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# A Framework to Automate Reliability-based Structural Optimization based on Visual Programming and OpenSees

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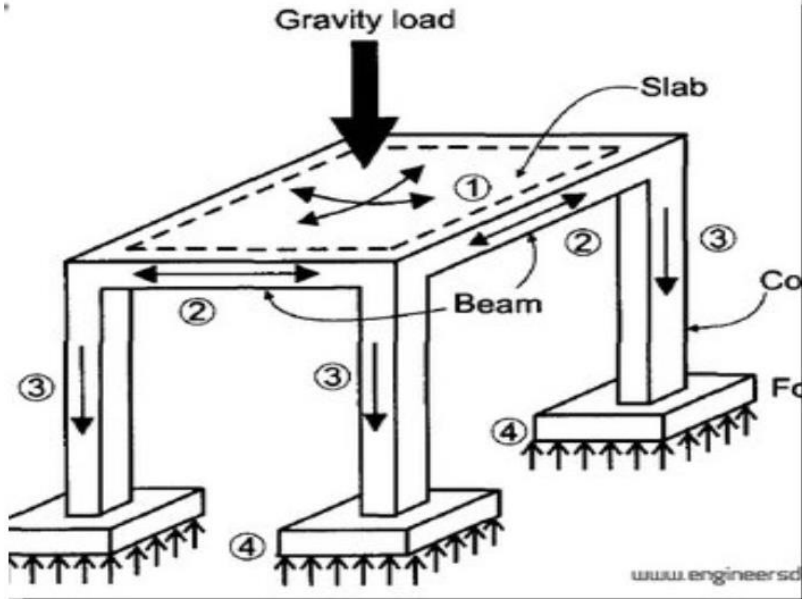
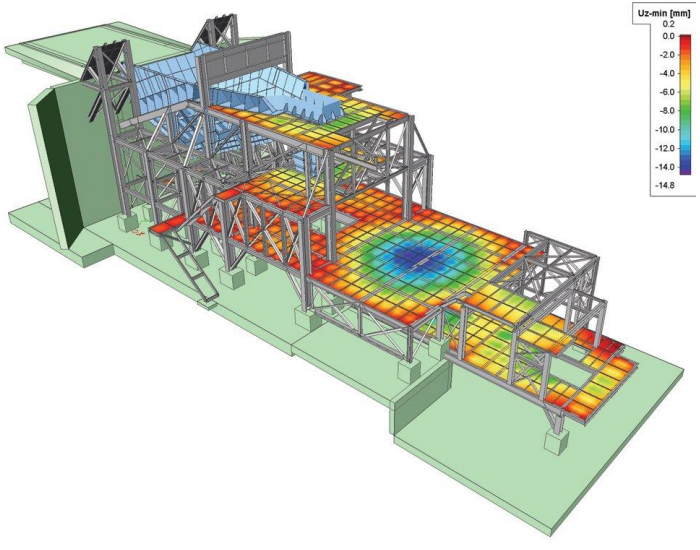
# Background

