

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



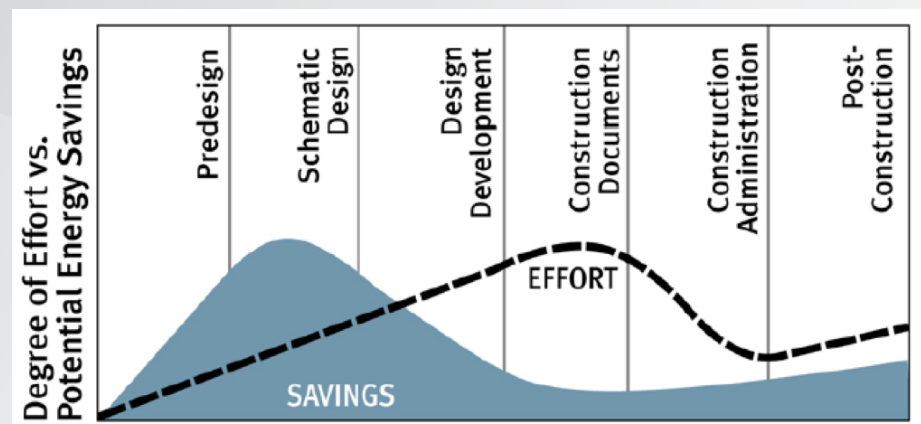
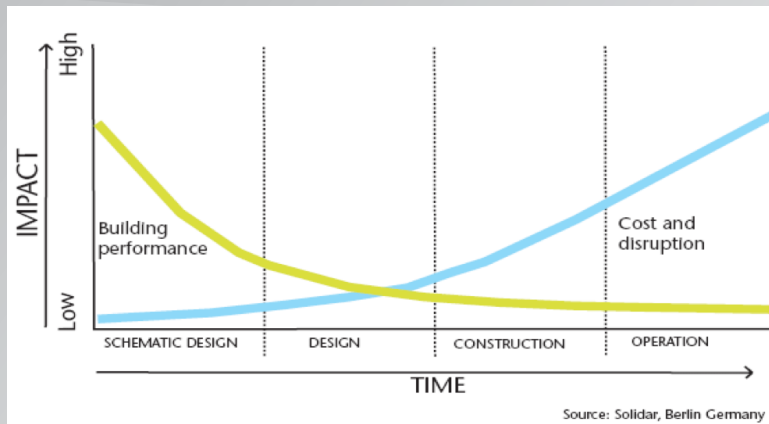
Introduction

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

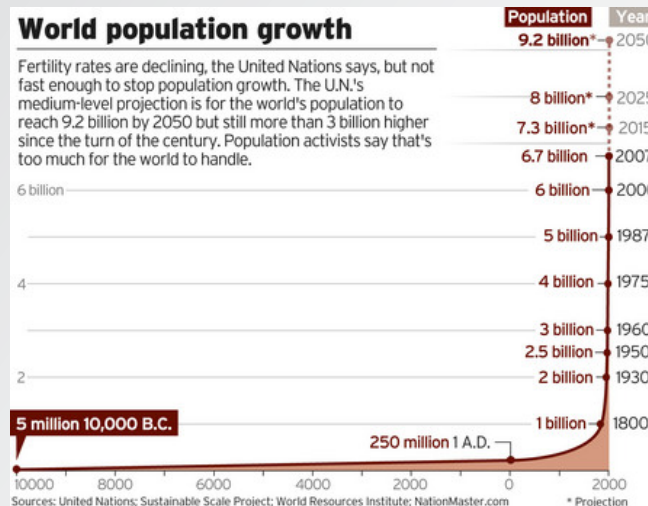


Problem statement

- Focus on frontend development



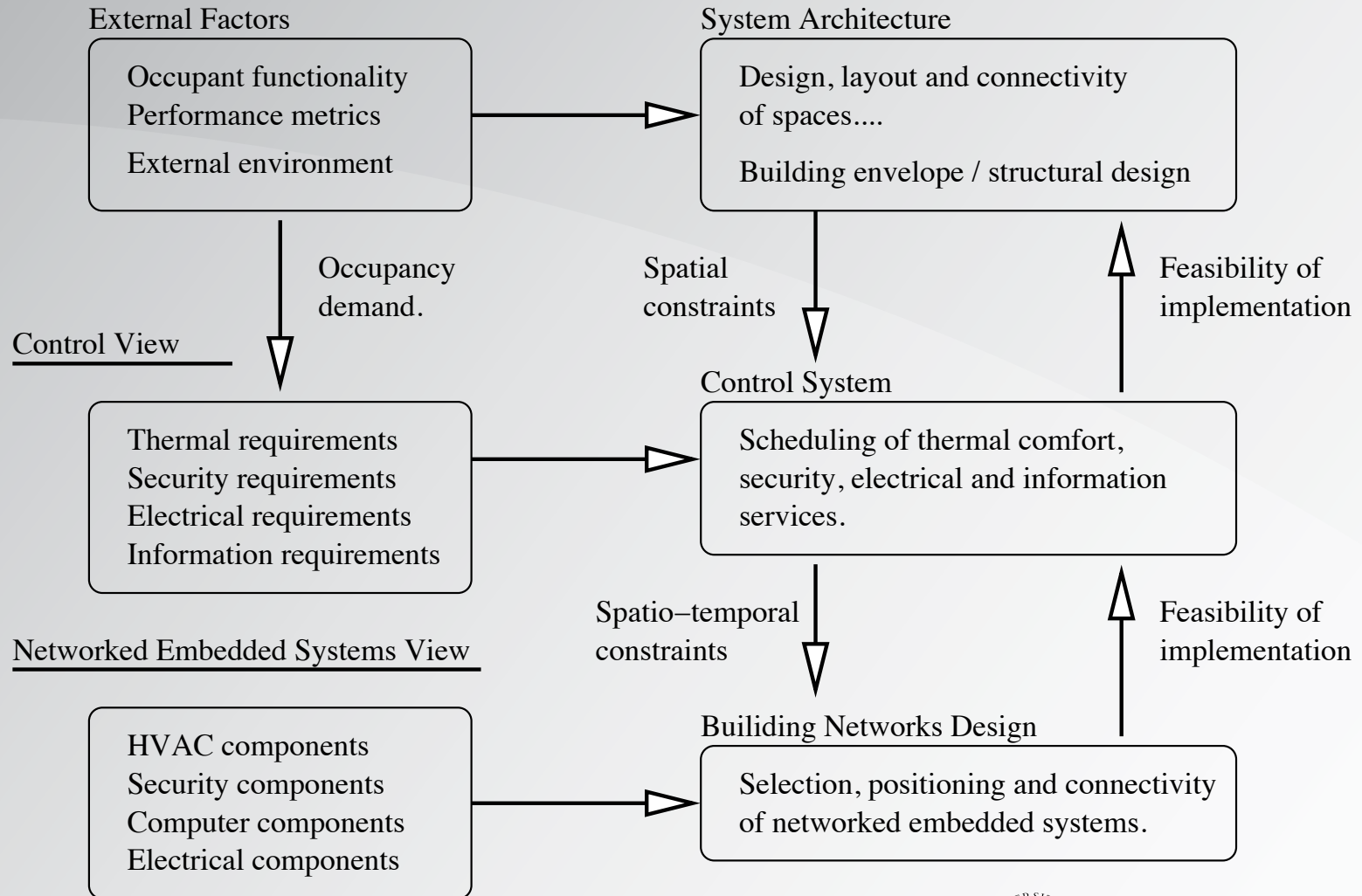
- Why buildings matter?



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Architectural Design of Buildings

Architecture / Structural View



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

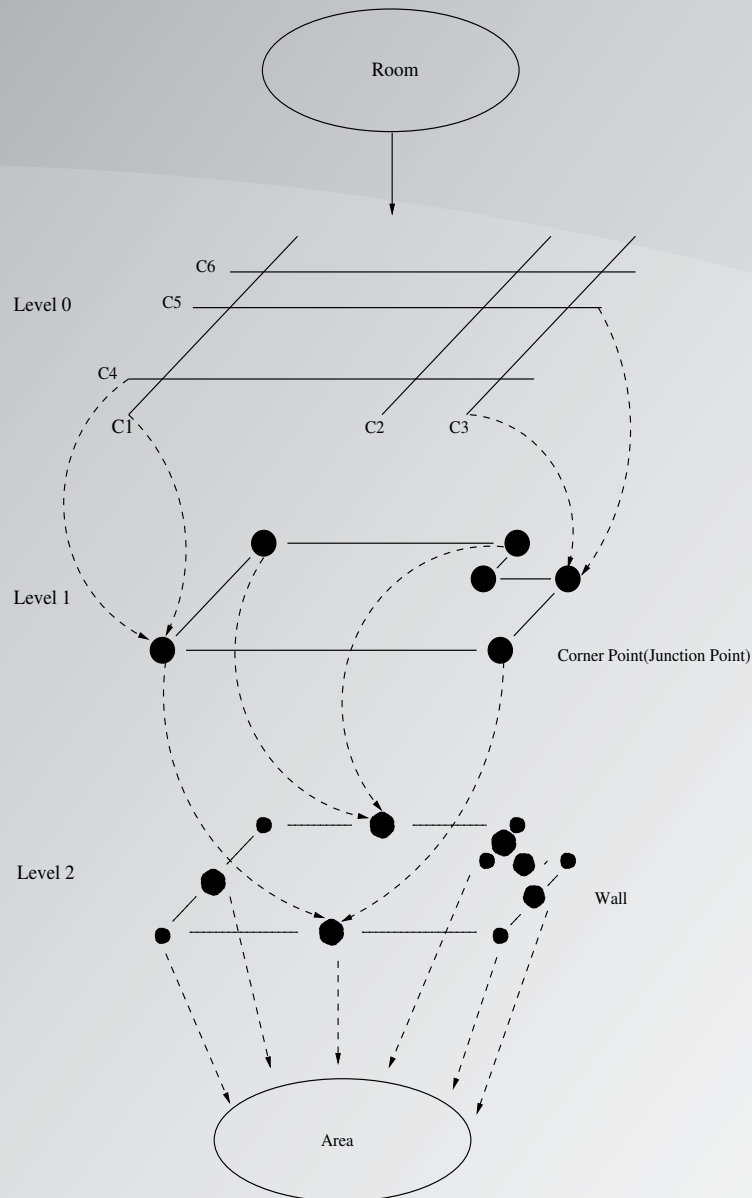
- Parametric Modeling of Floorplans
- Propagation of Dependency Relationships
- Area Computations with the Java Topology Suite
- Software Design Patterns
- Composite Hierarchy of Features



