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# Multi-criteria decision analysis for sustainability and resilience assessment of buildings subjected to earthquakes

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## INTRODUCTION

- key characteristics contributing to the building design: Sustainability; Resilience
- Ideal building design: minimizing direct (economic) and indirect (downtime, casualties, injuries) losses, negative environmental impacts (e.g., carbon emission), and life-cycle building energy use, while ensuring safety requirements.
- To attain such multi-objective building design, a key target in the new generation of building design, a holistic approach to account for all those factors, optimize and prioritize the decision process is required.

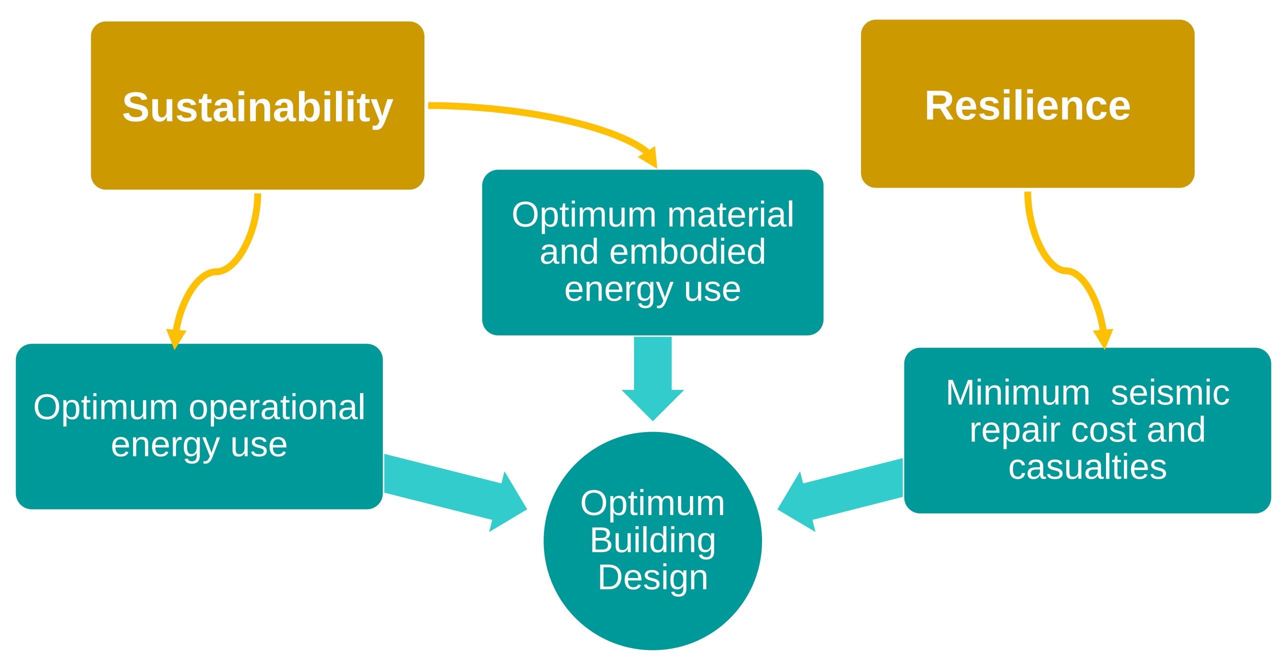


Figure 1. Optimum building design aspects

## FRAMEWORK DESCRIPTION

A decision-making framework is proposed to:
- Investigate the tradeoffs between seismic loss and life-cycle energy variables in the design,
- Considering seismic repair cost and casualties, operational and embodied energy as the performance objectives.

