Computer-Generated Residential Building Layouts

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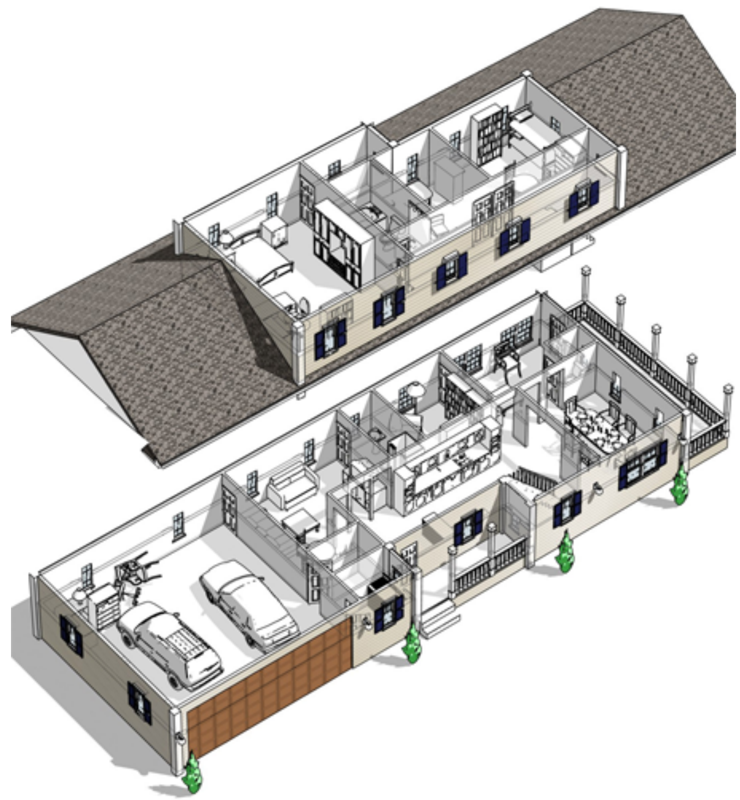
Modeling Buildings with Interiors

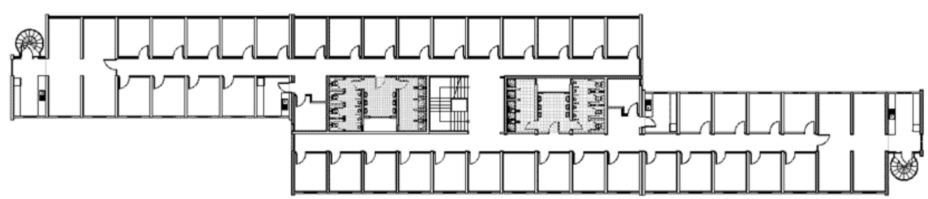
- Goal: Model the internal structure of buildings
- Crucial in many interactive applications
  - Buildings that can be entered and explored
- Commonly created by hand



Residential Buildings

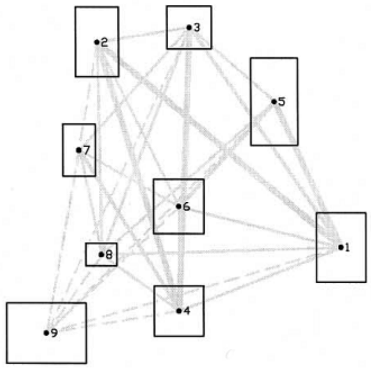
- Focus on residential buildings
  - Common in games, virtual worlds
  - Have complex structure

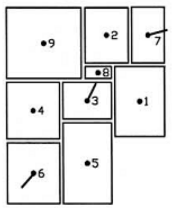
- Office buildings and schools
  - Highly regular layouts



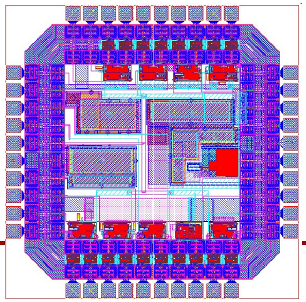
Related Work

- Automated Spatial Allocation
  - March and Steadman, 1971
  - Shaviv, 1987
- Physically Based Modeling
  - Arvin and House, 2002
  - Mass-spring system
  - Sensitive to initial conditions