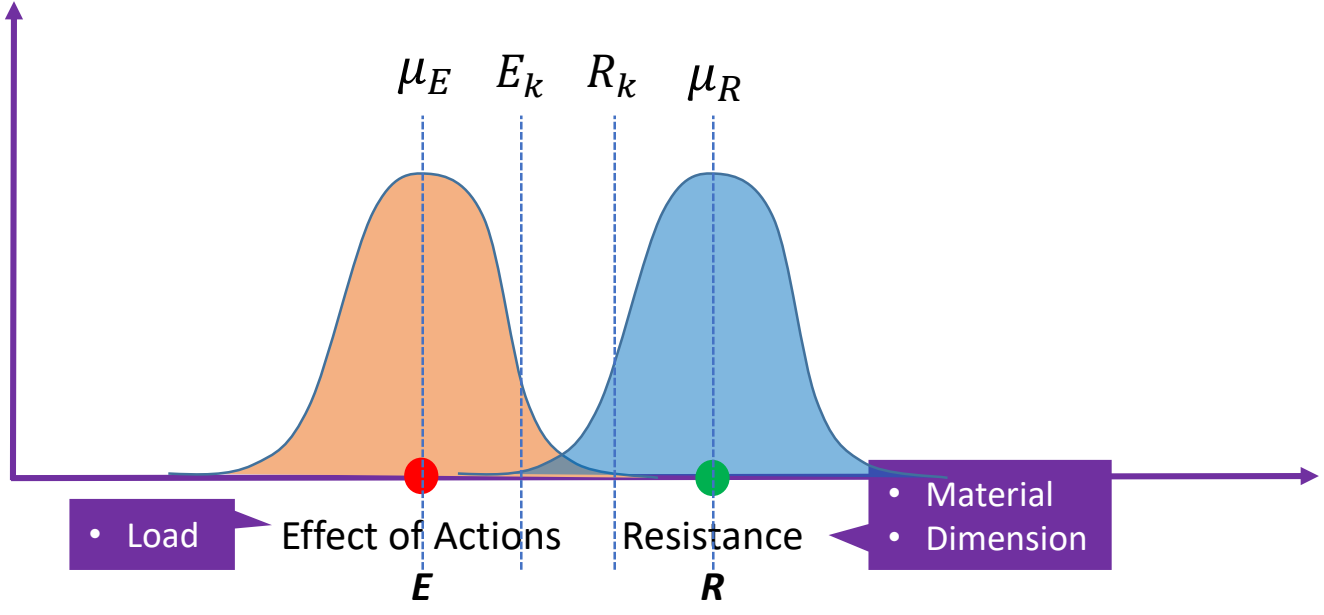
- Structural design
  - Investigation of the stability, strength and rigidity of structures
  - produce a structure capable of resisting all applied loads without failure