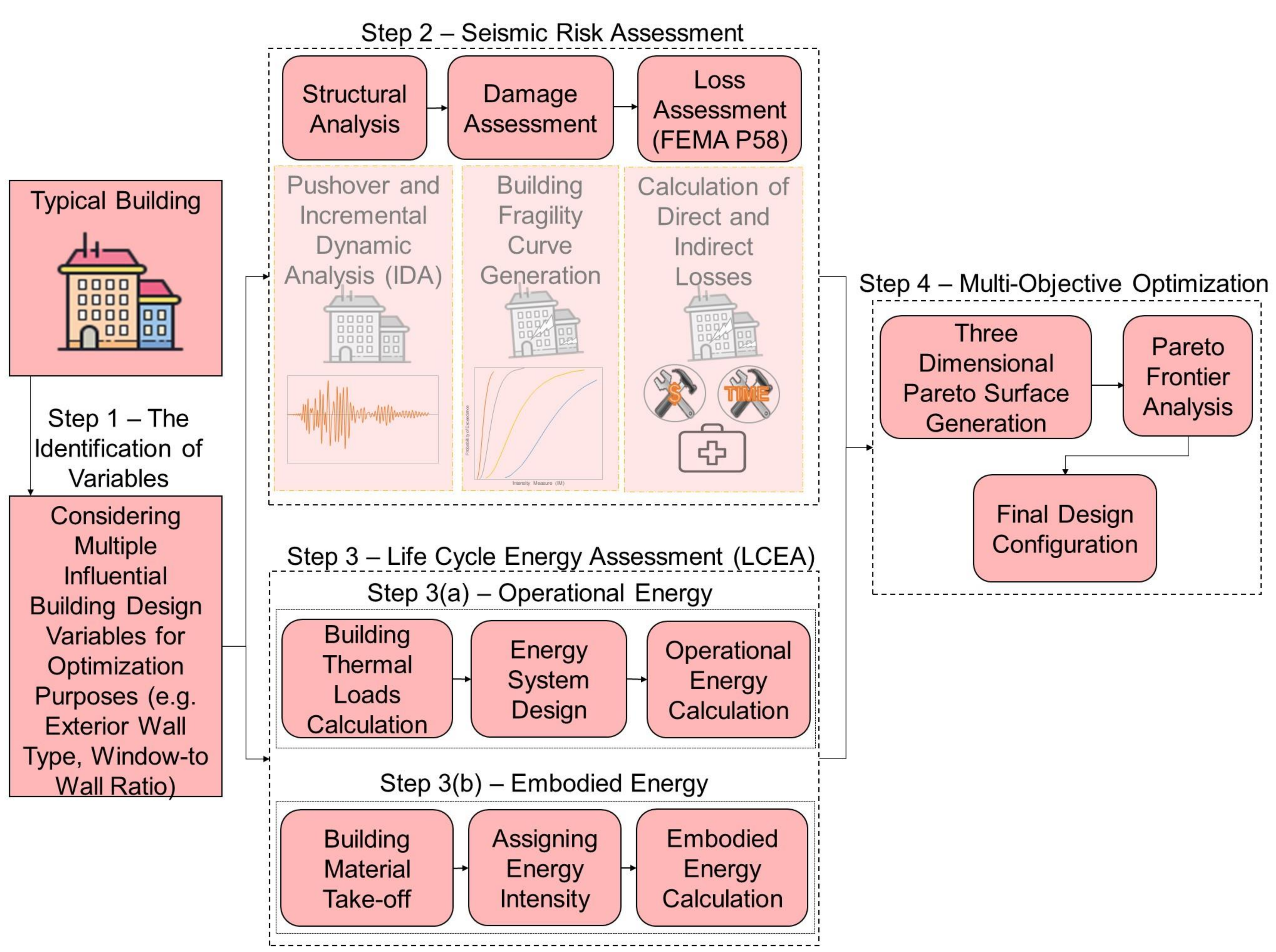


Figure 2. Schematic representation of the proposed multi-criteria decision-making framework

## A CASE STUDY TO EXAMINE THE FRAMEWORK

- Three square-plan reinforced concrete building frames selected
- Various heights including 2 , 12, and 20-story buildings
- A novel "gradient inelastic flexibility-based frame element formulation used for structural modeling

