# Notes on the potential of simulation for architectural conception

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“If mechanical forces can be distinguished, it is not because living matter exceeds mechanical processes, but mechanisms are not sufficient to be machines. A mechanism if faulty not for being too artificial to account for living matter, but for not being mechanical enough, for not being adequately machined”

Deleuze, The Fold: Leibniz and the Baroque

“Evolutionary computing is the mechanization of the scientific method”

John Holland

## 1 Computational Chair Design project

In recent projects EZCT Architecture & Design Research ( hereafter EZCT ) investigated the potential of simulation applied towards architectural conception. What does it imply to know the structural, thermodynamic capacity as well as the daylight penetration of a building a priori for architectural conception? EZCT initiated the CCD project in order to understand this epistemological shift. The CCD project started the collaboration with Marc Schoenauer, who is a leading researcher in the domain of evolutionary computing and machine learning. For the CCD projec[1] a genetic algorithm was develop that evolves a volume such that the forces inflicted upon it are dissolved as efficient as possible, while reducing the volume. One of the aims of the project is to arrive at a mechanization of the design process, such that instances of the concept can be produced fully automated. This is indispensable to fully develop the potential of non-serial fabrication of objects. In his article “Towards a fully associative architecture”[2] B.Cache confirms this: “the design process itself would need to be automatized and we cannot have a piece of software written for each type of design problem”. Instances of an idea; J.Holland too defines evolutionary computing as the mechanization of the scientific method, appropriated to architecture the mechanization of the conceptual method.

Following Cache’s architectural and Holland’s computational theory the automation of design is precisely what the CCD project focusses on. Such an approach differs radically with that of Mass Customization, where commonly a parametrized design is adapted as such is the case in the Variomatic project of K.Oosterhuis. The project intended the idea of designing by means of simulation. The fitness function of the genetic algorithm developed for the CCD project consists of a structural evaluation analysing how forces inflicted upon the chair are dissolved throughout the volume. Assumptions and abstractions that are common in engineering have been left out. Evolutionary computing is applied to control the full extent of the complexity of the problem presented. The outcome of such a process therefore often is hard to interpret. Its undemanding to observe that the a pre-defined condition has been met, but its an entirely different issue to fathom why such is the case. Darwinistic evolution is capable of producing results that are so rational that it can be hard to interpret these as such! Hence it seems that evolutionary computing coupled with a fitness function based on simulation is capable of generating hyperrational designs.

**Figure 1. Different stages of evolution of the Test-9 chair**

By controlling the complexity of the optimization process rather than reducing it, an object surfaces that is on the threshold of a mechanical form becoming organic. To converge a design, it is preceded by an vast series of possible designs. The model “Test1-860” shown below is 860 generations old. A generation is comprised of a hundred individuals, so that 86.000 potential designs have been generated before the design was converged. The vast number of potential designs that have been evaluated explain the dimension of the voxels which the chairs is built from. If a structural evaluation took 10 seconds then the evolutionary development takes up 9,95 days for the design of a single chair to complete. Fortunately the process can be easily distributed over a large number of computers. The grid computing facilities of the INRIA[3] have been applied for the design of the 25 chairs of which the CCD projects consists of. Since the application of a genetic algorithm leads not to a single solution but rather a family of solutions, it is only natural that the project has resulted in a series of chairs.

**Figure 2. Matrix of all chairs that make up the CCD project, as installed at the permanent collection of the Centre Pompidou, Paris, France**

**Figure 3. Chair model T1-M, after 860 generations**

## 2 Seroussi Pavilion

Recently EZCT participated in an architecture competition appointed by miss Seroussi, art dealer living in the former estate of André Bloc[4]. For the competition several agencies working in the domain of computational architecture were invited: DORA, EZCT, Gramazio & Kohler, IJP and Xefirotarch[5]. EZCT won the competition in execo with DORA.

One of the concepts EZCT developed for the project is the idea to design a pavilion that will be illuminated by approximately 200 Lux daylight, as homogenous as possible throughout the whole year. The aim of this design was that the exhibited works are best presented and protected of overexposure of UV light.  To develop such a condition on say the 21st of June at noon is not a mundain task , but certainly assumptions can easily be made regarding atmospheric conditions. To deliver  a homogenous distribution of  200 Lux annually therefore requires a very precise model of atmospheric and solar conditions. A standard CIE sky model, an aging standard from 1906, certainly will not meet this needs, since a uniform hemispheric distribution of 200 Lux anywhere on the planet is assumed. Hence the application of climate based modeling becomes a necessity. Rather than representing the the solar and atmopheric conditions on a moment in time, where either a clear or overcast sky is assumed, the model that J.Mardaljevic developed, is based on satellite climate data. The Radiance atmospheric and solar model is based on the irradiation data of all annual 4380 sun hours. This way a highly accurate model was obtained that is a precise representation of the local climate.

