COMPUTATIONAL FRAMEWORK FOR PARAMETRIC MODELING AND SYSTEM-LEVEL ASSESSMENT OF BUILDING FLOORPLANS

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Outline

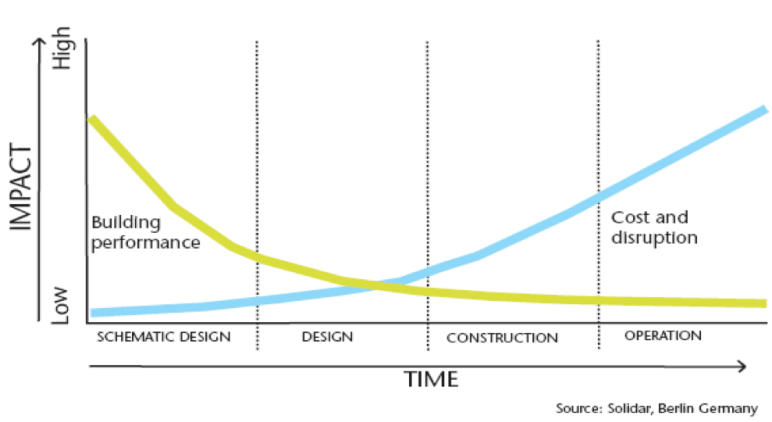
- Introduction
- Parametric Modeling of Building Floorplans
- Approach 1: Scripting Floorplan Specification
- Approach 2: Interactive Graphical Specification of Floorplans
- Building Floorplan Case Studies
- Conclusions and Future Work
- Questions
- References

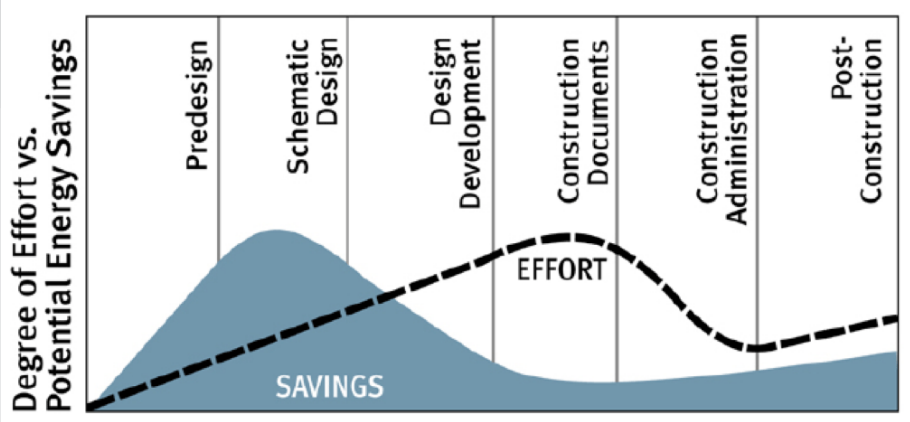
Introduction

- Problem statement
- Architectural Design of Buildings
- Building Information Modeling
- MBSE for Building Systems Design
- Objectives and Scope

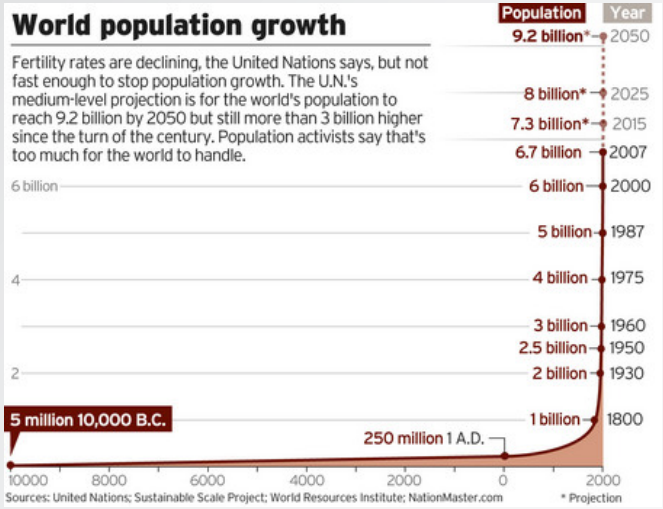
Problem statement

- Focus on frontend development





- Why buildings matter?



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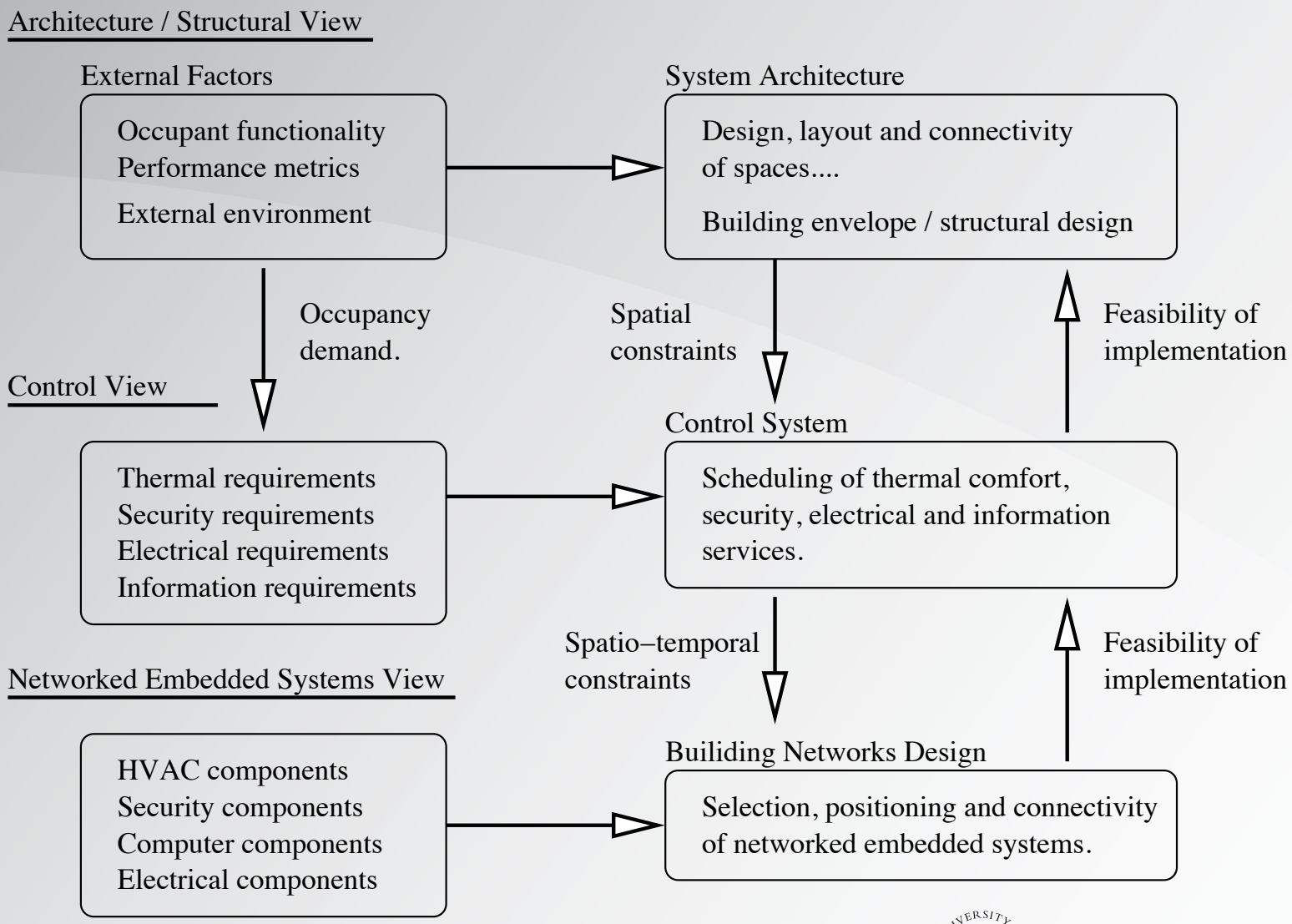
Architectural Design of Buildings



Building Information Modeling

- Usage:
  - Models of building for drawing and support documents
  - Define parametric constraints to enforce relationships on the geometry of objects
  - Performance-based assessments
- Weakness:
  - Linking fragments of behavior to system components
  - Expressing dependencies and interdependencies among disciplines

MBSE for Building Systems Design

- Focus on models
- Multidisciplinary aspect:
  - System functionality
  - Evaluation of system performance
  - System validation and verification
  - Economics
  - Sensitivity Analysis and Tradeoff.
- Extremely complex for large-scale buildings.

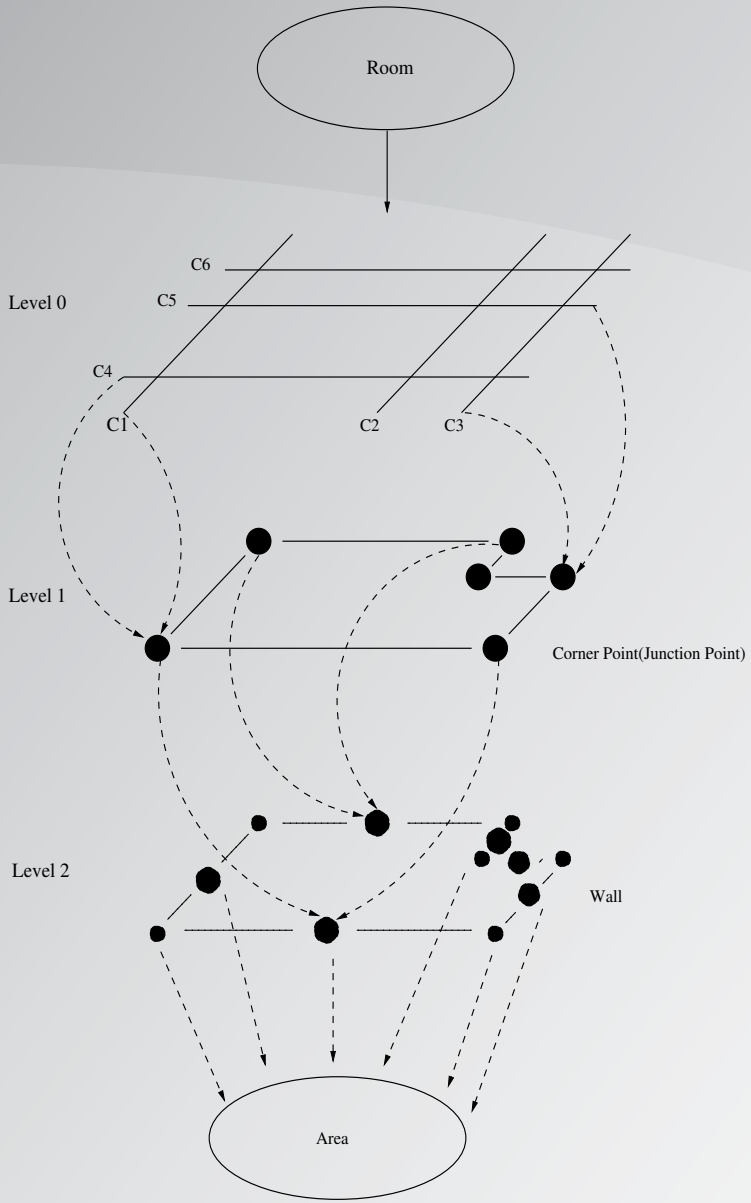
Project Objectives and Scope

- Long-term:
  - Model-based systems engineering (MBSE) procedures
  - Computer-aided tools
  - Focus:
    - Parametric modeling
    - System-level assessment
    - Trade-study analysis