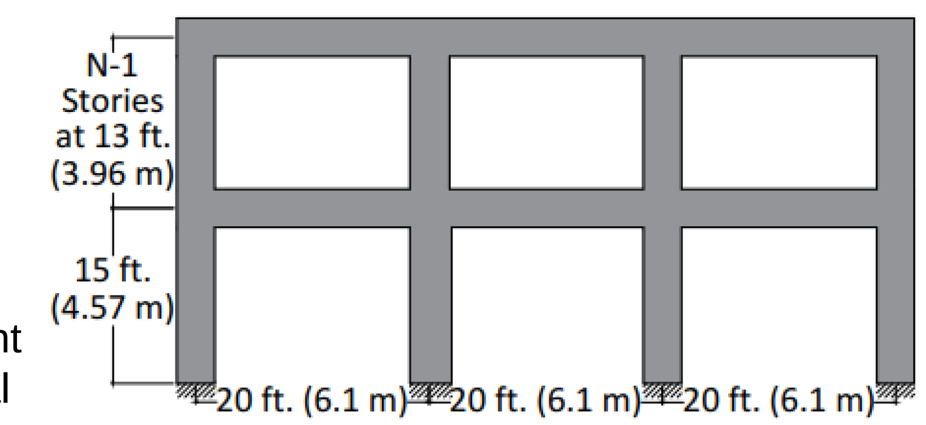


Figure 3. Schematic view of the simulated RC buildings

### *Step 1: The Identification of Variables*

- Building design variables effective and sensitive to the performance objectives are selected.
- Four Window-to-Wall Ratios (WWR) and six exterior wall detail

Table 1. Exterior wall details

| Exterior wall detail |
|---|
| Assembly 1 (Wood panel) |
| Assembly 2 (Stucco) |
| Assembly 3 (Metal panel) |
| Assembly 4 (Stucco + Metal panel) |
| Assembly 5 (Concrete) |
| Assembly 6 (Brick) |

&

Table 2. Window-to-Wall Ratios

| Window-to-Wall Ratio |
|---|
| 20% |
| 40% |
| 60% |
| 80% |

24 models in total for each building design

### *Step 2: Seismic Risk Assessment*

- Applied FEMA P58 methodology
- Fragility and repair cost data of building components from FEMA P58 database (using Performance Assessment Calculation Tool-PACT by FEMA)
- Injuries calculated per 1000 sq.ft. (92.9 m$^2$), turned into dollar for consistency with repair cost ($262000 per capita)
- Results shown at Median Collapse Capacity (MCC) for 2-story building

