Optimal Conceptual Design of High-Rise Office Buildings

by

Siavash Khajehpour

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Abstract

Design of a high-rise office building, like any engineering design, is a complex multidisciplinary process with the objective to discover, detail and construct a system to fulfill a given set of performance requirements. The success of this process is highly dependent upon the cooperation taking place between the members of the design team. Although present-day engineering computer technology allows for precise analysis and design of the different subsystems of an high-rise building, it does not readily provide insight for choosing among alternatives of these subsystems to arrive at the best overall design.

This research study presents a computer-based computational method for optimal cost-revenue conceptual design of high-rise office buildings. Specifically, a Multi-criteria Genetic Algorithm (MGA) is applied to conduct Pareto optimization that minimizes capital and operating costs and maximizes income revenue for a given building project, subject to design constraints imposed by building codes and fabrication requirements.

The conceptual design process involves the coordinated application of approximate analysis, design and optimization. To commence the design process, a population of different alternative designs are generated. Using approximate analysis and design based on pre-developed data bases, the values of the conflicting cost-revenue objective criteria are established for each design. Then, a MGA is used to explore the design space and find improved designs having enhanced values of the objective criteria. The results, for a given building project, is a set of Pareto-optimal conceptual designs that define the ‘trade-off’ relationships between the three competing objective criteria to minimize capital cost, minimize operating cost and maximize income revenue. The corresponding three-dimensional criteria space is populated by feasible conceptual designs that are ‘equal-rank optimal’ in the sense that each design is not dominated for all three objective criteria by any other feasible design possible for the building. Life-cycle costing is introduced to investigate the profit potential of building designs over time. The conceptual design of four example office buildings are conducted from a variety of viewpoints to illustrate the capability of the computational procedure to create comprehensive computer-generated colour graphic representations of optimal cost-revenue trade-off relationships for office buildings taking into account architectural, structural, mechanical and electrical systems. While this study focuses on office buildings and corresponding cost-revenue criteria, the proposed computer method for conceptual design is directly applicable to any type of artifact and related objective criteria.

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To my parents

Notation

a	direction of the length of the building
a_{max}	maximum length of the building
ABE	Angle of Building with East (degree)
$ACDT_{max}$	max Average Cold Day Temperature (C ^{o})
$ACDT_{min}$	min Average Cold Day Temperature (C ^{o})
$ADBL_a$, $ADBL_b$	Average Distance Between column Lines in a & b directions
$AHDT_{max}$	max Average Hot Day Temperature (C ^{o})
$AHDT_{min}$	min Average Hot Day Temperature (C ^{o})
AOT_{max} , AOT_{min}	Ave. max. & min Outside Temp. (C ^{o})
AR	Aspect Ratio D_a/D_b
A_{req}	the required floor area of the building (m^2)
b	direction of the width of the building
b_{max}	maximum width of the building
BT	Bracing Type
$BWLP$	Basic Wind Load Pressure (kPa)
C_a , C_b	Core dimensions in a & b directions
$CCLF$	Concrete Cost Location Factor (ratio of local concrete cost to US national average concrete cost)
CDF	Core Dimension Factor: the ratio of a core dimension to the dimension of the building in the same direction
$CDRH$	Cold Day Relative Humidity (%)
$CDTR$	Cold Day Temperature Range (C ^{o})
CFA	Column-Free Area factor
CFT	Concrete Floor Type
C_LC	CLadding Color (greatly effects the HVAC system)
C_LCLF	Cladding Cost Location Factor (ratio of local cladding cost to US national average cladding cost)
CPD_{min}	minimum Core to Perimeter Distance for the building
CSP	Clear Sky Percentage (ratio of clear sky hours to total hours in

	a year) (%)
D_a , D_b	Building Dimensions in *a* & *b* directions (m)
DCDD	Direction of the Core Dimension to be Designed first (*a* or *b*)
DF	Depth of Floor (m)
DIT	Desired Inside Temperature (C ^{o})
ECLF	Electrical Cost Location Factor (ratio of local electrical cost to US national average electrical cost)
E_LCLF	ELevator Cost Location Factor (ratio of local elevator cost to US national average elevator cost)
FCLF	Forming Cost Location Factor (ratio of local forming cost to US national average forming cost)
F_ICLF	FInishing Cost Location Factor (ratio of local finishing cost to US national average finishing cost)
FLC	Fixed Land Cost ($)
h_{cle}	floor-to-ceiling clearance height
H	Height of the building (m)
H_{max}	maximum Height of the building
HDRH	Hot Day Relative Humidity (%)
HF	Height of Floor
IR	Inflation Rate (%)
IRH	Inside Relative Humidity (%)
ISA	Interior Surface Area of exterior walls
LA	Latitude Angle (degree)
LR_{max}, LR_{min}	max & min Lease Rates ($/m^2 Yr.)
MCLF	Mechanical Cost Location Factor (ratio of local mechanical cost to US national average mechanical cost)
MR	Mortgage Rate (%)
NCL_a , NCL_b	Number of Column Lines between the perimeter and core of the building in *a* & *b* directions
NE	total Number of Elevators
NF	Number of Floors

NOPF	Number of Occupants Per Floor
NRF, *NMF*	Number of Rentable and Mechanical Floors
NRSC	Number of Risers in a Stair Case for one floor
NS_a , NS_b	Number of Spans in *a* & *b* directions
NSC, WSC	Number and Width of Stair Cases
NSE, NPE,	Number of Service and Passenger Elevators
NTS_a , NTS_b	Number of perimeter Tube column Spans within spans S_a and S_b
OILSC	Overall Inside Length of Stair Case
OIWSC	Overall Inside Width of Stair Case
RCLF	Reinforcement Cost Location Factor (ratio of local reinforcement cost to US national average reinforcement cost)
R_OCLF	ROofing Cost Location Factor (ratio of local roofing cost to US national average roofing cost)
S_a, S_b	Span distance in *a* & *b* directions (m)
SCLF	Steel Cost Location Factor (ratio of local steel cost to US national average steel cost)
SFT	Steel Floor Type
SR	Slenderness Ratio for building
ST	Structural Type
TCS_a , TCS_b	Tube Column Spans in *a* & *b* directions
$TMAX_m$	MAX Temperature for sample day *m* of each month (C ^{o})
T_{mh}	hourly Temperature for sample day *m* of each month (C ^{o})
$TMIN_m$	MIN Temperature for sample day *m* of each month (C ^{o})
TNO	Total Number of Occupants
TR	Tax Rate (%)
UCEE, UCGE	Unit Cost of Electrical and Gas Energy ($/mwhr)
ULC	Unit Land Cost ($\$/m^2$)
WAT	exterior WAll Type (Cladding)
WCLF	Window Cost Location Factor (ratio of local window cost to US national average window cost)

WIR	WIndow Ratio(the ratio of window area to the maximum possible window area on the perimeter of a building)
WIT	WIndow Type

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