

Short-STPA analysis for VF balcony and living wall system on RC Buildings

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Sessions C <https://msteams.link/4OE0>

This presentation is part of a recent publication.

Vanian, V., Rousakis, T., Fanaradelli, T., Voutetaki, M., Macha, M., Zapris, A., Theodoridou, I., Stefanidou, M., Vatitsi, K., Mallinis, G., Kytinou, V., & Chalioris, C. (2025). Performance-Based Damage Quantification and Hazard Intensity Measures for Vertical Forest Systems on RC Buildings. Buildings, 15(5), 769. <https://doi.org/10.3390/buildings15050769>



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Με τη χρηματοδότηση
της Ευρωπαϊκής Ένωσης
NextGenerationEU

Presentation Outline

1. Introduction to STPA (System-Theoretic Process Analysis)
2. VF Systems and RC Buildings
3. STPA Methodology
4. System Definition: VF Balcony and Living Wall
5. Control Structure Diagrams
6. Hazard Analysis
7. Unsafe Control Actions
8. Safety Requirements & Constraints
9. Risk Matrix
10. Key Findings
11. Comparison with Traditional Analysis
12. Conclusions

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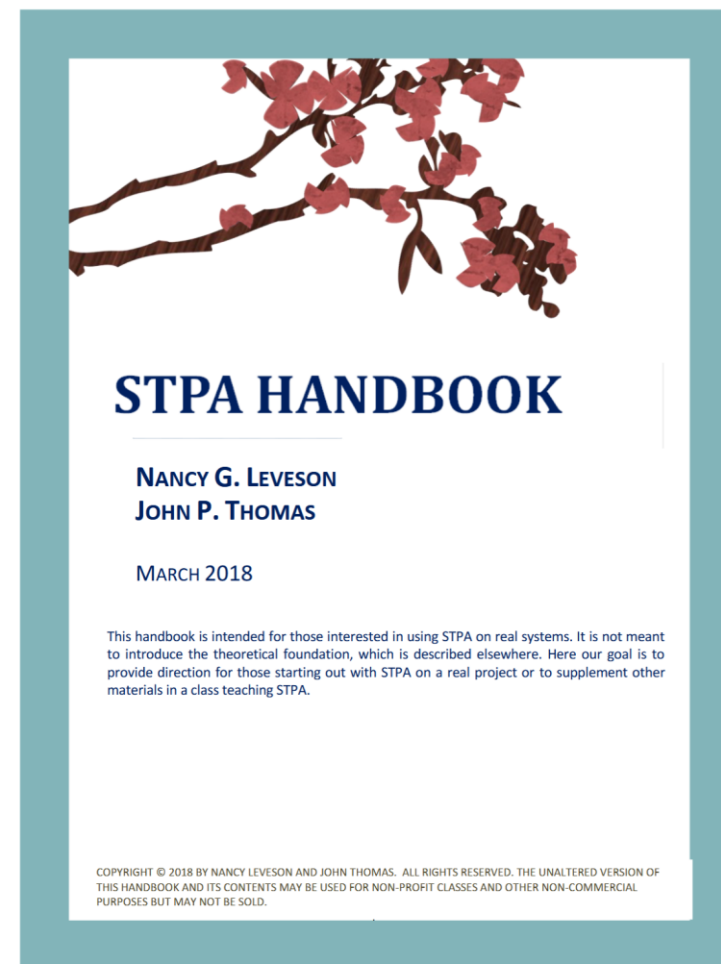
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Introduction to STPA

- STPA (System-Theoretic Process Analysis) is a modern hazard analysis technique
- Developed **at MIT by Nancy Leveson**
- Based on systems theory rather than reliability theory
- **Identifies hazards through control theory analysis**
- Focuses on interactions between components
- Particularly useful for **complex**, socio-technical systems



