# Geometry and Topology
# A User-Interface to Artificial Evolution in Architectural Design

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New AI, Genetic algorithms, Artificial Evolution, creative architectural design, interactive design, Topology

## Abstract

The paper presents a system that supports architectural floor plan design interactively. The method of problem solving implemented is a combination of an evolutionary strategy (ES) and a genetic algorithm (GA). The problem to be solved consists of fitting a number of rooms (n) into an outline by observing functional requirements. The rooms themselves are specified concerning size, function and preferred proportion. The functional requirements entering the fitness functions are expressed in terms of the proportions of the rooms and the neighbourhood relations between them.

The system is designed to deal with one of the core problems of computer supported creativity in architecture. For architecture, form not only, but also function is relevant. Without specifying the function that a piece of architecture is supposed to fulfil, it is hard to support its design by computerised methods of problem solving and optimisation. In architecture, however, function relates to comfort, easiness of use, and aesthetics as well.
Since it is extraordinary hard, if not impossible, to operationalise aesthetics, computer aided support of creative architectural design is still in its infancy.

The approach presented makes use of the fact that a good deal of the functional requirements to be observed in floor plan layout can be expressed in terms of geometry and topology. The fitness functions that the system is supposed to optimise are restricted to (1) eliminating gap between and overlap of the rooms to be accommodated, (2) approximating the proportions preferred, and (3) optimising the neighbourhood relations between the rooms. The rest is left to the human designer who interactively intervenes into the game of artificial evolution as displayed on the screen.

The strategy eliminating the gaps and overlaps that occur when the rooms (i,j) are tried to be fitted into the outline (u) consists of a mutation driven evolutionary strategy. The fitness function (Sg(o) minimises the sum total of overlap (S[i](S[i]), and overflow (S[i]\S[u]).

$$Sg = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} (S[i] \cap S[j]) + \lambda \sum_{i=1}^{n} (S[i] \setminus S[u])$$

After being initiated, a population of design variants is subject to random change concerning position and proportion. Selection acts through reproduction from generation to generation. The fitter a variant, the higher is its reproduction rate. The proportion preferred is approximated through filtering probabilities.

The search space of this particular problem is characterised by a multitude of global optima. Since the risk of being caught in a local optimum is minimal, this simple evolutionary strategy is adopted for reasons of speed.

The search space of optimising the neighbourhood relations is much more complex. Moreover, the search space asks to be worked through more thoroughly. In order to do this, a genetic algorithm (GA) is adopted which combines mutation with cross-over.

The operation performed by the GA is a kind of re-interpretation of the rooms arranged. It changes the functions attributed to the rooms in order to optimise the neighbourhood relations. The output of the GA is thus turned into an input of the strategy fitting in the rooms and vice versa. The fitness that the GA is supposed to maximise is measured in terms of the weights specified in the topological matrix (W). Elements $w_{ij}$ of this symmetric matrix express the importance of the neighbourhood of rooms i and j. The weights $w_{ij}$ are specified by the user (see figure 1). Solutions of the arrangement problem have the form of matrix T. The value of element $t_{ij}$ is higher in the case that rooms i and j are nearby and lower when they are not. The fitness function ($W_T$ ( max) to be maximised sums the products $w_{ij}$ * $t_{ij}$.

$$W=\begin{pmatrix} 0 & w_{12} & w_{13} & w_{14} & \cdots & w_{1n} \\ w_{21} & 0 & w_{23} & w_{24} & \cdots & w_{2n} \\ w_{31} & w_{32} & 0 & w_{34} & \cdots & w_{3n} \\ w_{41} & w_{42} & w_{43} & 0 & & \vdots \\ \vdots & \vdots & \vdots & & & w_{n-1,n} \\ w_{n1} & w_{n2} & w_{n3} & \cdots & w_{n,n-1} & 0 \end{pmatrix} \quad T=\begin{pmatrix} 0 & t_{12} & t_{13} & t_{14} & \cdots & t_{1n} \\ t_{21} & 0 & t_{23} & t_{24} & \cdots & t_{2n} \\ t_{31} & t_{32} & 0 & t_{34} & \cdots & t_{3n} \\ t_{41} & t_{42} & t_{43} & 0 & & \vdots \\ \vdots & \vdots & \vdots & & & t_{n-1,n} \\ t_{n1} & t_{n2} & t_{n3} & \cdots & t_{n,n-1} & 0 \end{pmatrix}$$

$$W_T=\sum_{i=1}^{n}\sum_{j=1}^{n}\left(w_{ij} * t_{ij}\right) \quad w_{ij}\in\Re, \quad t_{ij}\in[0,1]$$

The reason for adopting this mixed strategy lies, among other things, in speeding up the process. Speed is crucial for interaction with the user. In the same way in which strategies ES and GA interact, their interplay interacts with the interventions on the part of the user. The user intervenes into the game of artificial evolution via mouse and editing. The whole floor plan becomes fluent and movable