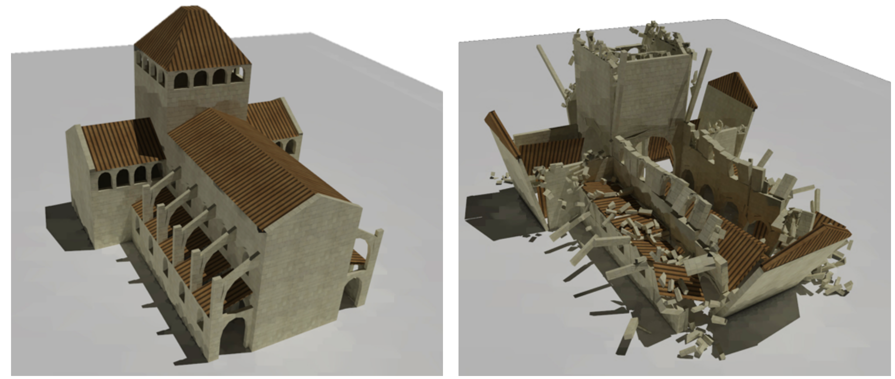


- VLSI Layout
  - Sarrafzadeh and Lee, 1993

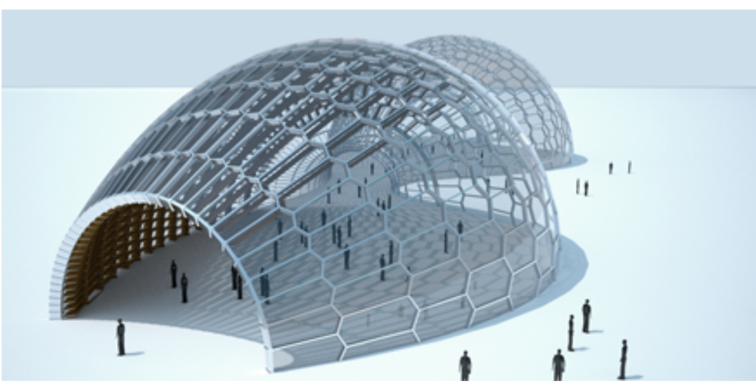


Computer Graphics Research

Müller et al., 2006

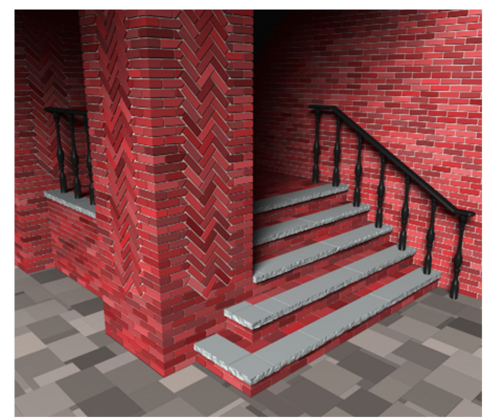


Whiting et al., 2009



Pottmann et al., 2007

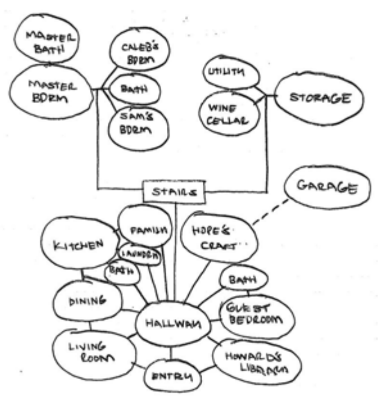
Legakis et al., 2006



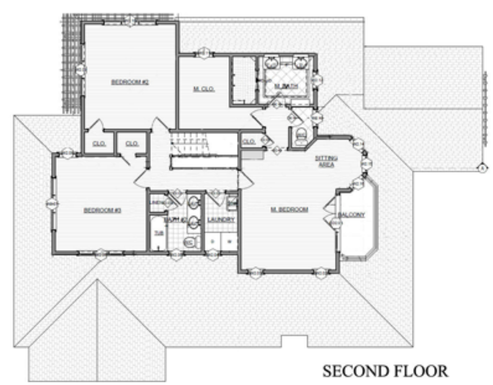
Architectural Design in the Real World

Client's high-level specifications

- Number of bedrooms
- Bathrooms
- Total square footage, etc.



Architectural program
Rooms & adjacencies

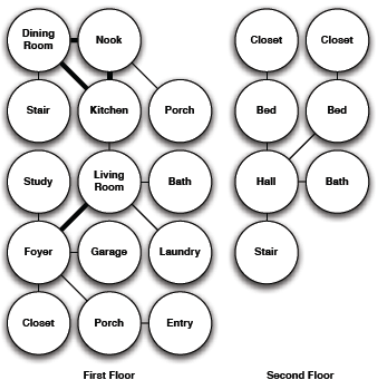


Set of floor plans

Exterior style

Overview

Client's high-level specifications



Architectural program
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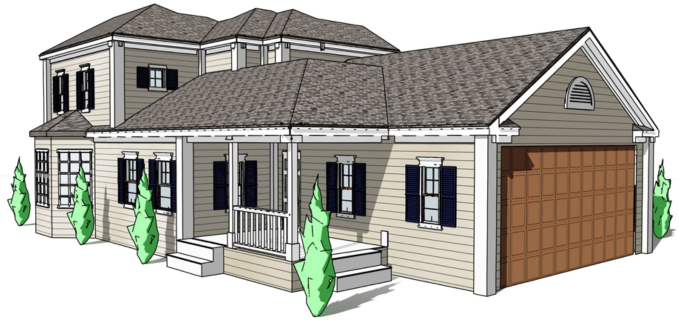
Set of floor plans



3D model

First end-to-end approach to automated generation of building layouts from high-level requirements

Possible Approaches to Building Layout Design

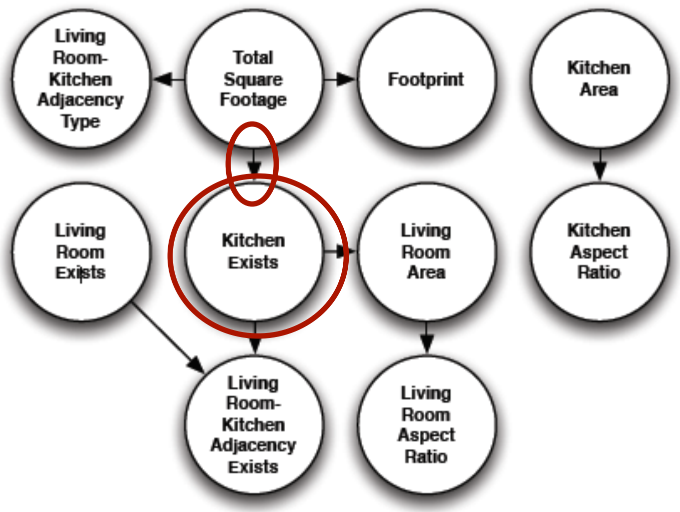
- Use a grammar
  - Shape grammar [Stiny, 2006]
  - Hard to capture the functional relationships
- Use guidelines from architects
  - Too many rules of thumb, ill-specified
- Use a data-driven approach
  - Infer design principles using machine learning techniques

Data-Driven Architectural Programming

- Sample from a distribution of architectural programs
- Conditioned on the high-level contraints

Bayesian Network

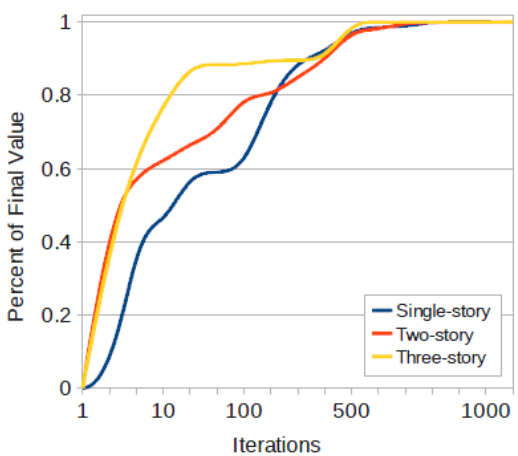
- Represent the distribution in a Bayesian network
  - Compact representation
- Nodes – probabilities
- Edges – conditional dependencies
- Sample from conditional distributions
  - Use high level specifications



