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Architectural design of apartment buildings using the Implicit Redundant Representation Genetic Algorithm

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ABSTRACT

In the architectural design process, the conceptual design stage is to devise a creative alternative in response to the intent of the architects. In this paper, we propose an alternative evolutionary-based architectural design method by using the Implicit Redundant Representation Genetic Algorithm (IRRGA) that is highly suited to explore unstructured problem formulation such as conceptual design. Also, a new string representation for apartment building designs is proposed such that the size and the number of apartment units with stairs are not fixed and can be changed during the design evolution. The design objectives are selectively applied in terms of symmetry, structure, circulation, and façade. Each objective is used respectively as a fitness function to demonstrate the performance of IRRGA. Finally, a multi-objective fitness function is applied and the resulting apartment building designs show their own level of creativity.

1. Introduction

In architectural design, determining the shape of a building is the primary activity of the design process. Architects usually start the design with an incorporeal concept and a vague image of the shape and then come up with broad solutions. This initial shape affects both the performance and cost of construction. Architecture differs from other arts, such as sculpture or painting, because it needs to be practically functional and structurally stable as well as aesthetically pleasing.

Architectural design is a complex process of drawing upon past experience and using creativity to generate new designs. Arlati et al. [1] argue it is an ill-defined problem with recursive activity involving goals and constraints. Design is considered an iterative trial-and-error process based on past experience, intuition, or a balanced state of both. After Alexander [2] introduced the use of the computer to find a possible solution for design problems, computer support for architectural design has significantly transformed the design process. For example, structural analysis tools provide quantitative measurements on structural performance and behavior. While computer-aided drawing tools are intended to create precision drawings replacing manual drafting with an automated process, building information modeling tools involve the generation and management of drawings and models based on parametric designs. Furthermore, integrating works between computational tools are explored within a design process. Optimization tools, such as evolutionary computation, are of particular interest in this study since they are now recognized as a powerful tool for various traditional as well as novel applications [3].

The major applications of evolutionary computation in architecture have been based on quantitative performance such as structural analysis with the objective of finding the optimal values as parameterized problems. On the other hand, there has also been some work in applying evolutionary computation methods for conceptual design [4–11], where the emphasis is put on the generation of creative designs and not on finding the globally optimal ones [12]. Granandeiro et al. [13] used shape grammars to generate the shape of buildings by considering its implications on energy performance. Rodrigues et al. [14] presents a multi-level floor plan design based on a hybrid evolutionary technique that is further developed for automated and optimized design generations according to their thermal performance [15,16]. Additionally, an automated computational process has been proposed in which spatial information can be transformed into structural models [17]. Moreover, there is a growing interest in the application of interactive approaches to incorporate human interactivity in the evolutional process [18–20]. Typically, traditional genetic algorithms predefine fitness criteria and then initiate an automatic search to find an optimal solution, whereas interactive approaches use user input as subjective criteria in evaluation. Such an approach also has been strongly supported by the development of user-friendly design environments by providing parametric

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variables, visual interface, fitness visualization, and performance feedback [21–25].

In this paper we propose an alternative evolutionary-based method for the conceptual apartment building design using the Implicit Redundant Representation Genetic Algorithm (IRRGA) [26–28]. IRRGA provides a mechanism that allows for the essential and redundant sections within the length of the string to interact dynamically. As the specific location of gene instances is not explicitly designated, the numbers of gene instances are changing between generations and individuals in the population. The potential benefit over existing genetic sections is that redundant segments lead to a higher diversity in the population, even after convergence to the maximum fitness is reached [27–29]. This diversity makes IRRGA highly suited to explore various design alternatives in conceptual design. In addition, gene instances in previous generations could be protected due to the possibility of a crossover occurring in redundant sections. Furthermore, mutation affects redundant sections so that search space could be extended by allowing previously redundant bits to form [27].

The application of IRRGA for generating conceptual apartment designs may prove quite useful in the initial stage of the design process, thus reducing some of the time-consuming iterative steps. Architects can explore a variety of potential conceptual designs in advance that might compromise the performance of the final design. Moreover, further incorporation of simple geometric-based indices [30,31] helps architects to quantify the performance of buildings in the early design stages. After addressing the methodology, some results of the application of the proposed method are presented to generate creative apartment building designs.

