Framework for the Optimal Design of Facilities for Contracting Operations

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ESD.77 Multidisciplinary Systems Design Optimization

Introduction

Motivation

British Petroleum's New Exploration Headquarters in Dyce, Scotland

- Current Facilities are obsolete – New space needed
- New facility currently in schematic design
- Architects in search of strategies to achieve flexibility
  - Operations are *expected* to diminish in 15 to 45 (!) years.
  - Local office space market in recess
  - Local Residential Market in growth

Introduction

Problem Statement

Provide a quantitative design framework for corporate facilities that minimizes lifecycle costs and accounts for uncertainty and managerial flexibility.

In other words,

Minimize Lifecycle cost as a function of design variables, subject to physical constraints and uncertain parameters.

Problem Parameters:

- Uncertainty regarding *Inherent Value* of Facility
- Uncertainty regarding *Market Value* of converted use
- Building obsolescence and drivers for change
- Cost (inherent value) for not meeting space requirements in size and performance at any time

Introduction

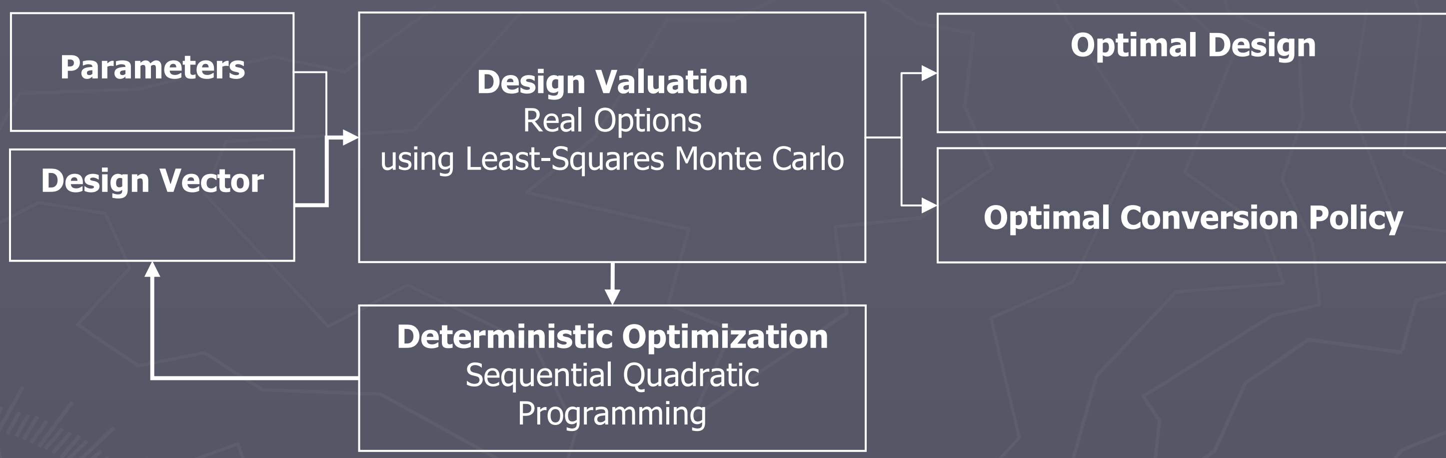
Previous Research

- Obsolescence in Buildings (Lemer 1996, Iselin 1993)
  - Technical
  - Functional
  - Regulatory
  - Cultural
- Building Tech research (Slaughter 2001, Fernandez 2000)
  - Mapping obsolescence and change mechanisms on design solutions and life-cycle costs
- Real Estate research on change of use (Riddiough et al. 1996, Geltner et al. 1996, Margrabe 1978)
  - Real Options for land valuation
  - Real Options for optimal exercise of the “right” to change (switch)