Parametric Modeling Of Building Floorplans

- Parametric Modeling of Floorplans
- Propagation of Dependency Relationships
- Area Computations with the Java Topology Suite
- Software Design Patterns
- Composite Hierarchy of Features

Parametric Modeling of Floorplans

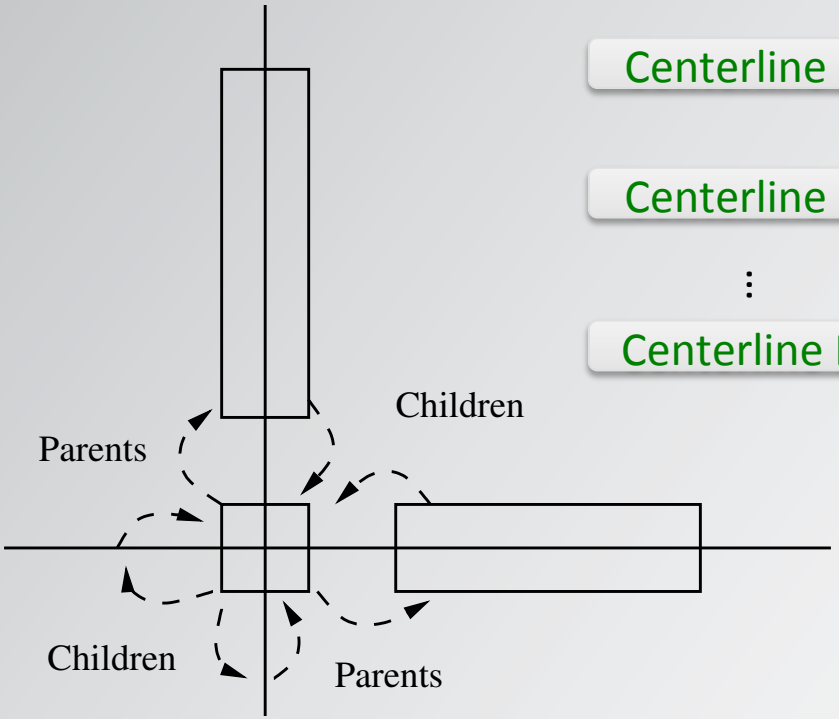


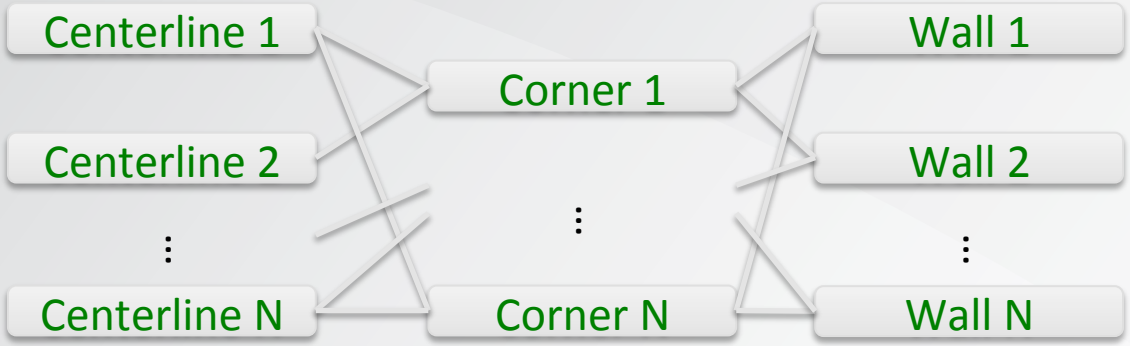
Multi-layer hierarchy

- Level 0: Centerline Layer
- Level 1: Junction Points Layer
- Level 2: Wall Layer

Propagation of Dependency Relationships

Many-to-many relationship

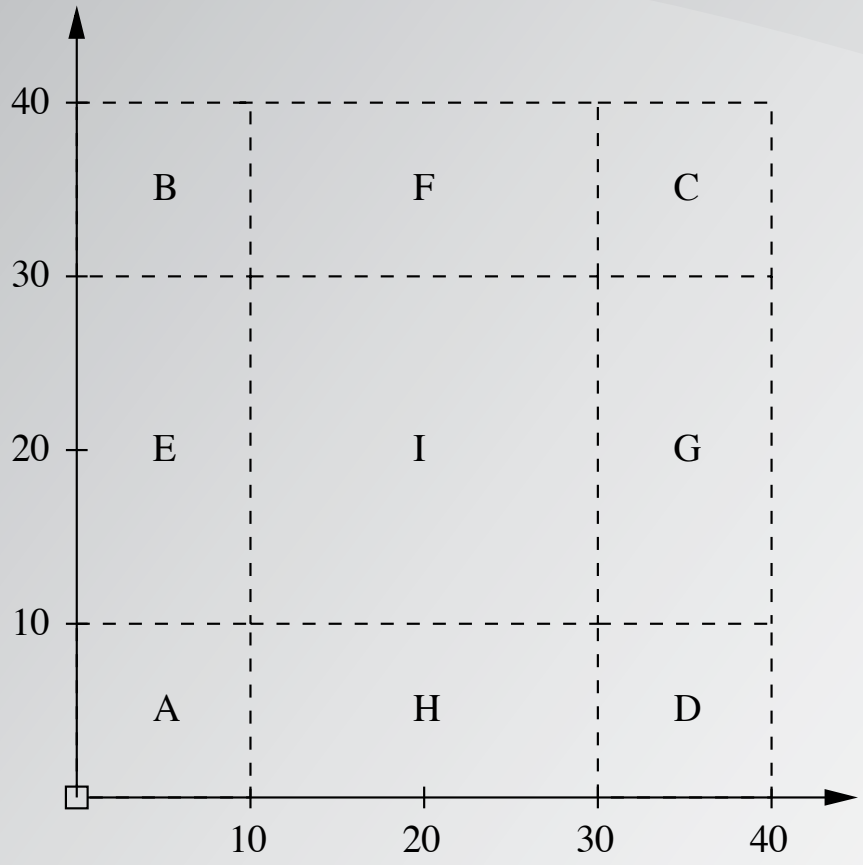




Multiple objects of type A associated with multiple objects of type B, and vise versa.

Area Computations with the Java Topology Suite

Basic Geometry Operations



- Union()
- Difference()
- getArea()
- getCoordinates()

Software Design Patterns

- Definition:
  - Good solutions to common software design problems

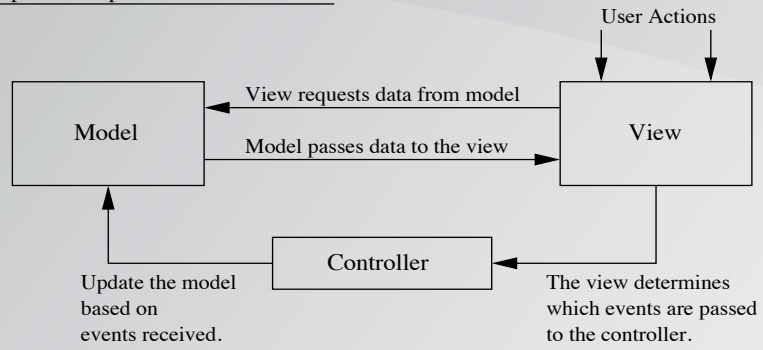
- Software Design Patterns used in this work:

Behavior	Structure	System
Mediator	Composite	Model-View-Controller
Observer		
Visitor		