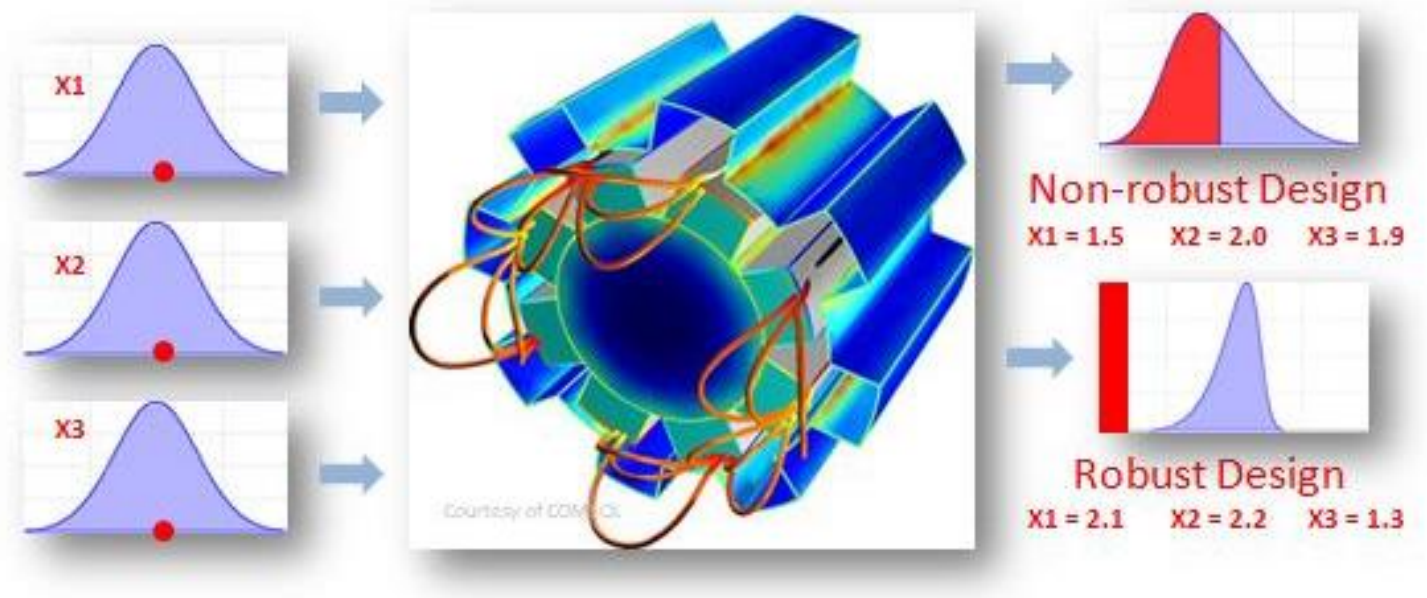
# Background

- Deterministic Design Optimization (DDO)
  - finds optimal shape or configuration in terms of mechanics
  - neglects parameter uncertainty and its effects on structural safety



# Objectives

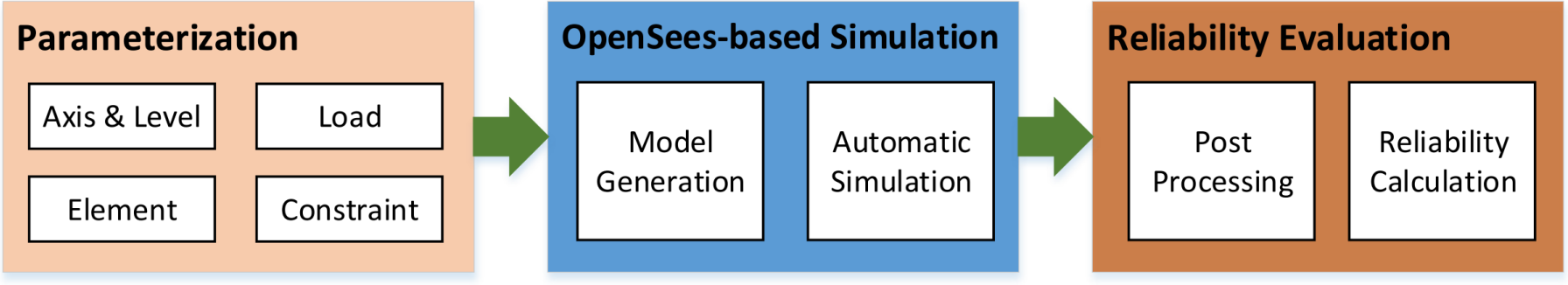
- Automate Design Generation and Evaluation Process
  - Generative design based on visual programming
  - Structural simulation based on OpenSees




src: https://www.optiy.eu/RobustOptimization.html

# Methodology

- A three-step framework
  - Parameterization: extract & define parametric equations for design generation
  - Simulation: generate design models and run simulation automatically
  - Evaluation: post-process results and calculate reliability of design candidates



