

Design methods, emergence, and collective intelligence□

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Abstract: *The two methods of adaptive top-down and bottom-up design are shown to be theoretically equivalent. Even though they differ drastically in their application, each one can help the other, and they may even be combined in a particular project. Both cases rely on traditional solutions encoded into the built environment, which represents the product of our collective intelligence. Implementing this realization to rebuild our world can lead to an unprecedented degree of support for human life from architectural and urban structures.*

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1. Introduction.

Today, practicing architects use design procedures that have been current for the last eighty years or so. Even though those procedures are taught by architecture schools the world over, many critics have argued that together they do not comprise a design method that produces pleasant, comfortable, and useful buildings. For example, the architect and urbanist Léon Krier asserts that they represent personal caprices rather than solid foundations for design, as evident by the uniformly unpleasant quality of the results [1]. Instead of providing a useful design basis, architectural theorists are alleged to be clinging stubbornly to narrow and outdated ideas of the 1920s, exerting thought and energy to create a corpus of work that is irrelevant to human needs.

Critics of contemporary architecture argue that a serious problem for mankind developed when design began to be driven by ideology, so that appearance, form, evaluation, and justification were no longer related to a building's use by human beings. In this intellectual atmosphere, it is very easy to ignore the effect that built form has on human sensibilities, and to use abstract criteria to justify a particular building style. Those criteria can then be dictated by ideas that have nothing to do with either human beings, or their relationship to the built environment, and which frequently turn out to destroy this critical relationship [1].

I will argue that we face a totally confused situation, and that the only way out is to understand adaptive design methods based on scientific analysis. I am well aware that this goal was already pursued in the 1960s, without many lasting consequences. Architecture and design should be based on artistic sensibilities. Nevertheless, I suggest that so many egregious errors are now part of the basic credo of today's architects that we can no longer continue to work in this intuitive fashion. The artistic/intuitive method is certainly valid within a culture of traditional buildings, but it fails totally when destructive influences act on design. There are indications that this is overwhelmingly the case today.

2. Darwinian design.

An earlier paper [2] proposed that all good design is necessarily adaptive, and that the optimal method of achieving an adaptive design follows a Darwinian process. By this I mean an evolution of a group of similar competing design solutions for a particular project, of which the most adaptive is selected in stages. This process requires a set of selection criteria that are used as the basis of selection or "culling" from amongst the various alternative design choices that are generated. I am describing an intentional procedure, not to be confused with an entirely random proliferation devoid of selection.

As in biological evolution, the selection criteria strongly influence what the final result looks like. Therefore, a set of selection criteria based on adaptivity will generate an adaptive design; whereas a set of criteria based on comparison to certain prototypes will guarantee that the end result will resemble that reference prototype. In biology, adaptive selection to different environments has taken place to produce what we today regard as entirely different animals -- starting from the same common ancestor.

Selection via comparison to a prototype is not necessarily bad, if the prototype itself is adapted to the uses of the required design solution. This can happen only if the prototype has been produced by evolutionary adaptation. While the end result of copying a prototype may not be the most original possible, it does guarantee a strong measure of usefulness, as the derived design inherits the adaptive properties of the original. This is the method of traditional design: copy a set of prototypes, which themselves have evolved by selection over millennia to adapt to particular uses, and the end result is guaranteed to be adequate. The only problem arises if local forces are not accommodated by the prototype.

Copying a prototype leads to disaster when that prototype has not evolved, but is imposed (i.e. is defined *ad hoc*). This occurred on a massive scale during the twentieth century, when arbitrary geometrical forms were presented as architectural and urban prototypes. Those prototypes were based on abstract reasoning that itself had only a tenuous connection to social and philosophical concepts; none of which relates to human activities, functions, or sensibilities. Matching to those prototypes produces non-adaptive designs that never achieve any degree of user comfort, either physically or psychologically [1, 2].