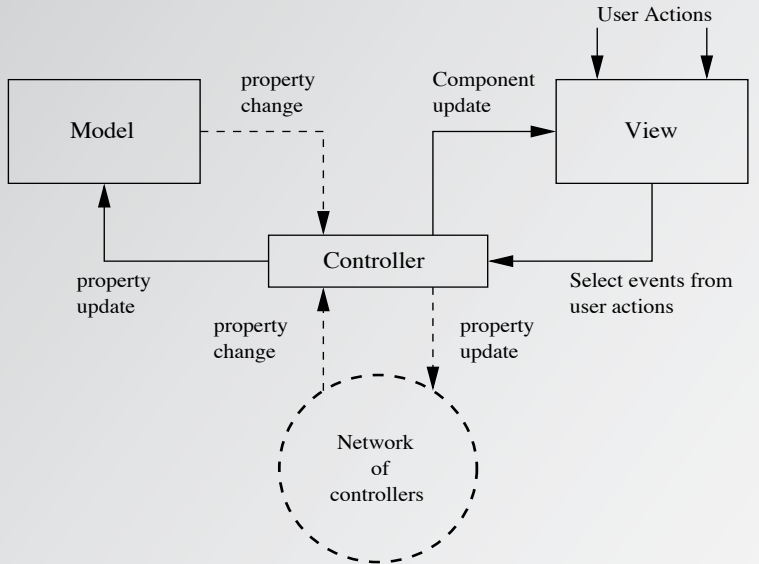
Software Design Patterns

- Model-View Controller

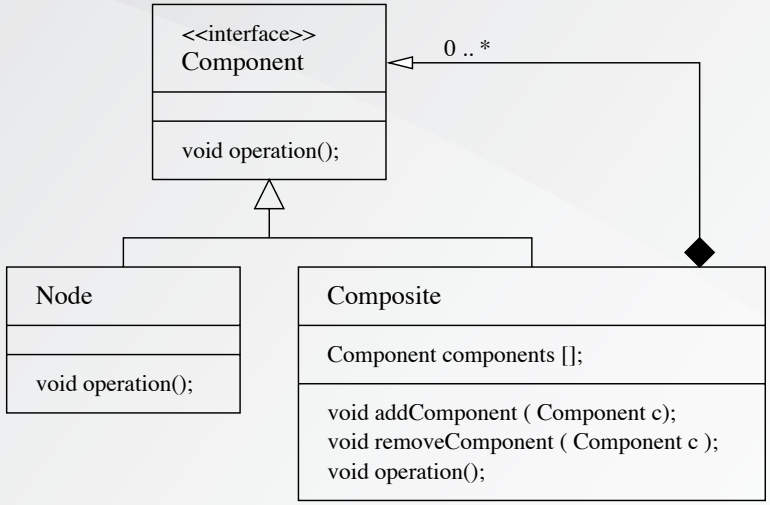
Simplified Implementation of MVC



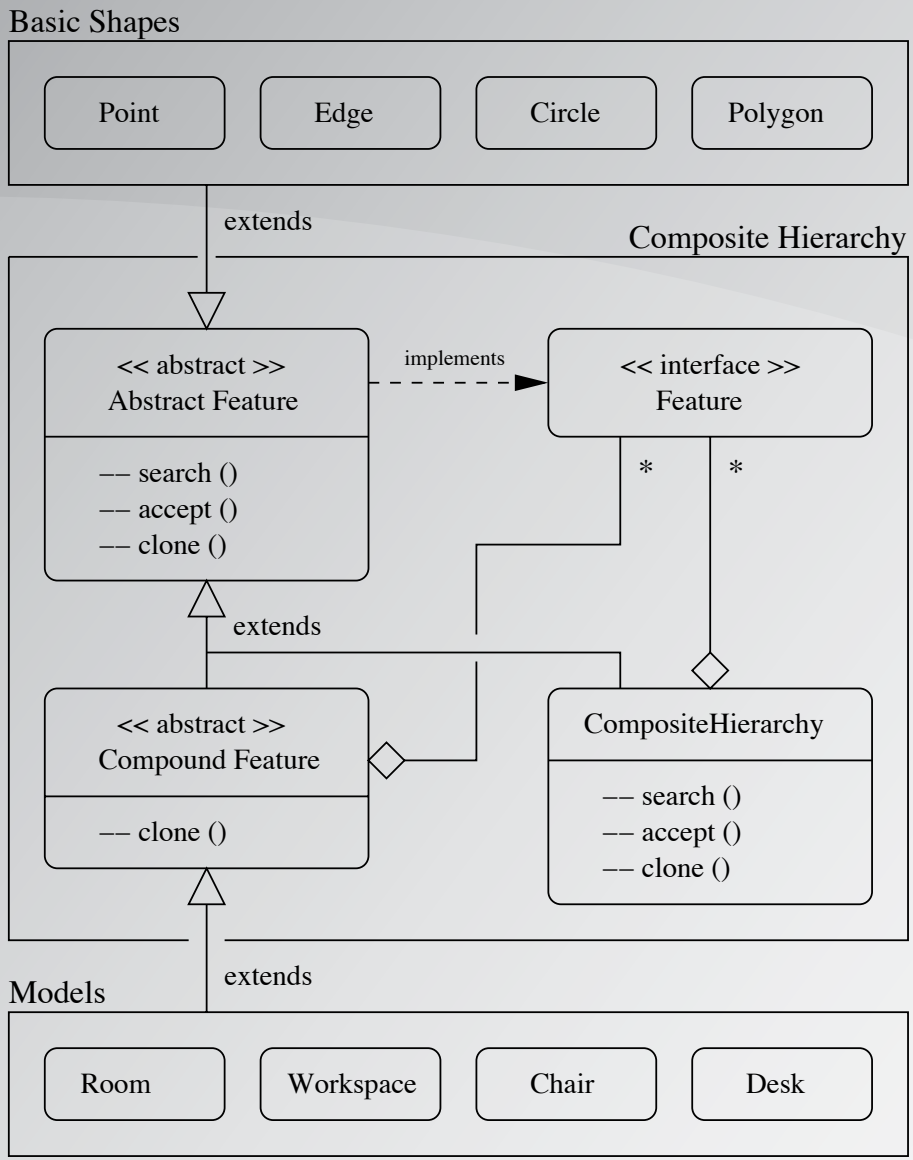
Implementation of MVC with the Controller acting as a Mediator



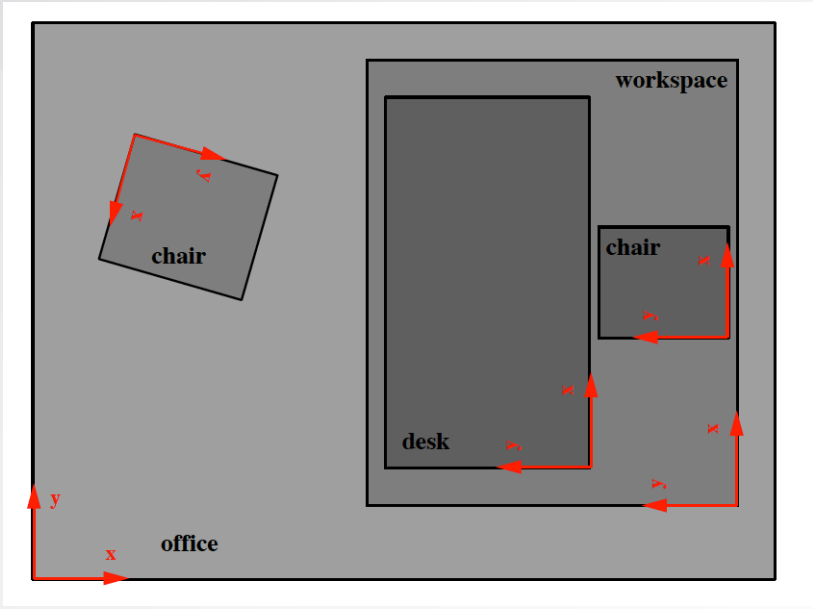
- Composite



Composite Hierarchy of Features



- Office space example



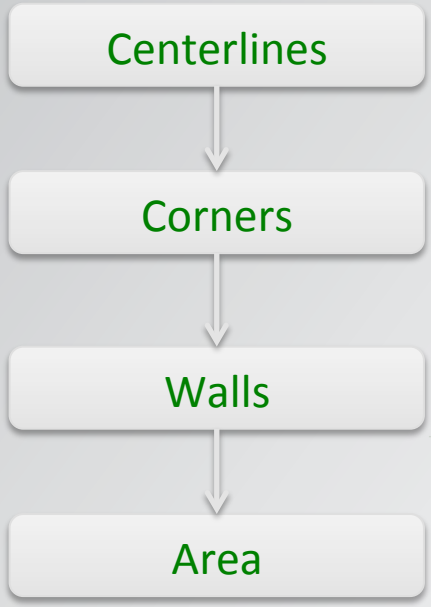
Approach 1: Scripting Floorplan Specification

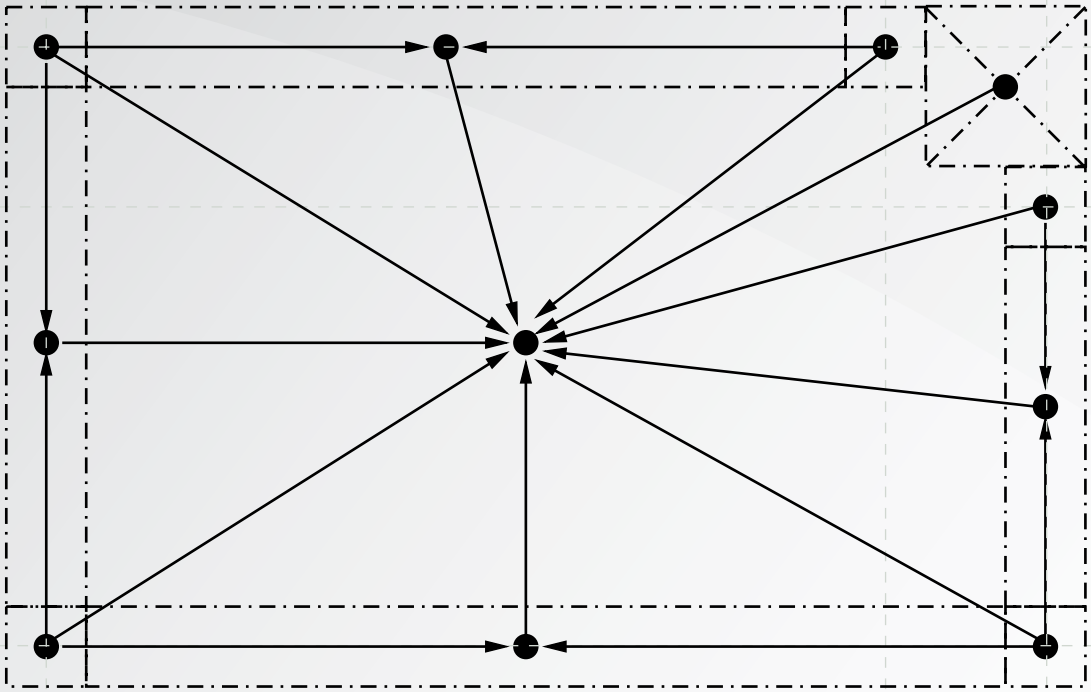
- Simple Room Example
- Simple House Example
- Assessment of Scripting Approach

