Evolutionary design systems: a conceptual framework for the creation of generative processes

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ABSTRACT

This paper presents an conceptual framework for the construction of generative mapping processes as a basis for creating active design tools in the domain of architecture. Such generative processes are seen as key components within evolutionary systems that manipulate populations of alternative solutions in order to discover previously unexplored possibilities. Solutions are represented in two forms: as highly encoded genotypes referred to as design seeds and as decoded phenotypes referred to as design proposals. The generative process maps the design seed to the design proposal. The discussion of generative processes is in two parts. In the first part it is argued that any generative process that aims to create a wide range of solutions that differ from each other in fundamental ways must focus on a limited subcategory of possible designs. It is proposed that the endeavour to create active design tools demands that the focus be on the designer's highly personalised style, called a design-schema. The second part discusses how to uncover the essence of an architectural design-schema. In particular, it is argued that implicit and familiar aspects of buildings must be scrutinised in order to reveal the knowledge that is essential to capturing and codifying a design-schema. A range of rationalisations and conceptualisations of built form are presented with examples to illustrate possible routes of analysis. Finally, in conclusion, the possibility of discovering universal generators common to many divers generative processes are discussed.

1 INTRODUCTION

A new phase of design tool is now under development. These tools are described as active as opposed to passive in that they will become and integral part not only of the manual design process but also of the cognitive design process. The task of these software tools is not only to allow designers to analyse and evaluate, but also to generate and explore alternative design proposals. Such tools aim to free designers from 'design fixation' and the limitations of conventional wisdom, thereby allowing them to explore a huge number of possible proposals for a design problem. (Bentley1999)

1.1 **The evolutionary process as a model for design**

It is often presumed that, in order to automate any part of the design process, one must start with a cognitive theory of how humans design. This is based on the assumption that humans offer the only example of a successful design system. However, alternative successful design systems do exist. One such system is biological evolution in nature, which has been evolving biological designs that far exceed any human designs in terms of complexity, performance and efficiency. Evolutionary programs use biological evolution in nature as a source of inspiration, rather than a phenomenon to be accurately modelled. The un-natural evolutionary system maintains a population of alternative designs.

Genetic algorithms are today the best known and also the most widely used of all evolutionary programs (Holland 1975). However, a number of researchers in various specialised fields, including design, have found that most real-world problems can not be handled with the classical genotype representation and the corresponding genetic operators (Michalewicz 1996). When applied to complex problems, these representations and operators do not allow the knowledge within the domain to be succinctly described. In order to overcome this hurdle, stronger assumptions must be made about the problem domain. Thus, whereas genetic algorithms require key elements to remain domain independent, evolutionary systems in fields such as design will typically allow them to become more complex specialised domain specific components.

The mapping process from genotype to phenotype is a key area where domain specific knowledge has been incorporated. The use of genetic algorithms in optimisation problems required only a straightforward direct mapping from the binary string genotype to the parameter being optimised that is the phenotype. However, in attempting to capture a wide range of alternative solutions that differ from each other in fundamental aspects, evolutionary systems are now employing highly complex problem specific mapping processes.

In design systems, this process takes the form of a growth process that starts with encoded design seeds and decodes them into fully developed design proposals. Peter Bentley emphasises the biological analogy by referring to these growth processes as embryogenies (Bentley 1999). John Frazer describes them as generative processes. (Frazer 1979) Such a generative process is a crucial step within the overall evolutionary design system. The evolutionary manipulation of the population can be broken down into three stages: generating proposals, making predictions and creating populations. The stage of making design proposals involves the generative process. Thus each proposal for a built form is individually generated from the design seed in response to a simulation of the environment and context within which the built form would exist. The second stage involves making predictions of how the design proposal would perform within the environment and context. These can either be quantitative prediction calculated using various types of analysis software or the may be qualitative predictions made by evaluation algorithms and human choice. In the third stage, a new population of design seeds is probabilistically created through the transformation and duplication of those design seeds in the previous generation that produced the most favourable predictions.

2 THE GENERATIVE PROCESS

The design proposals for built form that are produced by such generative processes must strike a balance between two opposing criteria. First, the design proposals must all be recognisable as proposals for built form. The vast majority of three-dimensional forms have no relationship to built form whatsoever. For example, if one were to randomly place 'walls', 'floors' and 'roofs' in three-dimensional space, the likelihood of creating something that resembled built form would be extremely small. If the generative process were prone to creating such an unnecessarily wide range of proposals, then the majority would be fundamentally inappropriate, thus rendering the evolutionary system ineffective. Furthermore, the predictive process of analysing such widely varying forms would become untenable. Thus, any design seed passing through the generative process should either abort or result in a design proposal that could, in a fundamental sense, be interpreted as built form, however inefficient that proposal might be.