Nevertheless, twentieth-century design based on matching to simple abstract prototypes was extraordinarily successful, because it was very easy to use in practice [2]. This is demonstrated by counting the number of steps in the design method. We can estimate very roughly the number of steps in an intentional Darwinian processes corresponding to selections in each of the above-mentioned methods. In order-of-magnitude estimates: (1) modernist design requires only a few (usually less than five) steps to match pure geometric prototypes; (2) traditional vernacular design, including Classical, typically requires on the order of twenty to thirty steps to match traditionally-derived prototypes; (3) an innovative adaptive design that is not anchored to any traditional form may in general require up to one-hundred steps to evolve its adaptations.

Strictly in terms of economy in the number of design steps -- which corresponds to hard mental effort at developing design variants, and choosing the most appropriate ones among them --

modernist design wins out over any other design method. So, we have to recognize its tremendous advantage of economy. This economy in turn helps to explain modernism's widespread adoption during the twentieth century [2]. To replace modernist design with an adaptive design method, one has to be convinced of the benefits of such a change.

3. Sorting algorithms as an analogy for design.

An excursion into computing will serve to illustrate two basic approaches to design: (i) intentional, top-down design, versus (ii) evolved, bottom-up design. It will also help us to understand adaptivity. I claim that both techniques can be made to work to achieve a final product that is of comparable utility. I will then argue that they are equivalent in an abstract mathematical way. The central question of design adaptivity will only be addressed afterwards.

A recent result in computer science has important implications for design. This result is not widely known in architectural or urbanist circles, so I present it here. It is useful to consider design as an algorithm: a set of instructions to be followed in order to achieve a particular result. There are deep connections between architecture and computer science, which first became obvious in the success that the "patterns" introduced by Christopher Alexander *et. al.* in architecture [3] eventually had in software [4].

The present discussion is distinct from design patterns. One of the simplest possible programs is a number-sorting program, which takes a list of numbers and sorts them into increasing magnitude. The reason such a program is so simple is that its generative components -- corresponding so to speak to the DNA in a biological entity -- are basically two: comparing, and switching. There are instructions to compare two numbers to see which is greater, and other instructions to either leave these two numbers in their original order, or to switch them. By a judicious combination of comparing and switching instructions, one creates a number-sorting algorithm.

In the specific example to be discussed here, a list of 16 numbers is sorted. This is known as a "sorting network for $n = 16$ ". It became something of a challenge for the smartest computer programmers to write the shortest (i.e. optimal) program that could sort a list of numbers. The

shortest programs for this task were written using fewer and fewer exchanges as follows: with only 65 exchanges in 1962; 63 exchanges in 1964; 62 exchanges in 1969; and 60 exchanges in 1969 [5]. The question remains open whether it is possible to write an even shorter program to achieve the same task.

4. Darwinian evolution of algorithms.

The computer scientist Danny Hillis developed a Darwinian setting for evolving number-sorting algorithms [5, 6]. By generating an enormous variety of programs containing randomly-distributed switching components, he selected those that achieved some partial success in sorting number lists. (Actually, Hillis took the first 32 exchanges from the most successful existing programs for sorting 16 numbers, and allowed the number and character of all subsequent exchanges to evolve). He then combined those programs or introduced random shufflings in each one, and after each shuffling checked them for sorting ability. By doing this an enormous number of times on one of the most powerful computers (which he himself designed and built), Hillis was able to evolve a sorting algorithm starting from a random collection of basic components. The result was a sorting algorithm with only 61 exchanges.

The results are profound in their implication. First the obvious result: a Darwinian process evolved a program out of a mishmash of switching instructions, which is just as efficient as those developed by the best human minds. The second result was totally unexpected: *Hillis cannot understand how the evolved algorithm actually works* [6, 7]. The 30 or so evolved exchanges are in a configuration that does not reveal a recognizable sorting pattern. It is reasonable to suppose, then, that it is unlikely the evolved sorting algorithm could have been written by a human programmer.

This single example demonstrates that a Darwinian process need not necessarily result in an understandable pattern. (This does not mean, however, that all the results of Darwinian selection cannot be understood). We can test such evolved algorithms to make sure they are correct and efficient, yet their internal complexity somehow escapes us. This was revealed in one of the simplest possible algorithms -- a sorting program for 16 numbers. Clearly, more complex systems are bound to have an even higher, and perhaps incomprehensible, complexity.