# Methodology

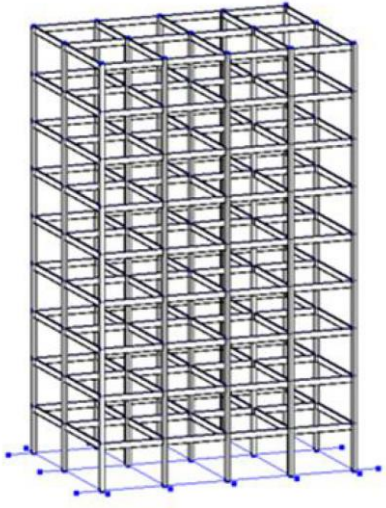
## Parameterization

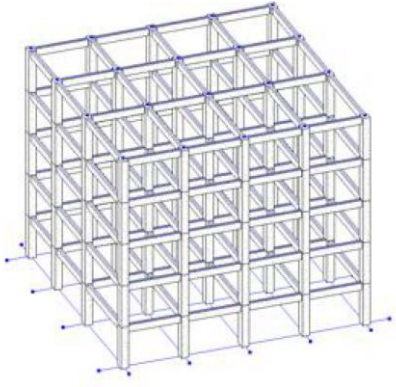
**Model Generation**

**Grid**: Xoffset,Yoffset, Xcount, Ycount, Elevation, Ecount

**Element**: Category, Material, Section, Location

**Other**: Connection, Constraint





**Load Sampling**

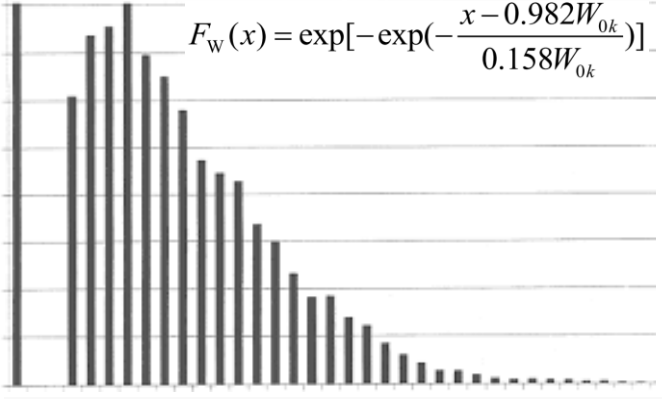
$$F(x_i) = \exp[-\exp(-\frac{x_i - \alpha}{\beta})]$$

