GACAAD or AVOCAAD ?
CAAD and Genetic Algorithms for an Evolutionary Design Paradigm

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The Darwinistic paradigm in architectural design

One of the dominant paradigms in architecture is about its creation: it is done by human designers supported by tools like sketching, drawing or modelling and evaluation tools. The Darwinistic paradigm demands a paradigmatic switch from drawing, modelling and evaluation to the breeding of forms with a much more integrated generation and selecting process embedded in the computer machinery. This means a paradigm switch from a designer as the performer of (sketch, draw or modelling) work to a machine driven creation and selection process of forms with the designer as the supervisor, fully entitled to steer the process in some preferred directions. The designer creates by establishing the evolutionnary rules and making choices among the architectural creatures emerging in rapid fire mode through the synthesis performed by the machine. Natural selection is a metaphor: in fact the designer plays Nature (or God). The creatures allowed to flourish are not adequate according to laws of Nature, but to the judgement of the designer (or to the designing team).

The Darwinistic paradigm made operational and computable

Architects have a long tradition going back at least to the Greeks in studying nature in order to get a grip on its perceived perfection and to design in accordance with the rules (of harmony for instance) found in nature. But only after Darwin (survival of the fittest) and the discovery of the mechanism of genetic replication (mutation and cross over) came the study of nature beyond the analogical and metaphorical understanding of the rules involved and the possibilities to translate them to architecture (Steadman, 1979). With the arrival of the population based genetic algorithms of John Holland (1975/1992, 1992 & 1995) the Darwinian paradigm could be formulated for the first time in an operational and computable way. It offers the architect and everybody else involved in the development of buildings the prospect of a creativity enhancing assistant. An always attentive device capable of suggesting unexpected, original and still applicable design options instead of an also useful intelligent AI-based knowlegde helper or a CAD-based drawing and modelling aide.

Observations in the design studio

Architectural studio supervisors are familiar with students taking on their design assignments by proceeding roughly as follows: they explore the brief, the situation and the concepts applicable eventually in not predetermind sequences of documenting, sketching and thinking. But then, once the first implementable solution emerges their willingness and/or imagination to generate more alternatives diminishes. It shrinks proportionally to the success of the first choice in the process of incremental improving the solution tending towards consistency. Only if this procedure fails are they willing or compelled to consider new possibilities. This corresponds with a very common human frailty which March and Simon (1958) among others (i.c. The Carnegie School) once studied in economics (earning Simon a Nobel prize). What Simon and others observed was that people in reality were only rational in a limited way. They are not capable of reasoning about and contemplating more than a few decision factors at a time and are inclined to stop their information gathering activities as soon as possible. They are also biased in their judgements and willing to accept the first solution they hit upon instead of going on searching for the best solution available. This is what tutors also see their students doing in the architectural studio.

Enabling group creativity with handtools

To discourage those anti-creative practices of fixation on the first design encountered, we conducted group oriented design sketch-exercises in our design studio, but succeeded only partially in our expectations. In the exercises students were asked to sketch their first imagined design concepts and exchange them on the basis of mutual support with everybody else in the group. Everybody looking at the first design concept given by someone, was then asked not to criticize but to contribute (with sketches and explaining text) to the solution with congruent ideas. The student-owner of the original first concept then reviewed the contributions and selected the ideas he or she preferred most for integration in a new concept or parti, whereupon he or she once again exchanged them in a new round with everybody else in the group. Discussions after the exercises and at the end of the studio assignment revealed a mixed reaction from very positive via positive-with-some-reservation to negative because they were either afraid to lose their best ideas to someone else or not willing to work in a group after having experienced group work in the studio for a few years. Working in a group was plagued, but to lesser extent, with the same problems as individual design: reasoning was still done with a few decision factors at a time, information gathering often reduced to a minimum, judgements largely biased and everybody mostly still happy to accept first instead of best solutions. If pencil-aided-architectural-designing (even organized in groups) only partly succeeds in enhancing creativity, will AVOCAAD succeed or do we need something quite different?