Introduction

Optimization Framework

- Framework



- Introduction to modules
  - Valuation model (performance model, cost model, contingent claims analysis)
  - Optimization
- Why is it interdisciplinary?
  - Building Technology → Performance and Cost Model, Technical and physical constraints
  - Real Estate & Finance → Valuation of Design under uncertainty

Optimization Framework

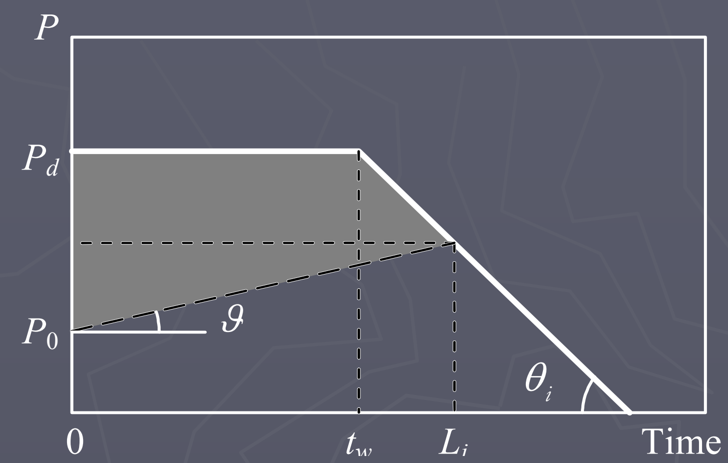
Performance and Cost Model

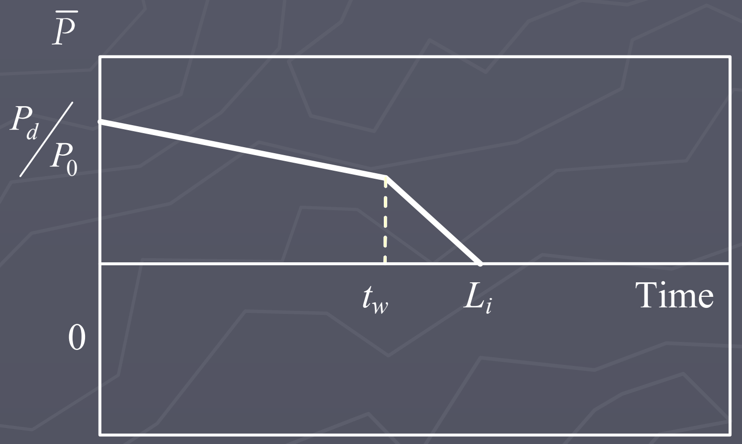
- Performance model
  - Quantification of Lemer's (1996) model for infrastructure obsolescence
  - Initial minimum performance requirement P_0
  - Initial design performance P_d
  - Rate of linearly increasing performance requirements ϑ
  - Rate of obsolescence θ_i after t_w
- Lifecycle Cost model

$$C(\overline{P}) = C_m e^{-g \cdot \max(\overline{P},0)}$$

- Development Cost model

$$C_{in} = A \cdot (\mathrm{P} \cdot P_d^{\rho} + \mathrm{T} \cdot t_w^{\tau} + \Gamma \cdot C_d^{\gamma} + C_{\min})$$





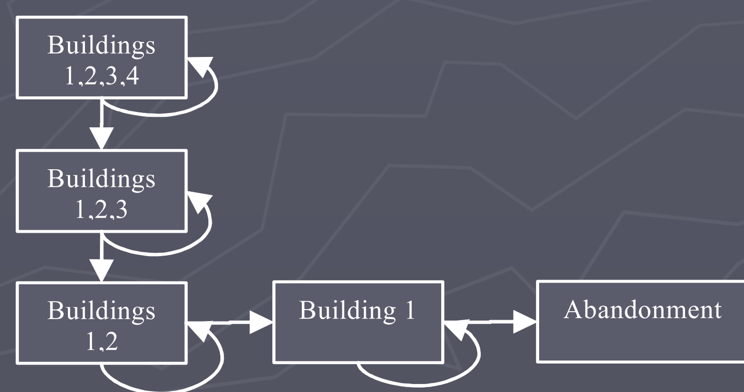
Optimization Framework

Enabling Life-cycle Managerial Flexibility

1. Decide on a facility's envelope architecture
2. Break up the facility into *n* subspaces of area A_i so that each can be converted independently of the others.
3. Design different performance and cost profiles for each subspace
4. Design different conversion/demolition costs for each subspace