Simple Room Example

Dependency Relationship

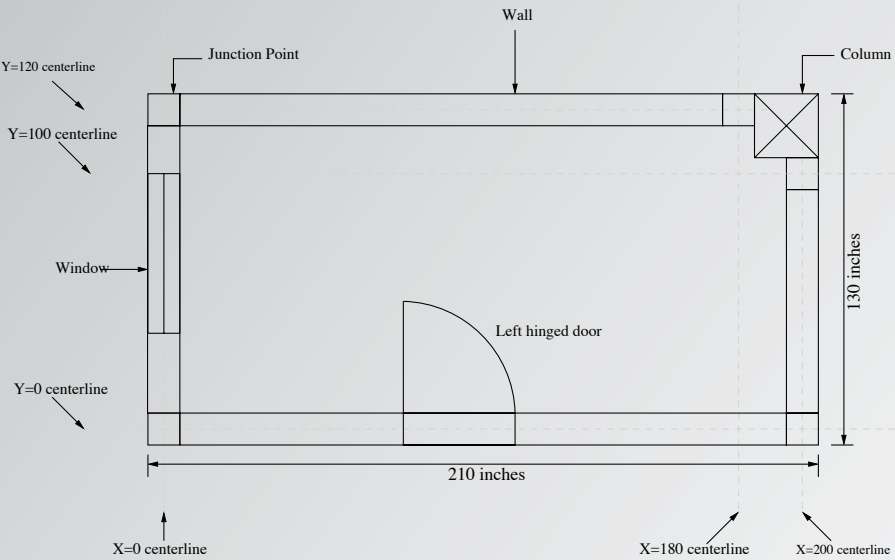
- Pathway of Dependency Relationship

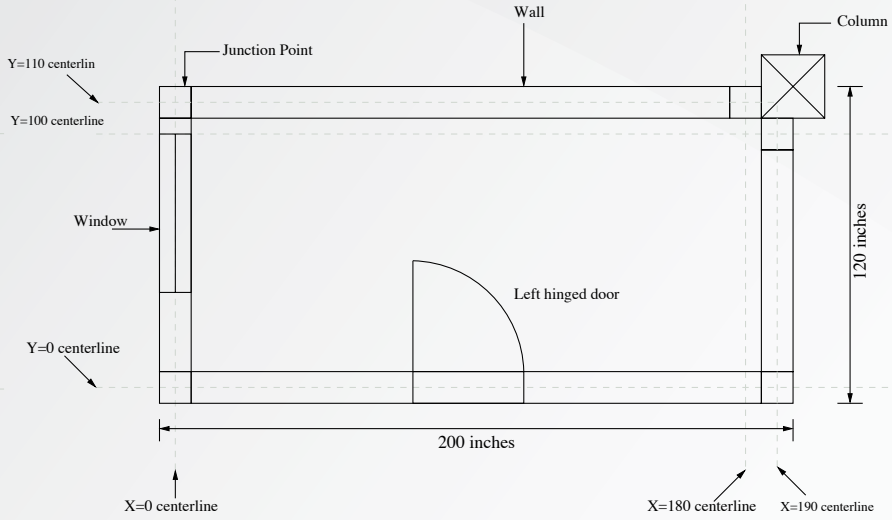




Simple Room Example

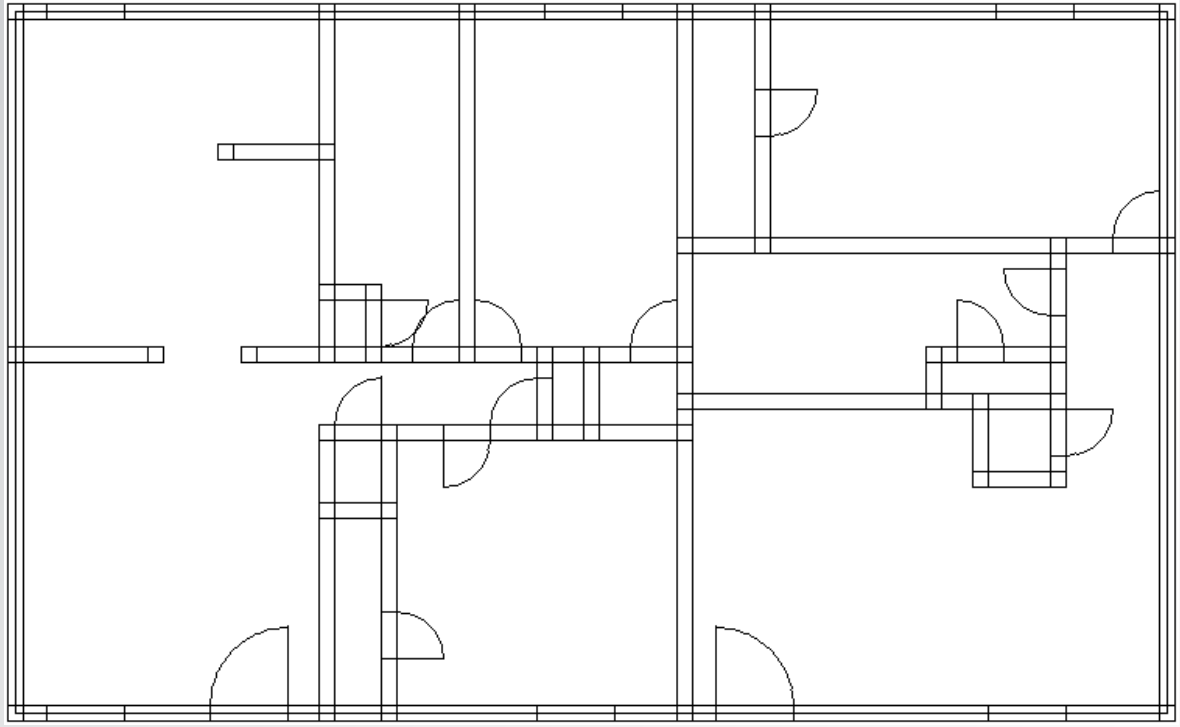
Simple Room Original & Redesign





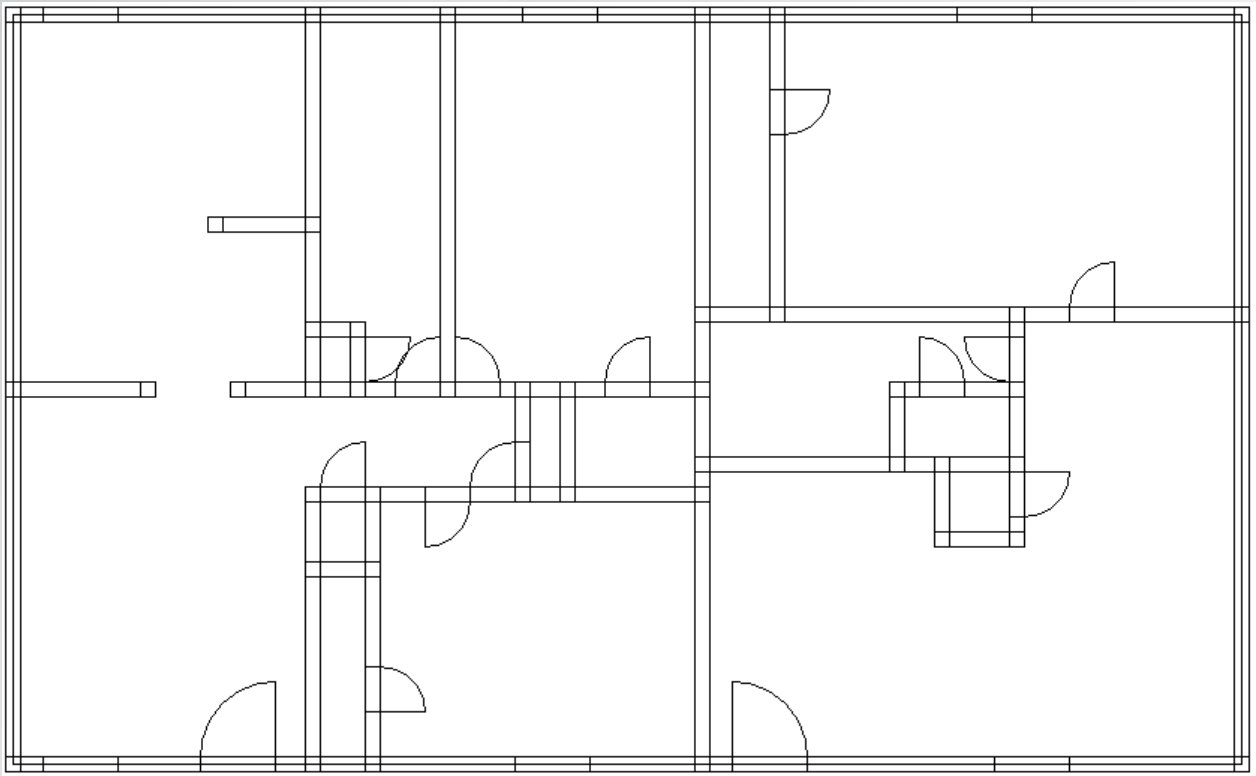
Simple House Example

Original floorplan design



Simple House Example

Redesign floorplan



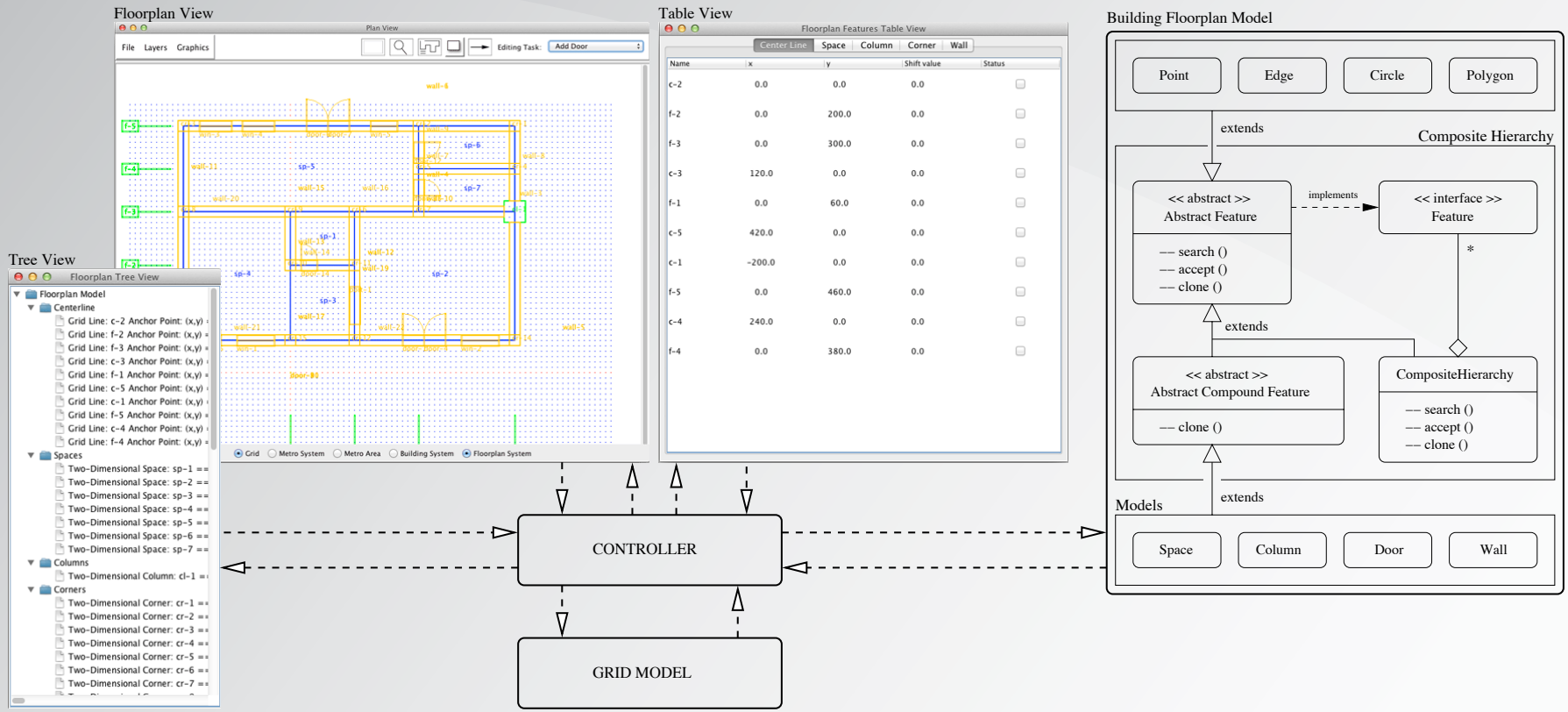
Assessment of Scripting Approach

- Provides high-level solution
- Not scalable – in fact, 2000 lines of Java needed to create Apartment model.
- Conclusion: We need a better approach for building floorplan systems

Approach 2: Interactive Graphical Specification of Floorplans

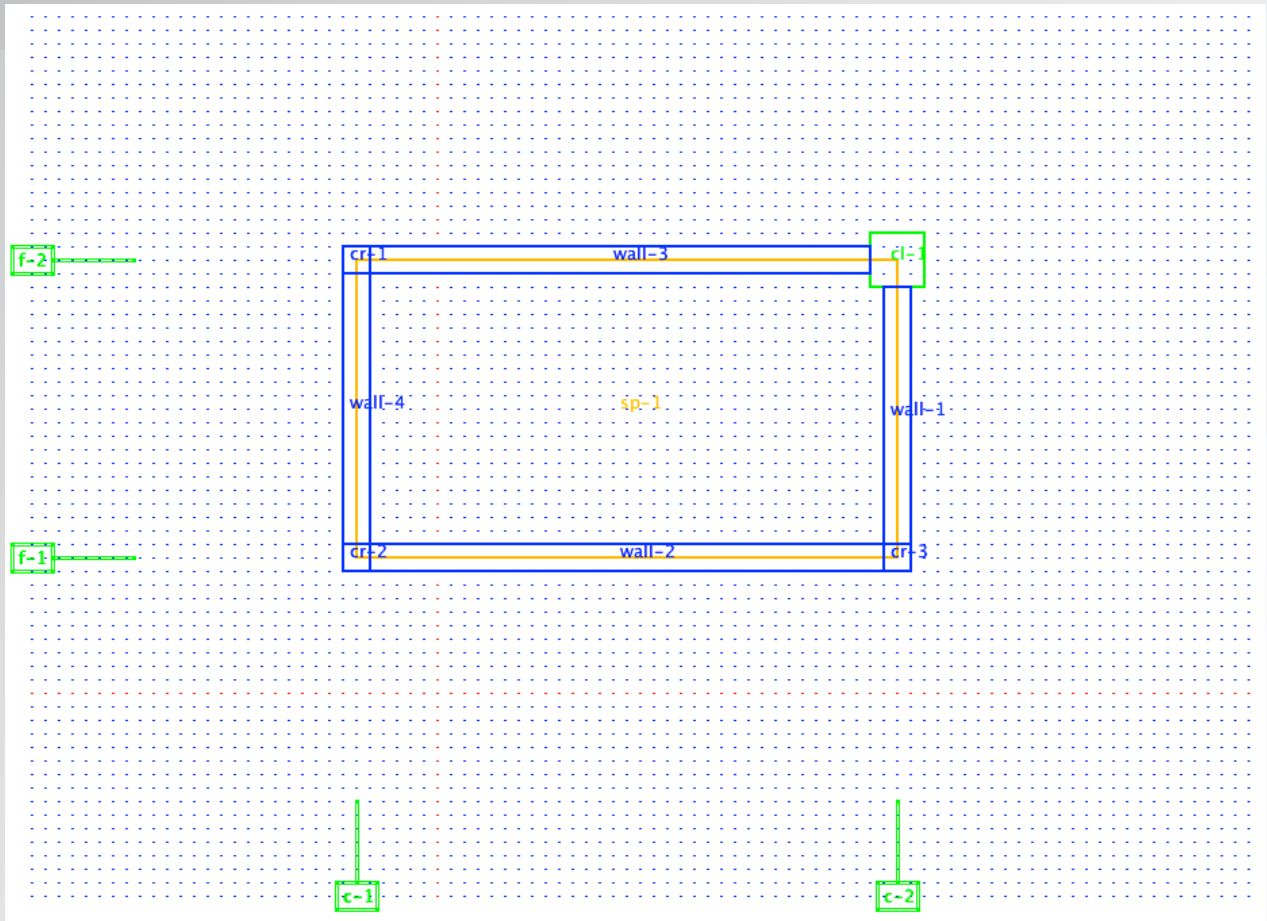
- Graphical User Interface Design and Implementation
- Simple Room Example
- Simple House Example