Absence of a natural picture-maker

Another suggested reason for the difficulties encountered to support creativity is that we lack a natural visualizing organ corresponding to the way our mouth works in conjunction with our ears when speaking and reacting to what we hear. Pencil-aided-architectural-designing is the best surrogate we have (Goldschmidt, 1991), but this does not work as outstandingly and consistently as ear and mouth, which allow perceiving sound as quickly as it is produced. Only very rough sketches are approximately able to produce images as quickly as we perceive them. In this respect CA(A)D still does not offer a better alternative. While the most fantastic environments can be modeled and rendered, they still do not play the role of sketches in the design process as a rapid feed-back, which is why people (rightly) still cling to their sketchbooks instead of embracing computers as sketching assistants. It is also questionable wether a trained and experienced architectural designer needs all the hyperrealistic sophistication available now and in the future, while still in the phase of the conceptual design process. The fact that designers do not surrender their sketchbooks is certainly not a question of technophobia, but of the unavailability of highly technized yet functionally superior surrogates.

Does CA(A)D come to the rescue?

The most motivated computer literates among students and practising architects are applying the available modelling programs (usually AutoCad) in a traditional way, which replicates what the architect did in pre-computer days, when handing a sketch to an assistant to transform it into a buildable model: making a few design sketches by hand and then modelling them once to modify them extensively afterwards. Then (in the case of folding architecture for instance) the morphing and warping facilities of the programs involved comes to the rescue, delivering possibilities not available by hand (at least in a practical way; see for an example Oosterhuis, 1995). A disadvantage of this approach is the reduced time spent to conceptualize with the help of design sketches. This is not necessary but actually practised in order to get enough time to model and modify the design for presentation. The incredible amount of time students have to spend on computer modelling is by the way rather a hindrance than an added value.

Drawing or design support?

Except for facilities like morphing and warping or parametric modelling, most functionalities of CA(A)D (and Paint) programs are still only applicable for drawing, not for conceptual designing. CA(A)D programs are too structured for the early phases of design. They require too much precision in a phase when the designer does not want to take those decisions (like the exact dimensions of rooms if he or she is only concerned with their relative positions). Paint programs on the contrary are not structured at all, making a identification of the parts in the whole of the picture impossible for more specific refinement and development and to establish links with databases. Basically CA(A)D and Paint programs are still tools supporting the motoric action of the hand, instead of extensions of the brain for intelligent and/or creative design behaviour. The draughting tables are disappearing from studios, but their imprint remain in the CAAD software and hardware which replace them.

Electronic Cocktail Napkin

To support the designing brain, knowledge and rule based AI techniques are deployed. One of the most interesting developments in this field for the early phases of designing is suggested and implemented by Mark Gross (1996): the electronic cocktail napkin, a program to sketch in a more intelligent way by hand on a tablet (available now on internet for the Macintosh). In the program, a potato-like shape might be correctly interpreted as a rectangle. Also the spatial relationships between the shapes might be analysed and compared wth earlier defined compositions. The program enables someone to sketch directly with a familiar pen and tolerates the input of inaccurate and therefore multi-interpretable shapes. At any moment it is possible to provide those shapes with additional meaning in order to work increasingly with more accurate, unambiguous and detailled interpretations of the shapes involved.

Embedded intelligence

With the pattern recognition features of the program it is possible to use the embedded case base knowledge and ideas for inspiration. Because the cocktail napkin program is working with CA(A)D equivalent data, it is possible to import those data in CA(A)D programs for simulations, analyses and follow-up phases of the design work. This is made easy with a function to smooth the shapes of roughly sketched circles and squares, characters and numerals and whole configurations of more complex shapes. With the program it is also possible to simulate sketching with transparent layers. It support cooperative work and records all the sketch activities for analysis later on. Also the link up with visual and knowledge intensive databases is envisaged just as the possibility to interpret isometric 3D sketches.

