Addressing design preferences via auto-associative connectionist models: Application in sustainable architectural Façade design

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1. Introduction

Architectural design is a principal representative of complex decision making. Complexity, on one hand, is due to the softness and the imprecise nature of the design objectives. On the other hand, it arises as a result of combinatorial explosion, and complex non-linear relationships between the object properties and their abstractions, be it objectives or constraints.

Computational optimization, and multi-objective optimization in particular, has enabled efficiently addressing problems of significant design complexity in engineering [1], and more recently also in architecture [2,3]. The principal aim of this research is to develop a computational decision support system, in line with the above mentioned line of research, with the aim of complementing and improving the decision-making that is taking place during designing. We note that successful designs are well performing with respect to design objectives, but also possess desirable physical features. The latter is an issue not directly addressed by computational optimization. Desirable physical features, albeit important for design, are not guaranteed to be present in the set of non-dominated solutions discovered by optimization.

Focusing on this issue, we propose a connectionist, auto-associative model that operates in the decision variable domain and is able to enforce constraints on the inputs, in accordance with the decision variable distribution of design solutions acquired through multi-objective stochastic optimization. The decision maker may utilize the proposed system by inputting a preference vector, i.e. a vector in decision variable space that corresponds to desirable design features. The system, based on the learned knowledge matter, is able to respond so that features and combinations thereof that negatively affect design performance are eliminated, to the degree possible by the problem definition. The ultimate aim is to offer a decision support alternative that is able to augment the cognitive capabilities of design professionals and decision makers.

The rest of the paper is structured as follows: Section 2 presents the general design problem definition that this study addresses. Section 3 presents a short overview of auto-associative models and application in decision support. Section 4 outlines the proposed method, the relevant models and techniques used to implement it, and also presents a short survey of relevant approaches. Section 5 introduces the architectural design problem on which the proposed method is validated. In addition,
it describes the process followed from problem formulation to acquiring and using the auto-associative model. Section 6 discusses model assessment criteria, and presents a new method that may be used for the assessment of model performance with respect to the decision-support task at hand. Section 7 presents a discussion of the results. Section 8 concludes the study.

2. General problem definition

2.1. Criteria and preferences in design

Generally speaking, designing is about identifying compositions of physical features that are generally desirable and suitable. Here, “suitable” and “desirable” reflect two distinct criteria, namely: suitability of a particular design is evaluated with respect to first-order design goals and objectives, that have been predetermined, e.g. as part of a design brief, and are mostly unyielding and essential for the acceptance of a design solution. Simply put, suitable solutions are those that maximize performance with respect to design goals or objectives, while satisfying constraints. The role of goals and objectives on the domain of object properties is that of imposing certain relationships between them. Designs that possess properties that adhere to the relations established by design goals, are those that maximize design suitability for the intended purpose. Through the establishment of such relations, decision makers are provided with the necessary mechanism to abstract away the excessive complexity that arises in design problems such as those in the field of architecture, for example, when dealing at the level of detailed properties of the objects.

On the contrary, desirability is a design quality that is to be found at the lowest abstraction level, which is that of design features. At this level, designers generally express preferences with respect to some or all the decision variable values that are involved in the design task at hand. These preferences are notwithstanding the design goals mentioned above, which need to be satisfied with maximum priority.

Through establishing goals and constraints in design, explicit relationships are formed between concrete object properties, design goals and constraints. These relationships are generally complex, and are not known by the design professionals and decision makers at the time of designing. It should be understandable, nonetheless, that successful designs combine the requirements for suitability and desirability; in other words, they are well performing designs that are characterized by desirable feature compositions. This is the quintessential nature of design, and at the same time a challenging task to be carried out, solely by relying on human cognition alone.

2.2. Multi-objective optimization

Computational decision support tools, such as multi-objective optimization algorithms, offer a valuable asset in dealing with the complexity of real-world architectural design tasks, e.g. as reviewed in [2,4], and in particular in the topic of façade design such as [5,6], among others. Through multi-objective optimization, it is generally feasible to achieve a set of solutions that are evenly distributed along the Pareto surface in the objective function space. These are termed non-dominated solutions. However, relationships in the objective function space do not extend to the decision variable space and vice versa. The reason behind this phenomenon is rooted in the non-linearities introduced by the objective functions defined in the context of the design problem. As a result, neighboring relationships between solution representations in the objective function space do not necessarily correspond to relationships in the decision variable space. Two solutions that demonstrate similar decision variable compositions (neighboring solutions) may occupy far-away points in objective function space. Similarly, solutions nearby in the objective function space may occupy two distant points in decision variable space. It is thus impossible to make comprehensive design decisions by considering similarity of solutions in either space alone, since similarity in the other of the two spaces is not guaranteed. Fig. 1 graphically outlines this condition.

It is worth pointing out that real-world design problems usually entail decision variable spaces of much higher dimensionality that the corresponding objective function space. On the contrary, the dimensionality of the decision variable space is usually much higher. In such a configuration, solutions that seem to evenly occupy a surface in the low-dimensional objective function space may in fact be very sparsely located in the high-dimensional decision variable space. As such, it is evident that continuity in terms of object properties is not guaranteed to happen, and that we may expect some physical features that might be desirable, not to appear as part of the solutions identified by stochastic search.

2.3. Preferences in multi-objective decision making

Due to reasons mentioned above and others, satisfaction of preferences is a non-trivial matter in multi-objective optimization. Thus, multi-objective decision making constitutes a significant research field. According to [7], referencing [8,9] there are three main approaches to treating preferences, in general:

1. A-priori: Preference information is articulated by the decision maker prior to the optimization.

![Figure 1](image-url)
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