Human ingenuity using proven programming methods led to a program with 60 switches, whereas a Darwinian process led to a program with 61 switches. The results are almost exactly comparable in their efficiency. This suggests something about architectural design. Intentional, top-down design that is based on evolved prototypes can indeed be compared with evolved, bottom-up design. Both intentional and bottom-up approaches give optimal solutions of comparable fitness, while the results of an evolutionary approach are in a fundamental sense unexpected.

5. Understanding patterns and buildings.

I am analyzing how design methods arise by understanding the generation of adaptive form. The method itself is prescriptive -- we cannot allow for the time it would take for form to evolve in historical time, such as a cathedral built and modified over centuries, or a city evolving over an even longer time frame. The evolution of a design occurs on an artificially accelerated practical time scale, either in the planning stage before a building is put up, or during construction. Changes can be made during construction, and adaptive changes could also be allowed afterwards. Nevertheless, the form at every stage is understandable, as it adapts to its surroundings and uses.

All of nature works via complex processes that, in their details, remain outside our understanding. The enormous amount of physical, chemical, and biological mechanisms that we do understand is dwarfed by the amount that we still don't understand. Scientists respect nature's complexity, and we are constantly trying to deepen our understanding of its workings. Most important, we should refrain from arbitrarily imposing our own simplified understanding on nature itself. When we do, the result is often disastrous. Intervention in medicine, ecology, and the environment is most successful when we (1) use a basis of voluminous observations of cause and effect to guide our interventions; (2) go in with the understanding that the actual process may be much more complex than we think [8].

Our discussion of sorting algorithms suggests that evolved architectural and urban solutions don't necessarily have to be understandable -- but they are nevertheless optimal archetypes which can be copied subsequently. When Alexander and his co-authors described architectural

and urban patterns in "A Pattern Language" [3], they explained some of the patterns using scientific data. Other patterns they merely presented as valid because of their repeating occurrence, without formal proof. Indeed, one can state as a general principle that patterns, most of which have evolved over millennia, may not all be understandable, because we do not yet know all the factors that generate them.

Some contemporary buildings are not understandable, but for an entirely different reason to what was described above. They have not evolved adaptively to any purpose; they are arbitrary and only mean to shock by their disconnectedness [9]. For this reason, they resemble nothing that could possibly be considered as adaptive. Their *raison d'être* is an intentional breaking up of space and form so as to create psychological and physiological anxiety in the observer. There is no order here to be understood; only disorder. Our schools and media are now teaching that such a destructive state is the pinnacle of architectural creativity, rather than a dangerous expression of nihilism [9].

The early modernists were equally arbitrary in an opposite way. They rebuilt our environment with the arrogant assumption that they understood all there is to know; that their simplistic geometrical conception was in fact sufficient to create architectonic and urban structures. Furthermore, they convinced themselves that existing complexity encoded into the built environment was not only superfluous, but had to be eliminated because it held back "scientific progress" [2]. They were fooled by superficial appearances, and had only a sketchy and entirely mistaken idea of nineteenth century science (though they boasted that their preconceived and untested ideas were "scientific"). Such an attitude in medicine turns out to be lethal.

6. Top-down versus bottom-up design.

I wish to clear up an old problem that has prevented the useful collaboration between two distinct schools of thought about design. There exists a group of architects and urban designers who follow what can loosely be termed "Classical" rules. These impose forms which have been thought out entirely during the planning stage. Practitioners include formal Classical architects, Neoclassicists, and New Urbanists, who tend to apply typologies derived from Greco-Roman and Nineteenth Century models. Their results are comfortable, ordered, human-scaled, and figure prominently in the large-scale architectural and urban regeneration of our cities [1].

The other school of design (characterized as "Structural" by **Brian Hanson** and **Samir Younés** [10]) abandons already developed geometrical typologies and instead evolves solutions afresh

in each instance. Practitioners here try to evolve the design in real time, often with the explicit and ongoing collaboration of potential users. The design -- and building -- process is bottom-up rather than top-down. Since a main point of the method is the continuing influence of users to change form as it is being built, the design can evolve into an unexpected final state, much like our result from computer evolution mentioned above. A key tool of this design school is the use of Alexander

et. al.

