of the effectiveness of process design as opposed to master planning, and the municipal authorities must be willing to approve urban design with no fixed configuration. (Alexander, 2004). Political issues also create a significant obstacle. The long approval processes that one must go through to develop a new city or neighborhood have significantly increased the length of the feedback loops and favored large-scale development as well as made small communities less competitive. Even when long review or public consultation processes can be avoided, a development has to comply with weighty subdivision and building codes that consume time to absorb and understand, and in so doing contribute to lengthening the feedback loops and making the urban tissue less adaptive and less sustainable.

The Urgency of Emergent Urbanism

The recent disappearance of speculative real-estate financing makes "development" in the conventional sense an enterprise that fewer cities can continue. Many cities have been left with financial deficits along with new subdivisions in a state of arrested development, where "ghost grids" are occupied by only a handful of homes. In the developing world urbanization is either proceeding at an unprecedented scale, enticing municipal authorities to develop skyscraper suburbs, or has spun completely out of control to produce shantytowns. A middle ground must be found that can result in a sustainable human habitat.

The existence of low-density suburbs has been normal for all cities in history. These suburbs had socio-economic networks that were less dense and diverse but just as complex as those of urban centers. The pattern of suburban sprawl, characterized by housing subdivisions, office and industrial parks, and commercial strips, has little in common with those traditional suburbs. Life in suburban sprawl involves frequent and extensive automobile trips, which traditionally was not possible, that correspond in length to the scale of network development and feedback loops. Automobile dependency was not as noticeable when sprawl development was grafted onto an existing spontaneous city, and it was thus possible to live partially urban lifestyles, taking advantage of the local networks in a "central business district", while retiring every night to a house in a "dormitory" suburb such as the one in figure 9. In many places there are no such urban centers left or they have become insignificant in size compared to sprawl areas. Traditional suburbs were not so dependent on urban centers, they provided a complete living environment within a small area, and as they grew denser they eventually offered a greater range of lifestyles that made them indistinguishable from urban centers. Sprawl development has not followed this time pattern. The conclusion is that sprawl is not characterized by a low-density pattern of urbanization but is, far from it, an enormous increase in the scale of the urban web and the process of urban tissue growth. This has been shown by the negative consequences of density increases in Los Angeles, the model of sprawl development, where increased population densities, instead of reducing automobile use, have exacerbated the automobile dependency of sprawl. (Eidlin, 2005).

Figure 9. High-density suburban sprawl development outside Portland, OR, clusters homogeneous buildings and creates no internal networks other than with a few green spaces. (Google Earth image).

American-style sprawl, characterized by the housing subdivision, has provided no space for local pedestrian networks to form on top of its disconnected pedestrian structure. Sidewalks are built but they pale in comparison to the freedom and comfort of movement enjoyed in traditional cities where the entire street belonged to pedestrians. Since no space was left over for spontaneous urban growth to take place over time, and municipal zoning or community associations have made it impossible for spontaneous growth other than housing to take place, American-style sprawl deals two critical blows to local network growth. It should therefore be no surprise that subdivision-suburbs have been criticized for their anti-social properties. In a completely different style, Asian-type construction of large clusters of high-rise residential buildings connected to mass transit, although fitting the requirement for density many urban planners insist upon, shares more with the housing subdivision than the spontaneously dense city. It is a tree-like structure of repetitive housing programs that does not grow its own internal networks. Such development can also be tolerable when connected to spontaneous cities in the same fashion that American-style sprawl did, but as more of the spontaneous tissue is removed whole to be replaced with such clusters the drawbacks of sprawl appear.

The proliferation of slums in developing countries has been most severe where attempts at deliberate urban planning have been most intense. One model is the city of Brasilia, which is world famous as a gargantuan attempt at landscape architecture under the principles of modernism. The large-scale architectural structure of Brasilia has become complemented by spontaneous suburbs, favelas, which represent a complete opposite of the planning process of the government-dominated urban center. This is by itself a very clear demonstration of the concept of built equilibrium as the most ambitious attempt at deliberate urban planning has sustained itself only with one of the most unplanned forms of urbanization to balance it. Initiatives to normalize squatter settlements have been successful at improving living conditions, but they only reduce hardship after the fact. In order to prevent slums from appearing, spontaneous urban design for new cities must be adopted by the authorities. This same spontaneous urban design must replace sprawl.

