TÉCNICO LISBOA

Optimization in Architecture

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Thesis to obtain the Master of Science Degree in

Information Systems and Computer Engineering

Supervisor: Prof. António Menezes Leitão

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Publications

The development of this thesis resulted in several scientific contributions exploring different perspectives of optimization problems:

1. Caetano, I., Ilunga, G., **Belém, C.**, Aguiar, R., Feist, S., Bastos, F., and Leitão, A. (2018). Case Studies on the Integration of Algorithmic Design Processes in Traditional Design Workflows. Proceedings of the 23rd International Conference of the Association for CAADRIA, 1(Giedion 1941), 111–120.

2. **Belém, C.**, and Leitão, A. (2018). From Design to Optimized Design An algorithmic-based approach. Proceedings of the 36th eCAADe Conference - Volume 2, Lodz University of Technology, Poland, 549-558

Abstract

Keywords

Algorithmic Design; Black-Box Optimization; Machine Learning; Surrogate-based Modelling.

Resumo

Palavras Chave

Design Algorítmico; Otimização de caixa-preta; Modelos baseados em aproximações; Aprendizagem Máquina.

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Listings

Acronyms

MOO Multi-Objective Optimization

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Introduction

Contents

The act of making something as fully perfect, functional or effective as possible is a behavior that is constantly sought by us, Humans, in a process known as optimization [1]. Intuitively, through optimization one aims to improve a system in terms of different quantitative measurable aspects. Although usually striving to fully optimize these systems, i.e., to obtain *perfect* systems, it is often the case, that finding a better one or a near-optimal system suffices.

Generally, optimization processes are composed of two main parts: (1) the model of the system to be optimized and (2) the algorithm responsible for finding the optima. Conceptually, the model is a description of the system that is defined in terms of: a set of the system's characteristics, known as variables or unknowns, a set of quantitative measures of the system's performance, referred to as objectives or criteria, and, optionally, by a set of conditions that have to be satisfied to guarantee the system's feasibility, i.e., the system's constraints [2]. The objectives are usually functions of the variables being defined. Subsequent to the model definition, the obtained description can be interpreted as an optimization problem for which the optimal solutions are to be found, thus entering in the second part of an optimization process. In the second part, one executes an optimization algorithm, which encloses a description of the steps necessary to attain optimal solutions, which according to the user's intentions can be the maximization or minimization of the model's objectives.

Depending on the model representation, one is able to classify optimization problems differently with respect, for example, to its objective functions, variables, and determinacy. Due to their relevance in the developed work, in the next two paragraphs, we describe four different optimization classifications. However, we refer the interested reader to [2] for a more detailed and complete description of the different classifications.

One important classification is regarding the cardinality of the solutions sought by optimization processes, thus yielding the continuous and discrete optimization categories. In the former, optimal solutions lie in a potentially infinite set of candidate solutions, whereas in the latter, optimal solutions lie in a finite set. Optimization problems can also be classified as constrained or unconstrained, depending on whether the models explicitly define constraints or not. Moreover, optimization can also be distinguished in terms of the aim of the search that is performed, particularly, whether it is global or local. In local optimization, the search process strives to find a solution that is locally optimal, i.e., for which its value is better than all other points in its vicinity. The points that satisfy the previous property are known as local optima. On the other hand, there are optimization processes that strive to find the globally optimal solutions, i.e., the best of all the local optima.

Optimization is frequently used to address problems involving more than one objective. It is often the case that people face daily decisions involving two or more conflicting objectives, either to effectively manage resources, or just to ponder several factors associated with certain decisions. As an example, consider the decision of how to commute to work: either by car, or by bus. Indeed, in this case, the optimal solution is to take the transport that minimizes the cost and the time spent in the commutation. When considering the two transports, one must consider the time-cost trade-off corresponding to the two different transports: (a) taking the car will incur in more costs but in less time spent in the trip, whereas (b) taking the bus incur in fewer costs but more time spent. This example belongs to the subset of Multi-Objective Optimization (MOO) problems which consider the optimization of more than one objective function.

In addition to day-to-day life decisions, optimization is a useful tool for both decision and analysis purposes, having been applied throughout multiple areas, including economy, science, engineering, among others, to maximize the efficiency of the decisions involved.

1.1 From design to Optimized design

1.1.1 Building Performance Simulation

1.1.2 Algorithmic Design

1.1.3 Algorithmic Analysis

1.1.4 Architectural Optimization Workflow

1.2 Goals

1.3 Organization of the Document

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Background

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One important classification is regarding the cardinality of the solutions sought by optimization processes, thus yielding the continuous and discrete optimization categories. In the former, the optimal solutions lie in a potentially infinite set of candidate solutions, whereas in the latter, the optimal solutions lie in a finite set. Optimization problems can also be classified as constrained or unconstrained, depending on whether the models explicitly define constraints or not.

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2.1 Single-Objective Optimization

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2.1.1 Derivative-Free Optimization

2.1.2 Optimization Tools in Architecture

2.1.2.A Galapagos

2.1.2.B Goat

2.2 Multi-Objective Optimization

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2.2.1 Experimental Approach

2.2.2 Priori Articulation Approach

2.2.3 Pareto-Based Approach

2.2.4 Metrics for Multi-Objective Optimization

2.2.5 Optimization Tools in Architecture

2.2.5.A Octopus

2.2.5.B Opossum

2.2.5.C Optimo

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Solution

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3.1 Architecture Overview

3.2 Architecture Design Requirements

3.2.1 Problem Modelling

3.2.2 Simple Solver

3.2.3 Meta Solver

3.3 Architecture Design Implementation

3.3.1 Problem Modelling

3.3.2 Simple Solver

3.3.3 Meta Solver

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Evaluation

Contents

- Relembrar o objectivo do trabalho e dizer como o vamos avaliar de um modo geral introduzindo os proximos subcapitulos.

4.1 Qualitative Evaluation

- Number and Heterogeneity of Available algorithms - Differences / Benefits / Disadvantages when compared to Grasshopper's frameworks

4.2 Quantitative of Applications

- Dizer que de um modo geral começámos de forma incremental por considerar problemas single-objective, nomeadamente a casa da ericeira, que remonta a primeira publicação. Depois evoluimos para a avaliação bi-objetivo de dois casos de estudo reais - Pavilhão Preto para exposições e de uma arc-shaped space frame.

- Comentar a facilidade c/ que alguém que já tem um programa AD consegue acopolar optimização a AD.

4.2.1 Ericeira House: Solarium

4.2.2 Black Pavilion: Arts Exhibit

4.2.2.A Skylights Optimization

4.2.2.B Arc-shaped Space Frame Optimization

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Conclusion

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Rui Cruz
You should always start a Chapter with an introductory text

5.1 Conclusions

5.2 System Limitations and Future Work

5.2.1 Optimization Algorithms

5.2.2 ML models

5.2.3 Constrained Optimization

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