Bayesian network

Structure Learning Results

Architectural programs

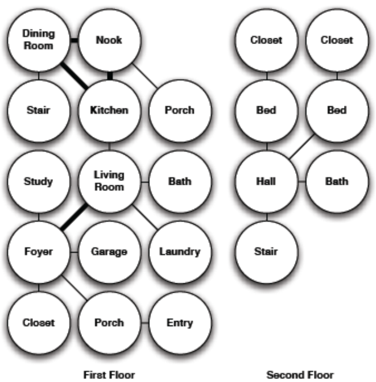


10 iterations 100 iterations 1,000 iterations

Output one sample

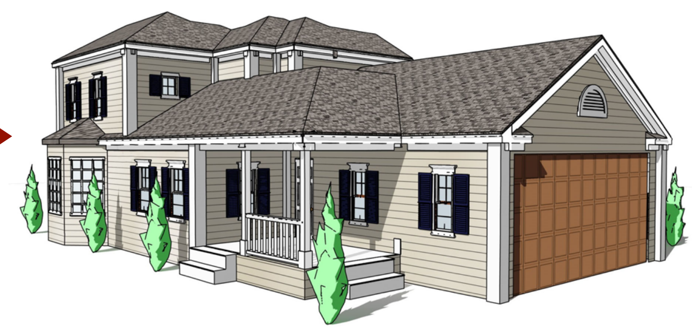
Overview

Client's
high-level
specifications



Architectural program
Rooms & adjacencies

Set of floor plans



3D model

Floor Plan Optimization

- Metropolis algorithm
  - Propose a new floor plan
  - Evaluate it, then accept or reject it
  - Not a greedy algorithm

Metropolis Algorithm

- Objective function

$$f(\mathbf{x}) = \exp(-\beta C(\mathbf{x}))$$

$\mathbf{x}$ Building layout

β Constant

$C(\mathbf{x})$ Cost function

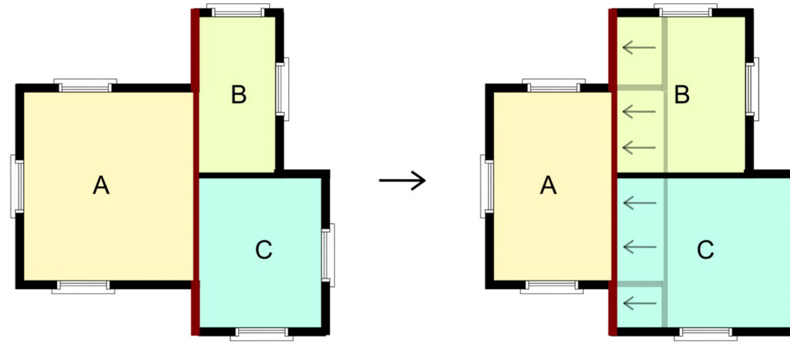
- In each iteration, propose a new building layout $\mathbf{x}^\star$
- Accept with probability

$$\alpha(\mathbf{x}^\star|\mathbf{x}) \quad = \quad \min\left(1, \frac{f(\mathbf{x}^\star)}{f(\mathbf{x})}\right)$$