Available: https://psas.scripts.mit.edu/home/get_file.php?name=STPA_Handbook.pdf

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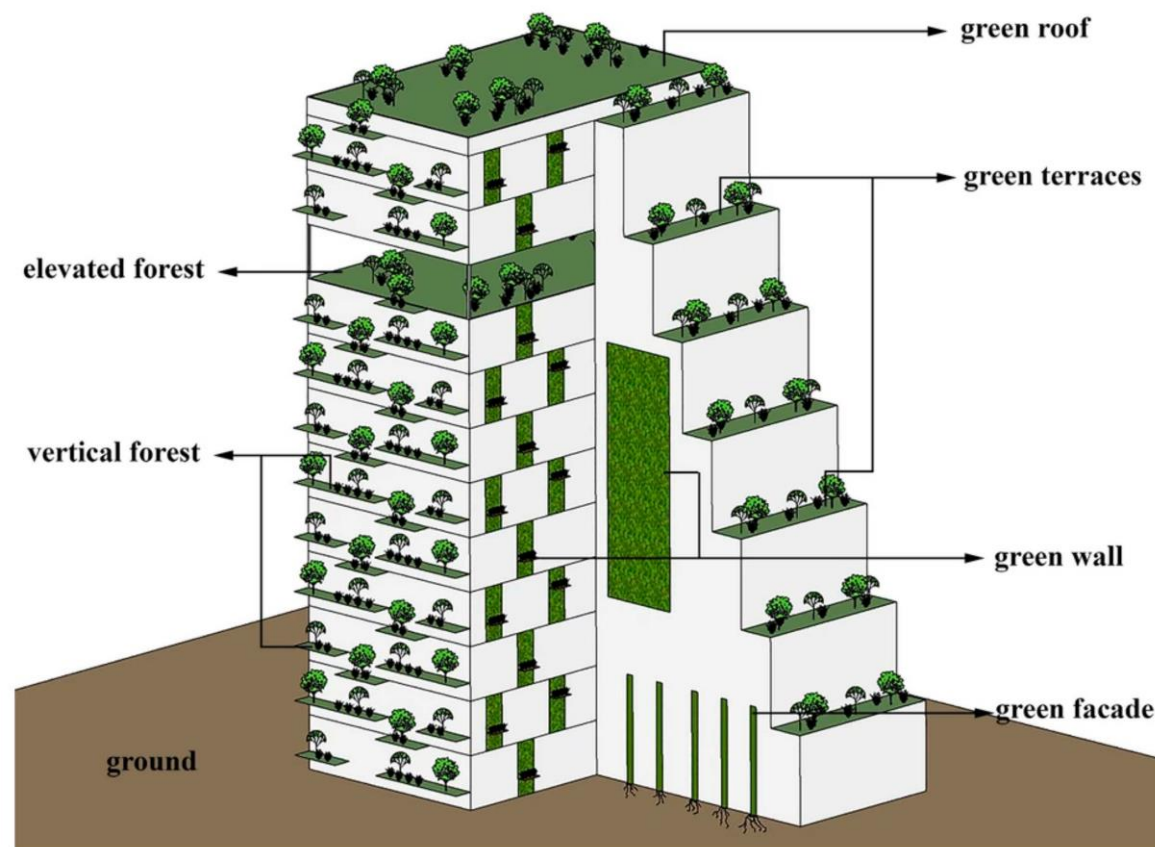
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VF Systems and RC Buildings

- Vertical Forest (VF) systems integrate vegetation with buildings
- Types include:
 - Green facades
 - Green walls
 - Green terraces/roofs
 - Vertical forests (cantilevered balconies)
- **Benefits:** Aesthetics, energy efficiency, air quality, ecological value
- **Challenges:** Structural loading, moisture management, maintenance



Classification of greenery infrastructure by Wang et al. 2020.