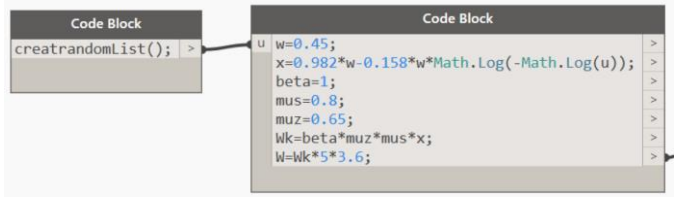
**Gumbel**

$$x_i = \alpha\text{-}\beta \ln(-\ln u_i) \quad u_i \sim Unif[0,1]$$

**Uniform**

$$F_W(x) = \exp[-\exp(-\frac{x - 0.982W_{0k}}{0.158W_{0k}})]$$





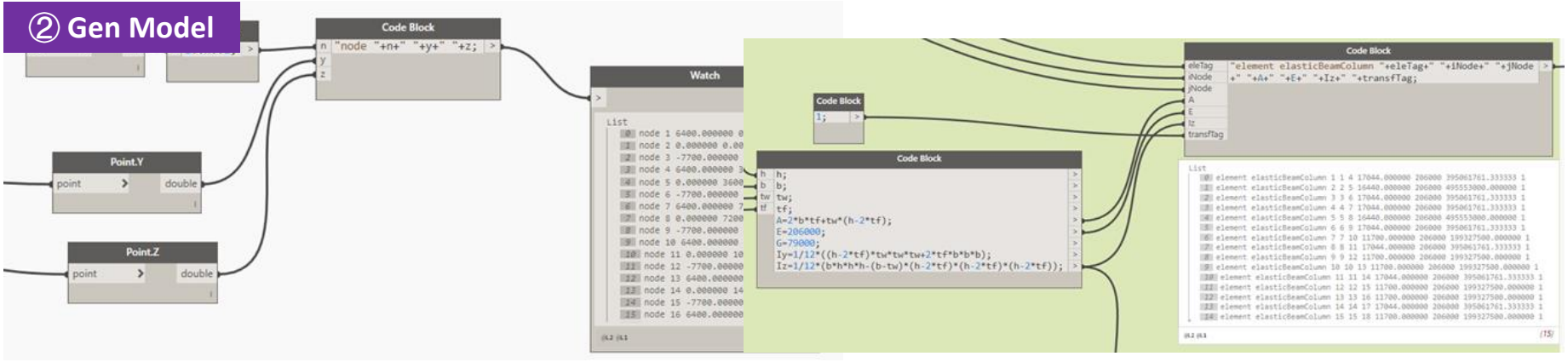
# Methodology

## Simulation

### ① Data Format

| | Definition |
|---|---|
| model | model basic -ndm $ndm -ndf $ndf |
| node | node $nodeTag (ndm $coords) |
| constraint | fix $nodeTag (ndf $constrValues) |
| transformation | geomTransf Linear $transfTag |
| frame element | element elasticBeamColumn $eleTa |
| load pattern | pattern Plain $patternTag $tsTag{} |
| uniform load | eleLoad -ele $eleTag1 -type -beamU |
| point load | load $nodeTag (ndf $LoadValues) |

### ② Gen Model




### ③ Run Simulation

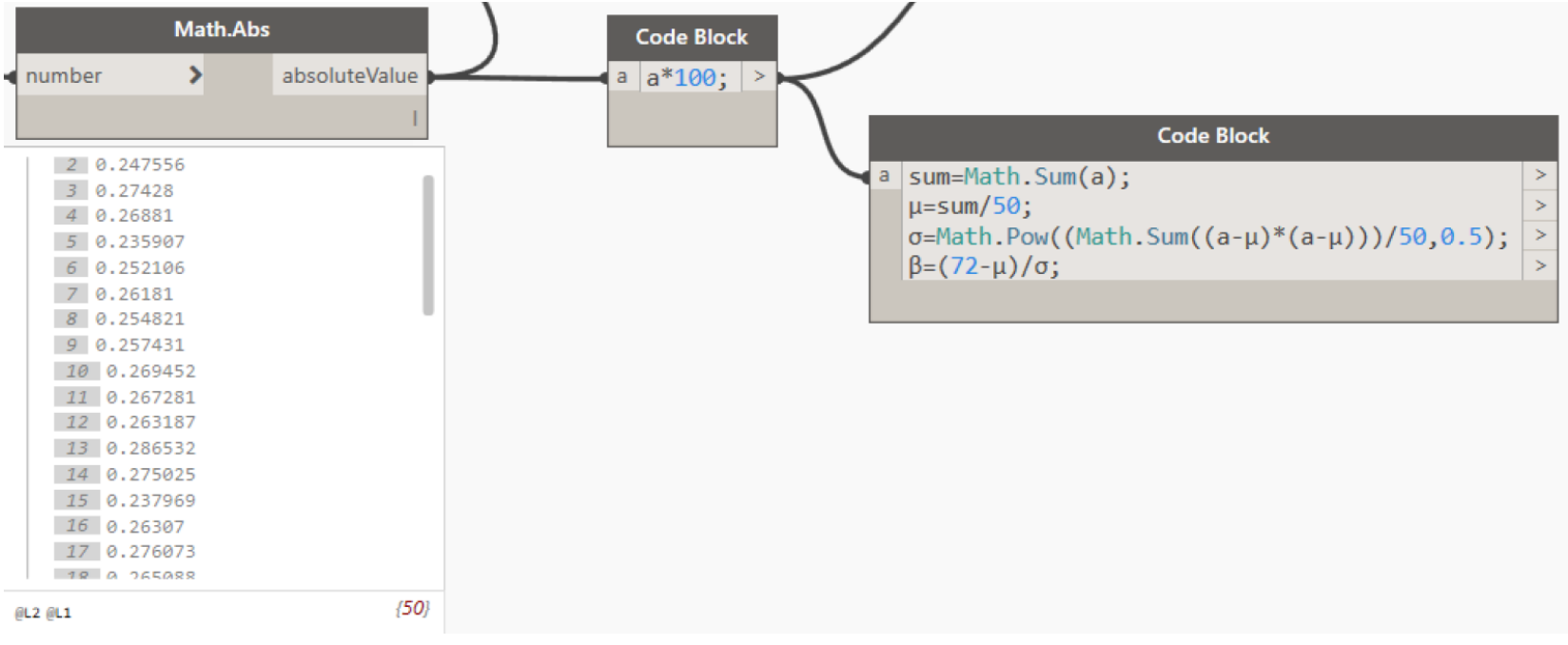
```
adr=IN[0]
str=IN[1]
ans=IN[2]
openseesadr=IN[3]
word=[]
for i in range(len(adr)):
    f=open(adr[i],'w')
    f.write(str[i])
    f.close()

p=Process()
p.StartInfo.UseShellExecute=False
p.StartInfo.CreateNoWindow=True
#p.StartInfo.RedirectStandardOutput=True
p.StartInfo.FileName='put your path Opensees.exe here'
for i in range(len(openseesadr)):
    p.StartInfo.Arguments=openseesadr[i]
    p.Start()
p.WaitForExit()
```