's

"A Pattern Language"

[3]. Those patterns are evolved solutions for accommodating human uses and needs: they are connective and configurational prescriptions rather than geometrical constraints [11].

At first glance, there would appear to be little in common between these two design approaches, yet both rely on a Darwinian process of selection. The difference is as follows. In the top-down design process, an intentional Darwinian selection occurs in two parts: (i) in the past, when the geometrical prototypes comprising the form language were evolved to adapt to human use and sensibilities; (ii) in virtual space in the mind of the designer before any construction takes place. The top-down instance uses a proven repository of forms. It is more efficient to concentrate the secondary selection within one mind, so the design tends to be less collaborative and more the result of the decisions of a single person.

In the bottom-up design process, we have a very similar division into two parts: (i) a Darwinian process has in the past generated Alexandrine patterns; (ii) Darwinian selection takes place further in real time during preliminary trials and actual building. The bottom-up instance, where a number of persons have significant input into the form as it is evolving, has opposite characteristics from the top-down process. Because of their fundamentally different approaches, top-down design relies more on geometry and an inherited form language, whereas the bottom-up approach dispenses with geometrical prototypes and instead works within the design constraints represented by "patterns".

The top-down design that I am proposing consists exclusively of traditional and classical prototypes, which have themselves evolved over time through Darwinian selection. A danger with top-down design is that it could employ prototypes that have never evolved, and are thus not adaptive to human needs. Also, it is possible to put together perfectly adapted prototypes in a non-adaptive manner, unless one is very sensitive to the local forces. This problem is best handled by employing some of the techniques from bottom-up design, which allows self-organization as discussed later in this paper.

Bottom-up design has a much better chance for adaptation, but the opposite potential weakness: unless it is intentional, and selection is governed by adaptation to human needs, it becomes random. Disorganized growth, however, is parasitic to healthy architectural form and urban fabric, as it is to biological tissue. Such growth is neither adaptive, nor the result of self-organization. It represents the proliferation of structure that does not relate to the whole. Evolved form generates organized complexity, whereas random growth generates disorganized complexity [9]. Organizational principles are in general so complex that they are best helped by evolved solutions, which brings us back to a reliance on top-down methods of organization (though emphatically not the imposition of forms).

For many decades, people have assumed that top-down and bottom-up design methods represent opposite and mutually contradictory approaches. One can trace the famous (and very regrettable) argument between Lewis Mumford and Jane Jacobs to precisely this difference. I, together with other authors such as Hanson and Younés [10], do not believe the difference to be one of substance, but merely one of application. Yes, the actual hands-on design will follow a different path in either of the two practices, yet the two processes rely on a basically similar mathematical structure, hence on each other. Both design methods can lead to optimal results that are adapted to human functions and sensibilities.

For certain situations, applying either bottom-up design or traditional top-down design is more efficient. Traditional top-down design gives consistent, predictable results, whereas bottom-up design gives unexpected, more novel configurations. The price for novelty and greater freedom is a larger number of steps, and consequently more time invested in the project. The possibility of combining bottom-up design with traditional top-down design has already been proposed by Hanson and Younés [10] (in what they call the "Third Way"). There is essentially one adaptive design process, and different practitioners may choose to carry out its steps either in a virtual environment (i.e. inside their heads), or in the real world. In the latter case, it is possible to involve more people in the selection process, so that the design becomes "participatory".

7. Collective intelligence.

This section draws on work by **Francis Heylighen** [12]. Heylighen defines intelligence as the ability to solve problems. Sometimes, as occurs in colonies of social insects such as termites and bees, intelligence is an emergent property, since each individual alone does not have the

requisite neuronal capacity [7]. In the case of human beings, each individual does have advanced intelligent capacity, yet it is sometimes necessary to use a combination of minds in order to solve a complex problem [12]. A city works with complex mechanisms that together are too much for any individual human comprehension. A city built over time is the product of the collective intelligence of generations of people acting together, either in a spatial grouping or in a temporal perspective.