By doing away with irrelevant, sometimes even corrupting assumptions, abstractions and simplifications, it becomes possible to start solving the problem at hand at its full complexity. Evolutionary computing is capable of controlling such dazzling complexity. By increasing the resolution of the problem dramatically, new solutions come to daylight

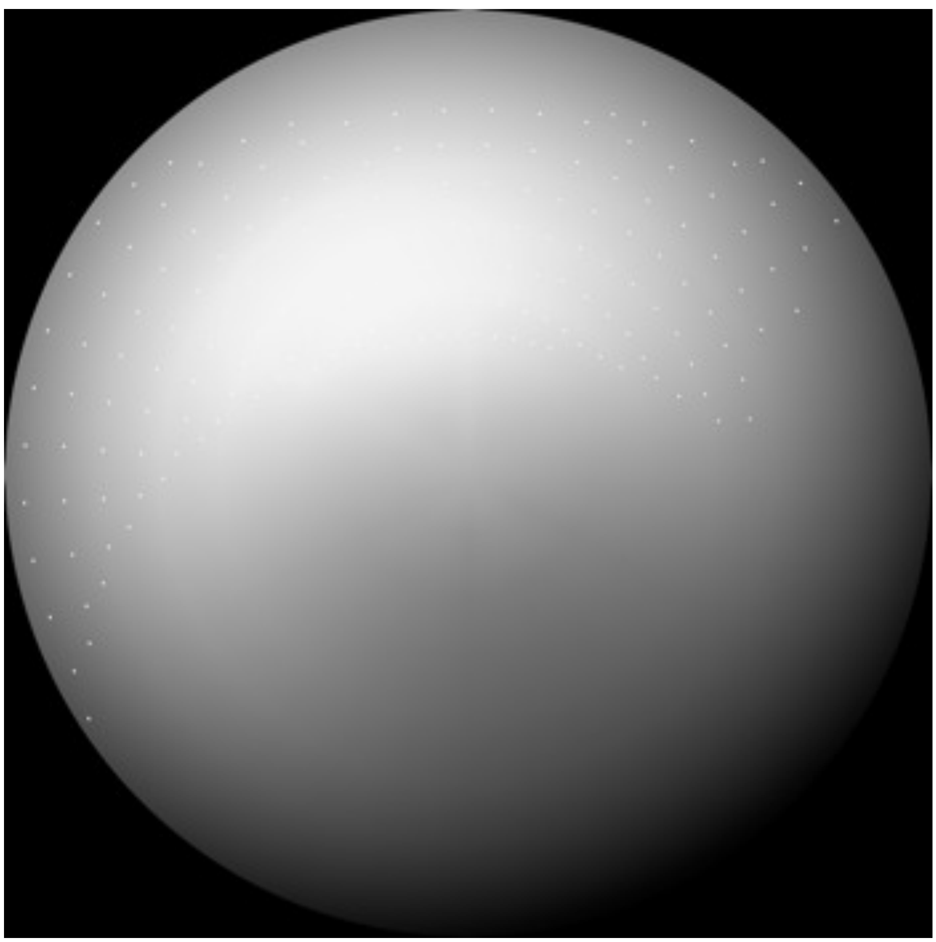

**Figure 4.  Radiance rendering of the sky model developed by J.Mardaljevic.**

## 3 Technical description of the Radiance GA

To develop the concept for the Seroussi Pavilion[6] rigorously EZCT implemented a program that evolves an architectural envelope approximating the ideal condition that of the homogenous distribution of ~200 Lux daylight, as close as possible. Since no analytic formulation exists or could be developed for the problem an exploratory optimization technique was applied such that the design would converge to its logical consequence. The architectural program, described in square meters first was interpreted to volumes, such to obtain a precise idea about the volumetric requirements to meet the architectural program. Next a domain was defined encompassing the complete architectural program. In the domain each architectural program is represented as a point. In the first generation of the evolutionary process, the domain will be populated by a set of random points. From this set, the Voronoi diagram is computed. Each cell within the Voronoi diagram is labeled a void or solid. Cells labeled as solids are assigned to Voronoi sites representing the architectural program, until the predefined volume representing the program has been met. Consequently, this set of points fulfills an embryogenic role in the evolutionary process. Since the architectural program is well defined, there is no interest in evolving it. Rather it is used as a seed from which the evolutionary process departs from. The barycenter of each cell labeled as void will be sampled in the Radiance simulation, such that the daylighting performance is evaluated. The sum of the difference of the measured values to that of the target value of all cells labeled void is the fitness