Then there exists a 1-1 mapping of the envelope architecture and a path-dependent Markov network for sequential conversion/demolition

Example:



Optimization Framework

Life-cycle Managerial Flexibility

- First user/owner holds the (put) option to convert a subspace, moving along the Markov network until final abandonment.
- At each time, decision is based on
  - Expectation for the state of the market for the alternative use after conversion, L_V
  - Expectation for the state of the inherent value of space, I_V
  - Current maintenance costs for each subspace $C_{m,i}$
  - Switching cost (i.e., cost of conversion), $C_{d,i}$
- Owner's decision will follow Bellman's principle of optimality:

$$C_t(\mathbf{S}_t) = \min_{\mathbf{u}_t}\{\kappa_t(\mathbf{S}_t,\mathbf{u}_t) + \frac{1}{1+r}\mathrm{E}[C_{t+1}(\mathbf{S}_{t+1})]\}$$

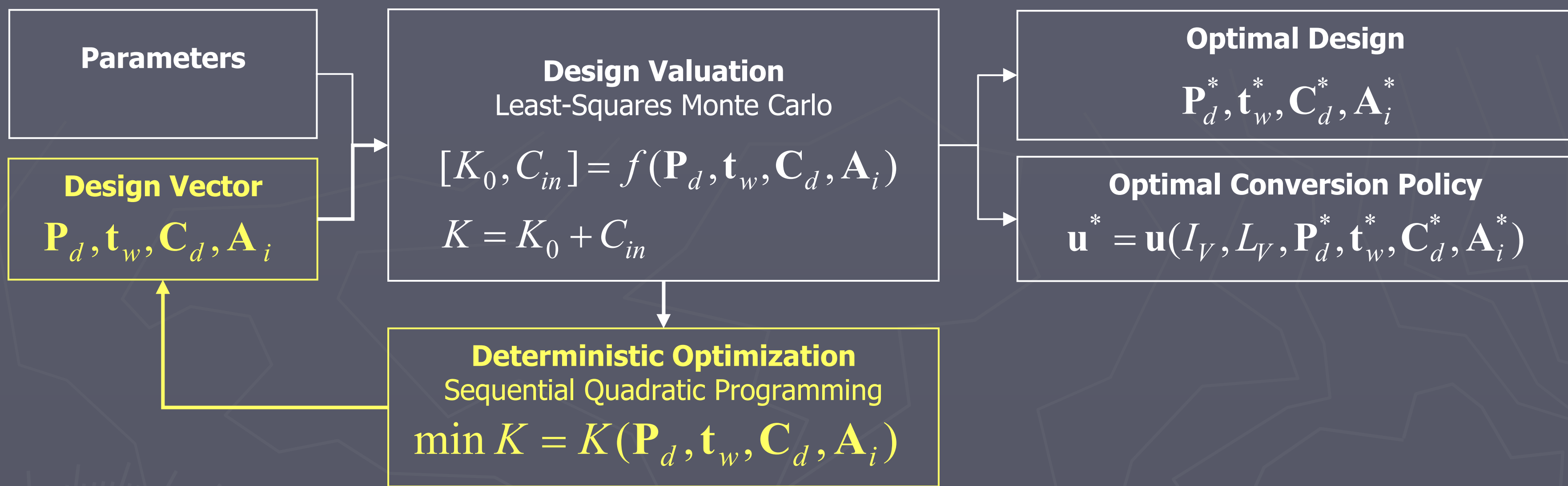
Optimization Framework

Valuing Life-cycle Managerial Flexibility

- We want to solve for:
  1. The time-zero life-cycle cost of the facility, incurred if the owner follows optimal policy (i.e., Bellman's rule)
  2. The decision rules for the optimal policy; i.e., under what conditions (I_V and L_V) to convert.
- Options Jargon: two-factor, sequential compound American option.
- Solved using Least-Squares Monte Carlo Method (LSM)
  - Longstaff & Schwartz 2001
  - Essentially, deterministic dynamic programming with cross sectional regression of the conditional expectation for future cash flows.