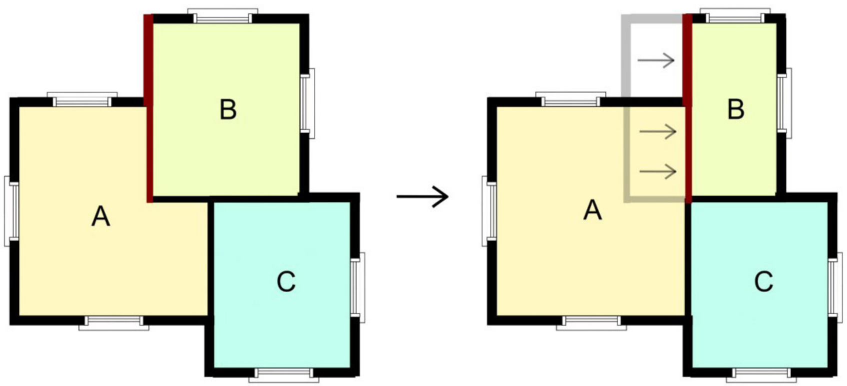
Proposal Moves

- Slide a wall

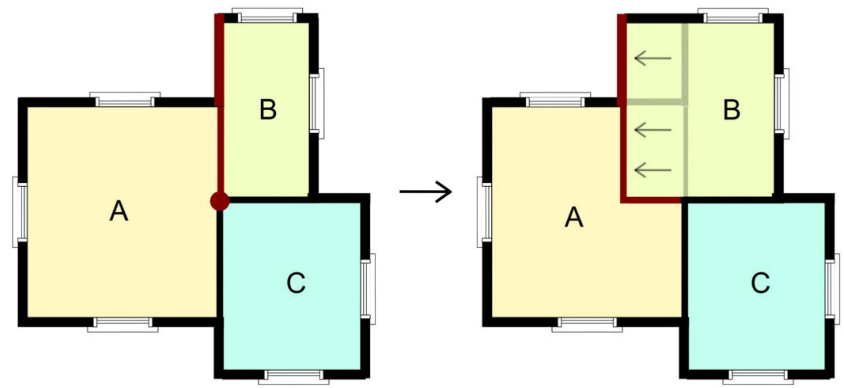
$$d \sim \mathcal{N}(0, \sigma^2)$$



Slide the entire wall



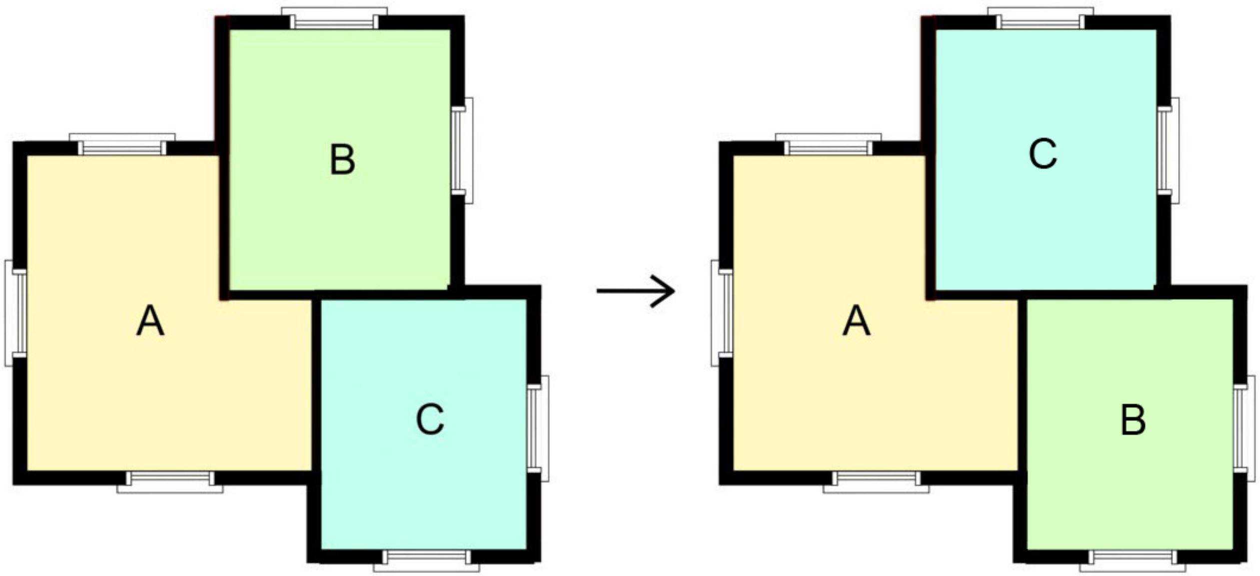
Snap walls together



Split into two collinear walls

Proposal Moves

- Swap two rooms



- Helps to explore the space more rapidly

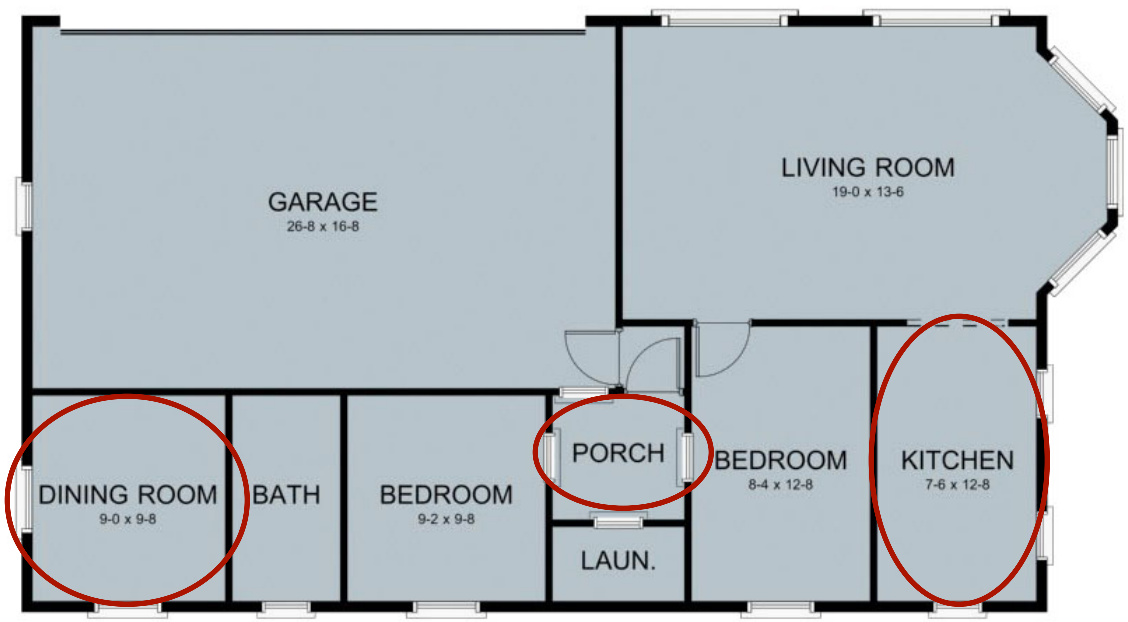
The Cost Function

- Evaluates the quality of the layout

$$C(\mathbf{x}) = \underbrace{k_a C_a(\mathbf{x})}_{\text{Accessibility term}} + \underbrace{k_d C_d(\mathbf{x})}_{\text{Dimension term}} + \underbrace{k_f C_f(\mathbf{x})}_{\text{Floor compatibility term}} + \underbrace{k_s C_s(\mathbf{x})}_{\text{Shape term}}$$

Accessibility Term

- Architectural program specifies adjacencies
- Outdoor access for entrances, patios, and garage.