Graphical User Interface Design and Implementation



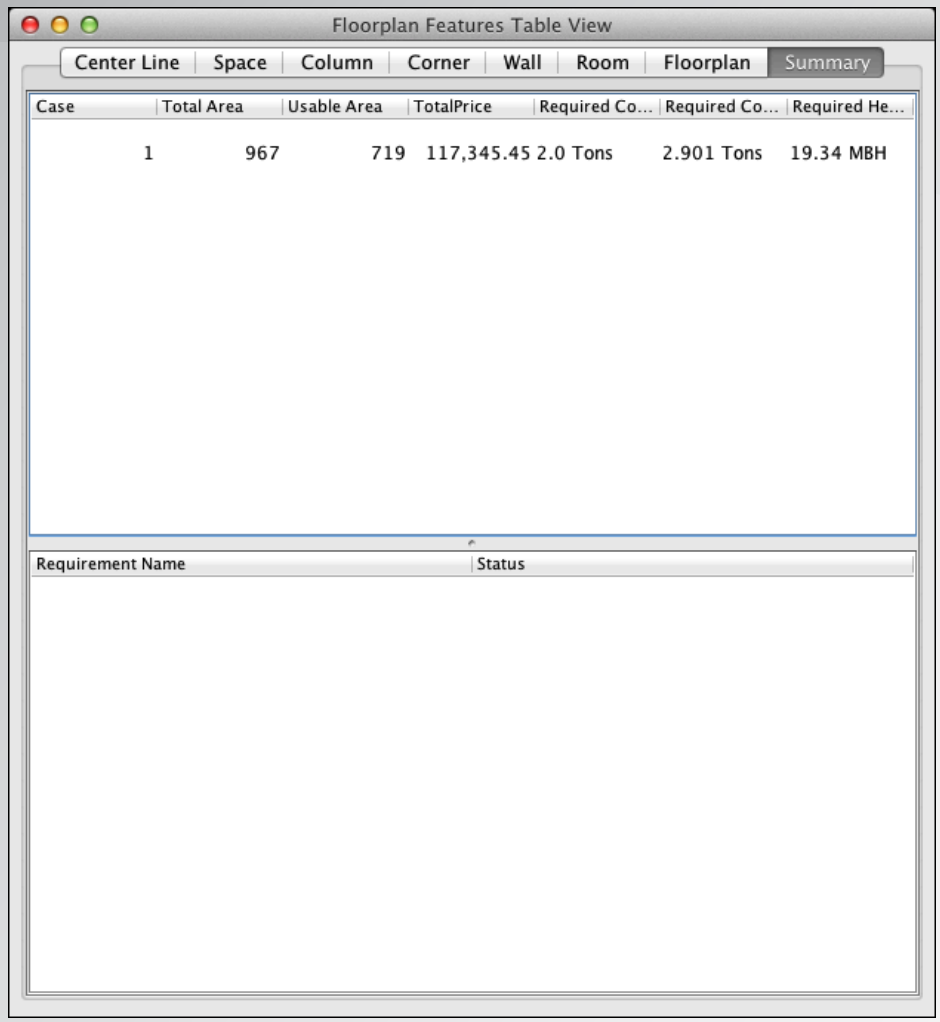
Simple Room Example

Editor view (Graphical)



Simple Room Example

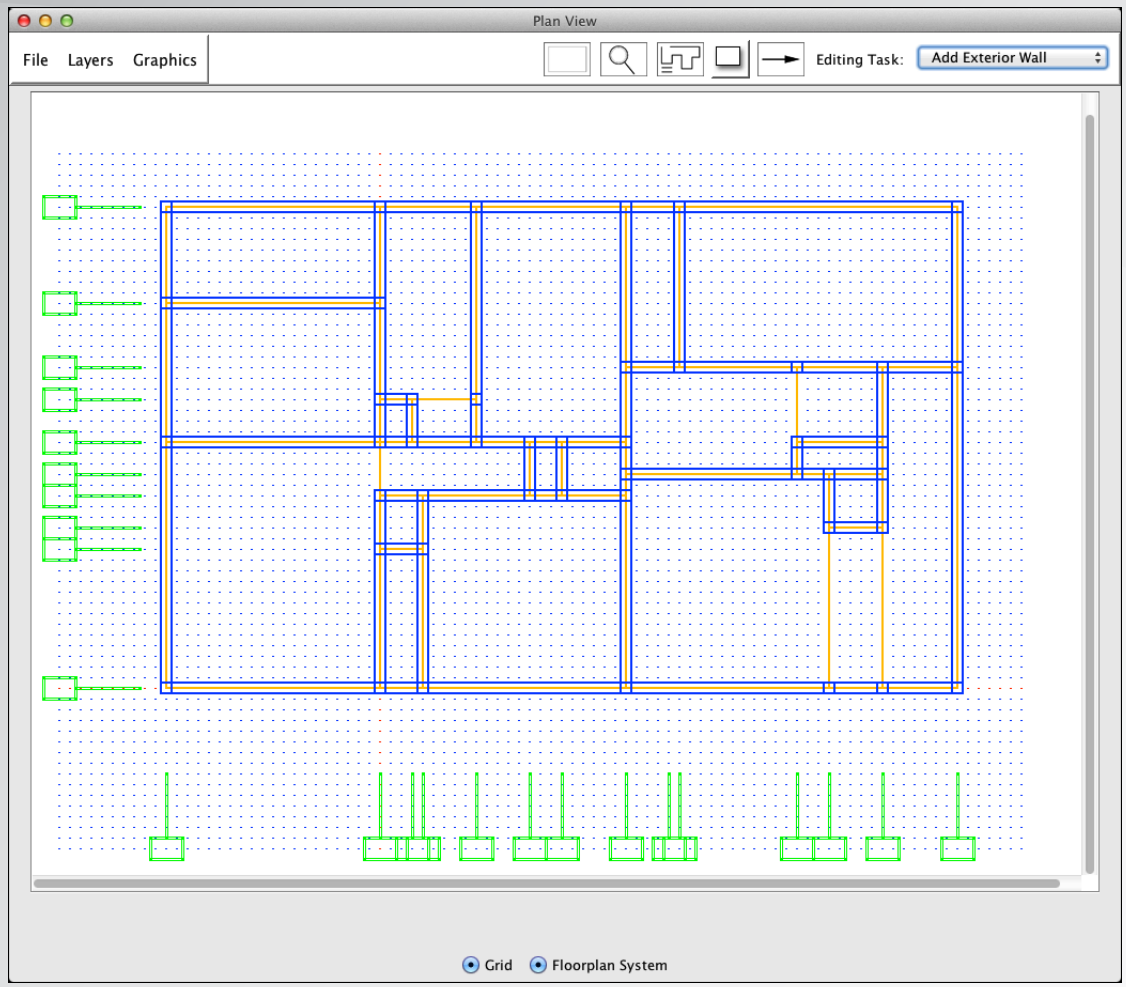
Table view



- Making comparison between multiple design alternatives
- Analyzing different floorplan designs

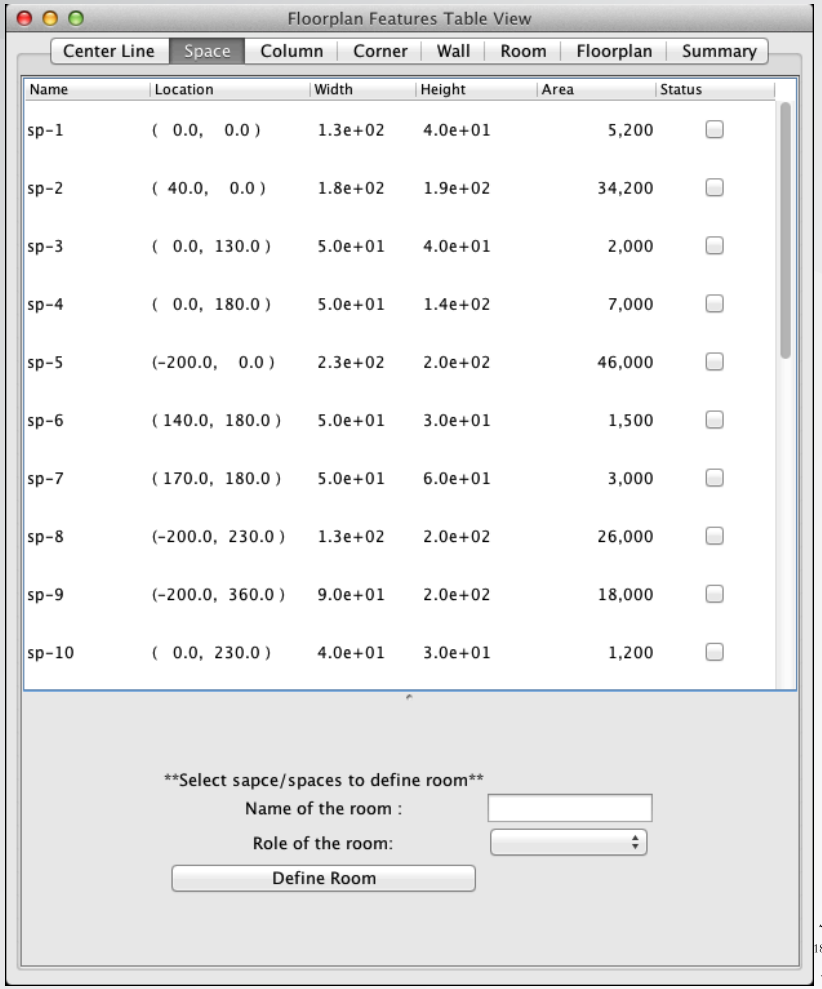
Simple House Example

Editor view (Graphical)



