Optimal Distribution of Architecture Programs with Multiple-constraint Genetic Algorithm

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I. Introduction

As architectural projects are becoming increasingly more complex in their formal manifestation as well as their functional requirements, methods are sought to address these complexities. Genetic algorithms offer an effective solution to the problem allowing multiple constraints to compete as the system evolves towards an optimum configuration that fulfills those constraints. A case study is presented that involves a distribution of architectural programs such as residential, office, and retail spaces with multiple environmental, functional, and economic constraints.

A genetic algorithm (GA) is a search technique for optimizing or solving a problem. Its mechanism is based on evolutionary biology, using terms and processes such as genomes, chromosomes, cross-over, mutation, or selection. The evolution starts from a population of completely random individuals and happens in generations. In each generation, the fitness of the whole population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness), modified (mutated or recombined) to form a new population, which becomes current in the next iteration of the algorithm.

Genetic algorithms originated from the studies of cellular automata, conducted by John Holland and his colleagues at the University of Michigan (Holland, 1992). Research in GAs remained largely theoretical until the mid-1980s when a dramatic increase in desktop computational power allowed for practical application of the new technique.

In architecture, GAs are of special interest mainly because of their ability to address a problem offering a multiplicity of possible solutions. Contrary to other algorithms where the objective is to accommodate a manually conceived parti or diagram, GAs are emergent procedures that evolve over time through multiple attempt cycles (i.e. generations) and therefore offer a bottom-up approach to design. In addition, by using the computational power of computers they can resolve complex interactions between multiple factors and under multiple constraints offering solutions that occasionally surprise the designer.

2. The Problem

One of the main problems in architecture today is the quantity of the information and the level of complexity involved in most building projects.

As globalization and economic development has started to arise at unprecedented levels, the need for large urban developments have become commonplace. Housing projects for a few hundreds to thousands of people have started to emerge over large urban areas. In such cases, the old paradigm for housing design was the development of high rises that served as stacking devices for multiple family housing units. Such a direction was unfortunately the only way to address excessive complexity using manual design skills mainly because it was simple to conceive but also simple to construct. The unfortunate nature of this approach lies rather in the uniformity, similarity, and invariability that these projects express in comparison to individuality, discreteness, and identity that human beings and families manifest.

Genetic algorithms solve local neighborhood behavior and then move further to resolve global to the system issues. In that way there is an emergent behavior embedded in the process of deriving possible solutions to a design problem. This behavior is based on the premise that individual units under certain constraints may emerge into globally functional configurations by resolving their local neighboring conditions in a repetitive manner. Contrary to common belief such seemingly chaotic local behavior does not necessarily result into chaotic overall behavior, but rather into an evolved form that solved the local constraints.

One of the main areas of complexity that could benefit architecture is in planning. In these projects there is a series of architectural programs that need to be arranged in various schemes that will fulfill multiple functional, environmental, and economic constraints. While small buildings may be solvable within one architect's design capabilities, the design and planning of large projects with several thousand inhabitants is a challenge. The problem here is to fulfill all complex requirements without using conventional repetitive high-rise patterns.

3. Methodology

The distribution of the various architectural programs is investigated within the given search space in this project. The programmed elements are represented as color coded cells (Red for commercial space, Blue for residential space, and Green for office space) in the hexagonal grid environments, and various adjacency relationships between the different cell types, the constructiveness of the resulting structures, real estates values, and the overall density are evaluated. Hypothetical 10x10x10 three dimensional grids are used as a generic sample environment space to view the distribution patterns of the three cell types. Hexagonal grid is chosen in horizontal direction to simulate homogeneous Cellular Relationships. Implementation of the Scale will be depending on the evaluation factors of the cells. Creating the distributions which satisfies the above requirements for the lowest cost and the highest profit became the main agenda for the project. Beyond the certain quantitative factors and the complexity of the problem, a search process was initiated that challenged the unpredictable domain of the human perception. Thus, a Genetic Algorithm was selected as a design/optimization method for this project.