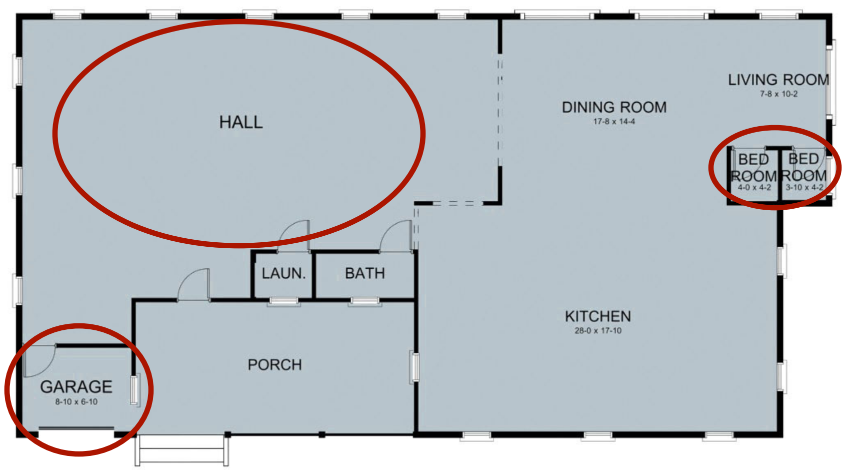


Accessibility term excluded

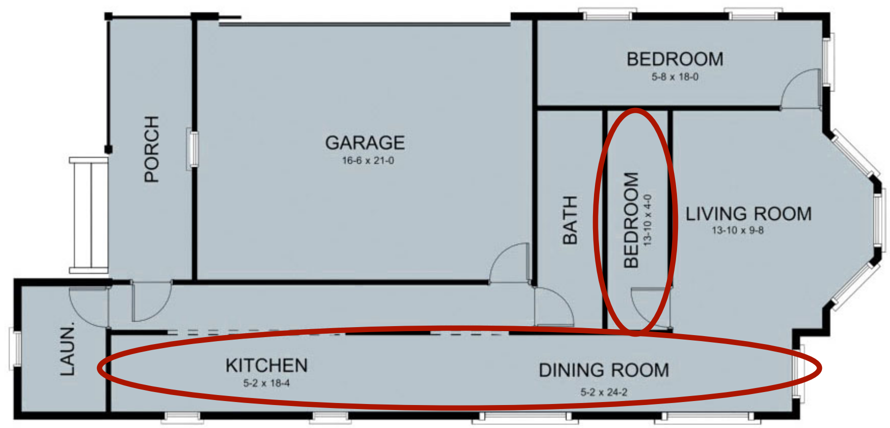
Dimension Term

- Likelihood of a room's area and aspect ratio
  - Uses Bayesian network

$$C_d(\mathbf{x}) = -\sum_{i=1}^{n} \left(\ell_{\mathrm{a}}^{i}(\mathbf{x}) + \ell_{\mathrm{as}}^{i}(\mathbf{x}) \right)$$