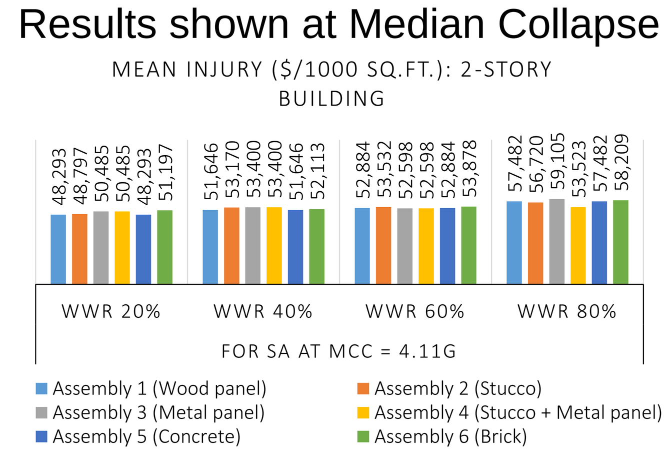


Figure 4. Mean injury for 2-story building

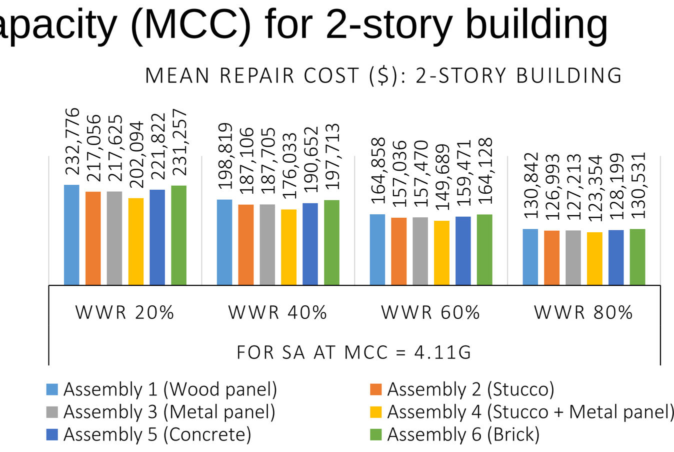


Figure 5. Mean repair cost for 2-story building

### *Step 3: Life-cycle Energy Assessment*

<u>Operational energy (OE)</u>
- The Operational energy is calculated using Energy Plus as a motor engine.
- The system boundary includes heating, cooling, and lighting loads.

<u>Embodied energy (EE)</u>
- The Embodied Energy and carbon emission replacement is calculated using the input-output based approach as recommended by FEMA P58.
- The system boundary includes material and demolition costs.

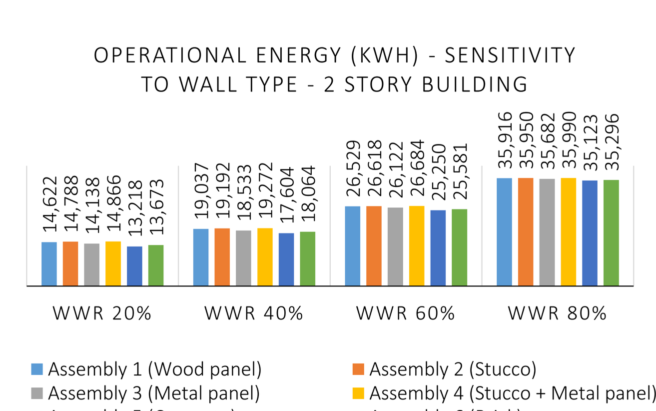


Figure 6. Operational energy for 2-story building

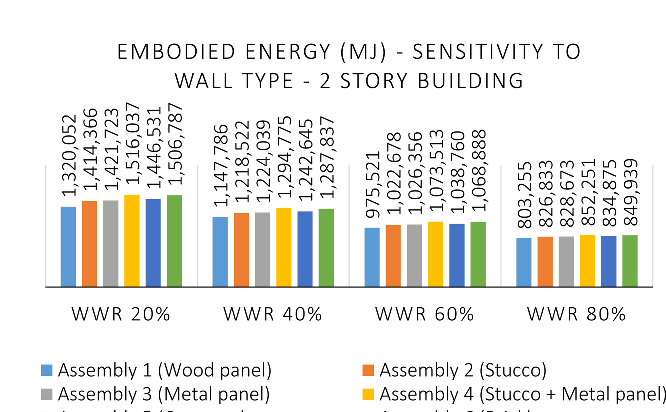


Figure 7. Embodied energy for 2-story building

### *Step 4: Multi-Objective Optimization*

The results are presented in a 3D space where the design solution points are based on the normalized seismic economic loss, OE, and EE values as the x y z coordinates.

**Comparing Pareto sets in terms of:**
1. the associated hypervolume indicator
2. the number of Pareto front points

Table 3. Hypervolume Indicator and the number of Pareto solution points for the three buildings' Pareto sets

| Building | Hypervolume Indicator | Number of Pareto solution points |
|---|---|---|
| 2-story | 0.1954 | 16 |
| 12-story | 0.2627 | 16 |
| 20-story | 0.1072 | 9 |

**Hypervolume indicator gives insight into:**
1. Diversity and distribution of the solution points
2. Proximity to the approximated true optimal solutions

- Higher intervolume indicator is interpreted as having closer to the minimum cost and energy and more diverse Pareto solution points.