Second, although the range of proposals must not be unnecessarily wide, it must also not be restrictively narrow. This range must accommodate the required scope of the evolutionary system as a whole. The scope must therefore be carefully considered prior to the construction of the generative process. For example, a process that creates timber-frame two bedroom houses is fine if that is all that is required. However, if for some reason an extra bedroom is required or an alternative constructional system is incorporated, the range of proposal would need to be widened. This would consequently result in the generative process having to be altered, or even recreated from scratch.

These two criteria affect the decision as to what the scope of the evolutionary system should be. On the one hand, a generative process that has a very wide scope will be more generally applicable. This generality will be valuable when new design problems are tackled requiring proposals of a different kind. On the other hand, an increase in scope will decrease the quality of the results achieved by the evolutionary system as a whole.

2.1 **Design-schemas**

In order to create an evolutionary system that has any chance of producing high quality design proposals that challenge an experienced architect, the generative process must be imbued with detailed domain specific knowledge relevant to the problem at hand. However, there is almost no knowledge that can be desceibed as being strictly irrelevant to the field of architecture. The knowledge to be captured and codified must therefore be restricted in some way. One possibility is to restrict the scope of the generative system to a relatively specific subset or subcategory of all built form. The question that remains is on what basis should this categorisation be

made? From a designers point of view, the most relevant category is the body of work that they have produced, are producing and will produce in the near future. The key aspect that unites this category of built form is the particular designers 'style'. John Frazer describes this personal trademark as a design-schema. “Most designers employ a methodology highly personalised yet can often be generic when the designer’s body of work is taken as a whole. It is part of their working method and hence characterises their ‘style’ by which they are known… This personalised but generic methodology can be described as a *design schema* in that it is an abstract conception of what is common to all designs. Inside the designer’s office, these implicit design-schemas often become formalised. It is common to find sets of standard details in architects’ offices that serve to economise in time, ensure details are well tested, but also to ensure a consistency of detailing and to reinforce the house style. In many offices this extends to design procedures, approaches to organisation and so forth.” (Frazer 2000)
The existence of such personalised design-schemas, custom created by each designer, has only recently had any effect on architectural design software. In an ideal world, the most useful piece of software for a particular design project would be highly specialised for the design-schema being used or even for the design problem. The ultimate would be the piece of software with a single ‘do it’ button; the button that always does exactly what you want. In the area of drafting software, a trend towards more specialised types of software is developing resulting in totally customisable drawing packages where highly generic core can be specialised to incorporate templates, libraries of parts, drawing procedures, drawing interfaces and even customised creation, manipulation and modification tools. The evolutionary paradigm being presented assumes a similar but more extreme type of specialisation. The evolutionary search system will remain largely schema independent and will therefore enjoy general applicability. The generative process used by the evolutionary system will, however, be highly schema specific. This approach requires methods for creating generative processes for each design-schema but also for adapting generative processes to allow for the more or less gradual evolution of existing schemas. These tools thereby refocused the process of creating design proposals. Rather than directly creating the proposal, a more abstract approach must initially be taken whereby the underlying principles of the design-schema must first be defined. Only then can the actual design proposal be tackled directly. The aim behind creating these design tools is therefore not to duplicate or mimic existing traditional design process. Rather, the aim is to create innovative tools that challenge the design process, allowing designers to work in ways that were previously not possible. The tools to be developed reject the traditional architectural methodology "on the grounds that, first, the present architectural design process is fundamentally unsatisfactory in any known form and not worth imitating and, second, imitating the human process is unlikely in any case to represent the most imaginative use of a machine." (Frazer 1979)

2.2 **Categorisations of built form**

This design-schema orientated approach categorises built form according to the designer that created the particular buildings. This is of course not the only possible categorisation. Alternative choices include divisions that depend on geographic location, on the constructional system used, on the historic style, on function or purpose, on phenomenological experience, or on cultural consensus. Even Pevsner's division of built form into the 'bicycle shed' category and the 'cathedral' category' is a possible alternative (Pevsner 1976). Some theoreticians like L. Krier, Graves and Venturi have proposed that the focus should not be on individual buildings but rather the superordinate category of city and the subordinate category of architectural element.