Simple House Example

Table view



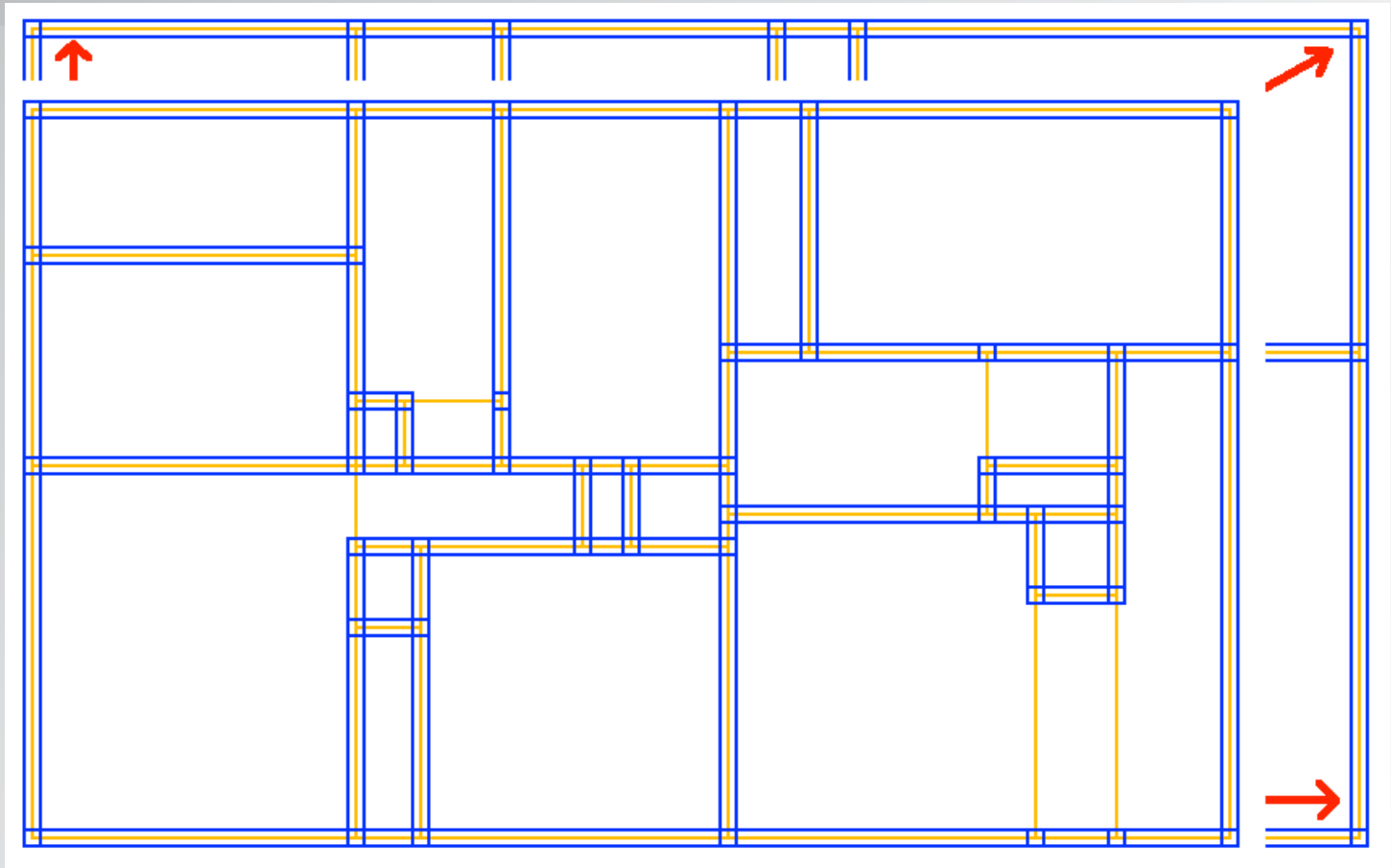
Assessment of MVC Approach

- Much better efficiency for creating floorplan models.
- Gives users a much better understanding of the building floorplan system

Building Floorplan Case Studies

- Case Studies Objectives and Scope
  - Building code regulation verification
  - Formulation of energy problem
  - City selection and basic information
- Electricity Cost Study
- Building/HVAC System Assessment and Tradeoff
  - Original floorplan system
  - Redesigned floorplan system
- Sensitivity Analysis for Two Design Floorplan Models

Case Studies Objectives and Scope



Case Studies Objectives and Scope

- Building Code Regulation Verification
  - IBC
  - IPMC
- Formulation of Energy Problem

$$LCC = Cost_i + E * Cost_e * \frac{(1+d)^t - 1}{d(1+d)^t}$$

$$E = S * 12000_{(Btu/Tons)} * U / ER / 1000_{(W/kW)}$$

$$U / ER = SummerUsage_{city} / SEER + W\,\mathrm{int}\,erUsage_{city} / HSPF$$

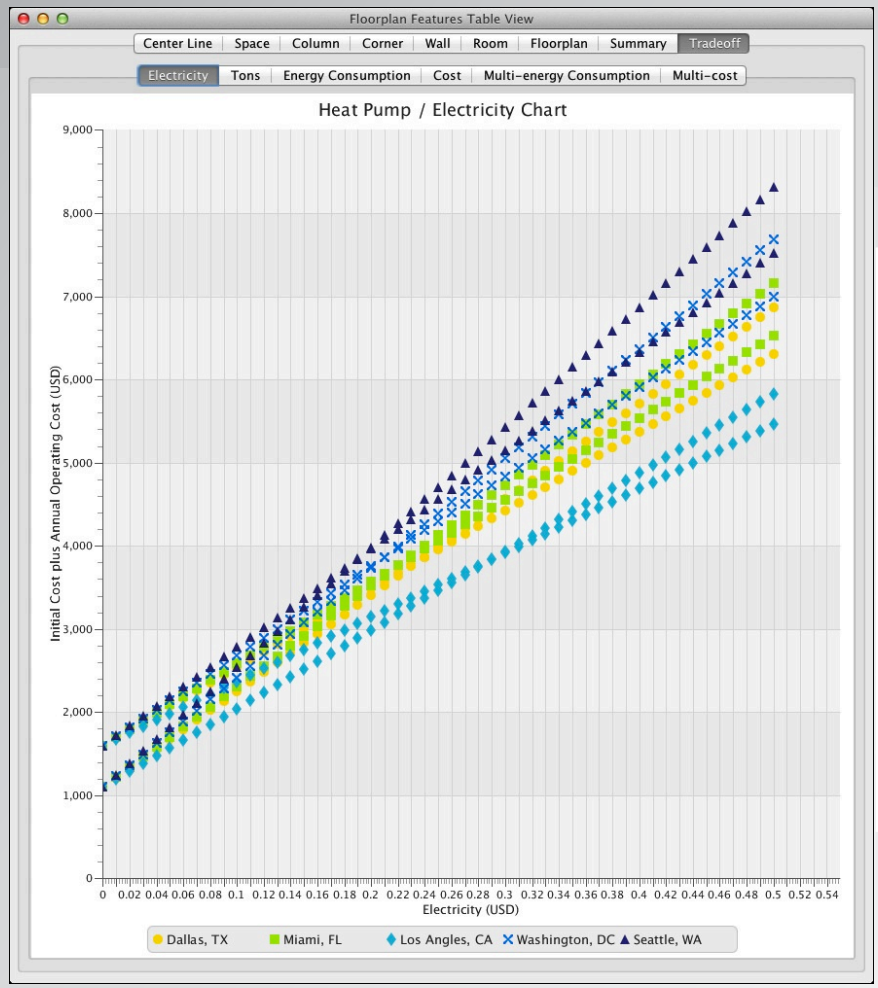
Case Studies Objectives and Scope

- City selection and basic information

City	Cooling Usage(hr)	Heating Usage(hr)	Electricity Cost
Seattle, WA	282	2956	$0.0877
Los Angles, CA	1630	1070	$0.1622
Washington, DC	1320	2061	$0.1284
Miami, FL	3931	265	$0.1198
Dallas, TX	1926	1343	$0.1179

- Heat pump library

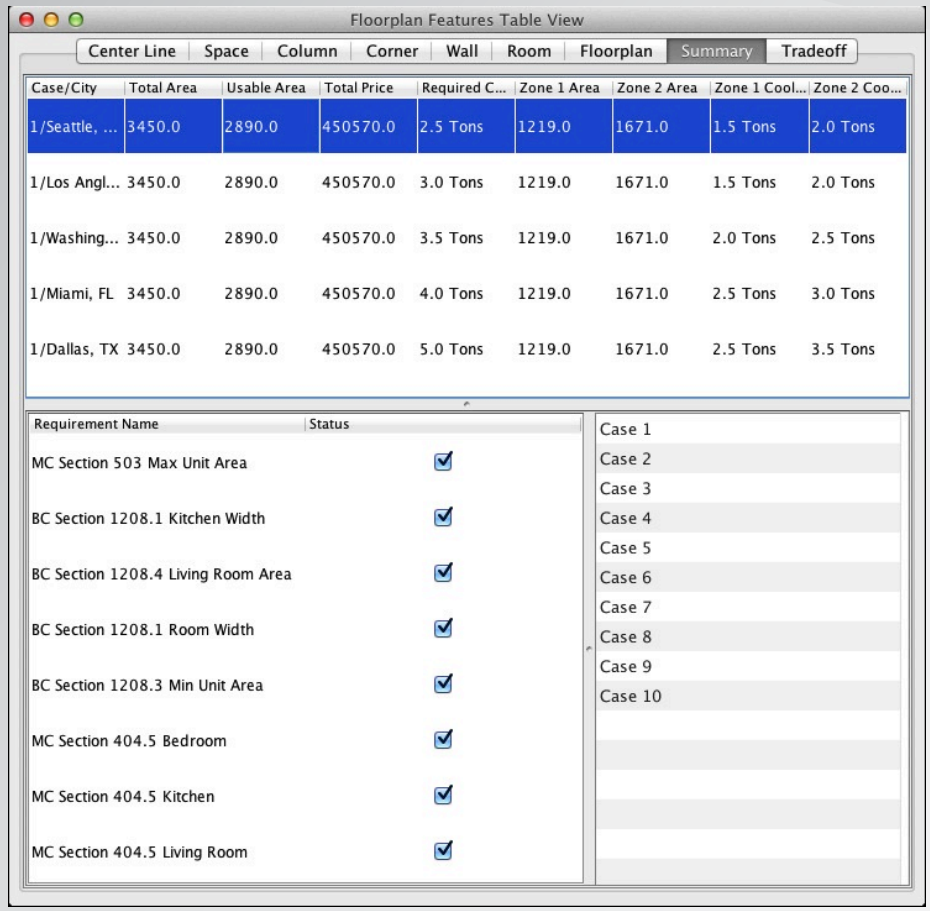
Electricity Cost Study

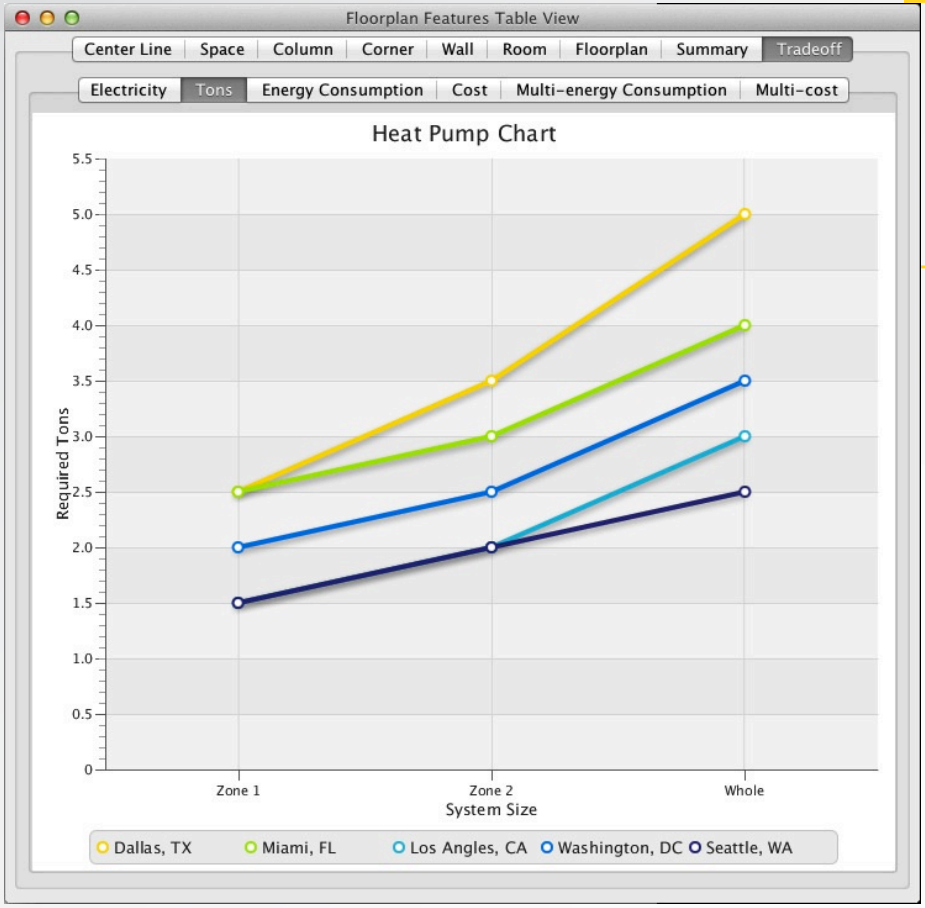


City	SEER 13	SEER 16	Electricity Cost Threshold
Seattle	14424.00	11836.18	$0.1932
Los Angles	9452.31	7722.24	$0.2890
Washington	13167.69	10780.11	$0.2094
Miami	12108.92	9848.96	$0.2212
Dallas	11532.00	9422.76	$0.2371