- the medium-rise building (12-story) has larger dominated solution space of the observed Pareto solution sets
- For the high-rise building (20-story), it can be more difficult to reach a compromise between seismic economic loss and building life-cycle energy assessment criteria in terms of the operational and embodied energies.

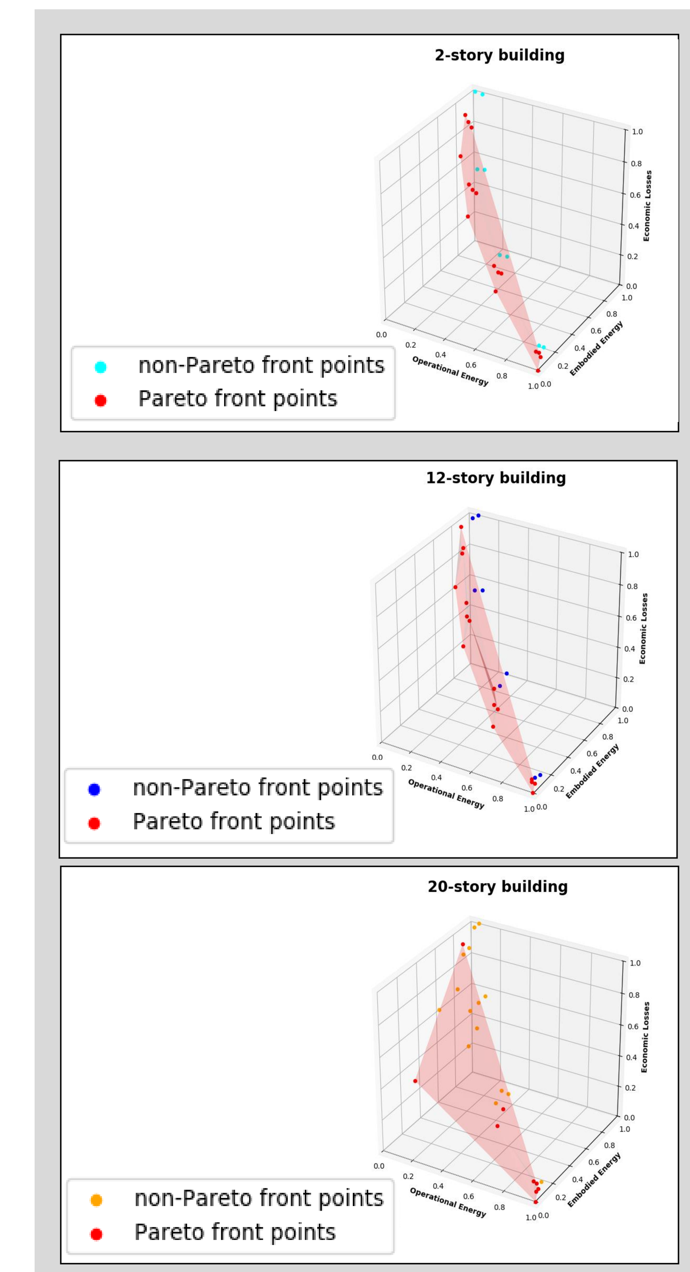


Figure 8. Pareto front surface for three buildings

## CONCLUSIONS

- The integration of seismic loss and the environmental impacts of buildings is crucial due to the potential conflicting outcomes each criterion may have.
- The tradeoff among the performance objectives associated with building sustainability and resilience is investigated by Pareto frontier analysis.
- The low and mid-rise buildings, relatively, have a higher number of optimized solutions and the solution points are of a higher quality in terms of diversity and proximity.
- Challenges in this area, such as lack of interoperability among computational tools, uncertainties in the calculation of performance objectives, etc., may be considered for future work.

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