STPA Methodology

1. System Definition

- Define purpose, components, and boundaries

2. Control Structure Development

- Map relationships between controllers

3. Accidents & Hazards Identification

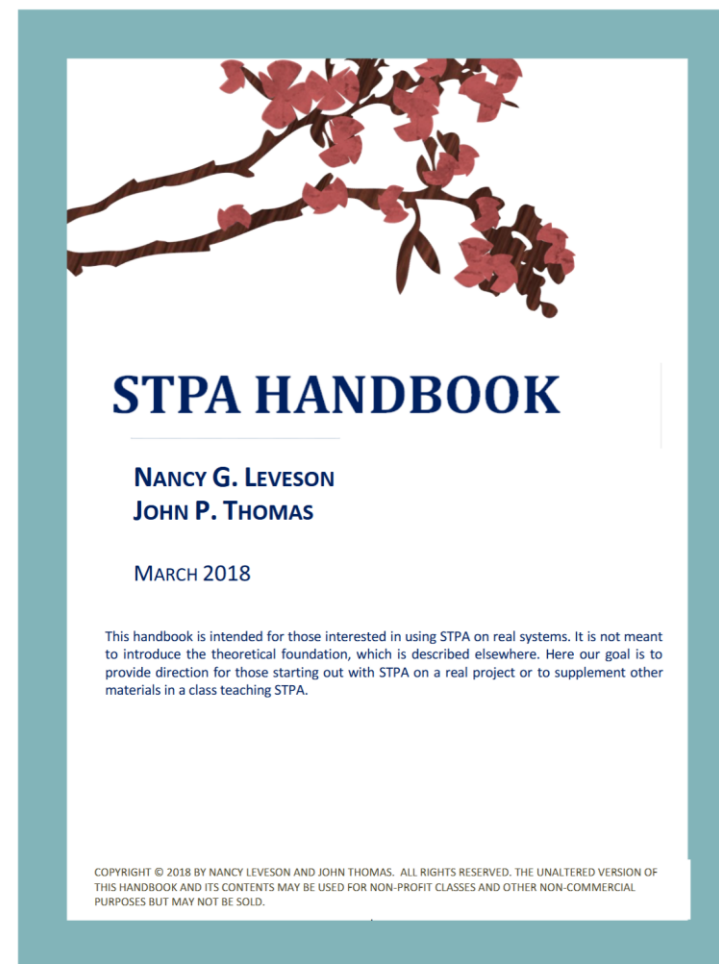
- Define potential losses and hazardous states