Despite the distinction between top-down and bottom-up design implementations, both represent an application of collective intelligence, but in very different ways. The selection process that generates a design solution via bottom-up methods is the result of actions and decisions by a host of individual inputs. A collective design project includes selection by the architect (or a group of architects), end-users, and environmental forces. All those forces are perceived and inputted into the selection process by human agents acting as a collective intelligence. Such forces may or may not be perceivable by the individual designer in a bottom-up process, because of their number and complexity.

Adaptive top-down implementation also uses collective intelligence. The built environment is a common repository of stored information. Developments having to do with forms and structures that are adaptive to human physical, sensory, and psychological needs are stored in pre-modernist built structures. This information represents the work of an enormous number of individuals, as well as collective efforts throughout the ages. It has the advantage of being accessible to everyone. Unlike information stored in books, which until relatively recently was accessible only to an educated class, information stored in built form is immediately accessible, and acts as a working memory for society.

The storage capacity of such a collective memory is far larger than the memory capacity of any individual human being [12]. Top-down design is helped by using encoded information from traditional typologies -- these broaden the intelligence of the individual designer or group of collective designers. A top-down design implementation that utilizes traditional typologies therefore extends human intelligence into the built environment, by incorporating the experience of other people from the past. On the other hand, the deliberate destruction of the traditional built environment, which was perpetrated by the modernists, erased society's collective memory. This act reduced society's collective intelligence, and severely limited its ability to solve architectural and urban problems.

The built environment is the medium in which adaptive design solutions have evolved (and are still evolving). Exploration of innovative designs relies on selection and checking against adaptive examples stored in the collective (built) memory. Adaptive designs enhance human

life; they are an inseparable part of humanity's healthy functioning. Designs that damage this life represent pathologies, which would normally be rejected when recognized as such. A particular group of people (incredibly, the professionals in those disciplines) have been promoting a pathological type of structure both on the architectural and urban scales. As human intelligence no longer extends to the built environment, it cannot protect us against architectural and urban pathologies, which therefore proliferate.

Results linking the human mind with our surroundings are slowly accumulating in the sciences. The fact that what we build reflects how we think is becoming more and more obvious; buildings and cities try to adapt to changing circumstances just as an intelligent entity does to changes in its environment. An adaptive design solves a problem -- and problem solving is what defines intelligence [12]. This requires the free evolution of alternative solutions, and unrestricted feedback and selection mechanisms to be in place. Positive feedback in a system helps to generate the pool of competing solutions, whereas negative feedback identifies the non-adaptive ones.

Human concepts of organization and complexity are encoded almost exclusively in our artifacts and built environment. Our innate grasp of complexity, reinforced by observations of natural complexity, makes possible all of our technological achievements. This knowledge has not been translated into a general theoretical formulation of complexity -- a great deal of what we do understand works on an intuitive level. Models describing organization and complexity are very recent, and far more limited than working examples of complex machines or software. Our collective intelligence thus relies on information stored in the environment to understand (and create) organized complexity, but the architectural and urban components of this external built memory are being erased at an alarmingly rapid pace.

8. Emergence and self-organization.

Every city, piece of urban fabric, and building is a product of emergence. This expresses the notion that a whole is more than the sum of its individual parts; urban and architectural components come together to create in the best instances a unity that takes on a "life" of its own [7]. The greatest buildings and urban complexes of mankind are just made of bricks, wood, stones, tiles, etc. Yet they transcend their materials so as to induce feelings of profound emotional intensity in observers. This is a manifestation of *emergence*. Something profound is

created by the coherent joining of mundane materials. In past centuries, people understood this process in religious terms -- an ecstatic experience was naturally associated with a great building or urban space.

The opposite effect is also instructive. Many megalomaniac architects and patrons have tried, unsuccessfully, to create an impressive structure by using the most ostentatious and expensive materials. The result is in many cases mediocre, whereas a truly great building may be seen to be composed of ordinary and even cheap (inexpensive, but not shoddy) materials. What communicates to human beings is the ensemble's overall coherence -- the emergent properties of all the components coming together.