Parametric Modeling of Floorplans

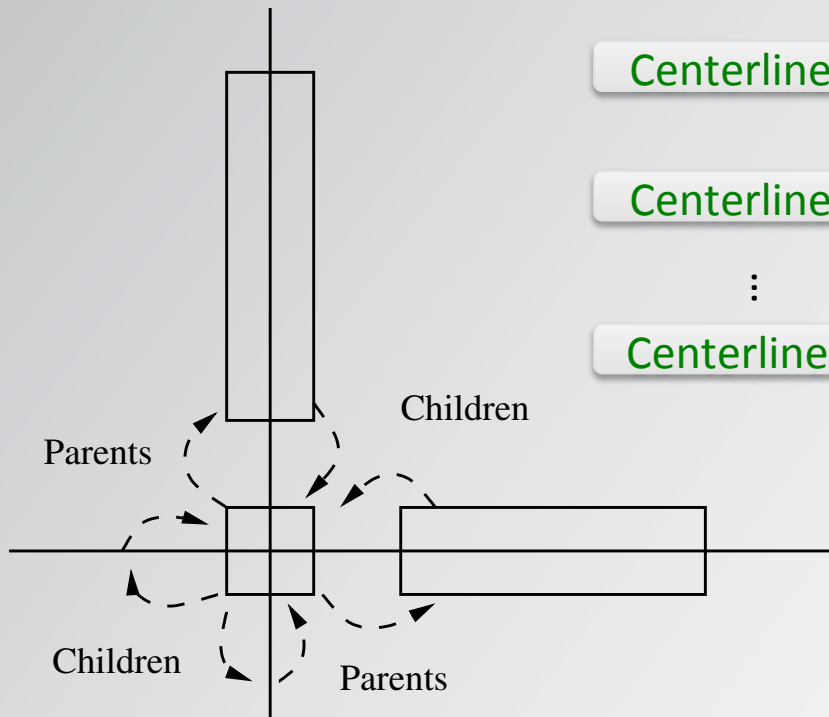
Multi-layer hierarchy

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



Propagation of Dependency Relationships

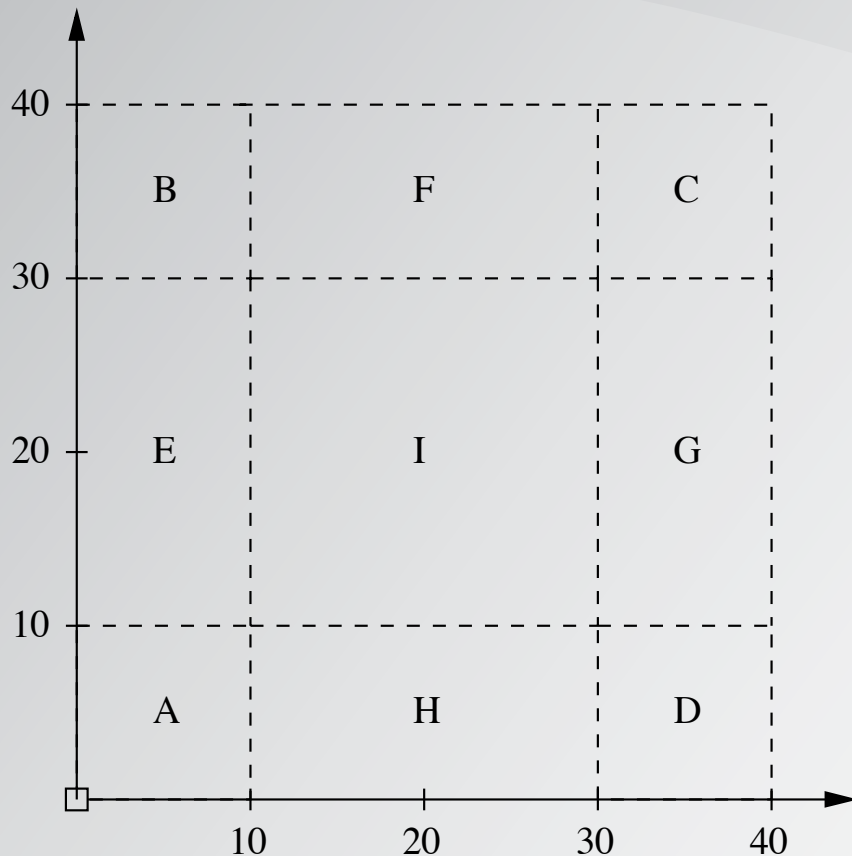
Many-to-many relationship



Multiple objects of type A associated with multiple objects of type B, and vice 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:

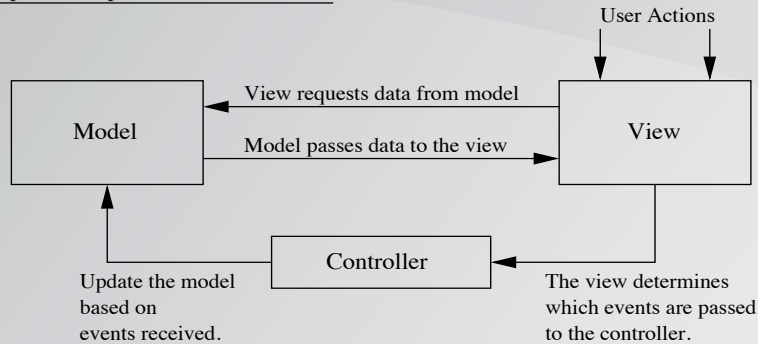
Behavior	Structure	System
Mediator	Composite	Model-View-Controller
Observer		
Visitor		



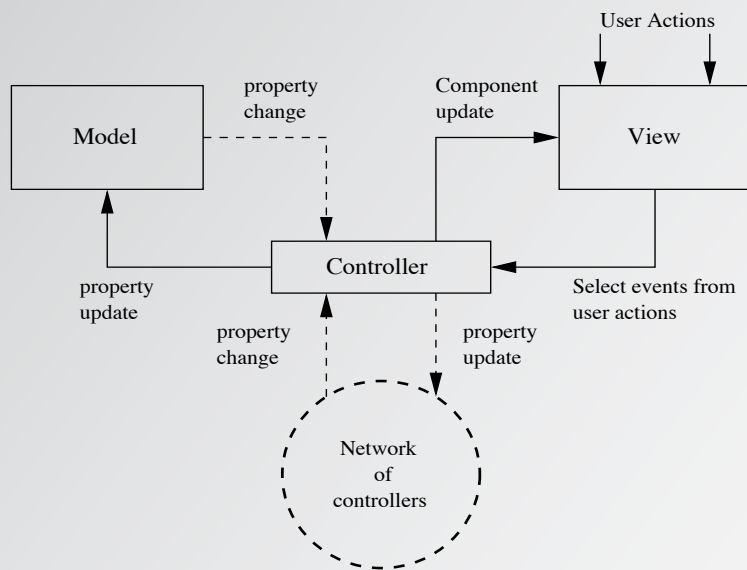
Software Design Patterns

■ Model-View Controller

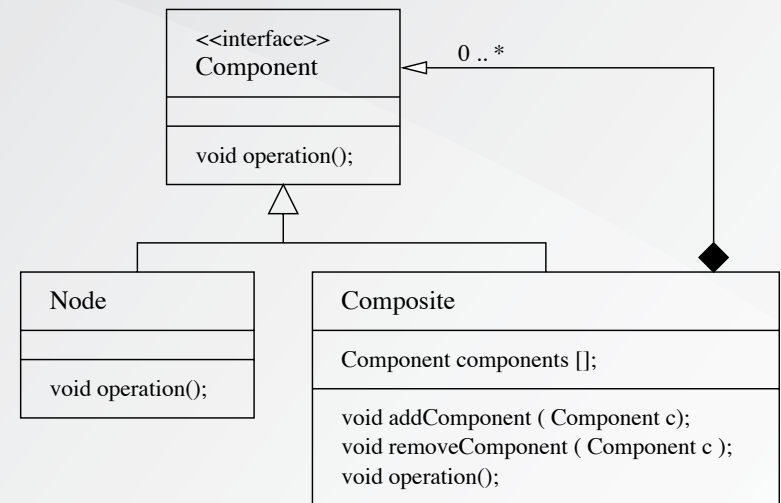
Simplified Implementation of MVC



Implementation of MVC with the Controller acting as a Mediator

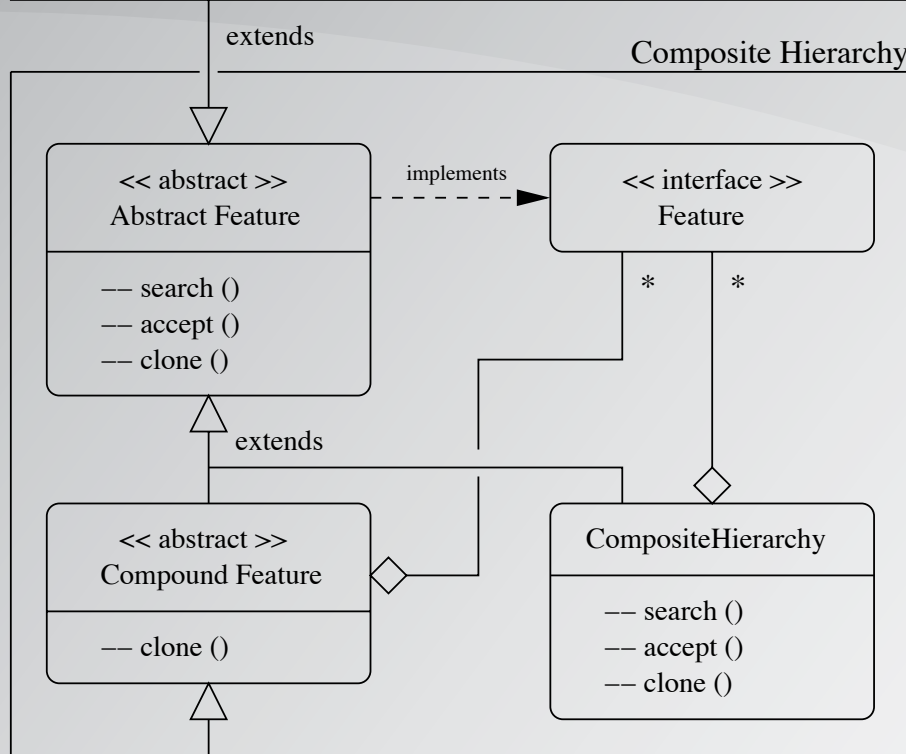
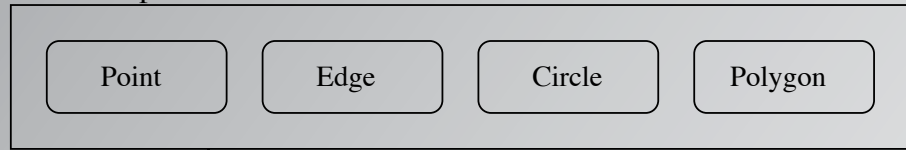