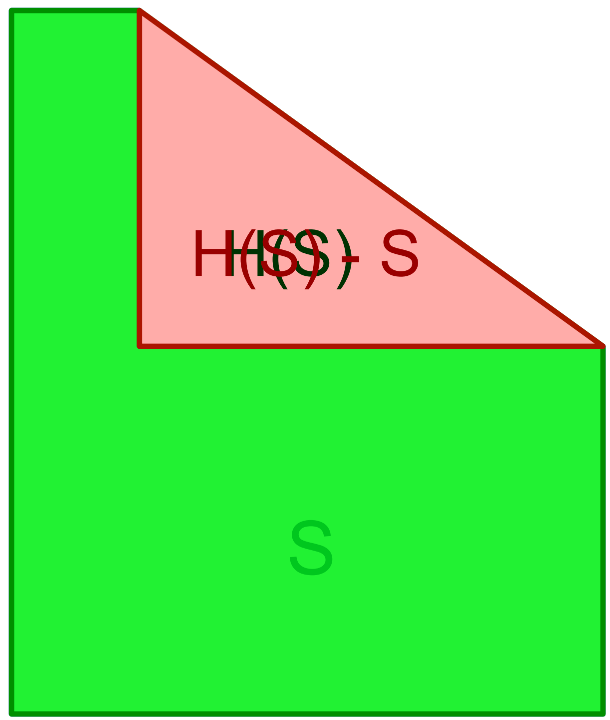
Area term excluded



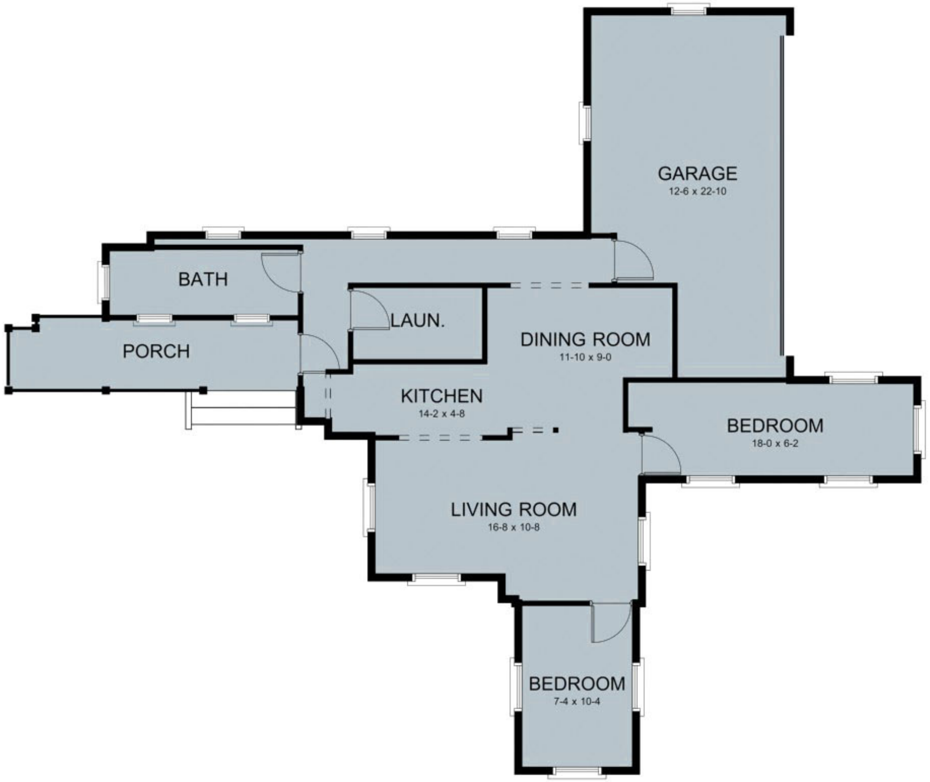
Aspect ratio term excluded

Shape Term

- Measure concavity of a shape, S



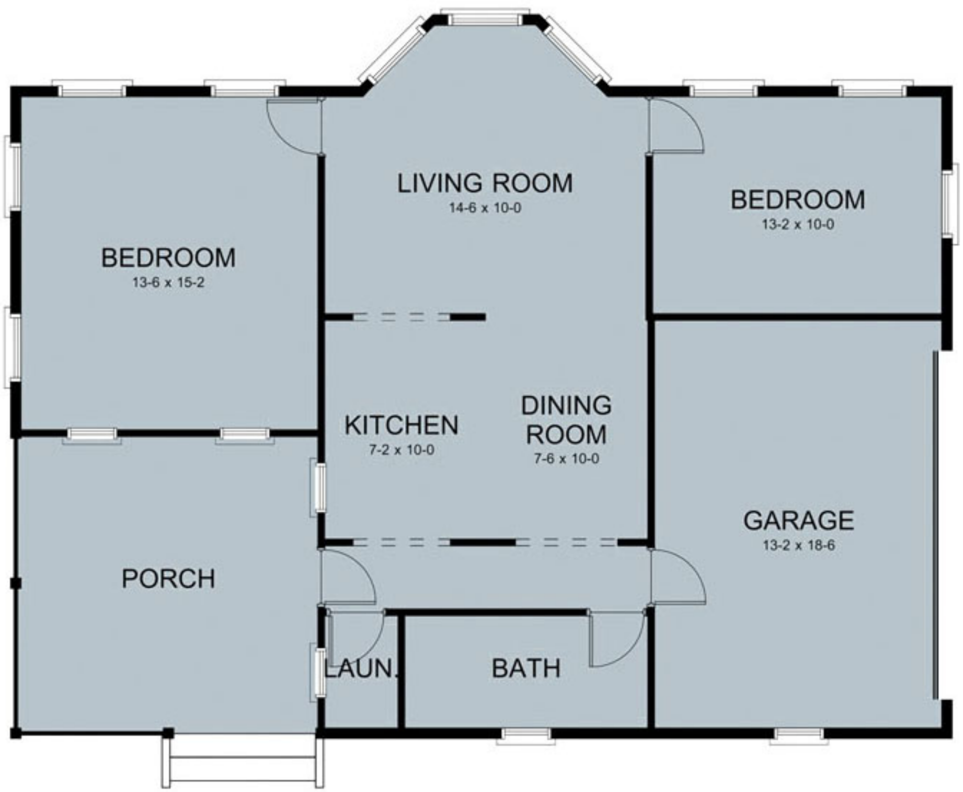
Shape Term



Shape term excluded

Cost Function

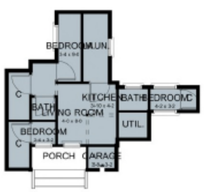
- All terms included



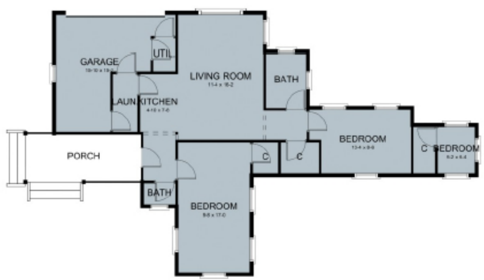
Floor Compatibility Term

- Each floor should be supported by the floor below it

Floor Plan Optimization



200
iterations



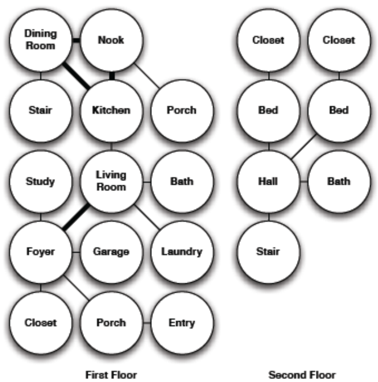
2,000
iterations

20,000
iterations

100,000
iterations

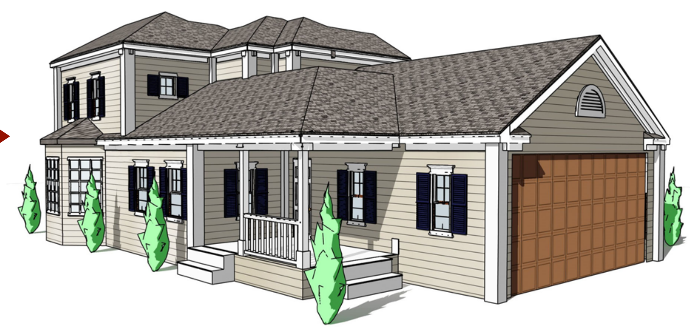
Overview

Client's high-level specifications



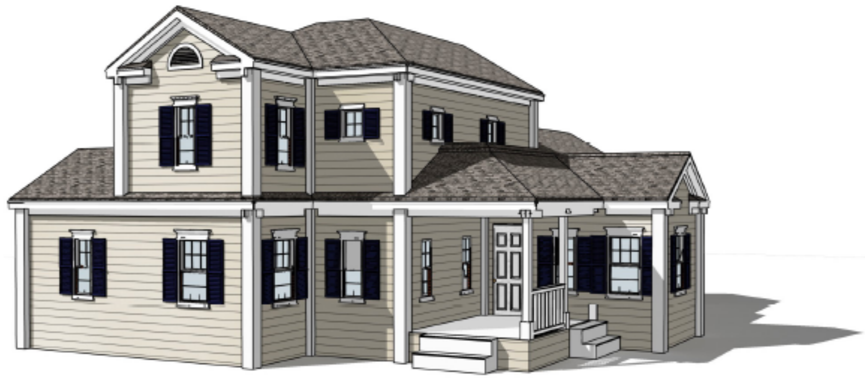
Architectural program
Rooms & adjacencies