criteria of the Radiance GA. After several hundred generations a generation of solid candidates develop that will be further advanced in the continuation of the design process. The Voronoi diagram is an excellent genotype for spatial applications. The power of evolutionary computing lies in the fact that the design is abstracted and encoded. The performance of the evolutionary processes therefore is directly related to the effectiveness of the genotypical encoding. The more powerful the abstraction represented by the encoding, the more likely that the evolution will be effective. The brain for instance consists of about a hundred billion connections, though only thirty thousands active genes describe the brain. Such a ratio is unprecedented in evolutionary computing, though the Voronoi diagram develop by M.Schoenauer is an important contribution to the development of an efficient genotype for spatial applications. A common representation in evolutionary computing is a binary matrix. The domain bounding the design space is discretized in a grid of cells. The evolutionary development hence is basically reduced to flipping the switch whether cells are represented as mass or void. Other than the binary matrix the Voronoi diagram is adaptive. The binary matrix, necessary to encode a volume increases in a cubic fashion, where in the case of a Voronoi diagram, a large or small volume can be encoded with a few points[7].

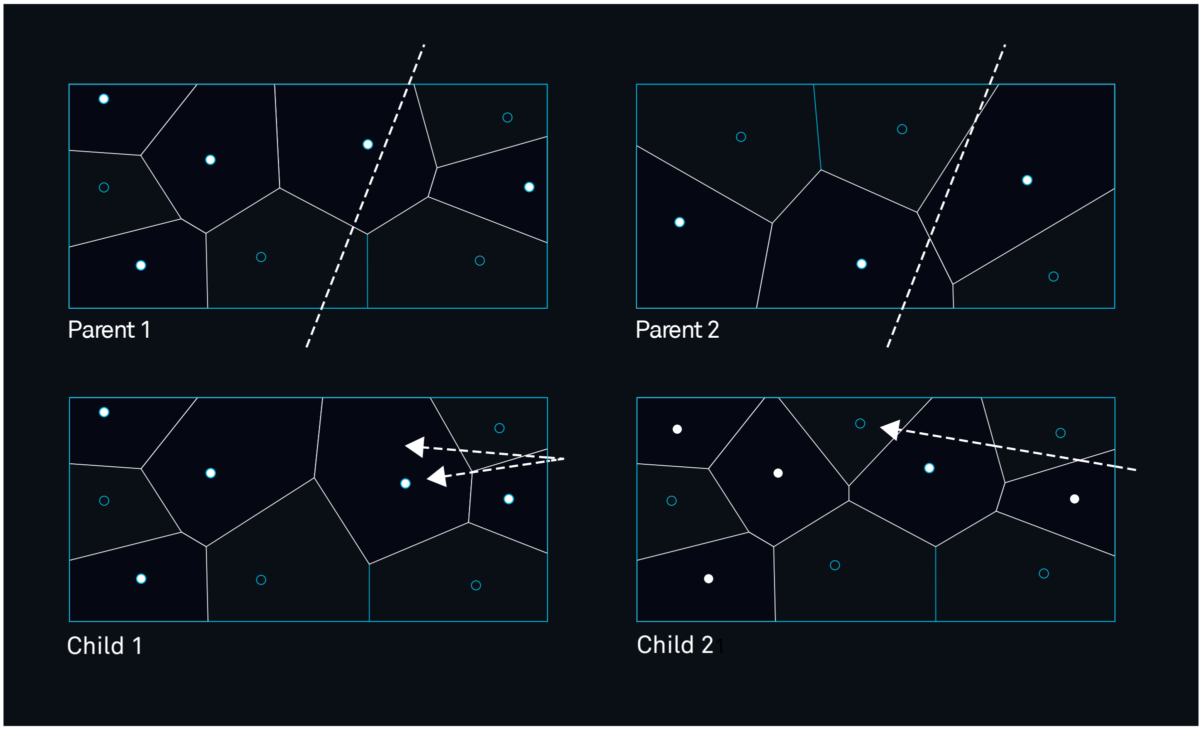


**Figure 5. Diagram of Voronoi sites being crossed over**

**( diagram by Philippe Morel[13] )**

Although the projects differ radically its been possible to apply the genotype based on the Voronoi diagram in both the CCD project as well as the Seroussi Pavilion project. Therefore can be speculated that its worthwhile to invest an effort in the development of software components. Architectural production deals with a severe degree of entropy since a relatively small subset of projects conceived ( a 1:10 ratio is not uncommon ) actually is realized. Hence the development of sufficiently abstract software components seems a viable method of capturing the knowledge materialized during the project.