■ Composite

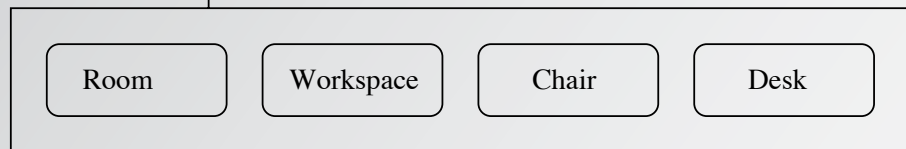


Composite Hierarchy of Features

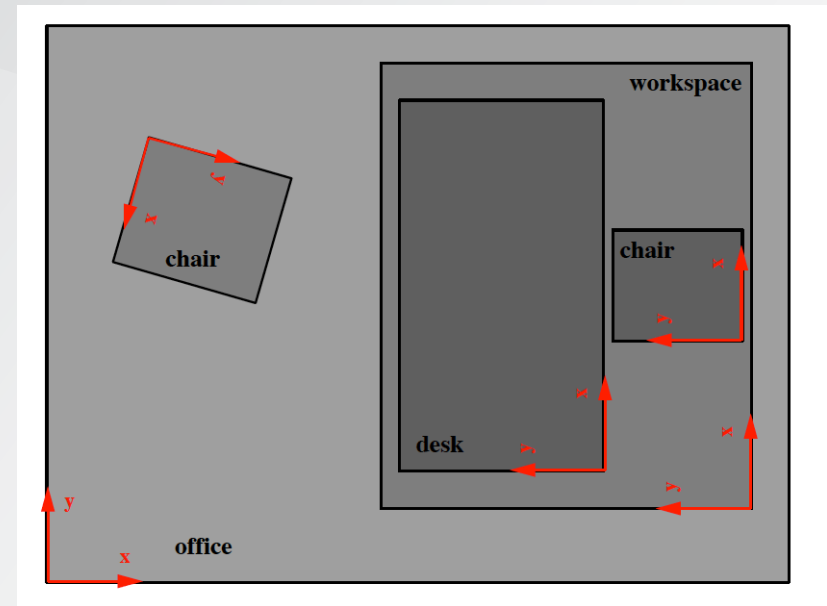
Basic Shapes



Models



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

Centerlines



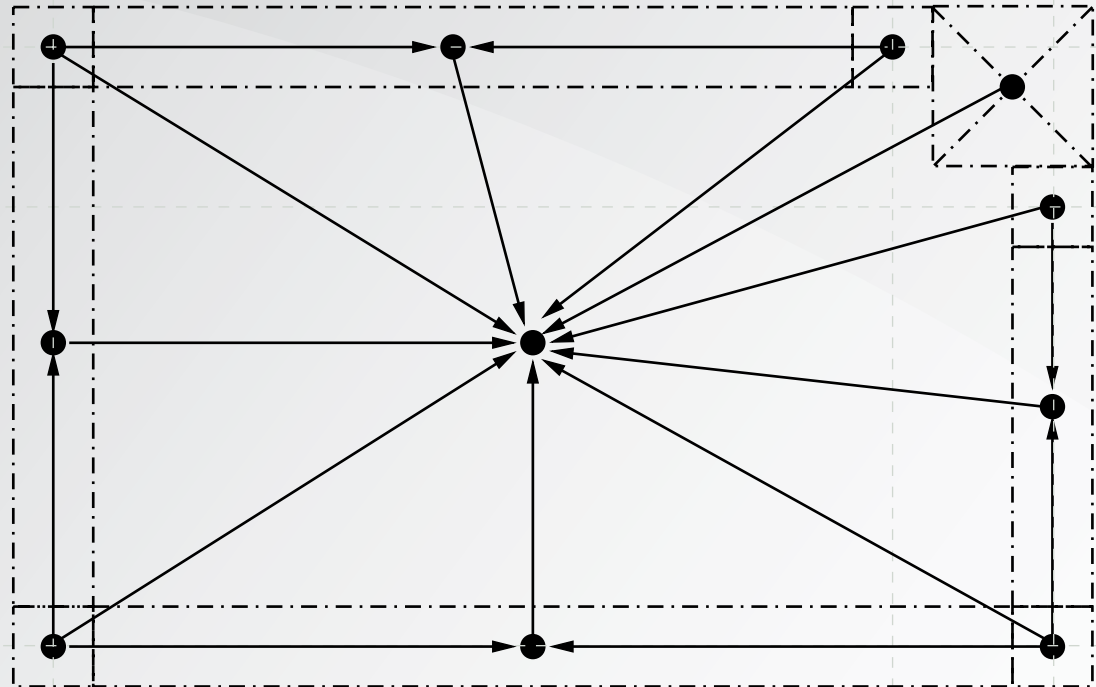
Corners



Walls

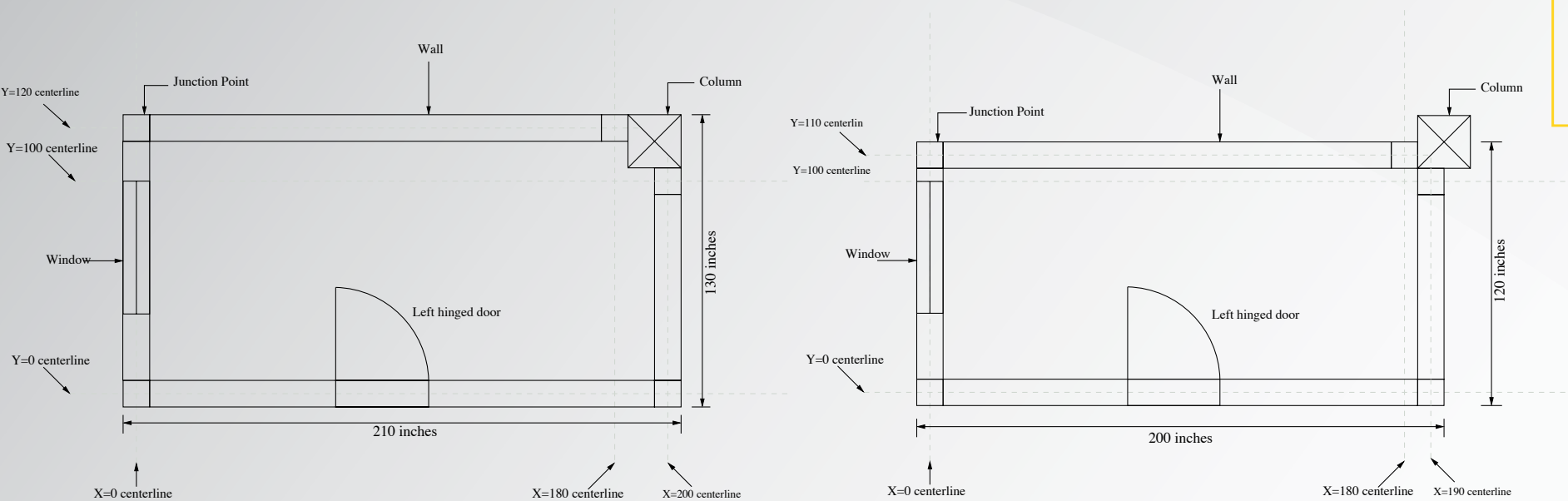


Area



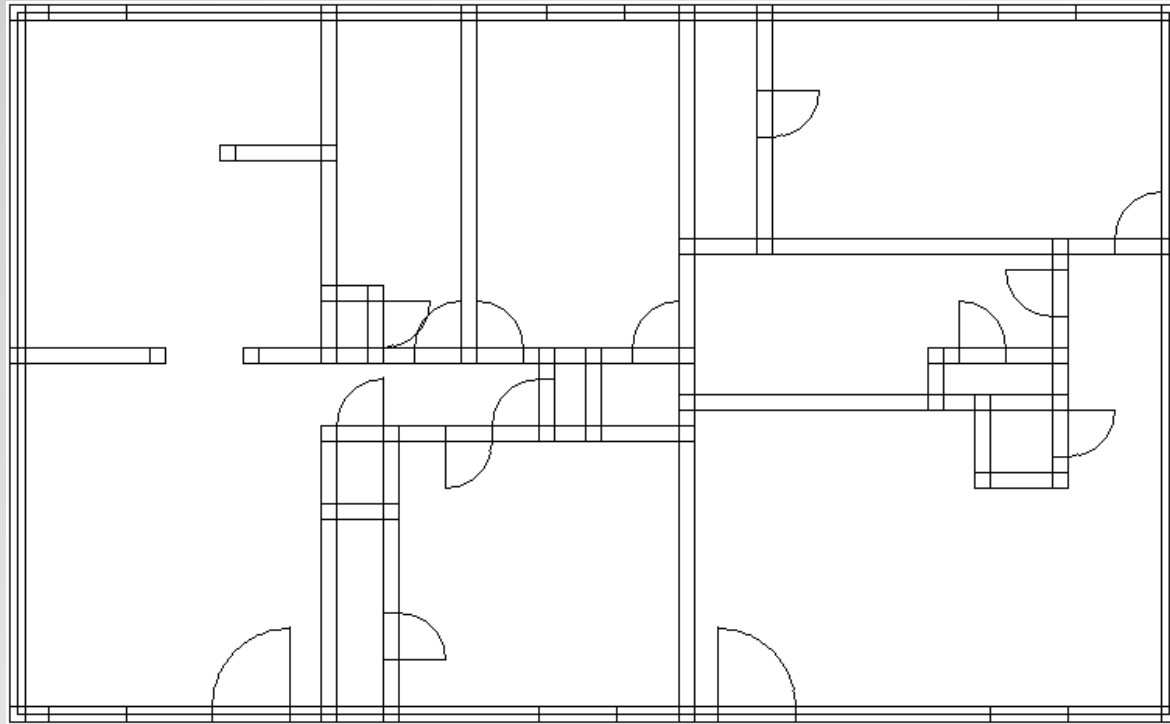
Simple Room Example

Simple Room Original & Redesign



Simple House Example

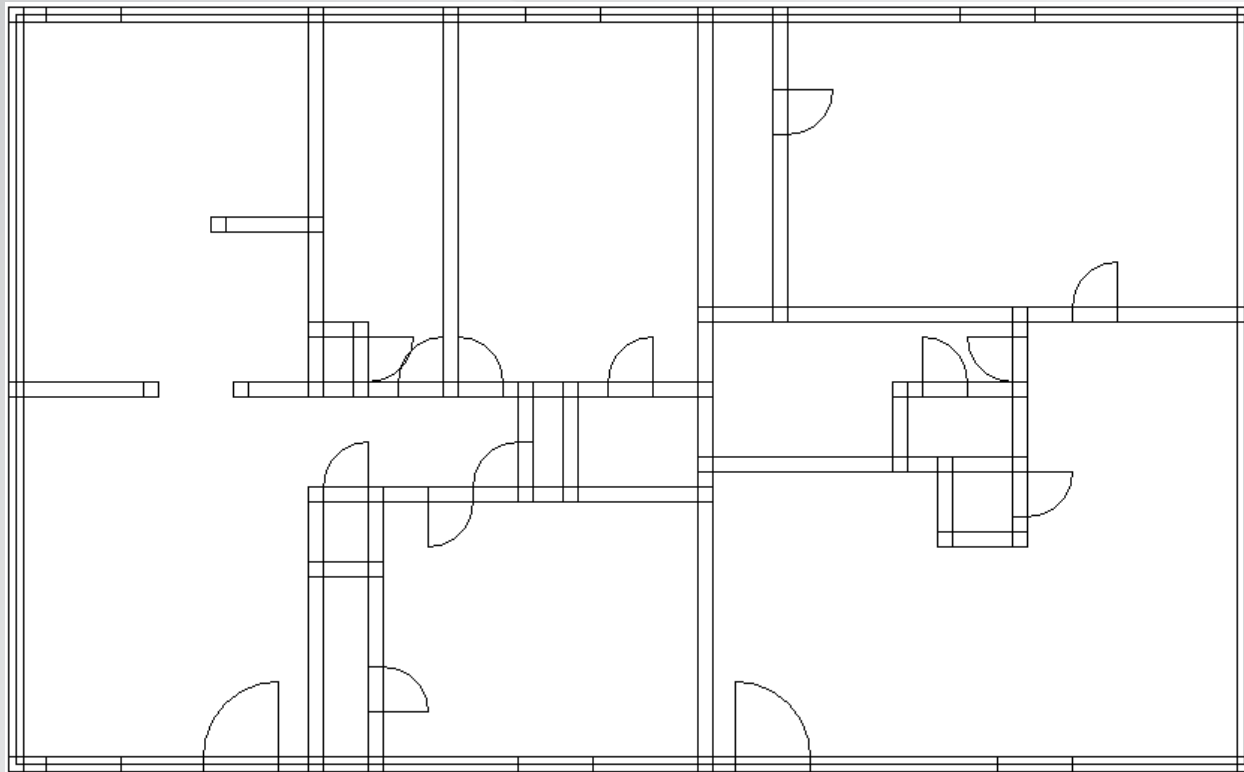
Original floorplan design



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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