AI restrictions

Although the cocktail napkin program breaks through the passivity of the usual Paint and CA(A)D programs (even object driven ones), it does not go beyond the capacity of association encouraged by hand-sketch capabilities. Associations take place by precedents collected in a library and are therefore largely predictable and limited in scope. In design sketching it is not first order logic and the application of infered rules and precedences which are pre-eminent, but more analogies and metaphors stretched out as starting points for designing. Like all AI techniques, the program might be sensitive for shortcomings and restricted in its application. Innovation of the whole coming from the interaction of the parts is also difficult to achieve because the parts are embedded in advance in the conceptualisation of the whole. This is an effect similar to shape grammars demanding anticipated specifications for their formal grammar and vocabulary and in doing so, engendering predictability. Last but not least, the maintenance of such a programme might be arduous and expensive.

Genetic algorithms as accelerators of sketching

The main disadvantage of both the CA(A)D and AI approach is though that the generation of shapes is still not accelerated beyond all capabilities of the eye-hand- brain coordination. In order to make this much needed jump in speed to generate (related families of) shapes, genetic algorithms can be put to use. Usually, modelling is done once by the programmer and then triggered endlessly by the user. In some programs however even this first modelling might be created and imported by the user as a bitmap scan or vector active drawing. Like in nature, out of such a basic startup model an endless variety of shapes can be breeded.

Genetic algorithms: complementing human cognitive limitations

Not only a tremendoes speed increase can be achieved in generating and drawing on screen with this type of programs. But also the incorporation of selecting criteria in an evaluation function might be accomplished. Both the generating and drawing of alternatives and the selection among them takes place in unison (figure 1). The automation of the selection process is possible if quantifiable (hard) criteria are employed. But also tacit (soft) expert knowledge (if captured within an neural network) can be applied within the evaluation function of the morphogenetic program. The clustering of people, departments or rooms for instance might be based on objective criteria and applied in an optimizing genetic algorithm but might also be based on subjective or fuzzy criteria and put to use in a trained neural network capturing the fuzzy knowledge of an expert. In this way the mentioned human reasoning restrictions to consider more than few decision factors might be avoided, necessary information incorporated, unbiased judgements implemented and best solutions aimed for. The introduction of extrinsic knowledge and preferences by the user is still made possible with the rapid visualisation facilities to picture the most promising generations of best fitting solutions (according to the applied evaluation function and incorporated neural network). This is accomplished by a visual display supplying the user with additional opportunities to select what he or she knows is best (thanks to some available additional information) or if the user is looking for aesthetically pleasing or otherwise interesting arrangements.

Artificial creation and universes of new creatures

Authors of genetic programs (like Dawkins, 1986, Sims, 1991 and Todd & Latham, 1992) all mention their astonishment at the incredible variety they got confronted with when their programs started generating forms based on a few simple rules. They explained that they would never have found them in an other way and surely not in the comprehensive manner offered by their programs. They even wouldn’t have the time to draw, model and render them all appropriately. Form breeding programs have the combinatorial capacity to produce immensely large sets of variants, without being troubled with the typical human effects of being satisfied with the first applicable solution one has hit upon (love at first sight). Additionally, with their built-in evaluation function they are able to detect and select the most promising ones for presentation to the user(s). Subsequently, humans (and especially designers and critics) are very well capable of spotting quickly and efficiently the qualities of variants in the remaining presented subset of the most promising options. As a result of all this, innovations emerge spontaneous out of the forced and unpredictable interaction and combination of the parts.