One theoretical paradigm that has entertained many of these divisions is the idea of a type or typology in design. How built form can carry meaning can be described as the fundamental issue at stake. The various theories surrounding the idea of type in architecture are manifestations of much more basic cognitive mechanisms of generalisation and categorisation. Paul Tesar identifies two aspects that are required for meaning to arise: "The notion of type rests upon two mutually dependent and conceptually inseparable aspects of: a thing (place, event) that bears some resemblance to other things, and a group of persons who perceives this likeness and conceptually subsumes these things as being of the same kind" (Tesar 1991).

The built forms that fall within particular design-schemas can also be interpreted as types. The 'things' that are similar are a set of built forms being created by the same design environment. The relevant group of persons is therefore those people involved in the design process. Thus the design-schema is not a basic category whose meaning is understood by society in general; instead it is a category whose meaning is only recognised by a small subset of the design community. The schema approach has been taken because it supports a personalised creativity not constrained by past precedent, program, function, construction system, or other factors external to the design environment. Of course, this does not mean that a generative process based on a design-schema division excludes the possibility of historical reference, functional typology or constructional pragmatism. It merely means that these concepts are not built into the core of the process. For particular projects, further restrictions on the scope of the generative process might indeed be found to be necessary. However, such restrictions should remain easily removable and replaceable with new restrictions without affecting the core design-schema.

2.3 **Creativity**

Whatever the delimiting factors of the design-schema are, the generative process must capture and codify as accurately as possible the essence of that design-schema. Quoting Walter Gropius: "A basic philosophy of design needs first of all a denominator common to all… Will we succeed in establishing an optical 'key', used and understood by all, as an objective common denominator of design?" Such a 'key' would provide "the impersonal basis as a prerequisite for general understanding and would serve as the controlling agent within the creative act." (Gropius 1962) However, there is an obvious conflict between the 'controlling agent' and the 'creative act'. Gropius himself states just prior to this phrase that such a key "can, of course, never become a recipe or a substitute for art."

The conflict of control versus creativity is evocatively exposed by Le Corbusier's discussion of the Modulor, his attempt at imposing a new system of dimensioning upon the world. Just as the continuos phenomenon of sound had been cut up "in accordance with a rule accepted to all, but above all efficient, that is flexible, adaptable, allowing for a wealth of nuances and yet simple, manageable and easy to understand", so Le Corbusier proposed to cut up space (Le Corbusier 1955). But he was acutely aware of the issues of artistic freedom, as is made poignantly clear by his own strident proclamation that "the 'Modulor' is a working tool, a precision instrument; a keyboard shall we say, a piano, a *tuned* piano. The piano has been tuned: it is up to you to play it well. The 'Modulor' does not confer talent, still less genius. It does not make the dull subtle: it only proffers them the facility of a sure measure. But out of the unlimited choice of combinations of the 'Modulor', the *choice* is yours.'" (Le Corbusier 1955)

In discussing the Modulor, Robin Evans elucidates this conflict as follows: "Any rule carries with it the eventual prospect of reduced liberty, but new rules can be surprisingly unruly, cleaning away customs and habits that have stood in the way for ages. Thus, for a time, perhaps quiet a long time, new rules can offer a way round the obvious." (Evans 1994) Generative process that aim to capture and codify particular design-schemas but that nevertheless also aim to enhance creative freedom should be seen in this light; as processes that must themselves dynamically change over time in order not to become the very 'customs and habits' that they initially 'cleaned away'.

3 BUILT FORM

Robin Evans starts his article *Figures, Doors and Passages* with the phrase "Ordinary things contain the deepest mysteries" (Evans 1978) Since artificial intelligence was formally initiated in 1956 at the Dartmouth conference, it has repeatedly fallen victim to its own seductive claims by underestimating this simple truth. Two dangers are worth highlighting. First, the wildly over optimistic claims about the future were the result of underestimating the complexity of the domains that were being tackled. Typically, general-purpose search mechanisms and reasoning systems were employed in order to find solutions to highly complex problems for which detailed domain specific knowledge was essential. Second, the over zealous claims about what has already been achieved reflect the temptation to assert that the programs were learning, thinking, being creative, making analogies, understanding stories, and so forth. The source of these behaviours can invariably be traced to the representations supplied by the programmer.

When attempting to create a generative process for built forms these two dangers must be kept in mind. First, the familiarity of built form must not allow one to assume that it is in anyway straightforward. The implicit and familiar aspects of buildings must therefore be carefully scrutinised in order to uncover the deep and implicit structures hidden within. Second, the generative process must be understood as a computational representation carefully crafted and tuned by the human mind. The aim of this crafting and tuning is to come as close as possible to giving away the answer without inhibiting the unexpected.