Building/HVAC System Assessment and Tradeoff

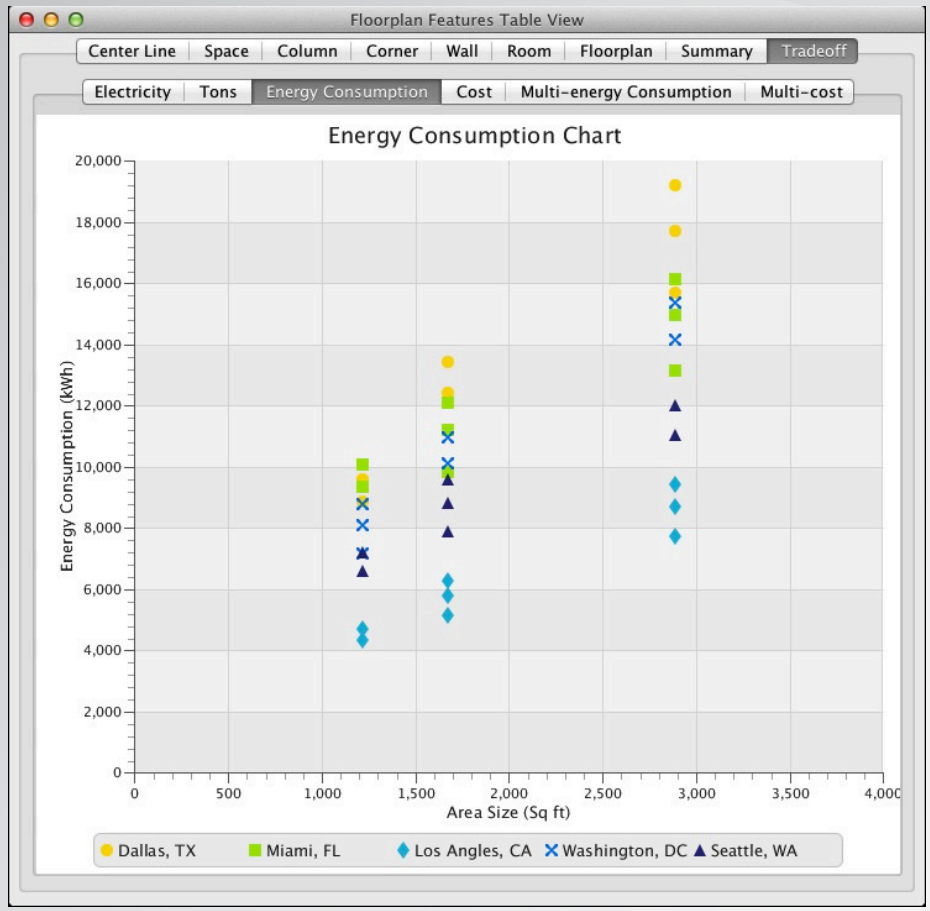
Original floorplan system

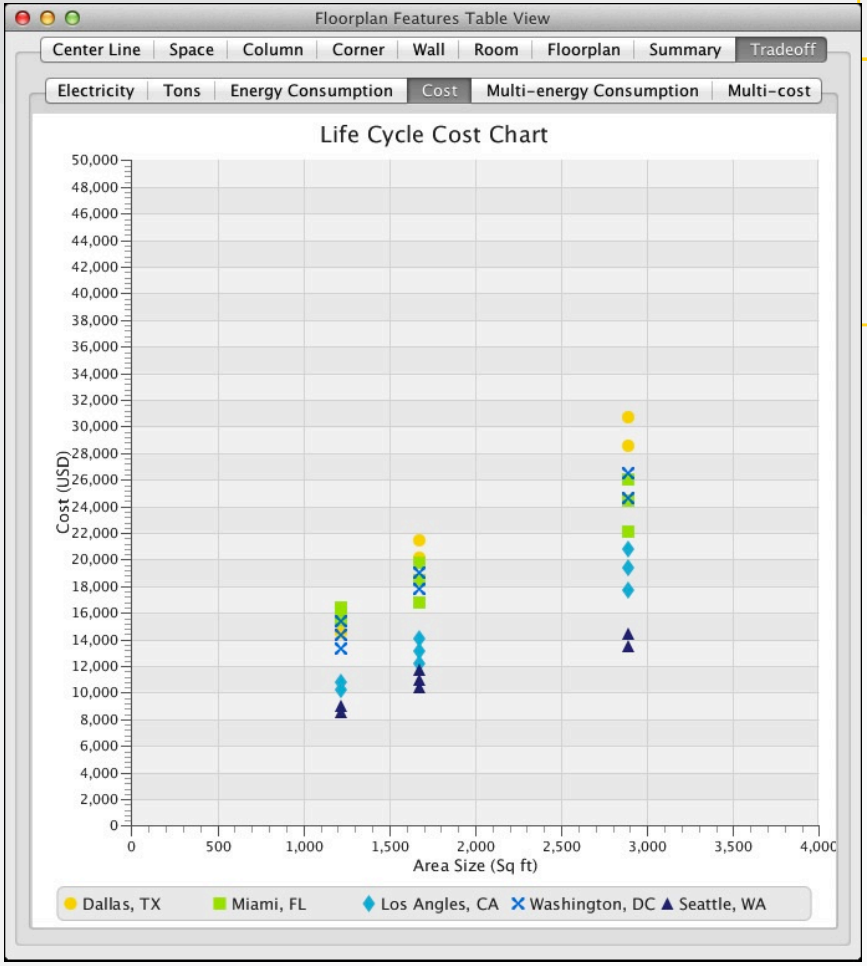




Building/HVAC System Assessment and Tradeoff

Original floorplan system





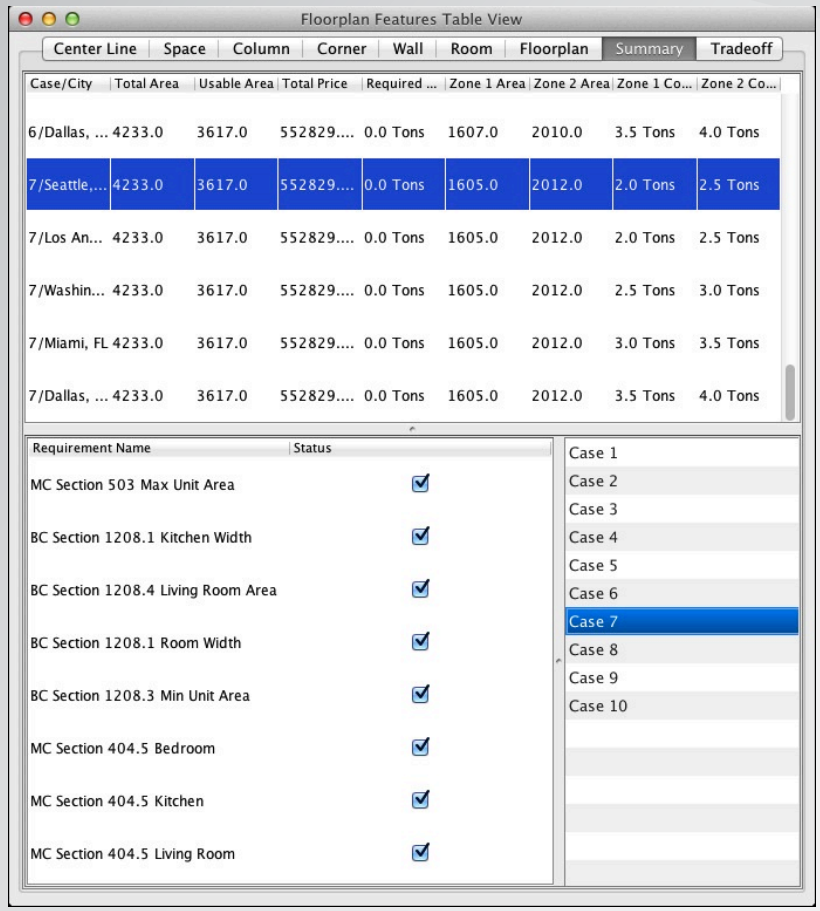
Building/HVAC System Assessment and Tradeoff

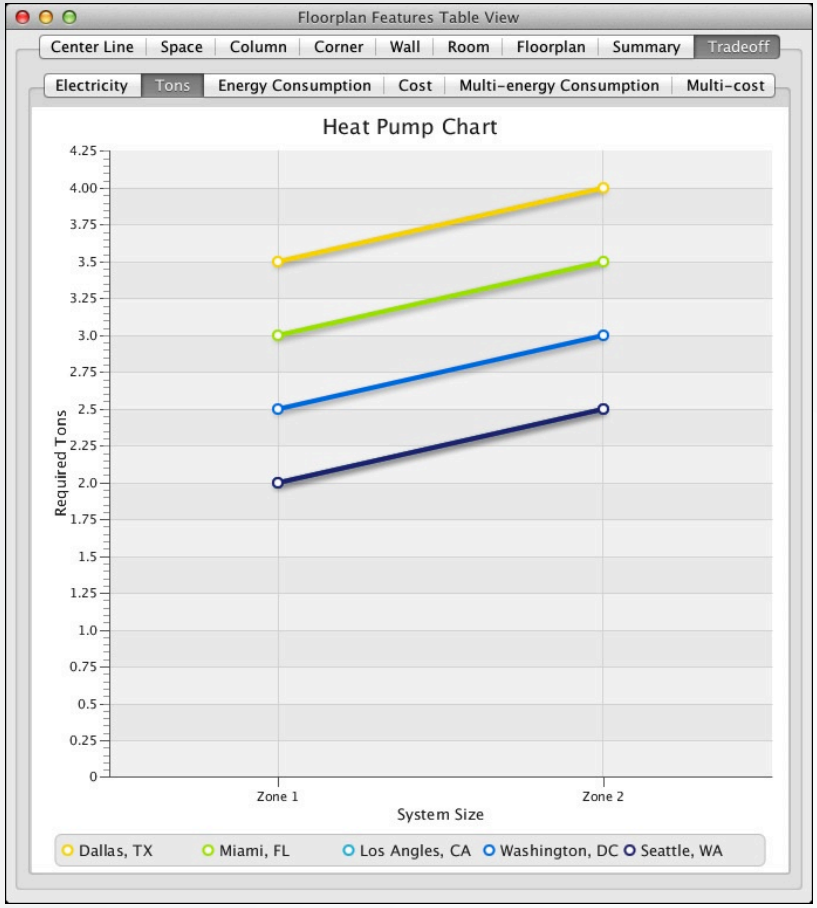
Original floorplan system

City	Two Zones Combined Consumption (kWh)	One Zone Consumption		Increased %
		Most Efficient Unit(kWh)	Least Efficient Unit(kWh)	
Seattle, WA	6622.3 + 7890.8	11037.2	12020.0	20.7%
Los Angles, CA	4361.6 + 5148.2	7722.2	9452.3	0.6%
Washington, DC	7186.7 + 10102.7	14143.8	15362.3	12.5%
Miami, FL	9358.9 + 9849.0	13131.9	16145.2	19%
Dallas, TX	8867.1 + 12414.0	15704.6	19220.0	10.7%