# Methodology

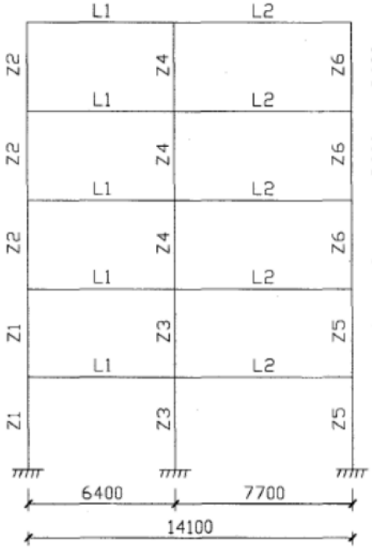
- Evaluation

$$Z = g(\mathrm{R},\mathrm{S}) = \mathrm{R} - \mathrm{S} \Rightarrow P_r = 1 - P_f = 1 - p(\mathrm{Z} < 0) = 1 - \int_{-\infty}^{0} f_Z(\mathrm{Z})\,\mathrm{dZ} = 1 - \Phi(-\frac{\mu_Z}{\sigma_Z}) = \Phi(\frac{\mu_Z}{\sigma_Z}) \Rightarrow \beta = \frac{\mu_Z}{\sigma_Z}$$

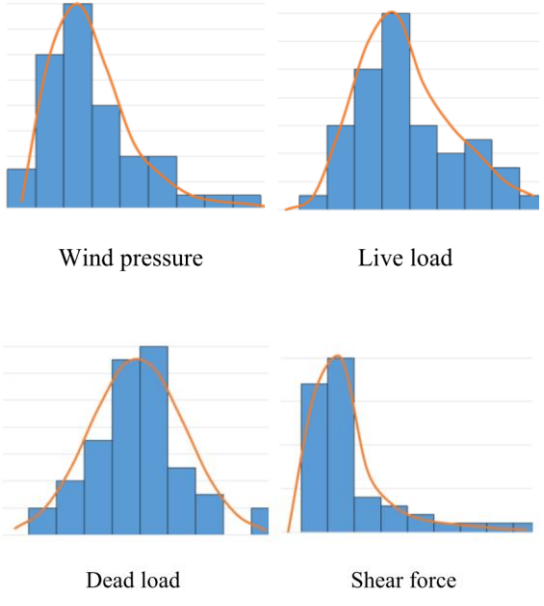


# Demonstration

- A five-story steel frame structure is used for validation
- Considered variables: section, load (dead+live+wind)