3.1 **Why is built form the way it is?**

In order to uncover the essence of a particular design-schema, various types of arguments and rationalisations of built form can be analysed. Such rationalisations are, in many cases, normative guidelines that describe how built form should be rather than how it is. In other instances they are analytical devices used to understand existing built form. Some are highly specific to a small number of built forms. Others are general theories that purport to be applicable to all built form. In science, theories of any value must be both highly universal and analytical. However, for the purposes of creating a generative process of built form all forms of rationalisation will be found to be worthy of investigation.

For example, the radical analyses of Ronchamp by Robin Evans provide archetypal examples of a rationalisation of built form that is relevant to only a small number of buildings by Le Corbusier. It was Le Corbusier who laid down the challenge within Ronchamp: "The Modulor is everywhere. I defy the visitor to give, off hand, the dimensions of the different parts of the building." However, after careful analysis, Evans rejects the Modulor as the generator of the freeform shape of carcass of the building. Instead, he discovers a hidden generator: the ruled surface. "Not Modulor measure but rigid lines of ruled surfaces and translated arcs lay behind the free form of Ronchamp. The Modulor, good fable that it is, tells a story about a hidden regulatory agency, but is not that agency itself… the ruled surface had usurped the Modulor. It was a secret; a secret not meant for modest folk" (Evans 1994) If Le Corbusier had created a generative process for himself, the rationalisation of ruled surfaces would no doubt have been an important element. What other rationalisations might he have used? Possibilities include the structural capabilities of reinforced concrete, the skills of local labour or maybe the path of the sun in the celestial sphere at that particular location.

The various rationalisations that have been proposed over the last two thousand years reveals that any theory must first assume a conceptualisation of what built form is. On the one hand, the order of conceptualisation is concerned with what built form is, in a factual sense. On the other hand, the order of rationalisation is concerned with various interrelated ideas and arguments about built form. The latter presumes the former; arguments and ideas about built form must necessarily make use of a conceptualisation of built form. Some examples will be given in order to show how these rationalisations are central to understanding why built form is the way it is.

3.2 **Conceptualisations of built form**

The conceptualisations used by the various rationalisations range from physical to abstract. This range of conceptualisations can be usefully categorised into four levels of abstraction. These will be referred to as *material form*, *spatial form*, *referential form* and *configurational form*. A brick wall is a material form that is both tactile and visible. A room defined by four brick walls is a spatial form. Spatial forms are more abstract in that they are no longer tactile, but they are nevertheless still visible. Walls, roofs and spaces can be arranged in a certain way to create a built form that can be labelled as a church. Although a particular church might be both tactile and visible, the generic concept of what is and what is not a church is much more ephemeral. The 'church' phenomenon exists only as conceptual category. The built form of the actual church refers to the 'church' conceptual category. The reference to the conceptual category is achieved via the built form's particular arrangement of material and spatial form. Finally, the church might be part of a monastery consisting of various carefully related and interconnected spaces. This reveals the most abstract type of form; configurational form. Whereas the referential form relies on the visual and tactile properties of built form, configurational form relies on the interrelationships, adjacencies, proximities and views between the various spatial forms. Configurational form thus consists of various types of connectivity between spatial forms.

3.3 **Rationalisations of built form**

Procedural rationalisations attempt to explain built form by focusing on various processes that lead up to the final product. Included are such long-term processes as the broad paradigm shifts in worldviews, developments in the socio-cultural condition of society, the gradual evolution of various architectural styles and changes in procedures and techniques of building construction. Shorter-term processes include the design of the particular building, the actual sequence of construction for the building and the transformation and alteration of the building after it has been completed.

In *Figures, Doors and Passages* Robin Evans gives an illustrative example of how cultural transformations have affected configurational form. Evans aims to shows how the configurational form of domestic architecture embodies concepts such as privacy, comfort and independence that are dependent on social, cultural and technological conditions. Evans starts by examining the Villa Madama, designed by Raphael and Antionio da Sangallo and partly completed in the first half of the sixteenth-century. He notices two characteristics in the plan that "we would nowadays never do." First, the rooms tend to have many doors. Second, there is no distinction between circulation spaces and inhabited spaces. A complete inversion is shown to have occurred in what was perceived to be convenient that was reflected in the configurational form of domestic architecture; from the matrix of highly permeable interconnected rooms to corridor systems serving terminal rooms (Evans 1978).