Optimization Framework

Design Optimization



- If, given a facility design, the owner follows the optimal conversion policy, what is the best design?
- Design Variables
  - For each of *n* subspaces:
  - Design Service Life — t_w
  - Initial design performance — $P_{d,i}$
  - Conversion cost — $C_{m,I}$
  - Area — A_i
- Iterate

Case: BP Exploration Headquarters

Initial Design

- General agreement among architects, that contraction should involve staged & controlled demolition.

- Actual initial design involved 8 subspaces and 2 contraction modes
- Initial conceptual design characterization (for every *i*)
  - $t_{w,i}$ = [45, 35, 30, 25, 25, 20, 10, 3]
  - P_d = 1.5 P_o
  - C_m = 5 $/SF
  - A_i = [36000, 10800, 21600, 21600, 28800, 14400, 18000, 28800]

Case: BP Exploration Headquarters

Optimized Design

- Simplifications:
  - 6 subspaces
  - 1 sequential contraction mode
  - No uncertainty about LV and IV (LSM reduces to deterministic dynamic programming)
- Simplified initial design vector
  - $t_{w,i}$ = 20 years
  - P_d = 1.5 P_o
  - C_m = 5 $/SF
  - A_i = [36000, 32400, 50400, 14400, 18000, 28800]
- Optimized Design:

Optimization Results — CPU Time for Optimization: 68.641sec

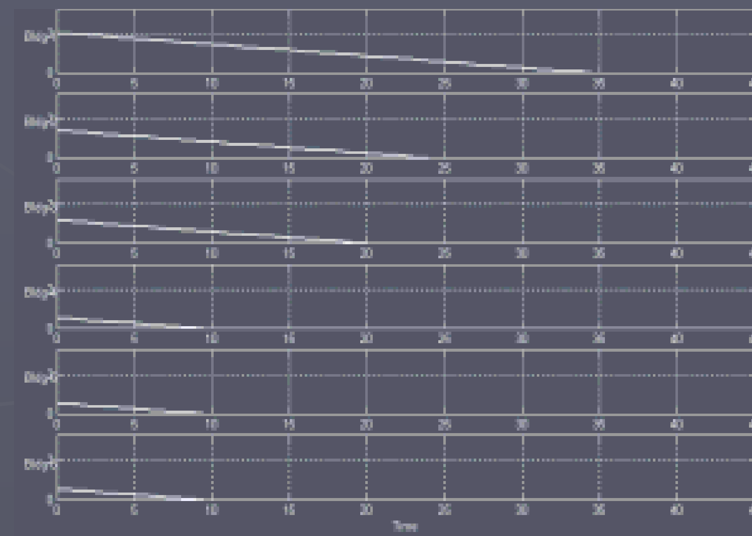
#	A_0	A	$t_{w,0}$	t_w	$P_{d,0}$	P_d	$C_{d,0}$	C_d
1	36000	53768	20	1	1.5	2.00	5	10
2	32400	37713	20	1	1.5	1.37	5	10
3	50400	56842	20	1	1.5	1.13	5	10
4	14400	22263	20	1	1.5	0.50	5	9
5	18000	21	20	1	1.5	0.50	5	8
6	28800	9391	20	1	1.5	0.50	5	8