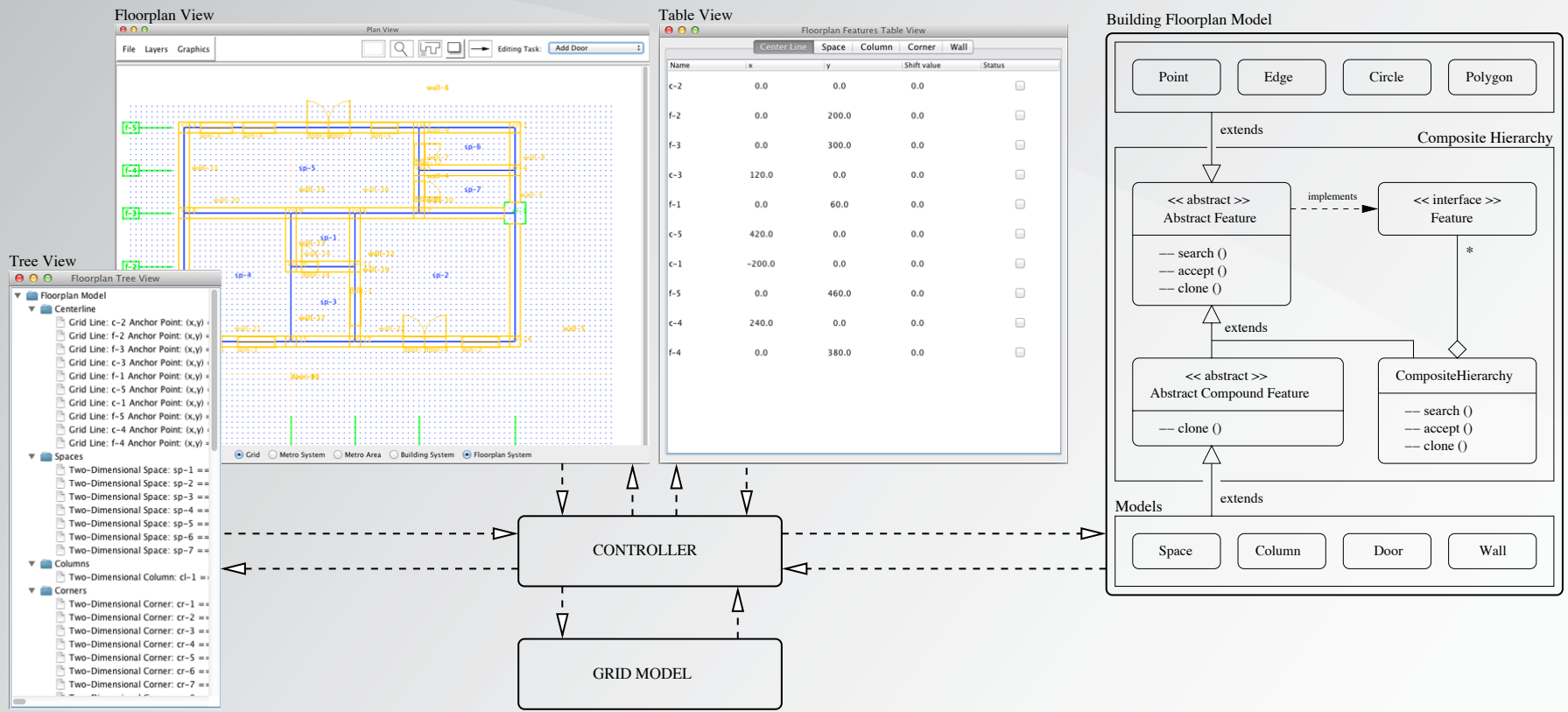


Approach 2: Interactive Graphical Specification of Floorplans

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

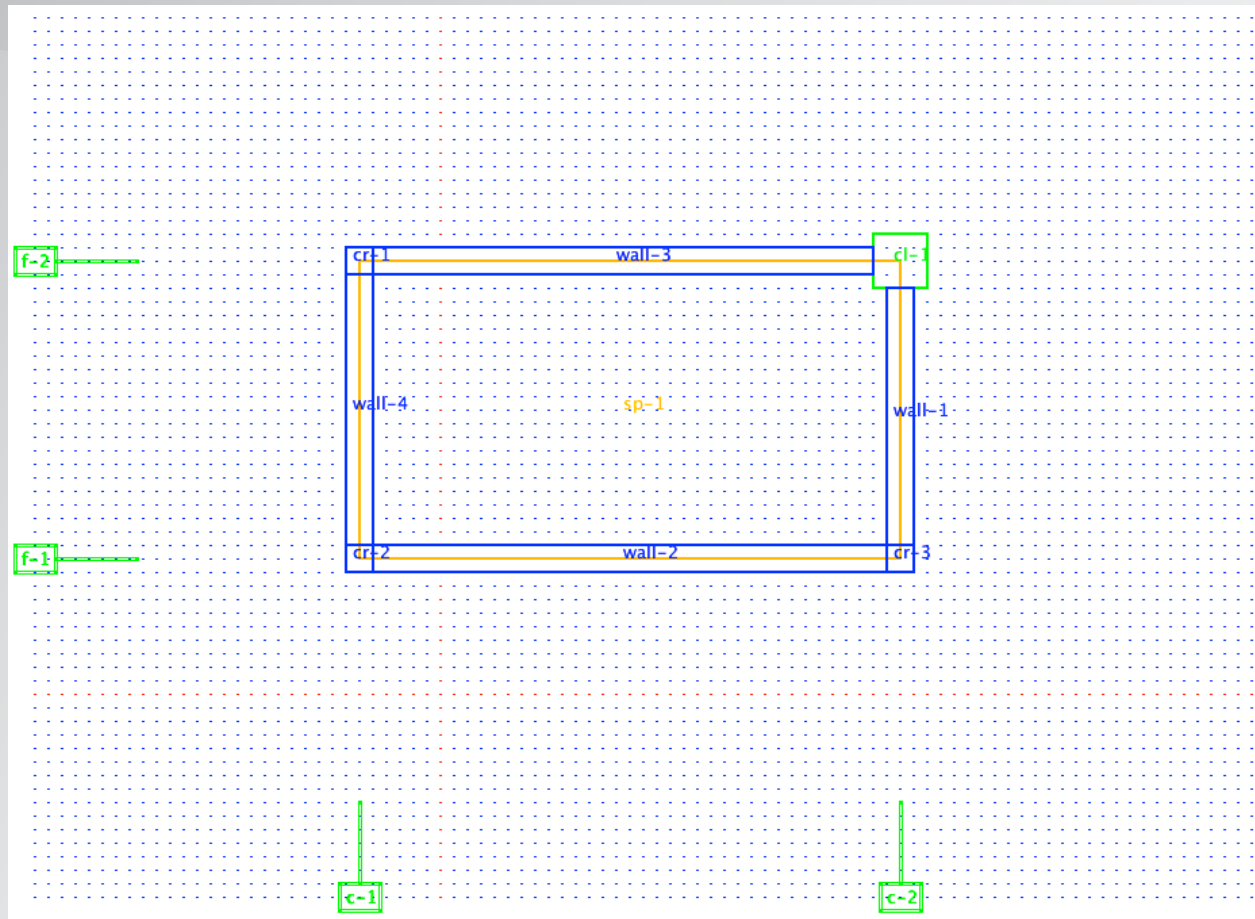


Graphical User Interface Design and Implementation



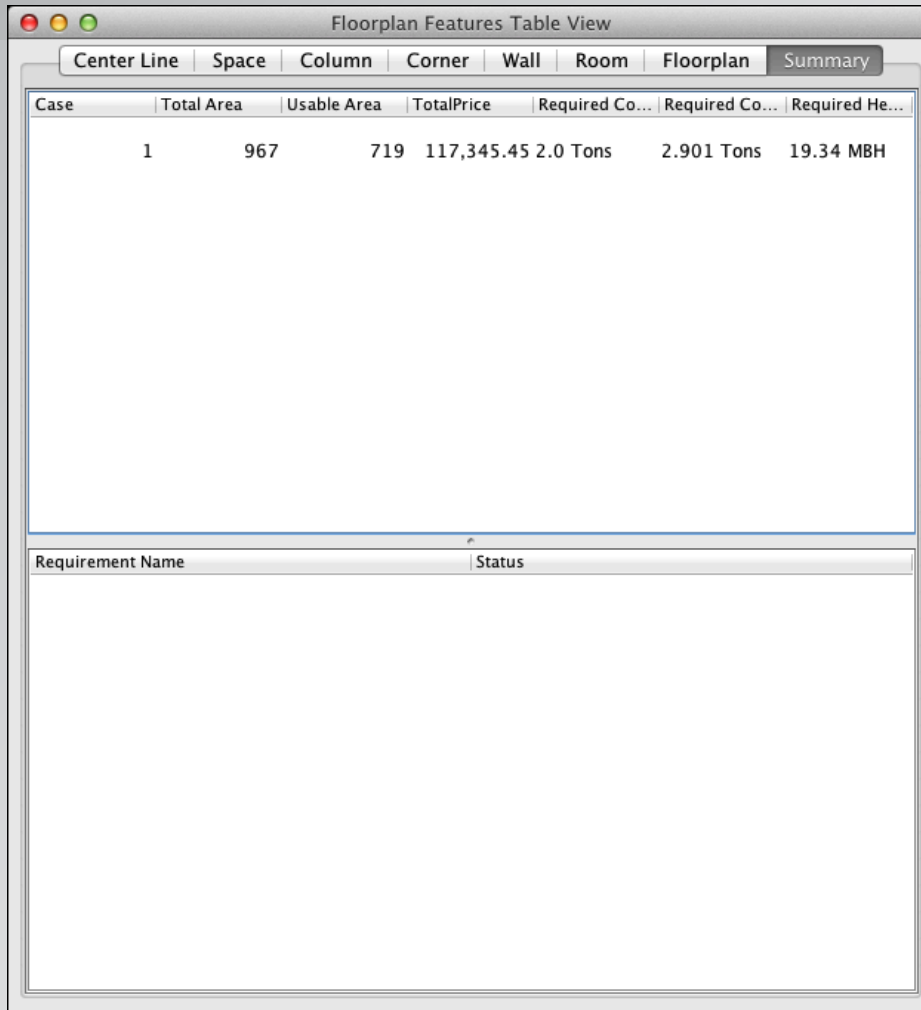
Simple Room Example

Editor view (Graphical)



Simple Room Example

Table view



Case	Total Area	Usable Area	TotalPrice	Required Co...	Required Co...	Required He...
1	967	719	117,345.45	2.0 Tons	2.901 Tons	19.34 MBH

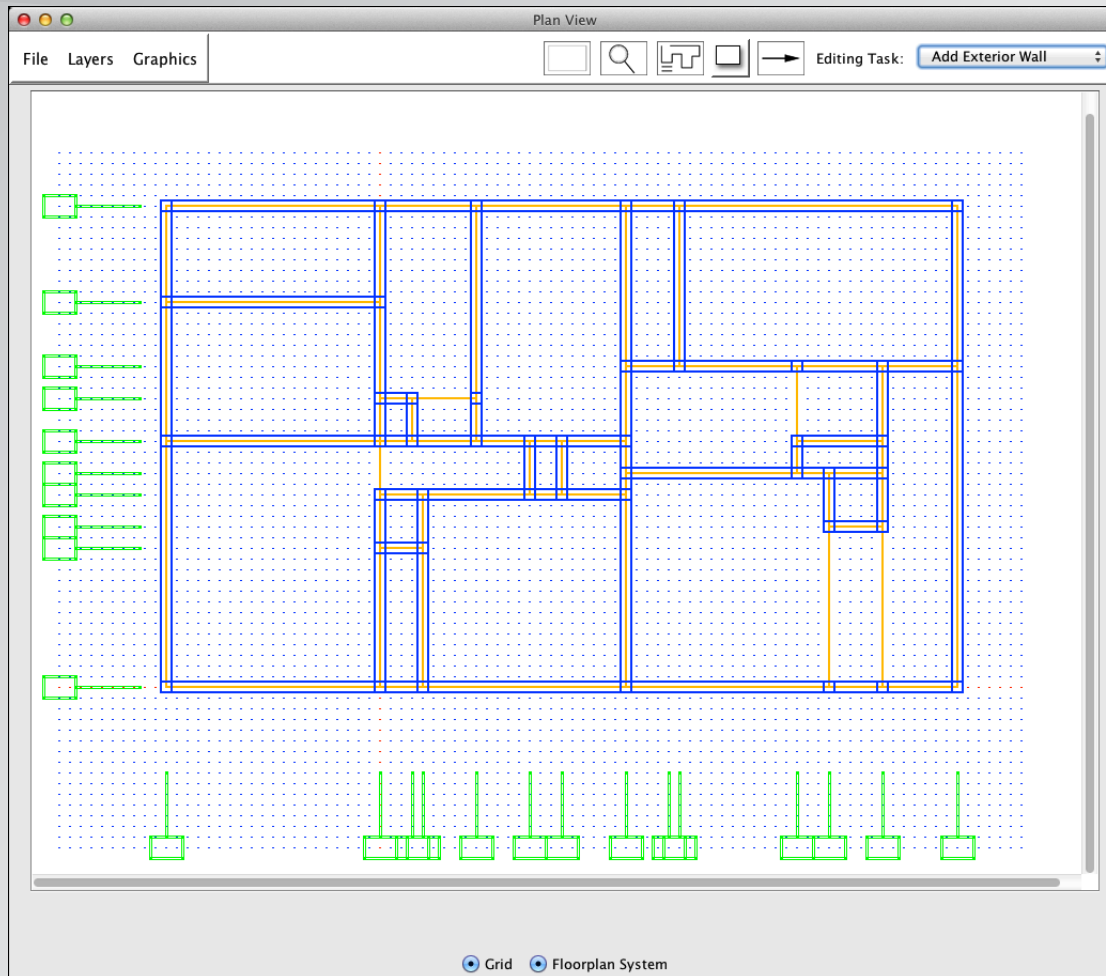
Requirement Name Status

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



Simple House Example

Editor view (Graphical)



Simple House Example

Table view

Floorplan Features Table View

Center Line | Space | Column | Corner | Wall | Room | Floorplan | Summary

Name	Location	Width	Height	Area	Status
sp-1	(0.0, 0.0)	1.3e+02	4.0e+01	5,200	<input type="checkbox"/>
sp-2	(40.0, 0.0)	1.8e+02	1.9e+02	34,200	<input type="checkbox"/>
sp-3	(0.0, 130.0)	5.0e+01	4.0e+01	2,000	<input type="checkbox"/>
sp-4	(0.0, 180.0)	5.0e+01	1.4e+02	7,000	<input type="checkbox"/>
sp-5	(-200.0, 0.0)	2.3e+02	2.0e+02	46,000	<input type="checkbox"/>
sp-6	(140.0, 180.0)	5.0e+01	3.0e+01	1,500	<input type="checkbox"/>
sp-7	(170.0, 180.0)	5.0e+01	6.0e+01	3,000	<input type="checkbox"/>
sp-8	(-200.0, 230.0)	1.3e+02	2.0e+02	26,000	<input type="checkbox"/>
sp-9	(-200.0, 360.0)	9.0e+01	2.0e+02	18,000	<input type="checkbox"/>
sp-10	(0.0, 230.0)	4.0e+01	3.0e+01	1,200	<input type="checkbox"/>

****Select sapce/spaces to define room****

Name of the room :

Role of the room:

Define Room



Assessment of MVC Approach

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

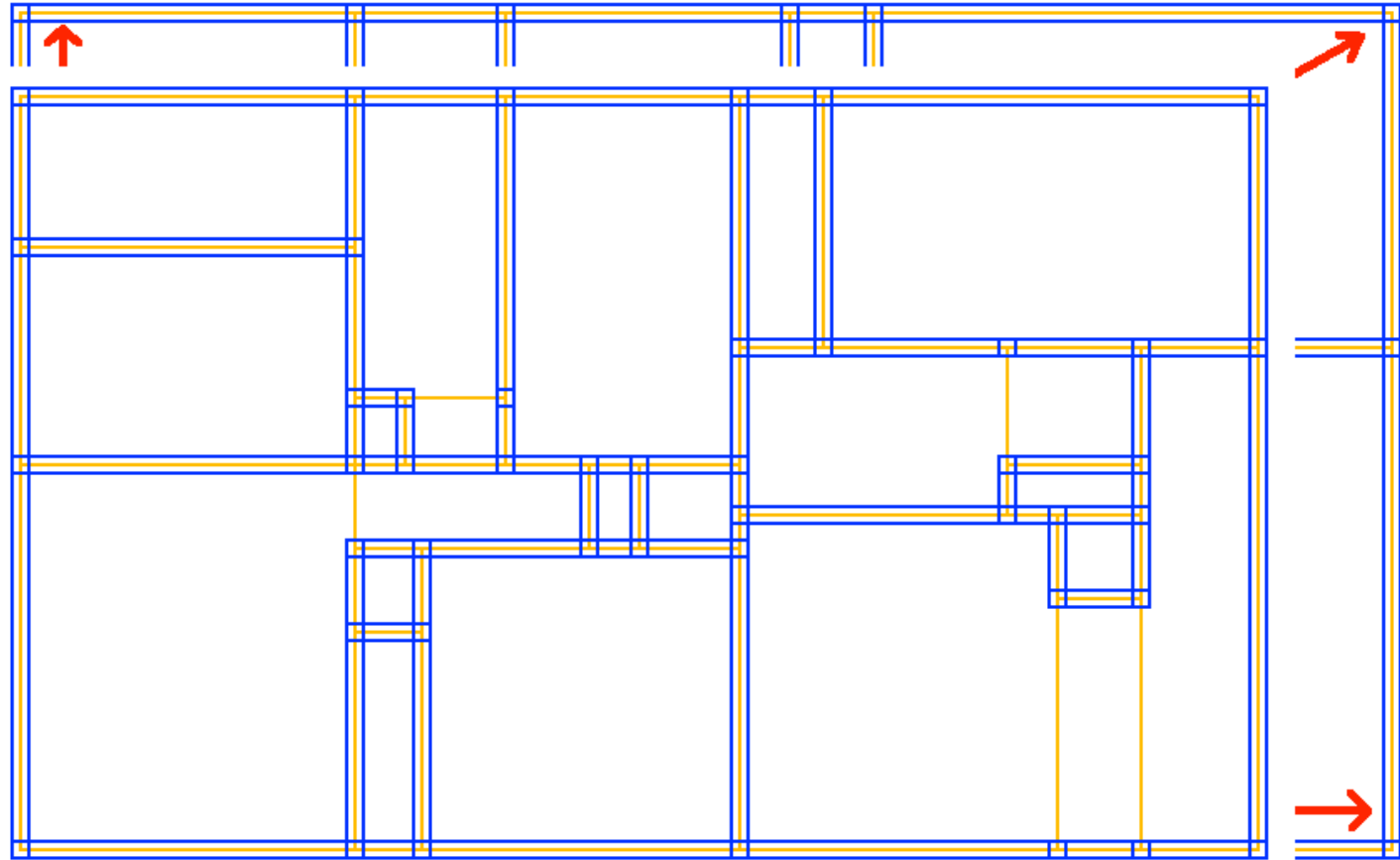


Building Floorplan Case Studies

- 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

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

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

$$U / ER = SummerUsage_{city} / SEER + WinterUsage_{city} / HSPF$$



Case Studies Objectives and Scope

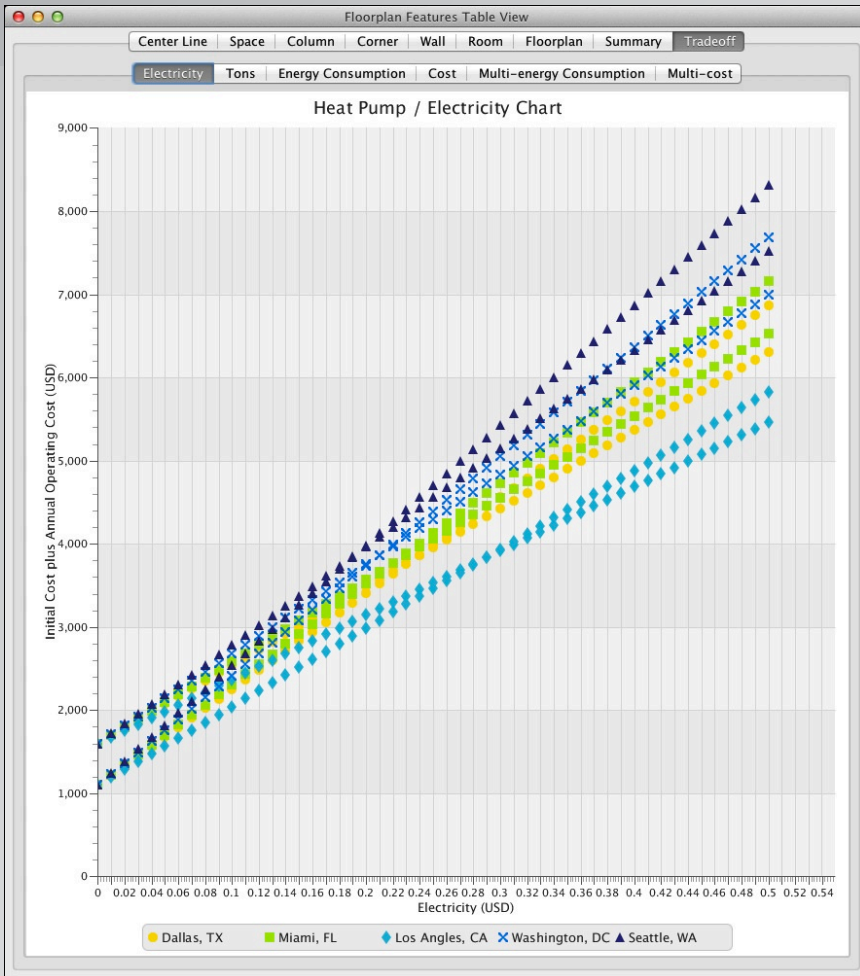
- City selection and basic information

City	Cooling Usage(hr)	Heating Usage(hr)	Electricity Cost
Seattle, WA	282	2956	\$0.0877
Los Angeles, 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 Angeles	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



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Building/HVAC System Assessment and Tradeoff

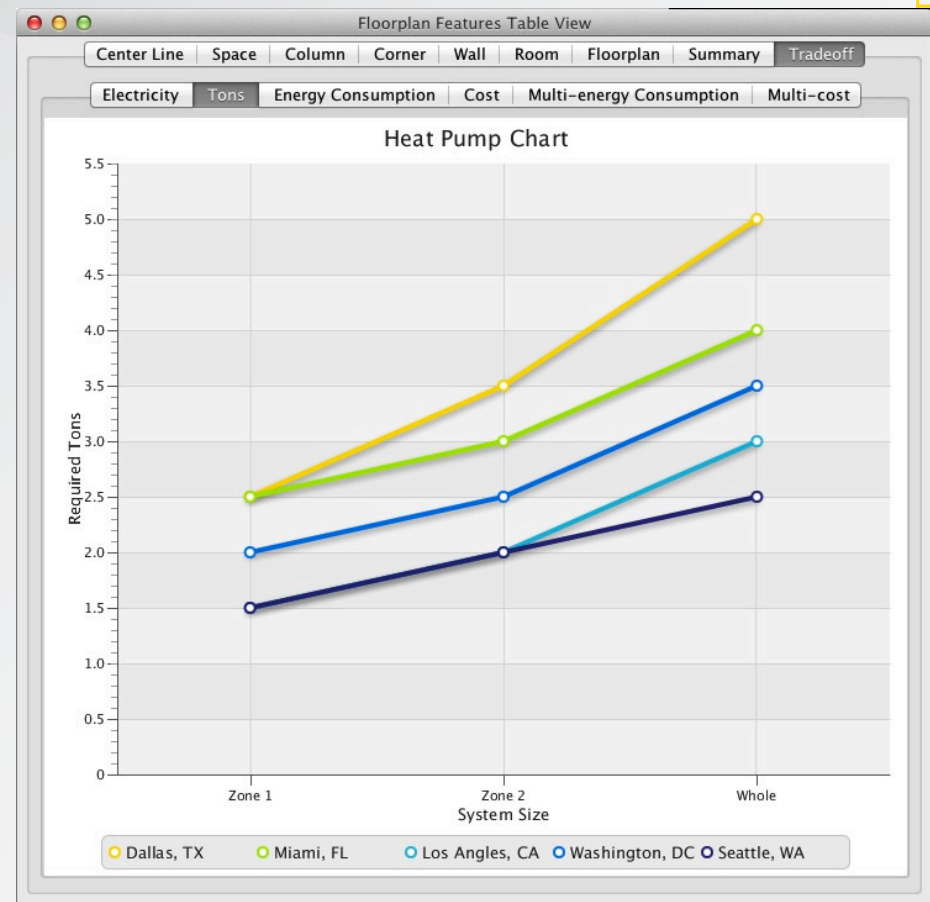
Original floorplan system

Floorplan Features Table View

Center Line	Space	Column	Corner	Wall	Room	Floorplan	Summary	Tradeoff
Case/City	Total Area	Usable Area	Total Price	Required C...	Zone 1 Area	Zone 2 Area	Zone 1 Cool...	Zone 2 Co...
1/Seattle, ...	3450.0	2890.0	450570.0	2.5 Tons	1219.0	1671.0	1.5 Tons	2.0 Tons
1/Los Angl...	3450.0	2890.0	450570.0	3.0 Tons	1219.0	1671.0	1.5 Tons	2.0 Tons
1/Washing...	3450.0	2890.0	450570.0	3.5 Tons	1219.0	1671.0	2.0 Tons	2.5 Tons
1/Miami, FL	3450.0	2890.0	450570.0	4.0 Tons	1219.0	1671.0	2.5 Tons	3.0 Tons
1/Dallas, TX	3450.0	2890.0	450570.0	5.0 Tons	1219.0	1671.0	2.5 Tons	3.5 Tons