2. Methodology

First presented by Holland [32], the genetic algorithm (GA) has become an important computational tool for problem solving and optimization in many fields. In the field of structural engineering, researchers have applied GA to structural optimization problems, such as size, shape, and topology optimization. In the period of early applications, GA was applied to a relatively simple size and shape optimization whose topology was fixed. Later, applications of GA in topology optimization presented a new challenge to researchers. Initial topology optimizations consist in determining the optimal element connectivity from a finite number of possible connections that still limited the flexibility of creating diverse designs. Shrestha et al. [33] proposed a new way of using the GA string to evolve optimum truss designs free from preconceived designs, an unstructured domain. Furthermore, IRRGA was presented using an implicit redundant representation of the GA string and has proven to be favorable to model such an unstructured problem domain [26,27].

IRRGA has an advantage over other GAs by providing a self-organization of the string representation and by maintaining a diverse population to provide adaptive behavior. Both of these features are also observed in a biological population and considered to be beneficial. To obtain these features, IRRGA uses a redundant segment that separates the gene instances in the string that are similar to biological chromosomes. Each gene instance is made of two sectors, a gene locator (GL) pattern identifying the location of gene instances in the string and a specified number of bits that encode the variables. An example of gene instances in the string is shown in Fig. 1, compared with the GA string. In this example, the three bits of GL is |111|. A string is parsed from left to right, and when the GL pattern is encountered, the next specified number of bits represents one or more encoded variables. The remaining bits between the gene instances are redundant segments. During evolution, gene instances can be turned on or off by crossover and mutation, and the number of gene instances, as well as the location, can change. The average number of gene instances and the total length of redundant segments can be estimated in the randomly initialized string. The redundancy ratio (the ratio of the total bits of redundant segments and the total bits of gene instances) changes during evolution. The fitness and selection pressure depends on the number of gene instances as well as the value-encoded variables. As a result, a novel solution can evolve from the redundant segments unused in the previous generation [8,27].

So far, applications of IRRGA have focused on near-optimal problems in structural engineering where fitness value is evaluated from the results of structural analysis, such as deflection, stress, or mass. In comparison, the current work applies IRRGA to generate creative architectural design alternatives, not near-optimal ones. It only uses design criteria at the conceptual design stage and does not include any structural analysis.

2.1. Apartment building designs by IRRGA

In this paper, an apartment building design is chosen for the application of IRRGA where the design objectives are selectively applied in terms of symmetry, structure, circulation, and façade. In related work by Chouchoulas [34], the same sizes of apartment units and circular spaces (i.e. stairwells or lift) with 22 explicit rules governing the shapes were defined and the list of rules is optimized using GA to produce the architectural design. The results were limited in a sense that the fitness value did not increase significantly through evolution. This is possibly related to the lack of flexibility from the simplified shapes and a dependence on explicit rules. Here, a unit is defined as a main compositional element to create one design that is not limited by any shape grammar and makes the best use of the capability of IRRGA. The unit needs to be the simplest form that provides the flexibility to add and remove units. Each unit consists of a stair space for vertical circulation and residential

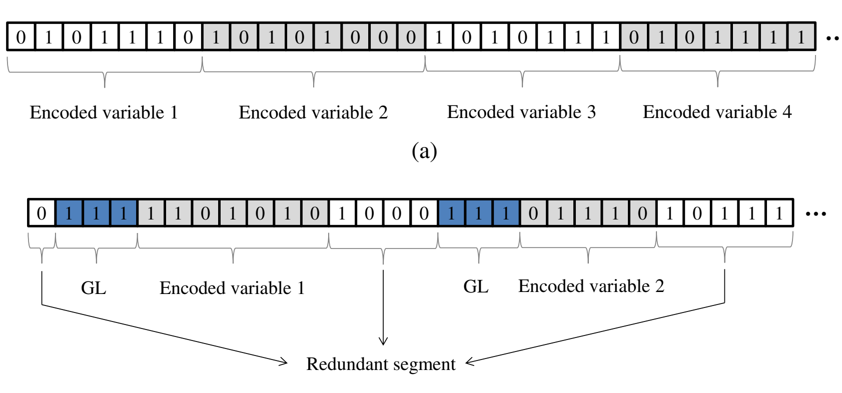

Fig. 1. Example of IRRGA string, compared with GA string.