4. Unsafe Control Actions (UCAs)

- Identify problematic control actions

5. Safety Requirements & Constraints

- Develop safety measures



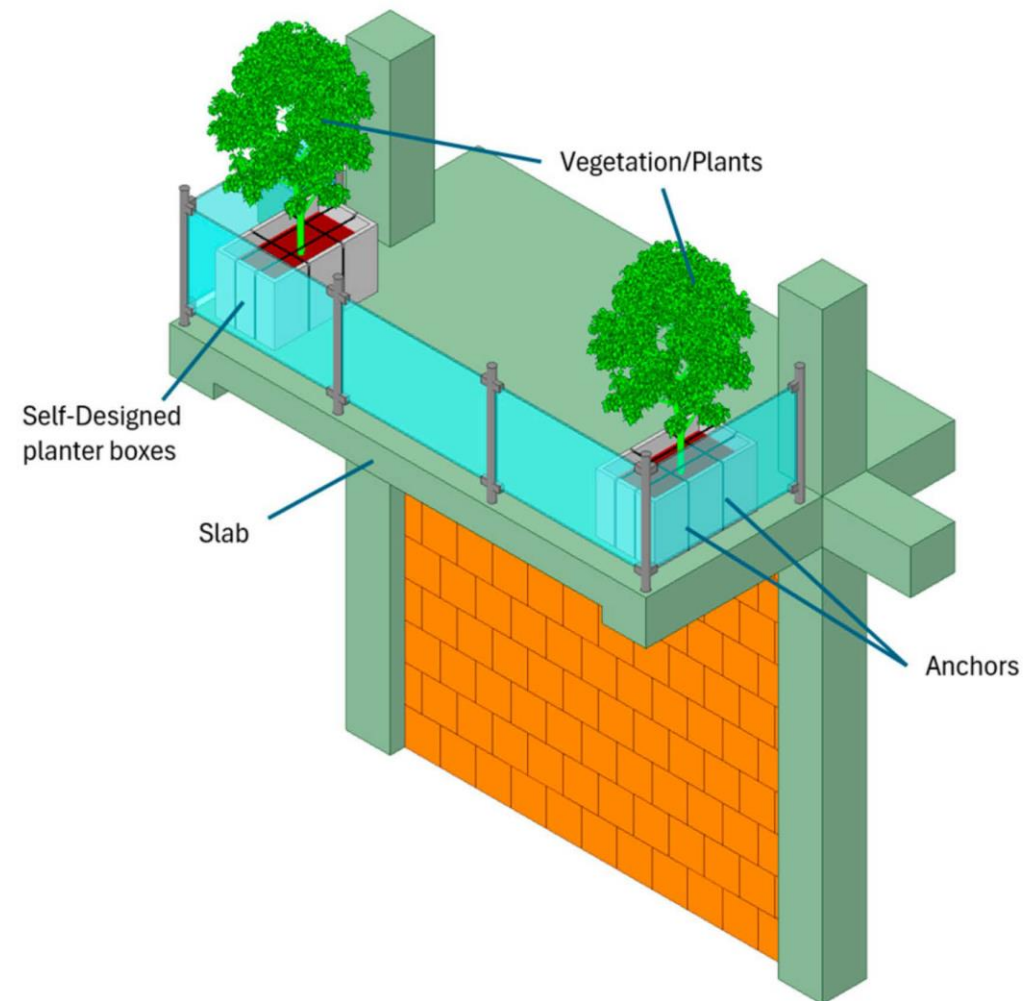
Available: https://psas.scripts.mit.edu/home/get_file.php?name=STPA_Handbook.pdf

System Definition: VF Balcony

Primary Components:

- Structural elements (concrete slab, beams)
- Plant support systems (planter boxes, anchors)
- Plant care systems (irrigation, nutrients)
- Monitoring framework (load, structural health, moisture sensors)
- Human interface (residents, maintenance staff, engineers)

Purpose: Enhance aesthetics and energy efficiency
while maintaining structural integrity