Case: BP Exploration Headquarters

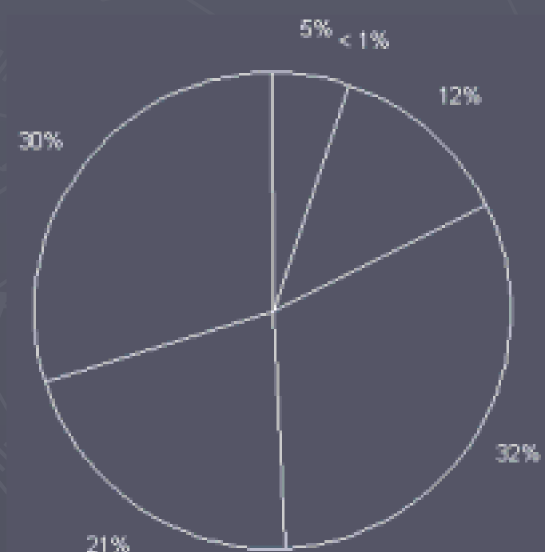
Optimized Design

Simulation Report

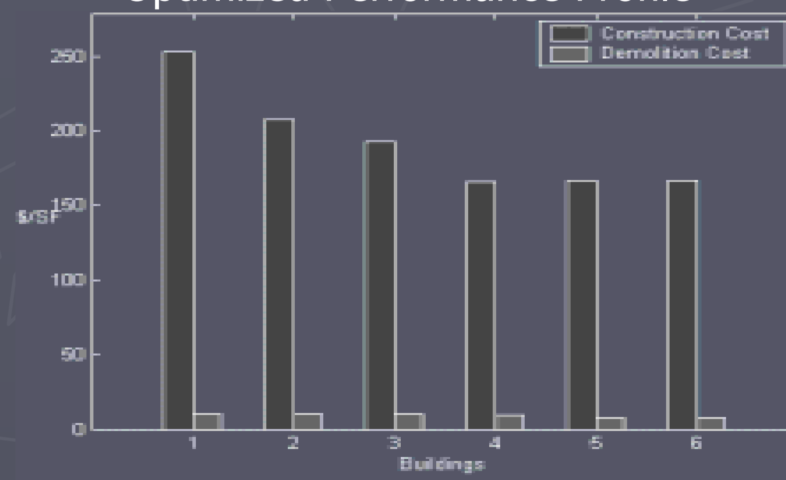
Optimal Lifecycle Cost of the Design Solution	$11,556,645
Construction Cost of the Design Solution	$37,646,701
TOTAL Cost of the Design Solution	$49,203,346
Number of Buildings after 1st decision	4



Optimized Performance Profile



Optimal subspace definition



Optimal development and conversion costs

Optimal Design for Contraction

Insights from the case example

- Improvement from Optimization
  - Decrease in Development costs: -22%
  - Decrease in Lifecycle costs: 33%
  - Total Cost Decrease: 25%
- Sensitivity (most significant)
  - Lower bound on design performance for short-lived subspaces
  - Lower bound on design service life of short-lived subspaces
- Pitfalls:
  - Unexpectedly "bumpy" design space
  - Solution sensitive to initial vector
  - Solution sensitive to parameters (especially IV and LV) trends
- 69 sec. on a 2.0GHz P4 interpreting MATLAB functions

Optimal Design for Contraction

Conclusions

- Quantitative, Multidisciplinary framework and algorithm for the design of facilities to respond to change.
  - Real Estate & Finance (real options)
  - Building Technology
- (To the best of my knowledge,) modern approach in the way it disassociates deterministic optimization from probabilistic analysis.
- Using imaginary data on a single example, the concept of Diversified Lifetimes for buildings seems to be encouraging.
- Recommended Implementation:
  1. Try different initial vectors with deterministic model (faster)
  2. Slowly increase volatility to historical levels
- Worth further research (I think)

Optimal Design for Contraction

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Optimal Design for Contraction

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