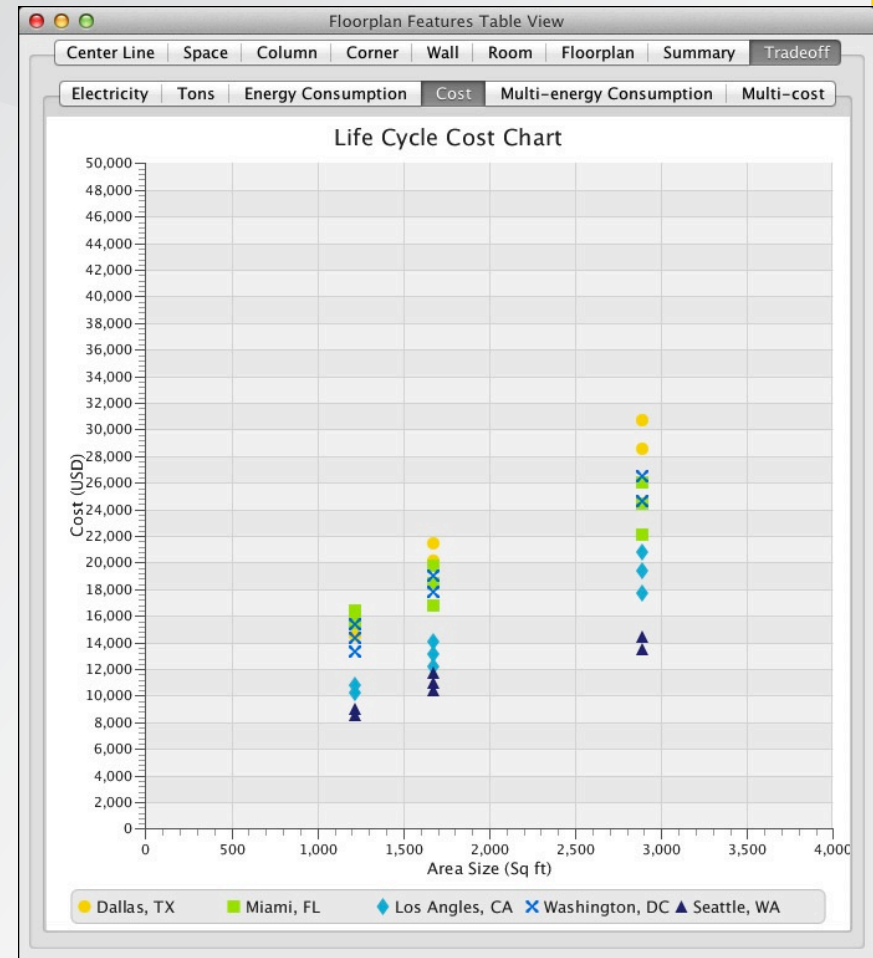
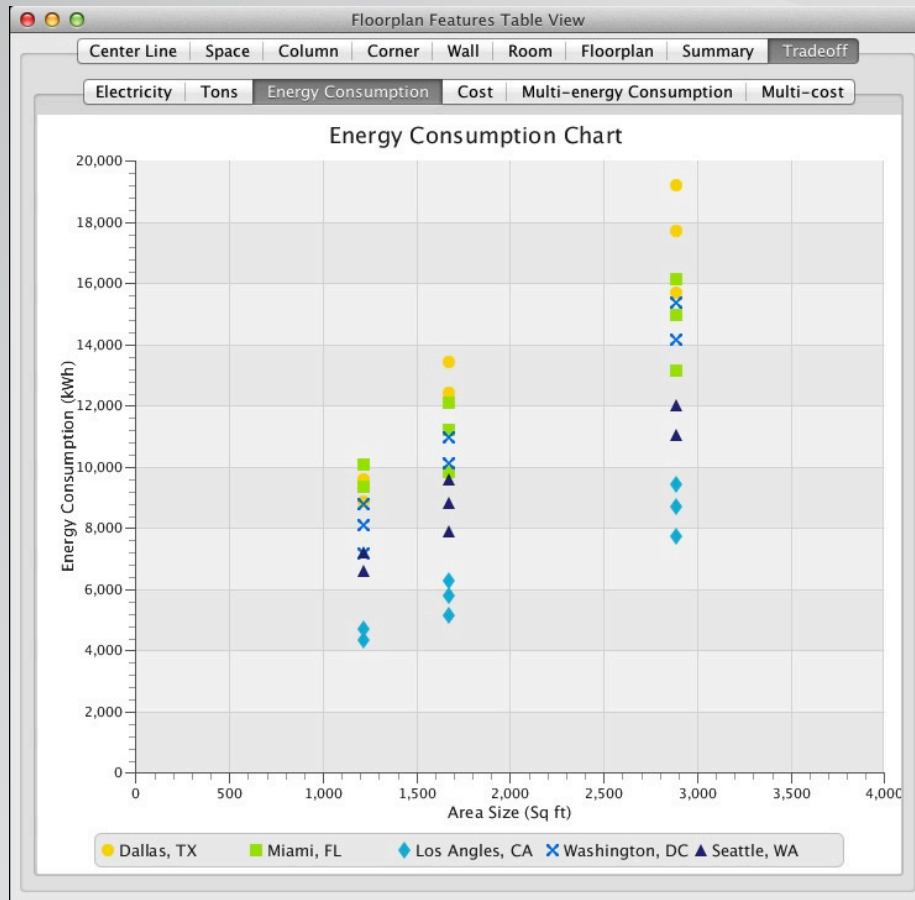
Requirement Name	Status
MC Section 503 Max Unit Area	<input checked="" type="checkbox"/>
BC Section 1208.1 Kitchen Width	<input checked="" type="checkbox"/>
BC Section 1208.4 Living Room Area	<input checked="" type="checkbox"/>
BC Section 1208.1 Room Width	<input checked="" type="checkbox"/>
BC Section 1208.3 Min Unit Area	<input checked="" type="checkbox"/>
MC Section 404.5 Bedroom	<input checked="" type="checkbox"/>
MC Section 404.5 Kitchen	<input checked="" type="checkbox"/>
MC Section 404.5 Living Room	<input checked="" type="checkbox"/>

Case 1
Case 2
Case 3
Case 4
Case 5
Case 6
Case 7
Case 8
Case 9
Case 10



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 Angeles, 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

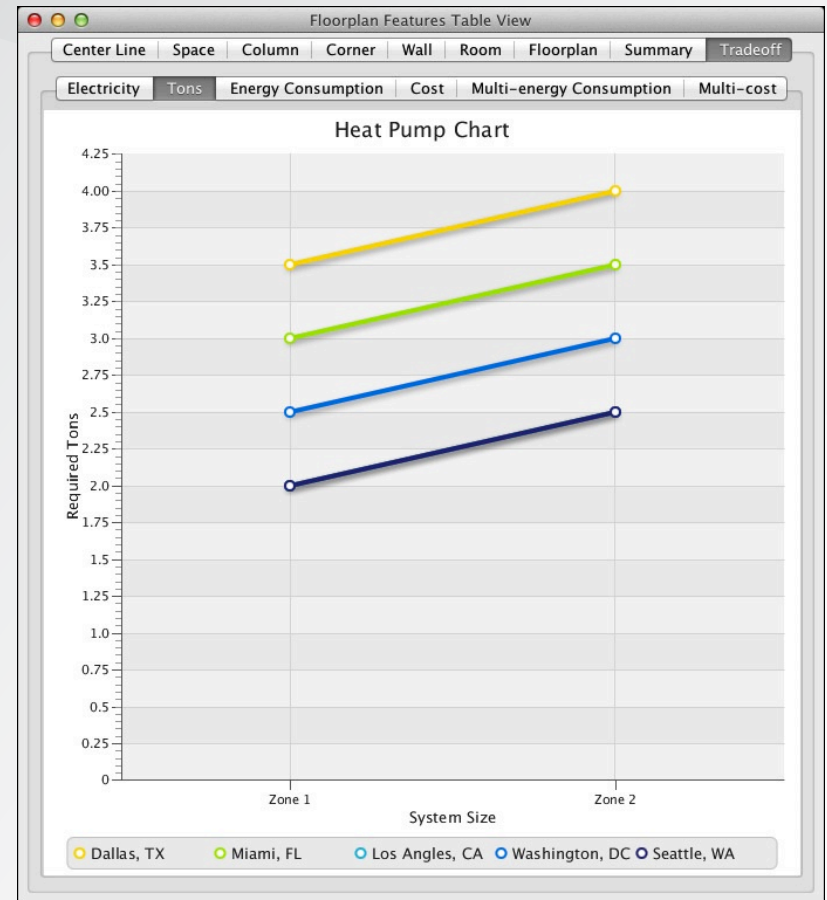
Redesigned floorplan system

Floorplan Features Table View

Center Line	Space	Column	Corner	Wall	Room	Floorplan	Summary	Tradeoff
Case/City	Total Area	Usable Area	Total Price	Required ...	Zone 1 Area	Zone 2 Area	Zone 1 Co...	Zone 2 Co...
6/Dallas, ...	4233.0	3617.0	552829....	0.0 Tons	1607.0	2010.0	3.5 Tons	4.0 Tons
7/Seattle,...	4233.0	3617.0	552829....	0.0 Tons	1605.0	2012.0	2.0 Tons	2.5 Tons
7/Los An...	4233.0	3617.0	552829....	0.0 Tons	1605.0	2012.0	2.0 Tons	2.5 Tons
7/Washin...	4233.0	3617.0	552829....	0.0 Tons	1605.0	2012.0	2.5 Tons	3.0 Tons
7/Miami, FL	4233.0	3617.0	552829....	0.0 Tons	1605.0	2012.0	3.0 Tons	3.5 Tons
7/Dallas, ...	4233.0	3617.0	552829....	0.0 Tons	1605.0	2012.0	3.5 Tons	4.0 Tons