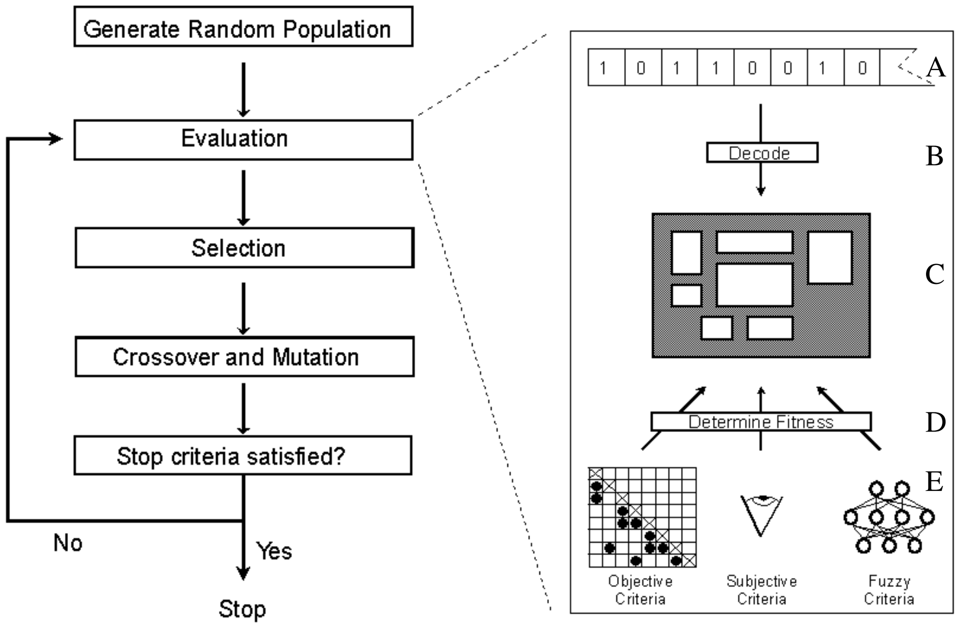

Figure 1: flow chart for the genetic algorithmic procedure of the layout program by Philip Snijder with a detail of the evaluation function to test the fitness of the creatures (the layout aternatives). A= strings defining the geometry as a genetic entity; B= genetic entity decoded into Euclidean geometry; C. Layout as a generated form or shape; D= fitness test; E= types of test criteria: left objective and automatic executed criteria (of proximity for instance), in the middle subjective criteria introduced by selections of the user on screen and right fuzzy criteria applied by a neural network trained by an expert in the field (about orientation for example).

Artificial creation and creativity

Creativity is about new thoughts, concepts or notions (Boden, 1994; Gero & Lou Maher, 1993; Runco & Albert, 1990; Sternberg & Davidson, 1995). It is about the ability to come up with new ideas out of either an unrecognized part of a pre-defined solution space or as an emergent result of transformation of some aspects of the conceptualized solution space. GACAAD applications are quite potent for provoking and supporting this kind of creative acts. They incorporate pre-defined solution spaces giving the opportunity to spot and explore the unrecognized parts of the solution spaces involved. And they offer the possiblity of intervention in the pre-definition of the solution space itself in order to tinker with them or transform them partly or radically.

Working styles of designing and diffusion of the GACAAD idea

It is left to the architects to determine how such programs might fit into their practice. From the point of view of working styles of architectural designing (van Bakel, 1995) the program should be designed to work from either a conceptual line of approach or starting from the brief or the site involved. In figure 1 the purely conceptual approach is provided for by the possibility of selecting subjectively by visual appreciation or by using fuzzy criteria. The approach from the brief is attended to by the introduction of objective or even fuzzzy criteria. Last but not least the site as a framework is looked after by incorporating penalty points for overstepping the limits of the site involved. But even the existence of adaptable morphogenetic programs is not enough to get architects to apply them in practice. As the preamble of this conference states, media diffusion techniques would then needed, accompanied by carefully selected case studies in practice, introduction of the results in workshops and training courses for students and professionals alike.

Genetic algorithms: suitable for design groups and everyone else involved

In (AVO)CAAD sketching and drawing is the exclusive domain of the individual architect. Or at least restricted to individuals with some experience in visualizing. If groupwork is asked for, the most practical design procedure is to leave the sketching, drawing and modelling to the most skilled people (the facilitator or operator) whereas others can concentrate on reasoning, asking for new or corrected pictures and selecting options for further development. To do the sketchwork instantly during a meeting is a very laborious job for the the facilitator or operator. With GACAAD no amount of sketching, drawing or modelling is needed during the meeting. This is done by the program and everybody else is involved in the decision making process of deciding on criteria to be employed and selections between optioms to be made in a very fast and highly interactive way. Because good visual observation, interpretation and selection are much more widespread than skill at visualizing, the GACAAD approach has a clear advantage. With a visually based GACAAD the tools of CSCW (computer supported cooperative work) - yet still under development mainly verbal or computational- might be expanded to the fields of design, architecture and artistic production.