An emergent property in a system may be understood as the organizational connective structure that evolves on top of the components themselves [7]. This is analogous to the meaning in a sentence compared to the individual letters presented in no particular order. Emergence is identified with information, meaning, learning, and connective subsystems. Architectural and urban components on all scales are the physical substrate on which information is encoded, and the organization of this information produces meaning. Both traditional architecture and "patterns" contain connective rules that can generate meaning from ordering and linking built components. A simplistic architectural language prevents emergence.

Emergent systems are irreducible: they cannot be understood in terms of their components alone, just as a sentence's meaning cannot be communicated just by knowing all the letters used. Emergence is invariably the product of evolution, which brings us back to the issue of understandability. Man-made systems that evolve in complexity eventually reach a complexity threshold beyond which it becomes difficult to understand how they work as a whole. That should not prevent us from using them, however. Whether we have a complex program, traditional mixed-use urban fabric, or traditional architectural forms and "patterns", such solutions represent an evolved exploration of solution space.

An emergent solution on the architectural or urban scales may be surprising, precisely because of its novelty, and would be eliminated by imposing a simple understandable form from above. That is how modernist and Fascist architectures prevent emergence. Traditional architecture accepts novelty and organizes it so that it is adaptive. At this time, however, an arbitrary non-understandable form is often imposed from above in an attempt to create novelty. This fashion reflects a fundamental misunderstanding of morphogenesis by the architectural and urban profession, which has unfortunately fooled the general public. Such non-adaptive novel forms are not evolved. Since they are not solutions, they do not increase our collective intelligence.

Any dynamic complex system, if it is able to do so, will try to organize its complexity so as to optimize energy flow. This response or self-organization can be interpreted as a kind of "learning", though it is not always in directions that human beings either approve of or understand. The sorting algorithm discussed previously is emergent, and sometimes emergence creates unexpected properties, as was noted. A system that is not selected for human use might develop unexpected features and unwanted (not particularly useful, or even harmful) properties. After all, viruses are products of evolution.

Self-organization is a property of a system that uses internal forces to influence its own structure or growth. That is, it is generated by some algorithm which causes it to develop internal coherence. We may not understand entirely how self-organization works, but it is seen in many natural systems. For example, snowflakes, spider webs, cauliflowers, eddies and whorls in fluids, etc. exhibit self-organization. Fractal form is an example of self-organization. Any natural pattern that shows organization on every level of magnification is the product of some mechanism of self-organization.

There is a crucial difference between self-organization and adaptivity, however. Whereas self-organization is driven primarily by internal constraints, adaptivity is driven by external constraints, so the system has to be open. A system may self-organize but not be adaptive; it is independent of its surroundings -- that is, closed [7]. A complex fractal need not adapt to anything outside its own symmetry. In that case, it develops the same intricate pattern regardless of where it grows. An adaptive system, on the other hand, whether it self-organizes or not, develops according to input from its surroundings. A snowflake-shaped city plan may be interesting because of the fractal interfaces it offers, yet it does not adapt to human activities. The same goes for a fractal pattern on a building -- it's really only an abstract decoration.

9. Adaptivity and feedback.

The key to adaptivity is having a mechanism for feedback. Without feedback, there is no way of incorporating ambient information into the algorithm for growing a complex system. Both the brain, and living structure, depend for their function on an enormous amount of feedback. Dead matter has no feedback. Contemporary architecture, following the early modernists, has

dispensed with feedback. Architects wish to impose their dead abstract forms on people, who are not supposed to question them. Indeed, any feedback about building and city form and functions is considered a nuisance, since it implies that the original "ideal" forms were not perfect.

Feedback is a two-way influence occurring in two distinct contexts: (1) among system components of the same size; and (2) among different levels of the system. Units or mechanisms act in parallel on any level, and their output is available to each other, and to the higher levels. An adaptive system will use feedback to influence both the smaller and larger scales. Without feedback, there is either no connectivity, or the connectivity is disorganized -- the opposite of what one requires in a coherent complex system.