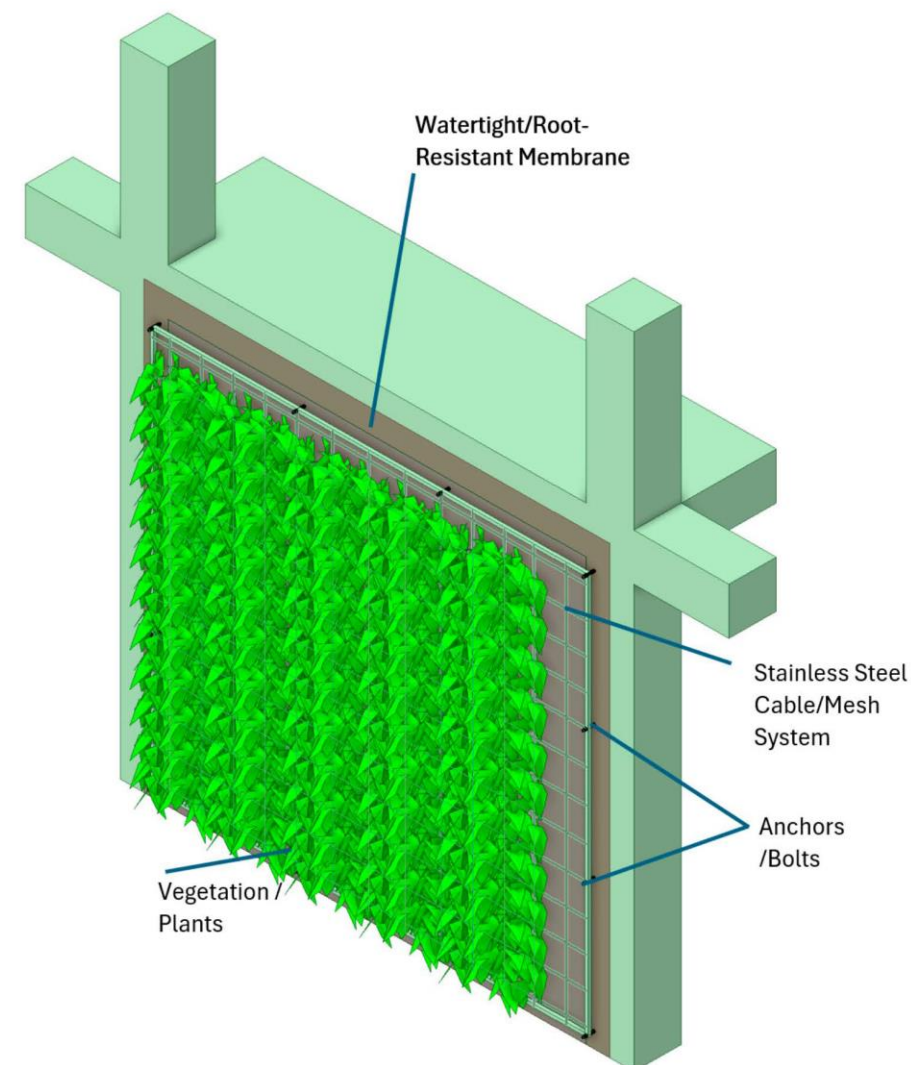
STPA analysis system: VF RC Building Balcony (Vanian et al. 2025)

System Definition: Living Wall

Primary Components:

- Building interface (RC façade, waterproof membrane)
- Structural support (anchors, steel cable/mesh)
- Vegetation (self-climbing plants)
- Irrigation and nutrient delivery systems
- Sensing and control systems
- Maintenance interface

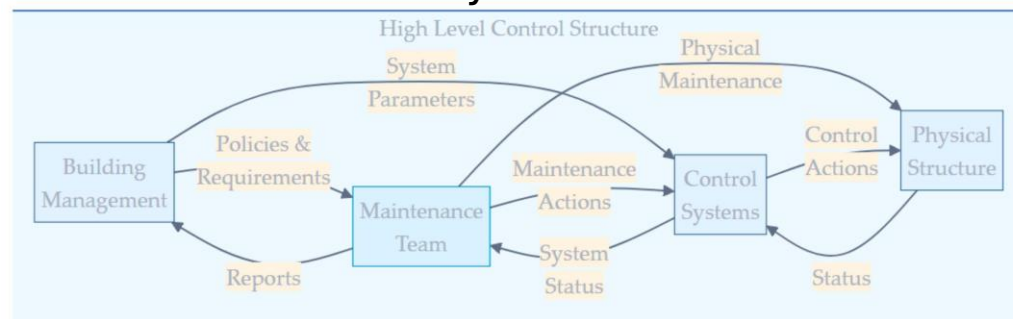
Purpose: Provide green façade with insulation benefits and ecological value



STPA analysis system: RC Building Living Wall (Vanian et al. 2025)