Integrating design research facilities and results

Design research might be performed as either ‘about’, ‘for’ or ‘through’ architectural designing (Daru & Snijder, 1996). To investigate the first the process of designing the programs could be equiped with automatic registration devises to facilitate observations and analyses of behaviour performed on the machine. The results could be fed back for the redesign of the interface or the other parts of the program involved. Research done on instruments to improve the design (like wayfinding in buildings) could be embedded in the evaluation function of the morphogenetic program. Research of the third kind ‘through’ or by way of architectural designing (experimental designing) could take full advantage of the shape generating capabilities of the morphogenetic program to explore and discover new, meaningful and valuable forms.

Designers as Darwin Machines

The functioning of a brain generating forms might also be seen as a Darwinistic system of creatures behaving within their environment. In a morphogenetic program, the creatures are the generated options and the environment is represented by the evaluation function together with the visual interface for selecting options to be reproduced in a next generation. Dennett (1995) makes a distinction between four types of creatures: Darwinian, Skinnerian, Popperian and Gregorian living beings. Morphogenetic programs are capable to support or even to simulate those types of creatures, according to the sophistication of both the creatures learning capabilities and the morphogenetic programs involved.

Darwinian creatures

Expressed in the context of an architectural competition a Darwinian creature is a participating architect with his design entry submitted to the jury as the environment. The ideas embedded in the winning entry will propagate themselfs in both the next projects of the prizewinner and the minds of competitors, due to its success in the selection process. Morphogenetic software is capable of simulating this type of Darwinian creatures: it is able to generate alternatives, carried out by the selection function, first randomly, and after each selection round, more and more goal directed. If the software is equipped with a visual selection display the software is transformed into an enabling tool. In morphogenetic art programs (like the paint program by Karl Sims (1991) or the sculpture program of Stephen Todd and William Latham (1992)) the applied genetic algorithms generate new images from pre-defined images, based only on visual selections. In an applied art like architecture, Fraser (1995) and Möller (1996) have done the same, but they developed also programs with some objective criteria inserted. Philip Snijder (Snijder & Daru, 1996) is doing this in the same vein with a layout generator for the earliest phases of architectural design (figure 1)

Skinnerian creatures

Skinnerian creatures differ from Darwinian ones by their conditional plasticity: they learn by trial and error. Within the context of design competitions this might be compared with an architect full of design ideas trying them out one for one, or in a variety of combinations in competion entries, until one hits a prize. The ideas applied in the prizewinning scheme might then be adapted for forthcoming competition projects. Those architects let themselves be conditioned by the jury environment. As newcomers (in an other country for instance) without any informal information about the vision and behaviour of jury members and how they will argue and select, this trial and error approach is perhaps the most appropriate to follow. The problem with this type of 'blind' respond in nature is that you might first try out by chance the least appropriate answer and get wiped out: there is no reinforced second chance to respond more suitably to the situation. This type Evolutionary Reinforcement Learning (ERL) is (perhaps for the first time) implemented in the program by David Ackley and Michael Littman (1992). They linked together a genetic algorithm with two types of neural networks: an evaluation network with fixed goals, giving reinforcements to a modifiable action network which maps the current state of the actual alternative to be used for an appropriate response in a next round of tryout.

Popperian creatures

In order to avoid a bad start with the trial and error procedure of the Skinnerian approach Popperian creatures have developed preselection devices to make better-than-chance first trials. This feedback mechanism is structured like the outer environment and (based on lots of information) sorts out the best actions to take in a hostile environment. Within the setting of a design competition, an architect (relying on information he or she has collected) might for instance imagine how the members of the jury will behave (their ways of observing, reasoning and selecting) and develop out of those depictions an internal environment as a reflection of the real external jury environment. In that way the architect is able to reflect on the probability of positive impact that his or her design ideas might impose on the jury. Design ideas that survive such an internal criticism might have a better chance to succeed in the real world of competion judgements by juries. This type of thinking is simulated on behaving automata (on supercomputers in a very restricted and simplified way) by a team lead by Nobel laureate Gerald Edelman (1992), based on his neural Darwinistic population 'Theory of Neuronal Group Selection' (TNGS, Edelman, 1978).

