



Universiteit
Leiden
The Netherlands

Multi-objective mixed-integer evolutionary algorithms for building spatial design

Blom, K. van der

Citation

Blom, K. van der. (2019, December 11). *Multi-objective mixed-integer evolutionary algorithms for building spatial design*. Retrieved from <https://hdl.handle.net/1887/81789>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/81789>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/81789> holds various files of this Leiden University dissertation.

Author: Blom, K. van der

Title: Multi-objective mixed-integer evolutionary algorithms for building spatial design

Issue Date: 2019-12-11

Multi-Objective Mixed-Integer Evolutionary Algorithms for Building Spatial Design

Proefschrift

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van Rector Magnificus prof.mr. C.J.J.M. Stolker,
volgens besluit van het College voor Promoties
te verdedigen op woensdag 11 december 2019
klokke 10.00 uur

door Koen van der Blom

geboren te Berkel en Rodenrijs

in 1990

Promotiecomissie

Promotors:	Dr. M.T.M. Emmerich	
	Prof. Dr. T.H.W. Bäck	
Co-promotor:	Dr. H. Hofmeyer	(Technische Universiteit Eindhoven, NL)
Overige leden:	Dr. M. Baratchi	
	Prof. Dr. H.H. Hoos	(secretaris)
	Dr. C.J. Hopfe	(Loughborough University, UK)
	Prof. Dr. A. Plaat	(voorzitter)
	Dr. M. Preuß	
	Prof. Dr. B.D. de Vries	(Technische Universiteit Eindhoven, NL)
	Prof. Dr. H.A.G. Wijshoff	

Copyright © 2019 Koen van der Blom.

This work is part of the TTW-Open Technology Programme with project number 13596, which is (partly) financed by the Netherlands Organisation for Scientific Research (NWO).

Backcover: Quote from The Rake as recorded by Ruby Throat.

Contents

1	Introduction	1
1.1	Background	1
1.2	Research Questions	2
1.3	Terminology	4
1.4	Notation	4
1.5	Outline	4
1.6	Contributions of this Thesis	5
1.7	Other Work by the Author	7
2	Preliminaries	9
2.1	Optimisation	9
2.1.1	Constraints	10
2.1.2	Mixed-Integer Problems	10
2.2	Multi-Objective Optimisation	10
2.2.1	Pareto Optimality	11
2.2.2	The Hypervolume Indicator	12
2.3	Evolutionary Computation	12
2.4	Building Spatial Design	13
3	Design Space Representations	17
3.1	Superstructure or Superstructure Free	17
3.2	Supercube	19
3.2.1	Examples	20
3.2.2	Constraints on the Binary Variables	22
3.2.3	Constraints on the Continuous Variables	26
3.2.4	Analysis of the Supercube Search Space	27

Contents

3.3	Conclusions	30
3.3.1	Summary	30
3.3.2	Future Work	31
4	Basic Constraint Handling	33
4.1	Building Design Optimisation	34
4.2	Evolution Strategies	35
4.3	Objective Functions	36
4.4	Methods	38
4.4.1	Domain Specific Operators	39
4.4.2	Penalties	40
4.4.3	Repair Functions	41
4.5	Experiments	42
4.6	Results	43
4.7	Conclusions	50
4.7.1	Summary	50
4.7.2	Future Work	50
5	Problem Specific Constraint Handling and Multi-Objective Optimisation	53
5.1	Algorithms	56
5.1.1	Standard Algorithms Applied to Building Spatial Design	56
5.1.2	Tailored Algorithm for Building Spatial Design	57
5.2	Tailored Algorithm Evaluation	58
5.2.1	Experiments	58
5.2.2	Results	59
5.3	Unbiased Operators	62
5.3.1	Initialisation	63
5.3.2	Mutation	64
5.3.3	Tailored SMS-EMOA	66
5.4	Landscape Analysis	67
5.4.1	Setup	68
5.4.2	Results	68
5.5	Optimisation and Parameter Tuning	71
5.5.1	Optimisation Setup	71
5.5.2	Parameter Tuning Setup	73
5.5.3	Tuned Configurations	75

5.6	Conclusion	80
5.6.1	Summary	80
5.6.2	Future Work	81
6	Local Search with Set Gradients	83
6.1	Multi-Objective Optimisation and the Hypervolume Indicator	85
6.2	HVI Gradient Ascent Multi-Objective Optimisation	86
6.2.1	Hypervolume Indicator Gradient	86
6.2.2	Normalisation	87
6.2.3	Step Size Adaptation	88
6.2.4	Update	89
6.3	Algorithms	89
6.3.1	HIGA-MO-SC	90
6.3.2	SMS-EMOA-SC	91
6.3.3	MEMO-SC	92
6.4	Experiments	93
6.4.1	Objective Functions	93
6.4.2	Setup	96
6.5	Results	97
6.6	Conclusion	103
6.6.1	Summary	103
6.6.2	Future Work	104
7	Mining Optimisation Data for Design Rules	107
7.1	Features	108
7.2	Data Preparation	111
7.3	Results	114
7.3.1	Box Plots	114
7.3.2	Decision Trees	115
7.4	Conclusion	117
7.4.1	Summary	117
7.4.2	Future Work	118
8	Towards General Multi-Objective Mixed-Integer Optimisation	121
8.1	Algorithms	122
8.2	Experimental Setup	123
8.2.1	Algorithm Settings	125

Contents

8.3	Results	126
8.4	Conclusion	127
8.4.1	Summary	127
8.4.2	Future Work	128
9	Applications in Building Design	131
9.1	Combining Co-Evolution and Optimisation	132
9.1.1	Superstructure Free Representation	133
9.1.2	Conversion	134
9.1.3	Co-Evolutionary Design Simulation	135
9.1.4	Combination	136
9.1.5	Case Study	138
9.1.6	Results	139
9.2	Spatial Design Optimisation in Practice	141
9.2.1	Integrating BouwConnect BIM and Optimisation	142
9.2.2	Case Study	142
9.2.3	Results	143
9.3	Structural Design Optimisation	146
9.3.1	Structural Design	146
9.3.2	Design Response Grammar	147
9.3.3	Case Study	150
9.3.4	Results	153
9.4	Conclusion	155
9.4.1	Summary	155
9.4.2	Future Work	157
10	Conclusions	159
10.1	Summary	159
10.2	Future Work	162
	Bibliography	165
	Samenvatting	177
	Curriculum Vitae	181
	Glossary	183

Acronyms	185
Symbols	189