Building/HVAC System Assessment and Tradeoff

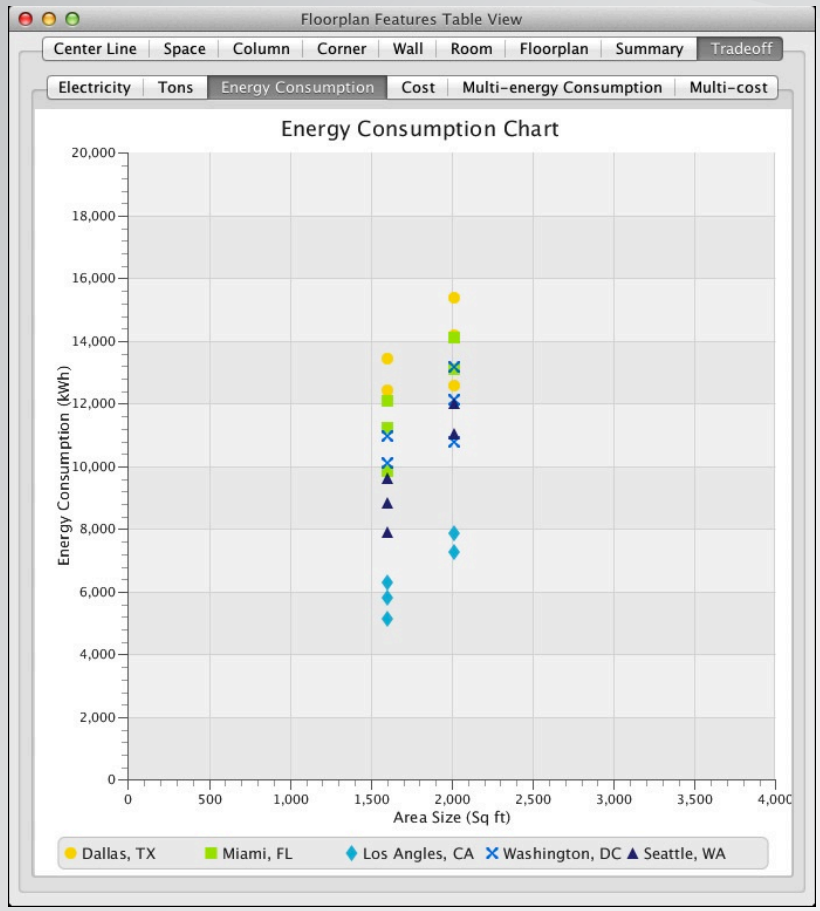
Redesigned floorplan system

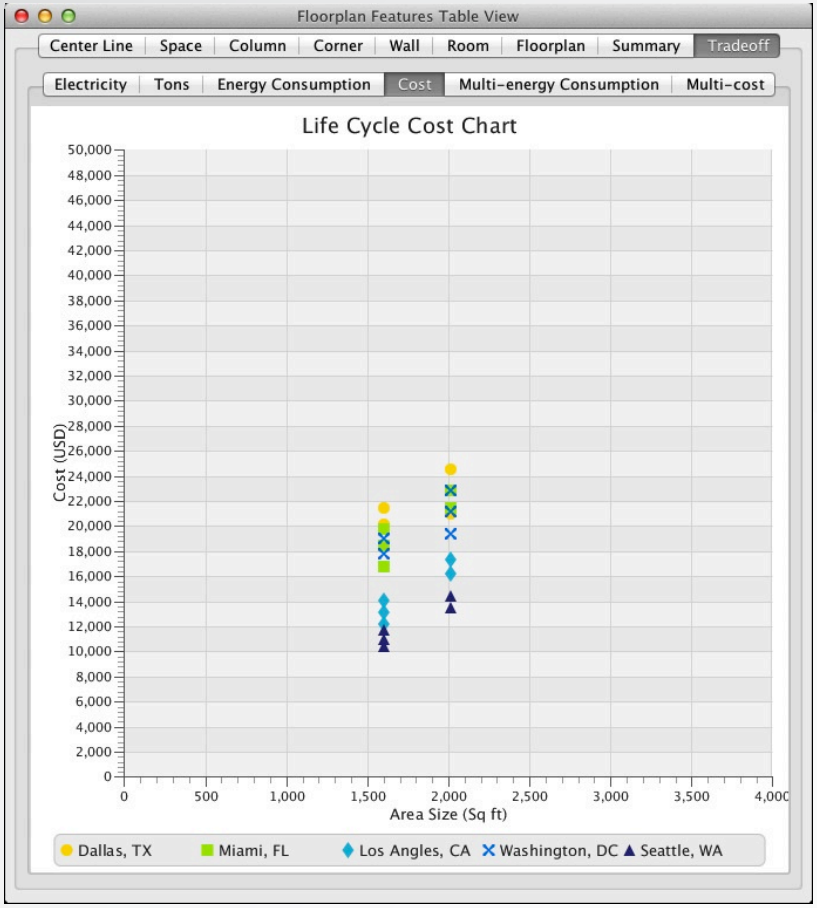




Building/HVAC System Assessment and Tradeoff

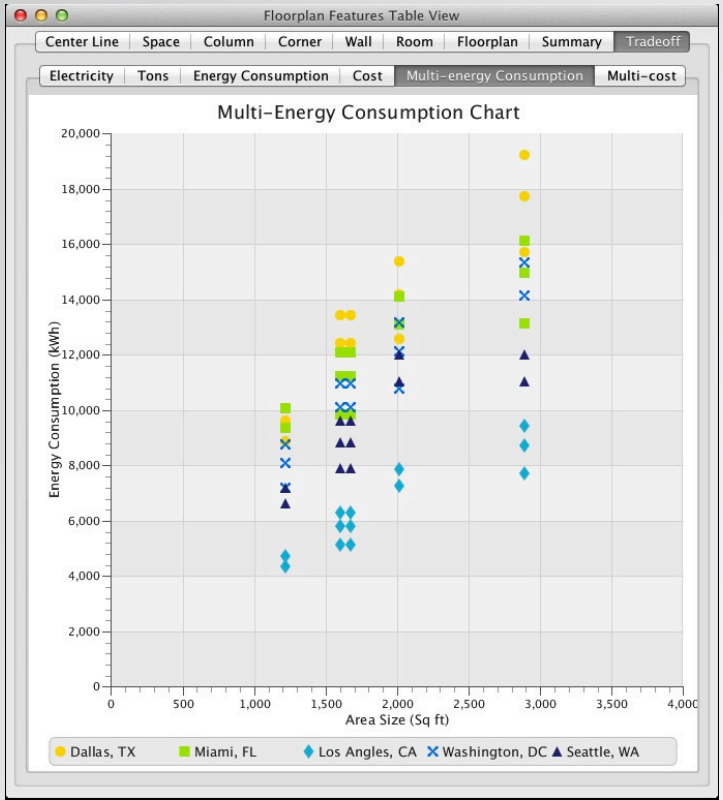
Redesigned floorplan system

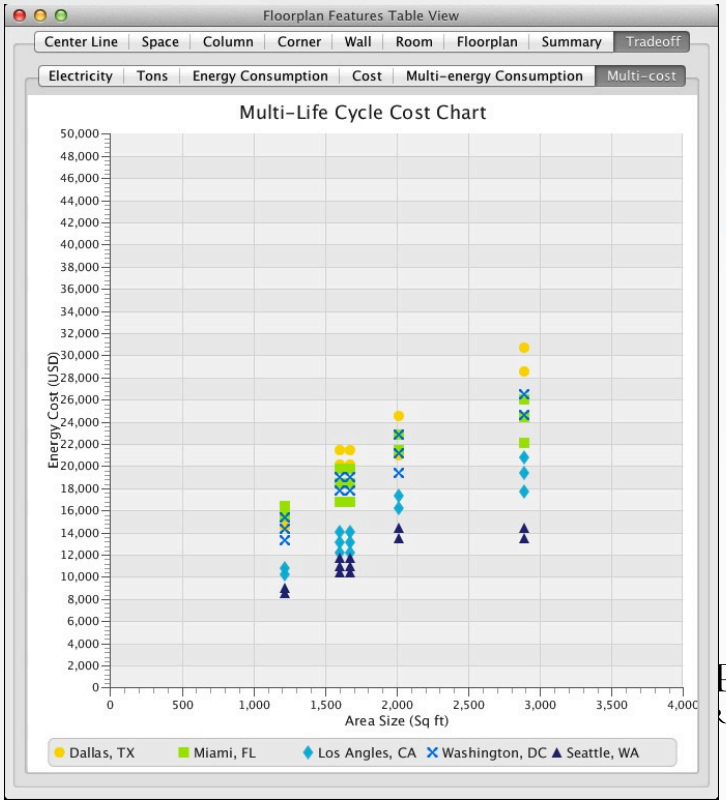




Sensitivity Analysis for Two Design Floorplan Models

	Original Floorplan	Redesign Floorplan	Increased %
Total Area (sq ft)	3450	4233	22.7%
Usable Area(sq ft)	2890	3617	25.2%





Sensitivity Analysis for Two Design Floorplan Models

	O	R	I%		O	R	I%
Seattle, WA				*Los Angles, CA*			
W EC	11037.2	18928.0	71.5%	**W EC**	7722.2	12417.5	60.8%
C EC	14513.1	18928.0	30.4%	**C EC**	9509.8	12417.5	30.6%
W LLC	13539.7	23933.1	76.8%	**W LLC**	17697.0	28484.2	61.0%
C LLC	18957.2	23933.1	26.2%	**C LLC**	22423.0	28484.2	27.0%
Washington, DC				*Miami, FL*			
W EC	14143.8	20882.8	47.6%	**W EC**	13131.9	22951.4	74.8%
C EC	17289.4	20882.8	30.6%	**C EC**	19207.9	22951.4	19.5%
W LLC	24638.9	37159.1	50.8%	**W LLC**	22117.9	38235.8	72.9%
C LLC	31129.6	37159.1	19.4%	**C LLC**	32272.3	38235.8	18.5%
Dallas, TX							
W EC	15704.6	24977.7	59.0%	**W LLC**	25995.3	41045.6	57.9%
C EC	21281.1	24977.7	17.4%	**C LLC**	34445.9	41045.6	19.2%

Conclusions

- Framework:
  - Computer-aided with MBSE procedures for building floorplans
  - 2D building fllorplans top-down parametric representation
  - Building code regulation verification
  - Simplified HVAC component selection trade-off
  - Architecture-energy sensitivity analysis
- Two-apartment building model case study
  - Frontend decisions for development can have a large impact on lifecycle costs

Future Work

- Extend current framework to simplified 3D models of buildings.
- Integrate discrete and continuous HVAC system behavior into the framework
- Automate parametric building geometry adjustments with algorithms for optimization-based design and tradeoff analysis

Questions

References

- [1]United Nation Sustainable Scale Project
- [2]Energy Efficiency in Buildings Summary – Business Realities and Opportunities, World Business Council for Sustainable Development
- [3]JTS Topology Suite by Vivid Solution, Inc.
- [4]Engineering Software Development in Java