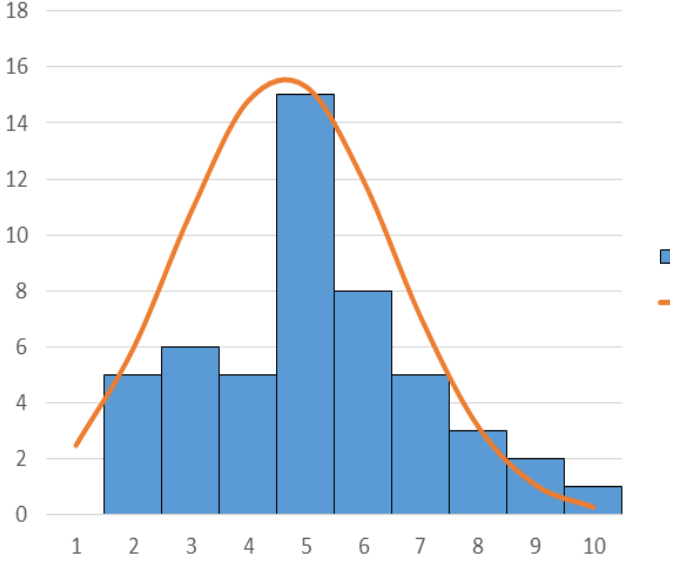


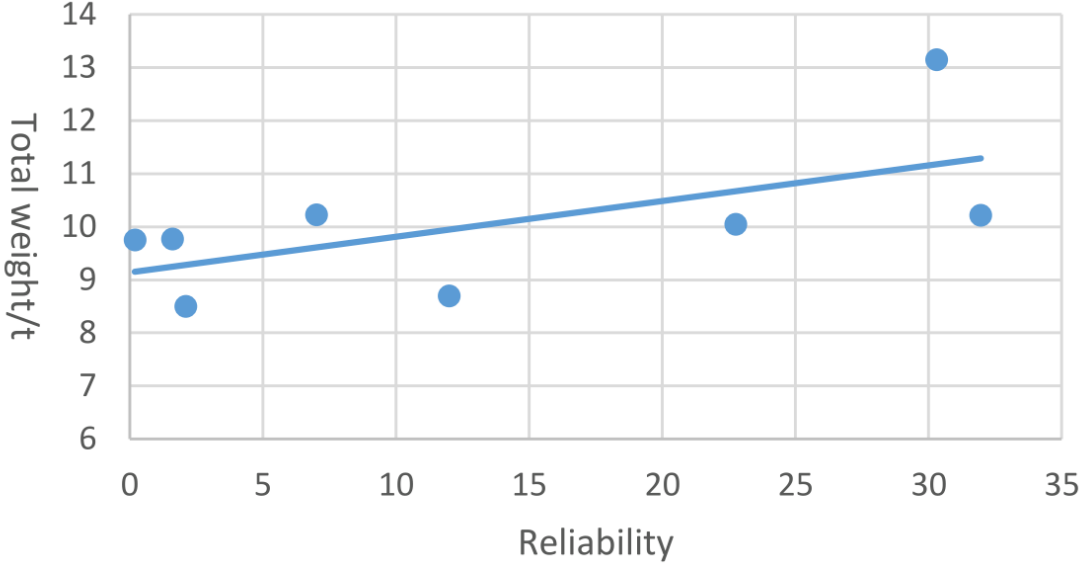

| Element ID | Section |
|---|---|
| L1 | HN496×199×10×14 |
| L2 | HN500×200×10×16 |
| Z1 | HW350×350×12×19 |
| Z2 | HW300×300×10×15 |
| Z3 | HW400×400×13×21 |
| Z4 | HW350×350×12×19 |
| Z5 | HW350×350×12×19 |
| Z6 | HW300×300×10×15 |



# Demonstration

- A five-story steel frame structure is used for validation
- Considered variables: section, load (dead+live+wind)
- Configuration: elastic simulation
- Indicators: total weight as objective function, maximum lateral movement for reliability



# Conclusions

- Framework to Automate Design Generation and Reliability Evaluation
  - Based on visual programming and OpenSees
  - Create load samples based on Monte-Carlo Simulation
  - Run OpenSees simulation automatically
- Benefits: Save Time + New Possibilities
  - Avoid manual model creation and save time
  - Explore a large parameter space
- Future Work: Extension & Improvements

# Thank You for Your Attention!

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