First, arrangements of the units are mapped (encoded) into an artificial chromosome of a certain fixed size of strings. In this case, they are characters composed of four different ASCII codes denoting four different spatial types of cells, ("0" for Void space, "1" for Residential space, "2" for Office space, and "3" for Commercial space). Initial populations of strings were randomly created for the manipulation using the genetic algorithm, and the fitness measure (function) was defined based on the above constraints factors. More precisely, evaluations (fitness) of the cells are systematically defined by the following rules, and coded as fitness functions for the GA's optimization process.

- Compatibilities between the neighboring cell types are evaluated based on the affinity of the proposed programs. For example, commercial cells directly next to the residential cells will be penalized and lose some real estates values. Clustering of the same program types are encouraged both horizontal and vertical directions for office and retail spaces. Commercial cells (shops) can gain better values by being a storefront at the ground level facing the open areas.

- Environmental evaluation was made based on the natural lighting conditions, sounds and views from each cell. For example, residential cells can acquire higher real estates values by having more open side faces without adjacent cells due to the better natural lighting conditions. The higher the cell locations, the more the value for the units is increased by gaining better views.

- Construction costs are evaluated based on the constructiveness of the resulting structure as an economic constraint. Extra foundation cost for cells at the ground levels, penalty cost for any cantilevered cells, and construction cost relative to the height of the structures are applied.

- Density of the overall structure is calculated relative to the whole space volume of the grid. Before execution of optimization, desired density ratio will be inputted by the user of the program. The deviation from the desired percentage will be penalized during the GA's optimization process, thus the generative process of GA expect to show convergence on the desired density ratio.

Relationships between the neighboring cells cause differences in values of the structures, and induce changes in particular tendencies and behaviors for the overall growth of the next optimized generations of the structure. The total fitness value was calculated by the following:

Fitness = Estimated real-estate value of the entire complex per year * Projected years considered for the study – Total construction fee – Density deviation penalty.

This fitness function assigns an evaluation score to each chromosome in population which is a cell arrangement pattern of each building scheme in this case. The higher a floor level, the more the value for the units are increased by gaining better views; yet adding another floor levels costs more in construction fees which will be deducted from the total fitness value. These contesting constraints are commonly seen in real architectural programmatic issues, and are increasing the complexities to the design problems. Under such multiple constraints conditions, search by the conventional deterministic methods may not be always effective. Over the course of history in design, decisions tend to be determined in a singularly deterministic manner, although a dramatic increase in desktop computational power opened new potential for designers to solve the problems by optimizations. The genetic algorithm manipulates a population by using the operations of reproduction, crossover, and mutation, and finally optimized solution strings were decoded into distribution pattern schemes by using visualization functions.

The best chromosomes from the population of every one hundred generations were sampled as schemes. Up to the first one hundred schemes, there were rapid changes and improvement in the cells' distribution patterns. After one thousand generation, reproduction slows down to show the convergence into a certain characteristics in their distribution patterns. proper search space and constraints may promise more practical applications into the realistic problems in urban settings.

4. Discussion and Critique

Architectural design has a long history of addressing complex programmatic requirements without a specific design target. Unlike other design fields where the target is to solve a particular problem in the best possible way,