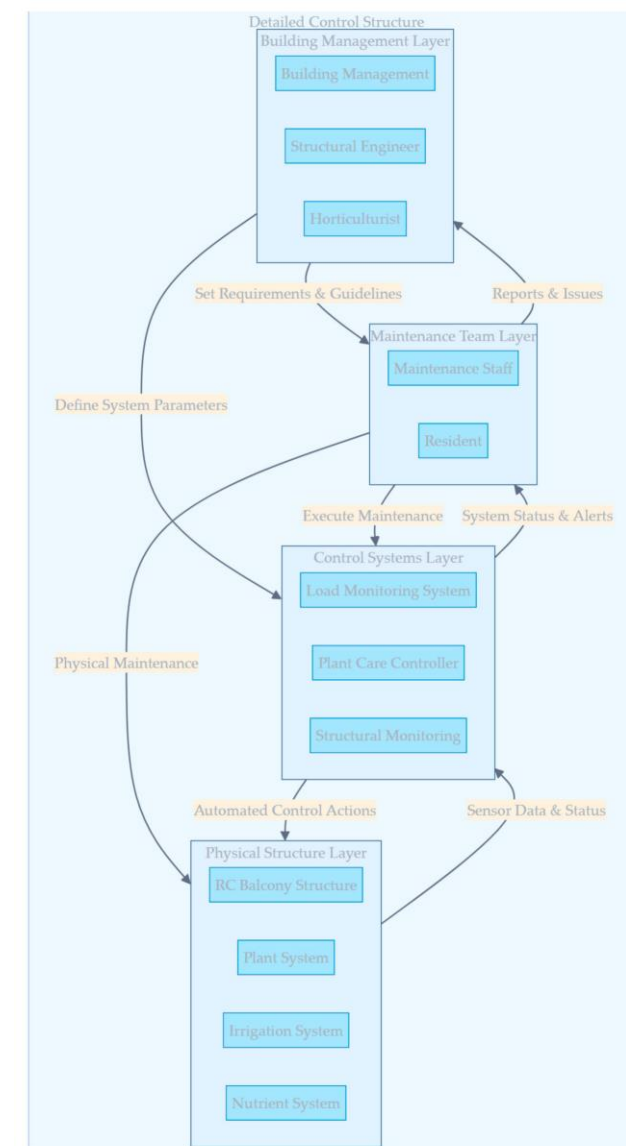
Control Structure Diagrams

- **High-level structure:** Management → Maintenance → Control Systems → Physical Systems
- **Detailed structure:** Specific controllers, feedback mechanisms, and control actions
- **Critical interfaces:** Human-system interactions and automated control systems



(a)

Control Structure for VF RC Buildings Balcony system: (a) high system approach;
(b) detailed system approach. (Vanian et al. 2025)



(b)

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Hazard Analysis

VF Balcony System - Key Hazards:

- H-1: Structural Integrity Hazards (load capacity, deterioration)
- H-2: Plant System Hazards (oversaturation, root invasion)
- H-3: Control System Hazards (sensor failures, monitoring deficiencies)
- H-4: Environmental Interaction Hazards (wind, extreme weather)

Living Wall System - Key Hazards:

- H.1: Structural hazards (excessive load, attachment failures)
- H.2: Water-related hazards (leakage, moisture damage)
- H.3: Plant system failures (uncontrolled growth)

Unsafe Control Actions

Critical UCAs for VF Balcony:

- Not providing shutdown when load exceeds threshold
- Providing excessive water causing oversaturation
- Growth limits not enforced
- No monitoring of critical feedback signals

Critical UCAs for Living Wall:

- No root barriers leading to membrane penetration
- Excess water flow causing building infiltration
- No monitoring of coverage gaps affecting energy efficiency