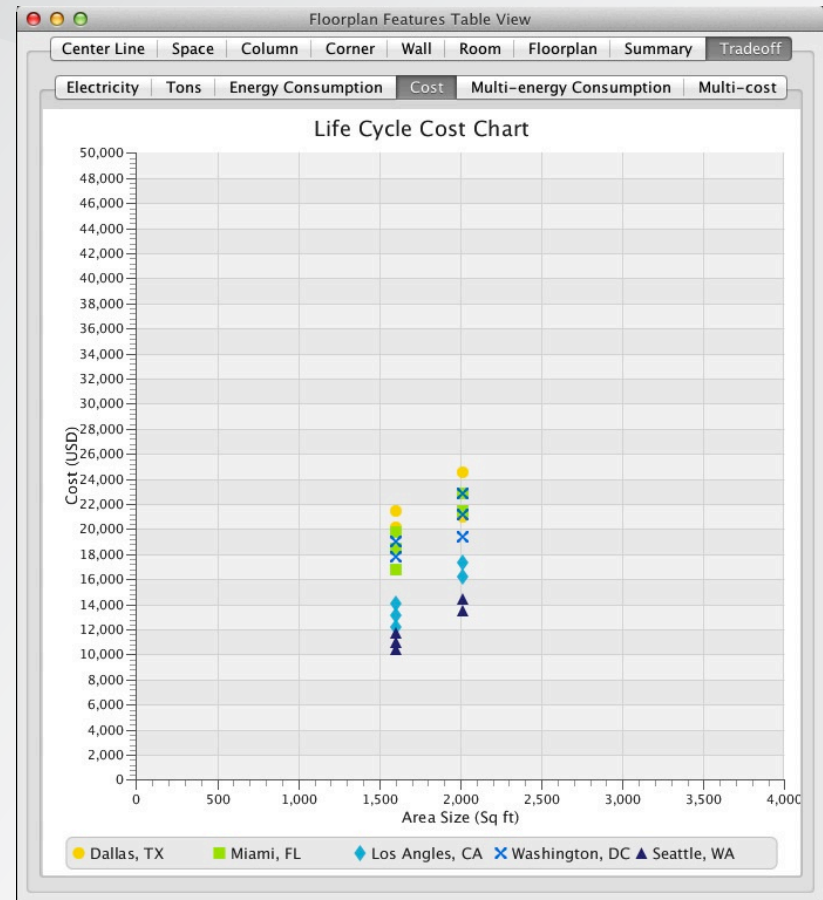
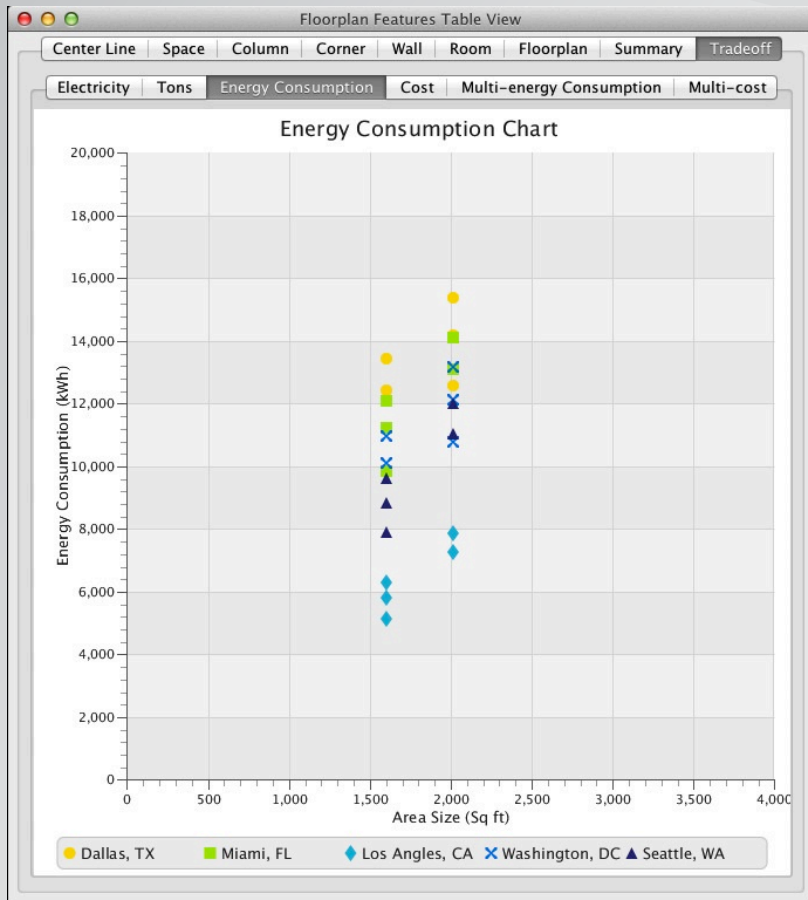
Requirement Name	Status
MC Section 503 Max Unit Area	<input checked="" type="checkbox"/>
BC Section 1208.1 Kitchen Width	<input checked="" type="checkbox"/>
BC Section 1208.4 Living Room Area	<input checked="" type="checkbox"/>
BC Section 1208.1 Room Width	<input checked="" type="checkbox"/>
BC Section 1208.3 Min Unit Area	<input checked="" type="checkbox"/>
MC Section 404.5 Bedroom	<input checked="" type="checkbox"/>
MC Section 404.5 Kitchen	<input checked="" type="checkbox"/>
MC Section 404.5 Living Room	<input checked="" type="checkbox"/>

Case 1
Case 2
Case 3
Case 4
Case 5
Case 6
Case 7
Case 8
Case 9
Case 10



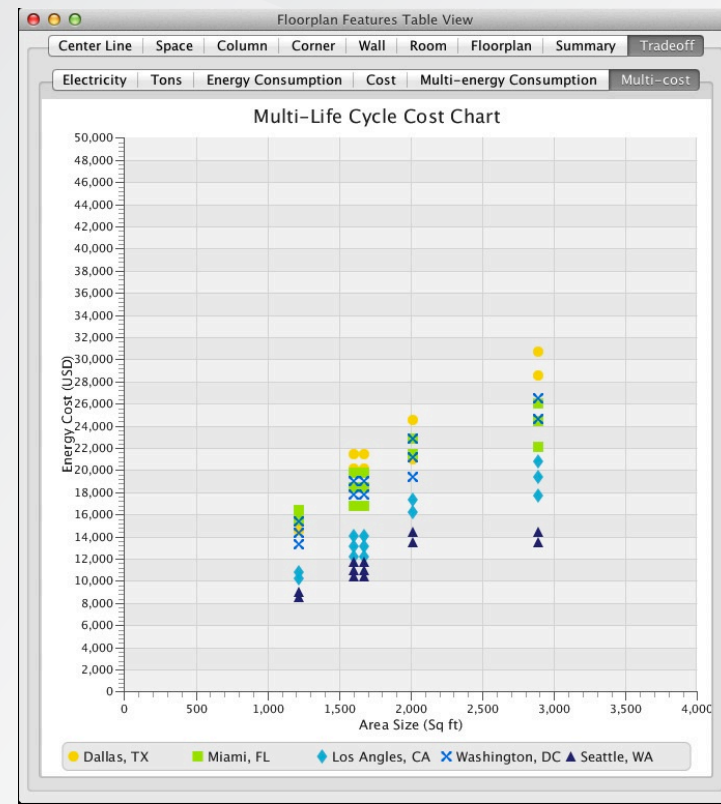
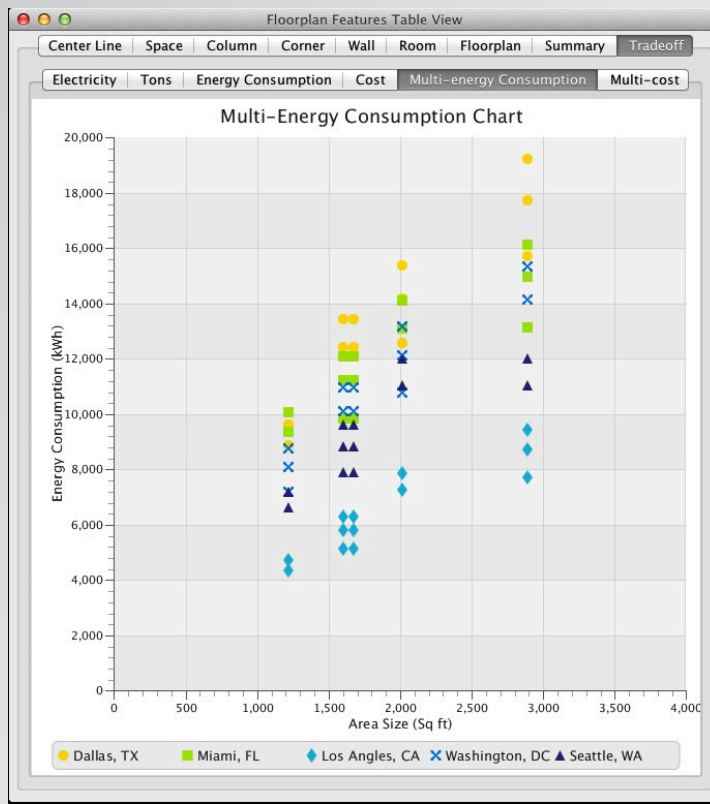
Building/HVAC System Assessment and Tradeoff

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%
<i>Seattle, WA</i>				<i>Los Angeles, CA</i>			
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%
<i>Washington, DC</i>				<i>Miami, FL</i>			
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%
<i>Dallas, TX</i>							
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 floorplans 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



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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