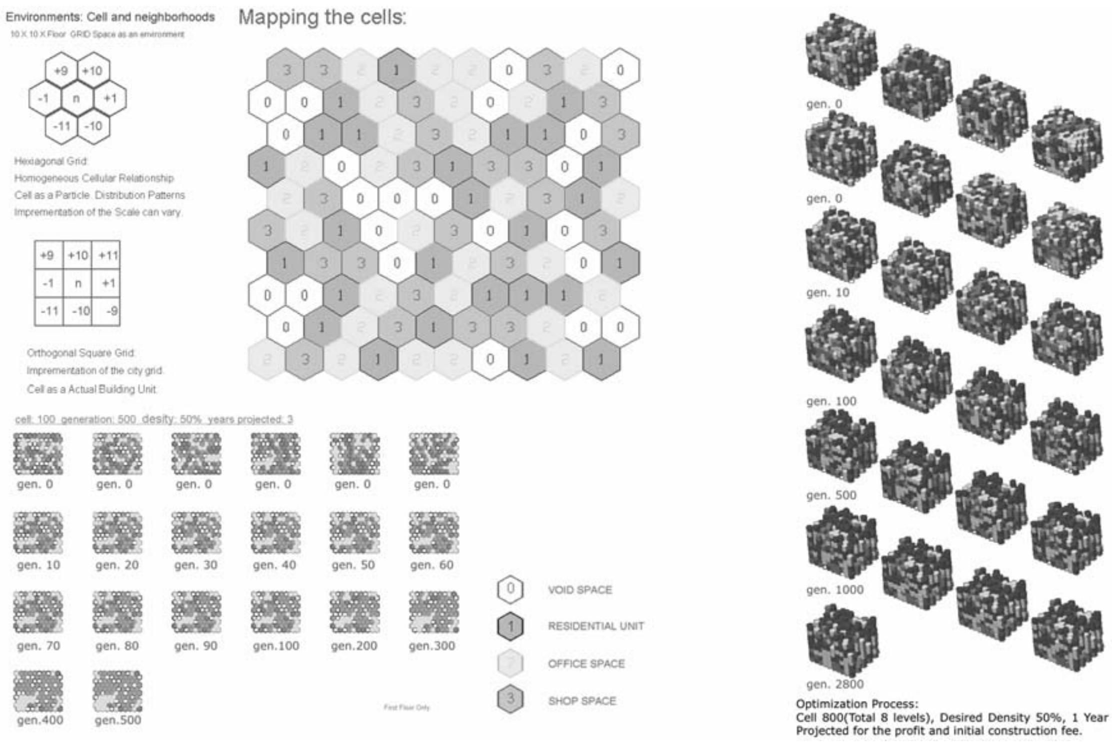

Figure 1. Encoding process and Stages of the genetic algorithm.

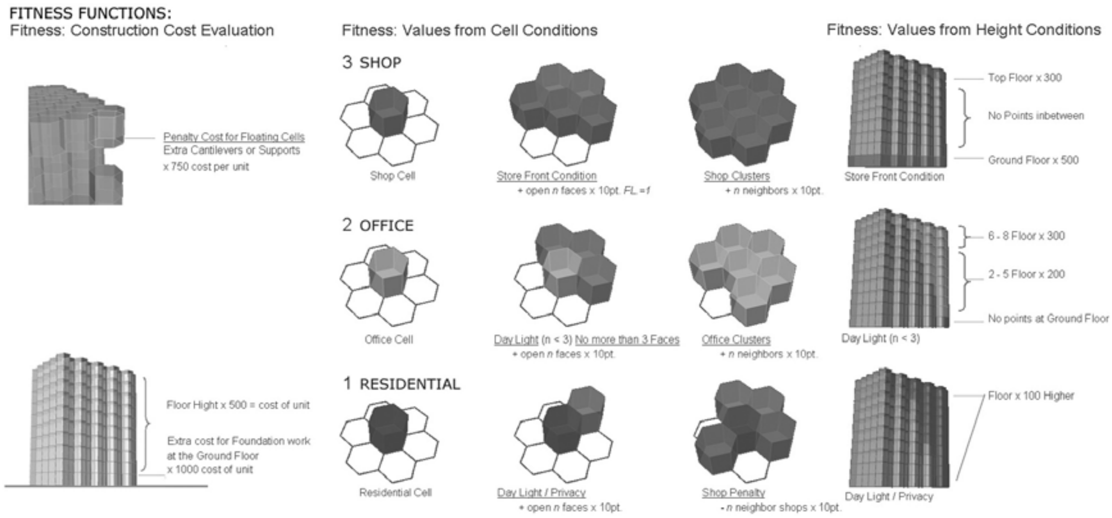

Figure 2. Fitness Functions: Evaluation based on cellular compatibility.