Set of floor plans



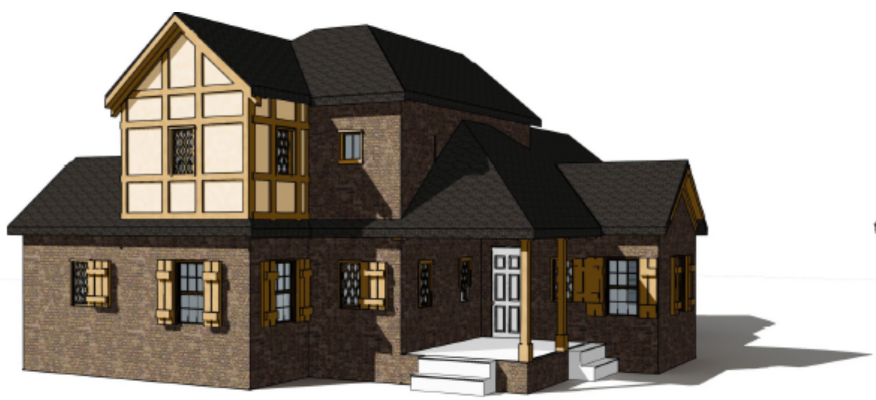
3D model

Different Exterior Styles

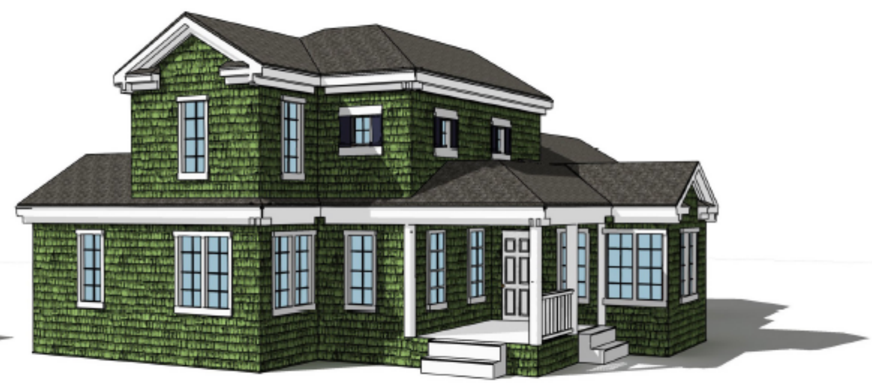


Cottage

Italianate



Tudor



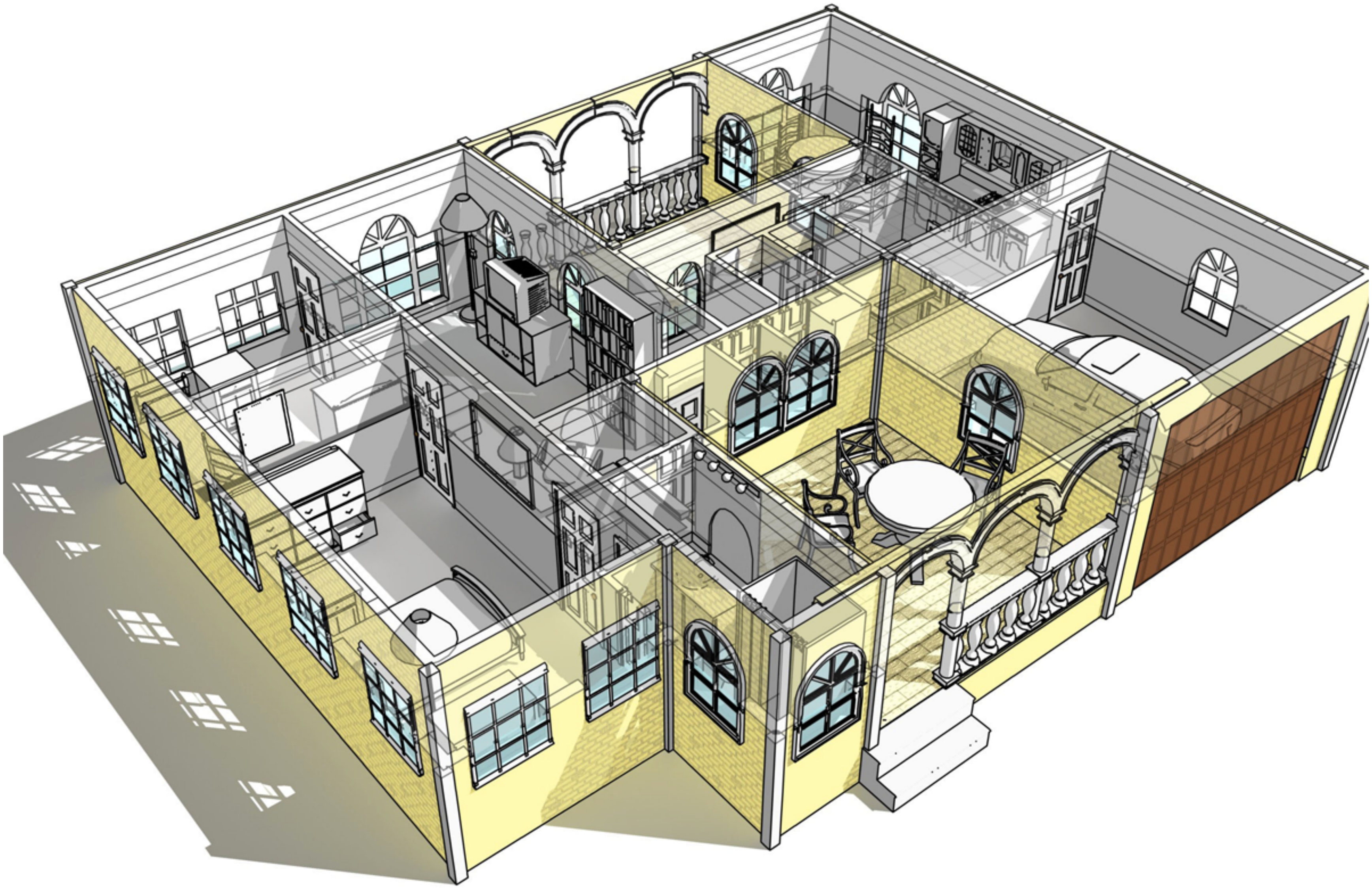
Craftsman

Results

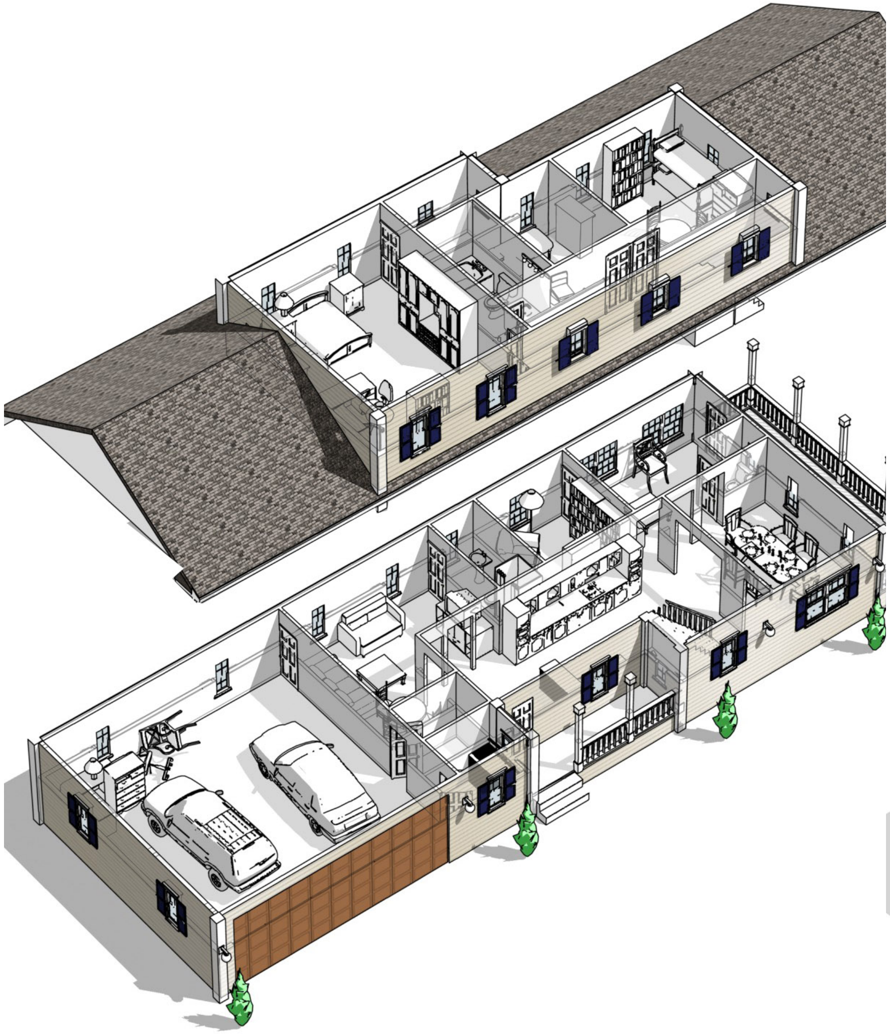
(a) (b) (c)

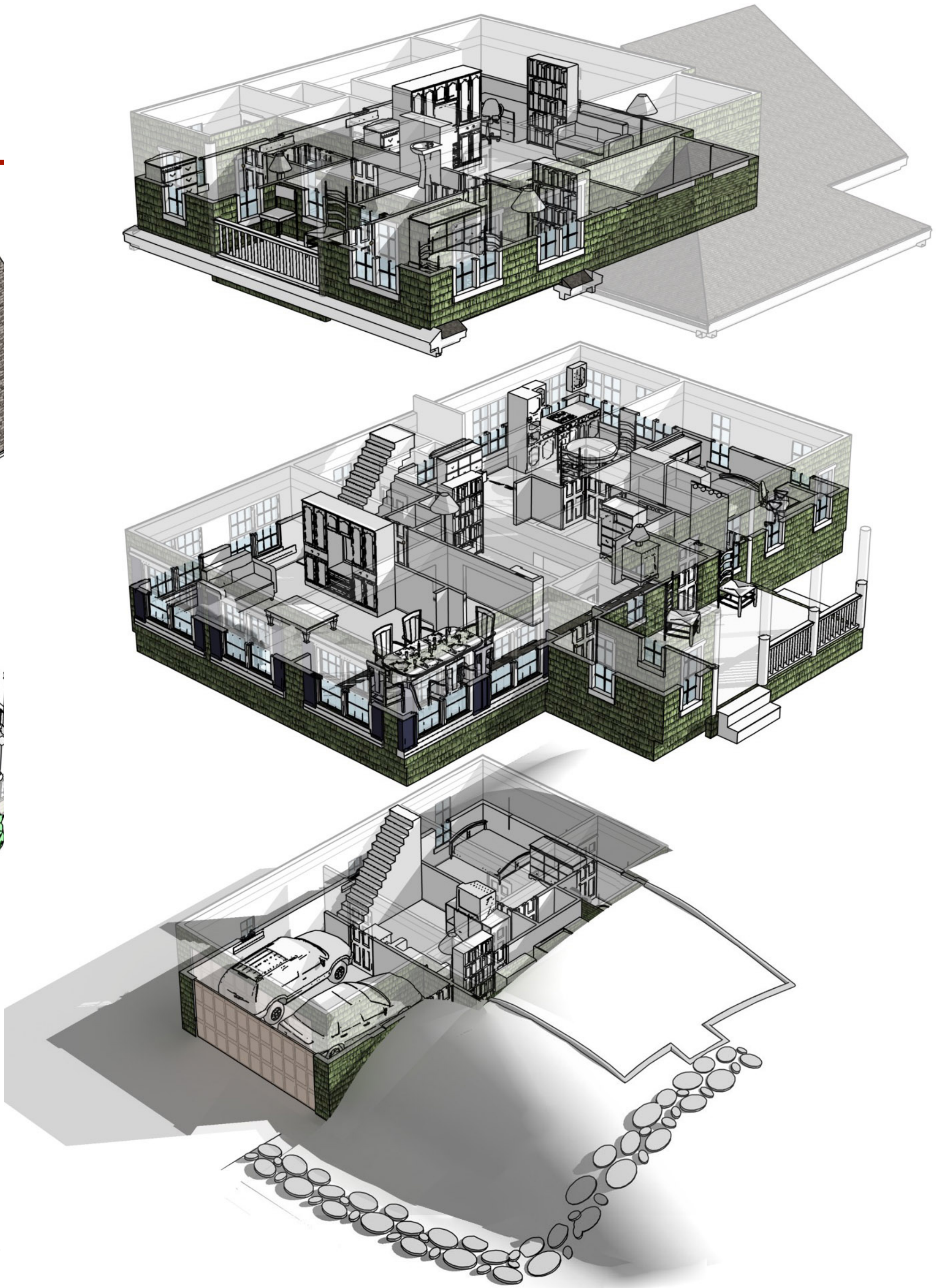
(d) (e) (f)

Results



Results





Results

Results

Future Directions

- Non-rectilinear / curved wall segments
- Site-specific and client-specific factors
- Integrate structural stability
- Interactive exploration of layout designs
- Other building types

Conclusion

- First end-to-end approach to automated generation of building layouts from high-level requirements
- Data-driven approach to procedural modeling

Questions?