**Figure 6. Evolutionary convergence of the Radiance GA**

**Figure 7 and 8. Interior view of the Seroussi Pavilion**

## 4 Software development

Other than for the CCD project which was implemented by H.Hamda, the software for the Seroussi Pavilion was written by M.Schoenauer and J.Feringa. M.Schoenauer implemented the genetic algorithm where J.Feringa implemented the fitness function. The program has been developed on top of a number of open-source libraries and software. The genetic algorithm is implemented in C++ on top of the Evolving Objects[8], a highly modular framework paradigm-free[9] for evolutionary computing. The fitness function was implemented in Python, using the CGAL[10] module to compute the Voronoi tesselation. Python generates the data that is the input for Radiance[11], a toolset for photometrically validated light simulation which is the de-facto standard for (day)light simulation.

## 5 Motivation for evolutionary computing

In his essay ‘Next Babylon, Soft Babylon’[12], M.Novak writes “Elegance is the achievement of maximal effect with minimal effort”. This statement can be interpreted as an aesthetic motivation to apply optimization processes to architectural conception. Elegance seems to be a property is that can be defined in terms of information theory; the more informed matter is, the more meaningful it is hence the more elegant it becomes.

The approach described in this paper is more related to minimalism, rather than a baroque bio-mimetic approach. Principles from biology have been applied in the projects, rather than there was a formal grammar that suggested a bio-mimetic aesthetics. When one thinks of the scientific achievements and the fundamental understanding of the principles of nature, it seems almost perverse to simply mime its results rather than applying its underlying principles. An example is the widespread adaption of Voronoi diagram. Where computational geometry exploits the fundamental properties of the algorithm, in architecture its seems to have been adapted for its capacity to mime patterns occurring in nature.

## 6 Conclusion

With the projects described in this paper, EZCT has demonstrated a reversal of the tradtional role of simulation in architectural conception. Traditionally the role of simulation has been to see whether a design complies to its aims. In the projects described in this paper simulation is at the heart of architectural conception itself. Optimization facilitates the role of simulation as a tool that can be applied towards design.

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University of Chicago Press. (1993). *The Chicago manual of style*, 14th ed. Chicago: University of Chicago Press, 1993.

[1] EZCT Architecture & Design Research (Philippe Morel, Felix Agid, Jelle Feringa)

Studies on Optimization: computational chair design using genetic algorithms 2004-2006

Concept: EZCT Architecture & Design Research

C++ programming, genetic algorithms and structural calculation: Hatem Hamda, Marc Schoenauer (INRIA Futurs - projet TAO)

Xd3d Software (visualization & finite elements method software, GNU General Public License): François Jouve (Ecole Polytechnique)Mathematica programming: EZCT Architecture & Design Research

[2] P.Beaucé, B.Cache. 'Vers une architecture associative', in Migayrou and Mennan, Architectures non standards (HYX 2003)

[3] The French National Institute for Research in Computer Science and Control

[4] Founder of L'Architecture d'Aujourd'Hui, a major French architecture review. Worked from 1962 until 1964 on the Sculptures-Habitacles, constructed on his former estate in Meudon.

[5] A catalogue has been published under the title Pavillon Seroussi (HYX, 2007)

[6] Project:

EZCT Architecture & Design Research

C++ programming, EO evolutionary objects programming:

Marc Schoenauer, INRIA Futurs, Projet TAO

Radiance simulation, Python/CGAL programming:

Jelle Feringa, EZCT Architecture & Design Research

Annual climate-data based Radiance sky / sun model:

John Mardaljevic, IESD, De Montfort University

Mathematica programming:

EZCT Architecture & Design Research

Mathematics & additional Mathematica programming:

Benjamin Collas, Université Paris VI Pierre et Marie Curie

Maryvonne Teissier, Université Paris VII

Structural Engineering:

OSD – Office for Structural Design

Harald Kloft

Jürgen S. Wassink

Rendering: Olivier Campagne

Intern: Pierre Cutellic

[7] H. Hamda and M. Schoenauer (2000). Adaptive techniques for Evolutionary Topological Optimum Design.

[8] EO, Evolving Objects, http://eodev.sourceforge.net

[9] EO allows one to easily mix paradigms coming from Genetic Algorithms, Genetic Programming, Evolutionary Strategies, Evolutionary Programming

[10] CGAL, Computational Geometry Algorithms Library, http://www.cgal.org

[11] Radiance, http://radsite.lbl.gov/radiance

[12] M. Novak. "Next Babylon, Soft Babylon", in AD (vol. 68, 1998)

[13] Image adapted from H. Hamda and M. Schoenauer (2000). Adaptive techniques for Evolutionary Topological Optimum Design.