Gregorian creatures

Gregorian creatures are like Popperian living beings, but with the additional trait of informing their internal environment of the artificial world of man-made-things with the intelligence invested therein and apprehendable in them. As Gregory (1981, pp 311 ff) put it: a pair of scissors is not just a result of intelligence but also an endower of intelligence; when you give someone a pair of scissors, you enhance his potential to arrive more safely and swiftly at smart moves. Until now the best mindtool for designers is still the design sketch pencil, perhaps now and in the future more and more amplified by devices out of the worlds of AVOCAAD and/or GACAAD. Deny a designer his pencil (or his sketchmodel) and he will suffer in (the fluency, complexity and consistency of) his imagination. Mindtools in designing are meant for both the generation and the evaluation of forms and form related ideas. For architects to support the generation and identification of potentially successful designs and for juries (being as it were the design environment) to select outstandingly fit and original design entries.

AVOCAAD compared with GACAAD

AVOCAAD might for instance support the imagination about folding architecture with morphing- en warping functions and with the description of the geometry, compare the generated with the required areas, the costs per area involved and the construction or building physics consequences of the chosen geometry. GACAAD supports the same but then fully and consistently integrated. The user is not supposed to be kept captive in low level handiwork like thinking about where to draw lines and rectangles in order to get some meaningful pattern while in the meantime the computer stays idle waiting for instructions. Instead the user in GACAAD is thinking in high level semantics about the design concept, the brief and the situation while studying the results of the computer busy with calculating, comparing, selecting and drawing acceptable alternatives on screen. The acceptability is defined according to the quantifiable and fuzzy criteria introduced with care by experts beforehand and as used in the fitness function (figure 1). This intrinsic information processing is thus fully automated. The user can concentrate on everything else he or she might think of as important, enjoyable, pleasing or interesting for the selection process as presented by the computer as appropriate alternatives on screen. This user-steered selection process is called extrinsic information processing or ‘breeding’ and cannot be automated. It is here that the human creative power of association and analog thinking used for identifying novel and original alternatives can be expressed entirely.

State of the art worldwide

On a global scale, GACAAD barely exists. GACAAD on the contrary has its own indexed bibliography (compiled by Jarmo T. Alander, 1996) with more than 452 titles and 663 authors. Compared with the total of GA papers GACAAD is however still lagging behind because it started more than ten years later, but is quickly gaining momentum (Bentley, 1995, Furuta et al., 1996, Rebaudengo et al., 1996 and Watabe et al., 1993). Considering the advantages of this approach for designing, it deserves more attention and research as a means of developing real design enablers instead of drawing or modelling tools. It has already led to the collaboration of practitioners of very diverse disciplines. Scientists in creativity (Boden, 1994) and brain researchers (Edelman et al. 1978, 1992 & 1992; Calvin, 1996) are working increasingly with GA-based models of creative behaving and brainfunctioning, defining the needed enablers to complement human capacities and shortcoming and scientists (studying the interactions between buildings and people) specifying the evaluation function of the needed GACAAD implementations.

Taking on the challenge

Designers and/or artists are already gaining experience with the developed programs as clients and testers, specifying the needed functionalities as a user, the needed geometry to realise buildings in the style of the moment and the performances needed to be evaluated automatically. But the architectural world has not yet taken on the challenge (except in rather metaphorical way; Jencks, 1995; Lynn, 1993), even though the Darwinian paradigm can add value to the designing process in a radically new way. We might hope for mutations following this move. But to become aware of all this implies a paradigm switch. A relearning of how we see and imagine the practice of design: either as a relatively slow but exhausting activity of conceptual sketching, drawing and modelling or as a much faster and nevertheless more relaxed effort of breeding and conceptual selection.

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