Title:
A Hybrid Approach of Dynamic Programming and Genetic Algorithm for Multi-criteria Optimization on Sustainable Architecture Design

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Introduction:
Sustainable building design is a growing global issue. One of its most important goals is energy efficiency over the entire life cycle of buildings. Design decisions for sustainable buildings are often concerned with a large set of decision variables and multiple criteria so complex that can hardly be resolved at once. Genetic Algorithms have been demonstrated to solve multi-objective optimization problems [2] and consistently get close to the best. However, GA requires tens of thousands of simulations to converge to the global optimal [4], yet multi-criteria GA will take more.

And it is widely acclaimed that the most important design decisions concerning building sustainability have to be made in the early design stages by the architect or building designer [7]. In this stage, an architect also has to consider other architecture aspects, such as regulations, views, construction cost, and so on. Therefore, an architect has to comprise all diverse decisions to find the possible optimal solution. However, most of the researches for sustainable architecture design only concern related issues. Chen Kain Wee proposed a design method for multi-criteria optimization of low energy architecture by using GA in the early design stage [1]. His research focuses on the exploration of holistic low exergy design on passive and active system with only energy related issue. In this paper, we propose that those diverse criteria could be separately optimized and re-structured in several stages by dynamic programming workflow formulation.

Main Idea:
The re-structured method is a hybrid approach of Dynamic Programming and Genetic Algorithm for multi-objective optimization on sustainable architecture design. This hybrid approach breaks down the multi-criteria into sub-criteria, which is the main concept of Dynamic Programming [5] and using Pareto-optimal GA evaluates sub-criteria. Then combining the solutions of sub-criteria reach overall possible optimal solutions. The relationship between sub-criteria could be defined by the formulation of design workflow at an architecture project in the early design stage.

This hybrid design approach is divided by two structures: one is the design workflow another is sub-criteria stages.

1. The design work flow structure:

   Defining all multi-criteria in an architecture project, then, designer breaks down the multi-criteria into several sub-criteria according to his design workflow, as stages in dynamic programming. There are existed the inter-relationship between sequential stages.

2. The sub-criteria stage structure:

In each stage, the sub-criteria could be reduced to one or two. The designer setup parameters only related to sub-criteria and object functions to optimize by Hajela-Lin GA (HLGA). HLGA makes use of weighted-sum aggregation of multi-objective function to search for a set of optimal solution [7]. Each objective is a weight *wj* = [0,1] for the *j*th objective such that $\Sigma wj = 1$, and the scalar fitness value for an individual i is calculated by summing up the scaled weighted objective values as given below:

$$Fit(i) = wj .* Fj(i) / Fj \quad (1)$$

where F*j* is a scaling parameter for the j the objective, which needs to be chosen properly for each objective F*j* in order to cater for the difference in magnitudes for various objective function.

In each stage, the front stage's states are the input condition of the back stage. That is, the search space of current stage will be limited by the front stage. In fact, this is our strategy to reduce all multi-criteria into sub-criteria, that is, following the sequence of stages, the sub-criteria will integrate all multi-criteria at final stage. In summary, this hybrid approach could be defined as follows:

1. n is defined as current stage.
2. Input states, Xn-1 (No input state, when this is the first stage).
3. Output states, Xn as possible optimal Set generated by GA in objective function Fj.
4. Decisions, Dn as scaled weighted Fn(X) = *wj* * Fnj(X), a weight *wj* = [0,1] for t he *j*th objective function Fnj such that Σ*w*j = 1.
5. Stage returns, Rn (Xn, Dn) = Fn (X).
6. The optimized result in each stage will be given by:

$$f'(X_n) = (Rn\ (Xn, Dn), Fn\text{-}1(Xn\text{-}1))$$
$$= (Fn\ (Xn), Fn\text{-}1(Xn\text{-}1))$$
$$= opt(\ w'j' * Fnj\ (Xn) + \ w'j\text{-}1 * Fnj\text{-}1(X\ n\text{-}1))\ , \text{ where } \Sigma w'j = 1 \quad (2)$$

An actual project is used to study the proposed approach. It is the design of a public apartment in a subtropical region, for which the environmental impact, sustainability and construction cost efficiency have been set as the objectives in the planning phase. The site of the project was in a special condition that this new building might affect the nice view towards open spaces of some neighboring apartments; and in the meantime, the architect would also seek for the best possible view for the apartment units of this new building. The government hopes that this public apartment should meet both the low-energy consumption and low construction cost criteria. Through a series of discussion with the design team, the design workflow of the project was studied and adopt as a three-stage decision process. At the front stage, the location and orientation of the building mass are decisions to be made, with the objectives based on the view criteria of the neighboring and own apartment units. In the middle stage, the window wall ratio (WWR) are to be decided based on the very likely conflicting criteria of building energy consumption and opening for natural lighting. As for the back stage, construction types and materials for each orientation of the envelope are decided based on the construction cost.

We developed a parametric design integrated system with Rhino, Grasshopper and Galapagos (Grasshopper plug-in for GA). In this system, a designer could specify his parameters and objective functions of HLGA in each stage (indicated in Fig.1). We also integrated a parametric design tool DIVA-for-Rhino [3] for the simulation of natural lighting and energy consumption. Following the design workflow, the designer could visually check the possible optimal results and make informed decision in each stage. After finishing all the evolution of GA, the designer derives a set of proposed solutions over all decision variables of the three design stages.

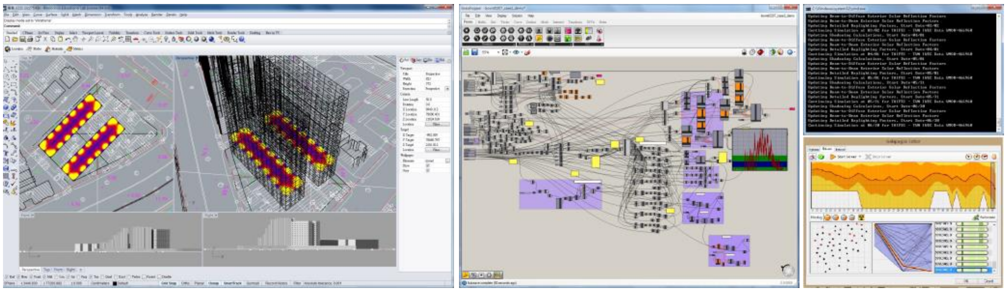

Fig 1: An integrated system with Rhino, Grasshopper and Galapagos.

Conclusion:

This integrated computer-aided design system, not only provided the visual linkage between architecture model and the simulation result, which helps the designer to realize his design strategies, but also gives him some possible optimal proposals. However, this pseudo-integrated system takes an architect more efforts to understand some issues specific to the sustainability aspects. Therefore, this system provided a platform, upon which architects and sustainability expert may efficiently work together. The future work will focus on finding possible optimal solutions instead of weighting-factor GA, we use pareto-optimal GA, which is a popular algorithm for multi-criteria optimization. Using weighting factor GA for two conflict criteria, it generates simple and easy readable optimized results, however, it has the bias factor owing to the value of weighting factors. Although, pareto-optimal GA could generate a set of pareto-optimal solutions without bias factor, it adds the difficulties for the designers to understand. Therefore, our future work also wants to overcome this problem.

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