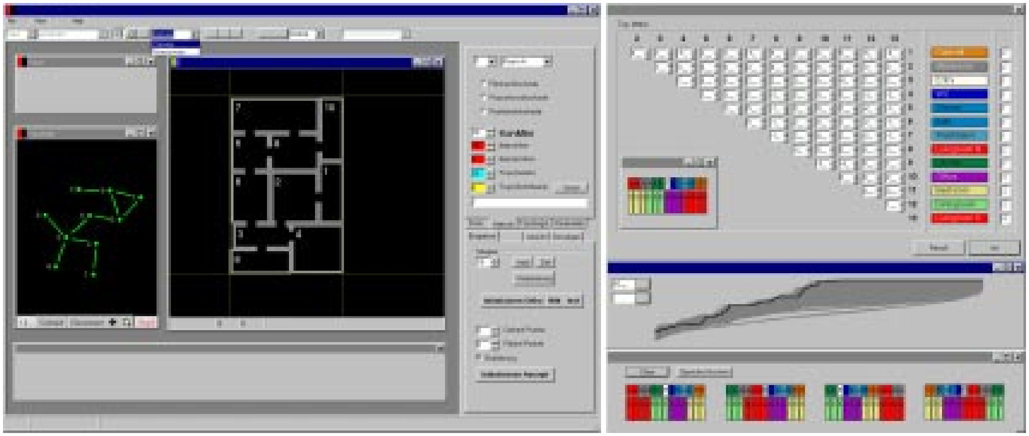
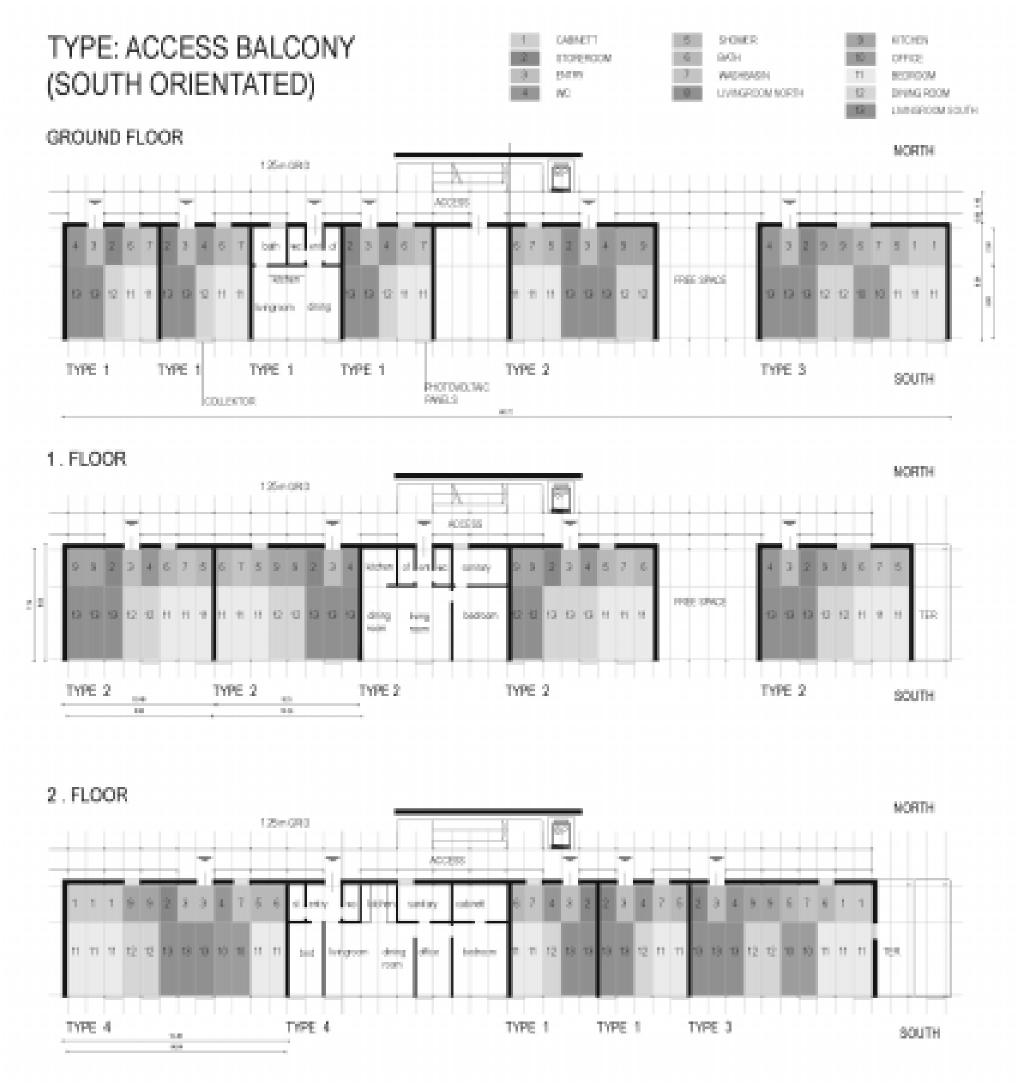


Figure 1

Figure 2




and reacts 'intelligent' on the human intervention concerning the areas, proportions, positions of the units (rooms) and in particular the topology. The interface through which the user interacts (see figure 1) with the system has the following features: (a) the design variant being the fittest at the moment is displayed on the screen, (b) the arrangement as well as the geometry of the rooms can be changed via the mouse, (c) the weights of the neighbourhood relations can be edited during the run.

The usefulness of the system as well as the easiness of its use were tested in a design studio held at the Vienna University of Technology in the winter term 99/00. The subject of the studio was solar architecture. The designs developed with the help of the tool were recalculated concerning energy use and solar gains of the building. The outlines proving viable in these regards were fed back into the system. The project presented below was done by a student, Christian Kadletz, using both the design tool and the performance calculator for the first time.

Outlook: The steps of development at the system lying ahead of the version presented are generalisations, in the main. First, the rectangularity of the rooms and outlines waits to be generalised by allowing any angles and higher polygons. Second, the floors treated separately until now should treated in a more integral manner by expressing the neighbourhood relations in three dimensions. Another route of generalisation lies in adapting the system for purposes of town planning.

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