BISCUIT: Building Intelligent System CUstomer Investment Tool

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Joint work with Ming Jin, Ruoxi Jia, Wei Feng, Costas Spanos
Design of smart buildings
Occupancy sensor selection problem

• Problem: which sensor to install to enable occupancy-based lighting?

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Cost</th>
<th>Precision</th>
<th>Computation level</th>
<th>Lighting compatible</th>
</tr>
</thead>
<tbody>
<tr>
<td>environmental sensor: CO₂, temperature, etc.</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>motion sensor: PIR</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>camera sensor</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>No</td>
</tr>
</tbody>
</table>

• What sensors are available? What are the costs?
• What are the precision? Do they require computational infrastructure?
• Are they compatible? Can they be shared by other systems (e.g. HVAC)?
Smart building design lesson #1:

In addition to costs,

we should also consider performance and functional constraints.
Heating ventilation and air conditioning (HVAC) system retrofit evaluation

• Problem: cost-benefit analysis of HVAC system retrofit plans

<table>
<thead>
<tr>
<th>Candidate</th>
<th>Control</th>
<th>Computation level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic retrofit, no intelligent components</td>
<td>Basic control</td>
<td>Low</td>
</tr>
<tr>
<td>smart variable air volume (VAV) box</td>
<td>Demand-based control</td>
<td>Medium</td>
</tr>
<tr>
<td>smart HVAC system</td>
<td>Human-building interaction</td>
<td>High</td>
</tr>
</tbody>
</table>

• What is the annual cost of operation for the given building profile?
• Do they require additional computational infrastructure?
Smart building design lesson #2:

In addition to investment costs, 

*we should also consider available control strategies and operation cost.*
“Knapsack problem” of smart buildings

• **Original knapsack:** which items should be chosen to maximize profits while not exceeding the weight limit?

• **Smart building version:** which smart building technologies should be invested to maximize user satisfaction given limited budget?
Challenges

• Large-scale: >100K variables

• Nonconvexity (discrete optimization)

• Human-centric designs (soft constraints)
BISCUIT: Building Intelligent System Customer Investment Tools

- Idea: Library + Optimization-based design space exploration

**Library**
- Sensor, HVAC, lighting, intelligent infrastructure, security, human building interaction

**Simulation engine**

**User specification**
- Cost, energy efficiency, comfort, indoor environmental quality, privacy, security, human building interactions

**Building information**

**Retrofit plan**

**Building services**
## Functional-level abstraction

- **Library**: sensors, HVAC, lighting, intelligent infrastructure, etc.
- **Component**: properties and constraints

<table>
<thead>
<tr>
<th>Library</th>
<th>Items</th>
<th>Properties</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
<td>Available sensor models</td>
<td>Sensing modalities (environmental parameters, sound, visual), functions (presence/occupancy/indoor position/identity detection), cost</td>
<td>User specifications (privacy, IEQ, etc.); compatibility with intelligent HVAC/lighting/infrastructure</td>
</tr>
<tr>
<td>HVAC</td>
<td>Intelligent/ traditional systems</td>
<td>Vendor, investment cost, maintenance cost, rate power, efficiency, lifespan, supported control strategies</td>
<td>User specifications (intelligence upgrade, safety), requirement on the existence of compatible sensors and intelligent infrastructures</td>
</tr>
<tr>
<td>Lighting</td>
<td>Intelligent/ traditional systems</td>
<td>Vendor, investment cost, maintenance cost, rate power, efficiency, lifespan, supported control strategies</td>
<td></td>
</tr>
<tr>
<td>Security</td>
<td>Available systems</td>
<td>Vendor, investment cost, subscription cost, lifespan</td>
<td></td>
</tr>
<tr>
<td>HBI</td>
<td>Available systems</td>
<td>Maintenance cost, lifespan, control strategies, efficiency</td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Available packages</td>
<td>Vendor, cost, maintenance cost, lifespan</td>
<td>User specifications</td>
</tr>
</tbody>
</table>
Formulation of intelligent building design

\[
\begin{align*}
\text{min} & \quad \text{investment cost} + \text{annual operation cost} \\
\text{s.t.} & \quad (1) \text{ user specifications} \\
& \quad (2) \text{ technology constraints} \\
& \quad (3) \text{ operation constraints}
\end{align*}
\]

• Mixed integer linear program

• Optimization over both integer and continuous variables:
  • Investment decision (binary)
  • System control strategy (binary)
  • Operational variables (continuous)
Case study: medium-sized commercial building renovation

• Setup: a medium-sized building (40 rooms, 100 occupants) in California, USA

• RSMeans cost manual and market prices
Acknowledgement

• Collaborators

Ming Jin    Ruoxi Jia    Wei Feng    Costas Spanos

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