The chief flaw in a top-down implementation is that it might ignore forces that would make it truly adaptive. The only way to guarantee that this does not happen is to make sure that each design step is adaptive to the situation at hand. By focussing on each step in the process, one defocuses from the final result, so that one allows for divergence from an initial rigid goal. It is often the case that the best result departs from an initial specification [13]. Going directly to a fixed end product, by contrast, does not necessarily follow a sequence of steps in which every single step is adaptive, and thus the final result is weaker.

Modernist architects confused people by substituting precision and elegance for human connections. Precision represents a matching to a mechanical ideal that has nothing to do with human uses or sensibilities. It is a strictly abstract idea that relates to pure geometry. Adaptation to human comfort, on the other hand, abandons mechanical precision, because structures that satisfy human needs are most often loose and accommodating. It is well-known that mankind's most memorable and inspiring architectural achievements are neither extremely precise, nor perfectly aligned, nor do they obey an absolute geometry. Furthermore, vernacular architecture, which is more psychologically comfortable than any of today's sterile mass-produced buildings, evolved by paying unrelenting attention to emotional and sensory feedback and not to mechanical precision.

An adaptive design evolves according to how it satisfies requirements for its use. It adapts to a set of conditions; usually having to do with its relation to internal and external forces. A building, for example, will be initially adaptive if its design has evolved so as to satisfy the needs of future occupants. A building may also evolve after it is built, by means of structural adaptive changes to its fabric driven by the need to satisfy the current needs of new occupants. This second adaptation is much more prevalent in practice and is a characteristic of successful architecture throughout the ages, even though it is insufficiently recognized by architectural academics [14].

It is difficult even to talk about architectural adaptivity, since architecture has cut itself off from feedback mechanisms. By contrast, adaptivity is the most obvious feature of other disciplines. For example, in Computer Science, the test is straightforward and uncompromising: does a program run; and does it compute what it is supposed to? The feedback is immediate; if either a program crashes, or if it runs but gives a result that is independently checked to be wrong, the program is dysfunctional. We really don't have an analogous solid test of adaptivity in architecture, and this lacuna in the very foundations of the discipline has created enormous problems.

I will use the sorting algorithm discussed previously in an analogy of what contemporary architects do. As a hypothetical illustration, architectural theorists might take an arbitrary set of switching and comparing instructions, and declare them to be a program. They would carefully avoid running it, since that would immediately invalidate their claim that this nonsense jumble of lines of code actually does anything. Their justification would rest strictly on superficial appearance: *since lines of code look like a program, that's all there is to programming*. They might go further, moreover, and declare this non-program's incomprehensibility to be a philosophical virtue, following the French deconstructivist philosophers [9]. I would not be surprised if then, someone picks 55 switching instructions at random and declares a new champion for the

n

= 16 sorting network, again without ever running anything on a computer.

10. Conclusion.

Architecture needs to be based on a scientific understanding of adaptive design principles. I described Darwinian processes and their role in design, using the evolution of a computer program (a number-sorting algorithm) to make a point. Evolved solutions acquire a complexity that often exceeds the intelligence of an individual human being. For this reason, the traditional built environment is a product of a collective intelligence (such as shown by social insects) applied to deepen the human understanding of form. Adaptive top-down and bottom-up design methods were explained with reference to results from complexity theory. An old misunderstanding, which considered top-down and bottom-up methods to be mutually contradictory, was cleared up -- in fact, as long as they are truly adaptive, the two methods are mathematically equivalent.

I also criticized the arbitrariness of non-adaptive design methods in widespread use for the past several decades. Architects who replaced historic solutions adapted to human needs with simplistic image-driven typologies revealed a total lack of understanding for the role of design. They also introduced an arrogance into the profession, which, combined with those non-adaptive design methods, has made the built environment more and more dysfunctional and even inhuman. It appears that despite repeated and well-publicized calls for design according to adaptive principles, these tendencies of contemporary architecture and urbanism show no signs of abating. I believe that it is time to rebuild a functional environment that better supports human life. This paper suggested a basis for doing so.

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