Environmental rationalisations attempt to explain built form by focusing on the influence of the environment upon the built form. The largest of these environments is the cosmos and its universal laws. Throughout history, many theoretical systems of laws and rules have been proposed as being universal. Inevitably, in each case it was discovered that these laws and rules were not quiet so universal after all and were in fact highly relativist. At a more planetary scale, included are those influences that are specific to what Buckminster Fuller calls spaceship earth. Particularly influential at this scale are factors such as the properties of global materials like steel and glass, the influence of gravity and 'global village' cultural tendencies that transcend the local culture. Below the planetary scale, ever decreasing neighbourhoods of influence can be identified. At the scale of the country or state, building regulations might be paramount. At the scale of the local city or town, the abundant availability of certain building materials and associated skills might be most important. Finally, of most relevance at the scale of the particular site might be the shape of the building next door or the cost of land per square meter.

An example of an environmental rationalisation that affects material form concerns the availability of building materials and building systems in association with the skills required to manipulate them. In a vernacular sense, this is often translated to the use of certain local stone or perhaps the skills involved in making a thatch roof. However, such local craft based labour intensive building trades have all but disappeared. Instead they have been replace by a group of organisations and industries performing widely differing functions. Groak splits the parties involved in the building culture into four sectors - the client organisation, the manufacturers, the designer/specifiers and the assemblers. (Groak 1992) Of these four sectors, it is the manufacturing industry that will define what materials are available for use and it therefore has a large impact on the material form. Groak writes: "There is an extraordinary array of suppliers of materials - such as cement, timber, bricks, thermal insulants, impervious membranes, etc. - and manufacturers of components - such as window-wall assemblies, roof trusses, radiators and boilers, switches and cabling, door and window furniture, etc." (Groak 1992) The design of material form has, to a large extent, become a question of choosing and combining such manufactured and prefabricated materials and components.

Intentional rationalisation attempts to argue that the built form is, to some degree, a result of the purpose, function or target performance of a built form. In the field of architecture, the Functionalist movement of the first half of the twentieth century has been a highly conspicuous form of intentional rationalisation. The limitations of Functionalism as an architectural theory has long since been acknowledge. However, the idea that the form of an artefact is in some way related to 'what it is for' has not been rejected. Furthermore, the interpretation of 'what it is for' has become much broader, encompassing such issues as cultural and social appropriateness and change over time. The term 'intended function' refers to this broader concept of the intended purpose, function or target performance of built form. An example of an intentional rationalisation that affects both spatial and configurational form is what is referred to by Bill Hillier as 'generic function'. Hillier argues that the spatial and configurational form of all buildings is constrained by very specific kinds of laws which relate 'generic function'. "Generic function refers not to the different activities that people carry out in buildings or the different functional programmes that buildings of different kinds accommodate, but to aspects of human occupancy of buildings that are prior to any of these: that to occupy space means to be aware of the relationship of space to others, that to occupy a building means to move about in it, and to move about in a building depends on being able to retain an intelligible picture of it. Intelligibility and functionality defined as formal properties of spatial complexes are the key 'generic functions', and as such the key structures which restrict the field of combinatorial possibility and give rise to the architecturally real" (Hillier 1996).

4 CONCLUSION

Research into the use of evolutionary system in design has been steadily increasing. This paper argues that the generative process within such evolutionary systems must focus on the designer's highly personalised design-schema. In order to uncover the essence of an architectural design-schema, it was suggested that implicit and familiar aspects of buildings must be scrutinised in order to reveal the knowledge that is hidden within them. This approach is based on the fact that domain specific knowledge must be the foundation of any design system that aims to challenge the designer. This paper therefore advocates focusing on a relatively limited subcategory of built form that can be captured and codified within a generative system.

Nevertheless, this approach does not exclude the search for that which is common to all generative processes of form. The current approach envisages the development of a large number of generative processes, each specialised to its own particular design-schema. However, in the long term these systems will inevitably have certain qualities in common. In effect, generators that transcend any one particular generative process. For example, all design domains make use of the concept of symmetry. The number of symmetry groups in one, two and three dimensions are universal and timeless and might therefore be presumed to be present in a similar form within all generative process.

What is the best method of uncovering such universal generators? One approach to this quest might propose a long-term centralised research initiative that attempts to uncover the universal generators of all design-schemas. However, this strategy would be unlikely to produce any short-term tangible results beyond a proliferation of conference papers. An alternative approach might propose an evolutionary methodology suggesting that the most effective way forward is to ignore the big picture and instead allow parallel development of a wide range of domain specific generative processes. In time, the universal generators will become obvious, as they will be the common denominators of the surviving generative processes. What is proposed is to employ this short-term methodology in tandem with a long-term overview. While creating various generative processes for particular design-schemas, the relative generality of each generator within the system will be analysed. Generators can be rated from the most specific to the most universal. Eventually, some generators might be discovered to be immutable laws of a universal reality.

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