Urbanism as a Science

Wolfram explained the scientific constraints of complexity science by proposing that any computation that demonstrates complex behavior is computationally irreducible, meaning that there is no other process or mathematical formula that can describe the behavior and predict outcomes in fewer computations than the process itself. For linear processes common in mechanical systems it is possible to predict action using known physical equations, and engineering of mechanical systems relies on this predictability. But, once again according to Wolfram, insisting on using predictable processes deprives us of processes that are truly complex. This explains why modern processes in planning and building cities have resulted in an inferior environment than the urbanity that was produced by spontaneous, evolved processes. It is also why Alexander introduced The Process of Creating Life by insisting that modern Cartesian processes had to be replaced with generative processes. (Alexander, 2004).

Wolfram's new scientific method, whose intent is to discover complex emergence, relies on explicit simulation of large numbers of different rules in the same process class to substitute for natural evolution. This means that it is not necessary to wait for a spontaneous order adapted to modern conditions to manifest itself naturally, that instead we can search for one scientifically. In Wolfram's system visualization and algorithmic search through the output patterns identify the rules which generate emergent complexity. This of course means a limit in predictability that has long been familiar in the social sciences, that only the general pattern of a process can be known from its rules and that no precise prediction can be computed. Computational irreducibility means that full knowledge is required of the input in order to compute the output. We cannot possibly centralize all the information that motivates all individuals who create a city (Hayek, 1945), and so we must accept that only patterns are predictable and not specific form.

What is possible with a methodology of explicit process simulation is to compare the quality of one process to another and find patterns that were not designed or engineered into the process (emergent patterns). Some of these patterns may be beneficial, in which case a wondrous new discovery will have been made, and some patterns may be undesirable. For instance, had modern American municipalities seen how their planning rules would result in the proliferation of surface parking lots in their urban core, these processes may not have been adopted.

Being random, we cannot know why and when socio-economic networks will form. All that we can simulate is how they will form. In order to achieve this we will need to study urban morphology as a morphogenetic process, and create the computational tools to make simulations of these processes possible. By understanding the how of morphogenetic processes through simulation, we can design and build cities that produce complex order.

Conclusion: the Art of the Space between Spaces

If architecture is the art of space, when then is urbanism? We know from the material evidence of historic cities that it is possible to create geometric order at enormous scale. However attempts by architects to design at such scale have met with failure because of either economic or social constraints. Where urban design has succeeded was as a small sector in the context of a much larger, pre-existing urban areas. The act of design was not upon the city but upon a small part of its tissue.

The question urban design must answer is how to connect random urban tissue transformations together into an ordered whole. Of greatest importance has been the design of the tissue of public space, roads, parking and transportation structures between buildings which itself is not fixed but is always being transformed by the addition of new buildings requiring connection. Maintaining functional order in such a tissue has been achieved in the 20th century by excessively over-supplying parking space, with terrible consequences on pedestrian connectivity and visual order. Inevitably this connective tissue, the structure that is the city's central purpose for existing, is a space that has no boundary in either space or time. The difference between architecture and urbanism is therefore not a change in scale, where a large enough design becomes urban design, but a change in dimension. With a working design in the urban dimension, any attempt at architecture, no matter how large or small, contributes to urban order.

With the additional insights provided by fractal geometry it becomes possible to conceive of spontaneous urban growth as a form of landscape art. For reasons of economic scarcity individual building architecture may remain constrained in materials and craftsmanship, but by carefully defining rules for urban growth it is possible to create very complex geometric order at the large scale. The drawback is that it cannot be a predictable geometric order the way that architecture is typically understood, but a geometric order that will adopt a predictable pattern in response to an unpredictable input that is local conditions and individual actions. Emergence thus limits what class of landscape art it is possible to achieve, but makes the class that is achievable an order of magnitude more powerful than what has so far been attempted.

The confusion of building and planning processes has produced a modern urban landscape that is often generic if not chaotic. Large-scale planning efforts to create a harmonious environment have come at the expense of network formation. The adoption of emergent processes instead will reduce this chaos and gradually produce a random fractal, the definitive outcome of a shared feedback function, onto a healing landscape. The

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sustainable city cannot be attained otherwise.

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