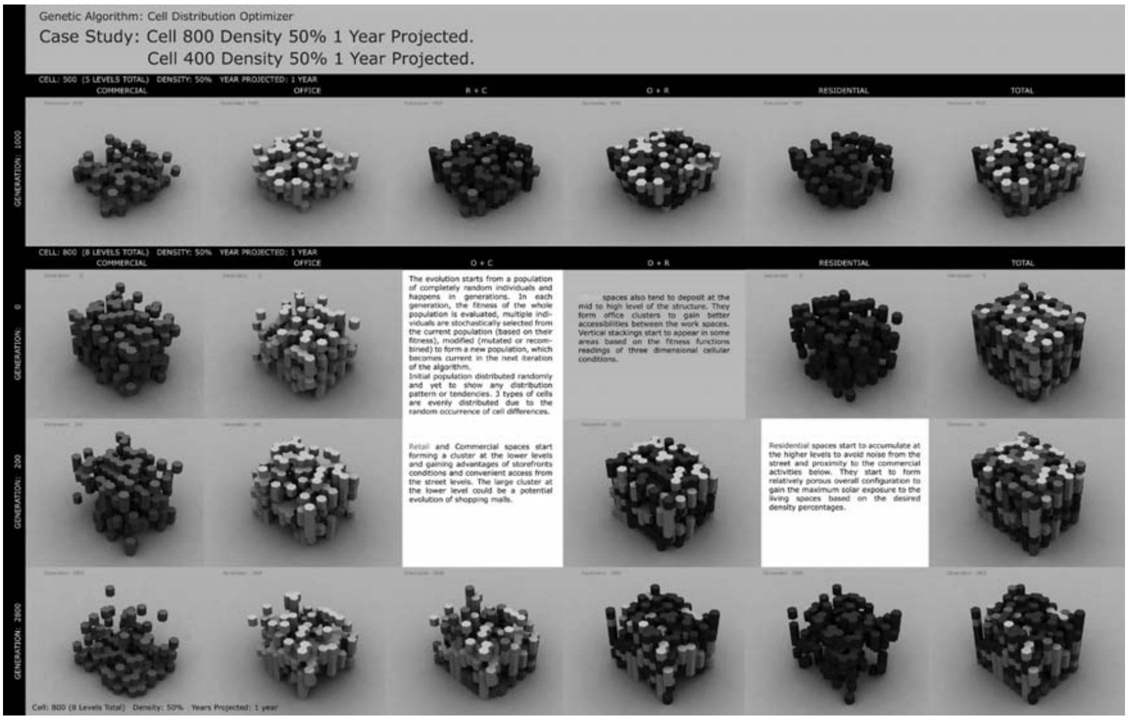

Figure 3. Emerging distribution patterns with various constraints.

architectural design is open-ended, flux, and uncertain. Codified information, such as, standards, codes, specifications, or types, simply serve the purpose of conforming to functional requirements, yet are not guarantees for a successful design solution.

While complexity may be a characteristic of many natural systems or processes, within the field of design the study of complexity is associated with artificial, synthetic, and human-made systems. Such systems, despite being human creations, consist of parts and relationships arranged in such complicated ways that often surpass a single designer's ability to thoroughly comprehend them even if that person is their own creator. Paradoxical as it may appear, humans today have become capable of exceeding their own intellect. Through the use of intricate algorithms, complex computations, and advanced computer systems designers are able to extend their thoughts into a once unknown and unimaginable world of complexity. Yet, the inability of the human mind to single-handedly grasp, explain, or predict artificial complexity is caused mainly by quantitative constraints, that is, by the amount of information or the time it takes to compute it and not necessarily to the intellectual ability of humans to learn, infer, or reason about such complexities.

While the quantity and composition of external data may appear to be infinite, random, or incoherent logical filtering will lead progressively to an ordered formation. Unlike blind randomness, genetic algorithms are capable of selectively controlling the shaping of information. Such algorithmic events result from factors that are neither arbitrary nor predictable yet seem to be guided by some sort of intelligence. While these events are made possible by simulating natural processes without involving human intelligence, yet it is inevitable to assume that some human intelligence is involved in the selection of the natural process that best fits the problem of randomness. Algorithms employ randomness, probability, or complexity the outcome of which is unknown, unpredictable, and unimaginable.

5. Conclusions

Recent advancement in tectonics and structural engineering enables the realization of buildings in mega scales and starts to introduce another layer of complexity into the building programs. Conventional design methods relying on the preconceived knowledge based approaches are no longer reliable. Beyond the certain quantitative factors and the complexity of the problems, search occasionally enters into the unpredictable domain of the human perception. Computational approaches to design allows us to go through thousands of iterations in a second and find the solution sets beyond the reach of designers' intuitive search spaces. Genetic Algorithm can be a potential derivative for finding optimal design solution from indeterminate search spaces constrained by multi dimensional factors.

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Keywords:
Genetic Algorithm, Architectural Space Planning, Optimization, Complexity