Safety Requirements & Constraints

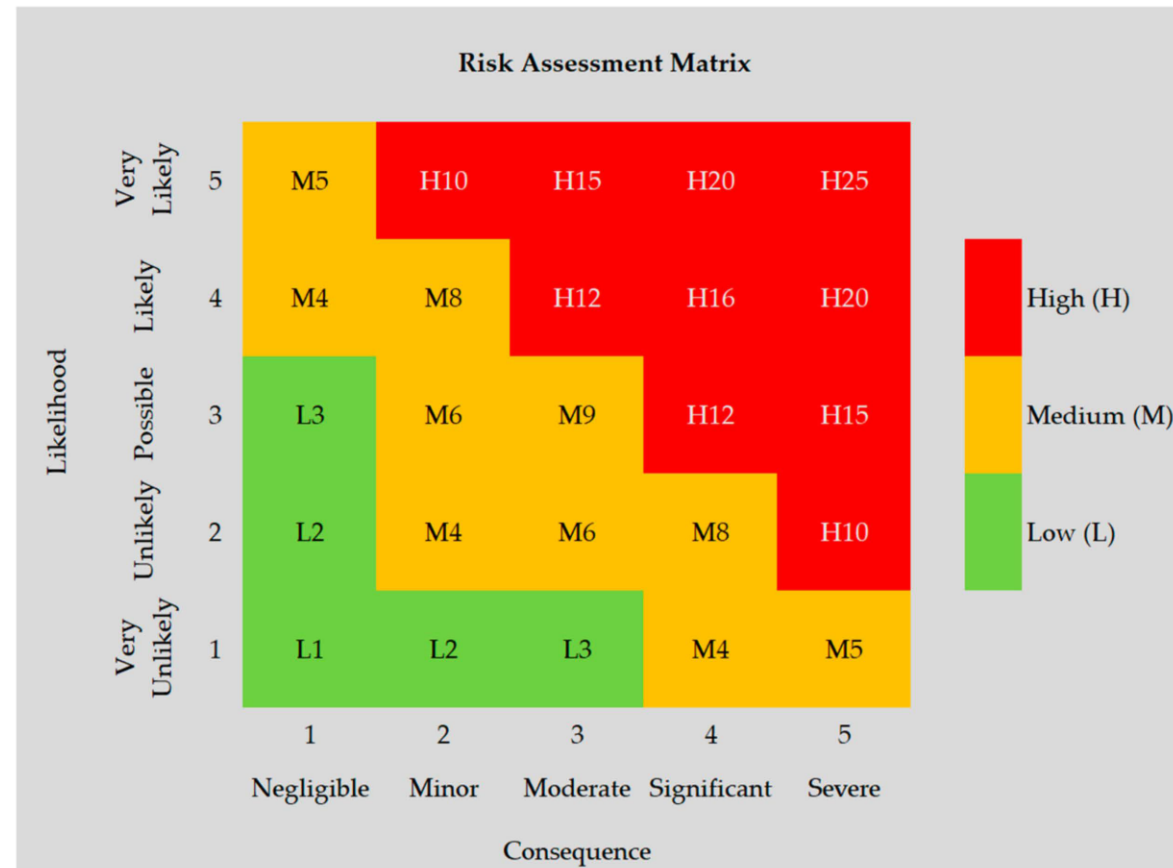
Key Safety Constraints:

- SC-1: Must prevent excessive loading
- SC-2: Must contain root system
- SC-3: Must prevent water infiltration
- SC-5: Must maintain irrigation system
- SC-6: Must control plant growth
- SC-7: Must prevent debris fall
- SC-10: Must maintain control systems

Implementation: Redundant monitoring, regular inspections, automated controls

Risk Matrix

- High risk scenarios (H10-H25): Critical structural monitoring failures (5,2), severe water infiltration (4,3)
- Medium risk scenarios (M4-M9): Control system malfunctions, growth management issues
- Low risk scenarios (L1-L3): Minor sensor calibration issues, temporary maintenance interruptions



Risk assessment matrix to evaluate the risks in systems
VF RC Building Balcony and RC Building Living Wall.
(Vanian et al. 2025)

Key Findings from STPA

1. **Moisture management** is a critical risk factor
2. **Structural integrity** monitoring requires redundant systems
3. **Control system failures** pose significant hidden risks
4. STPA identified **unanticipated failure modes** between subsystems
5. **Bio-structural feedback** creates complex interrelationships (root barrier degradation affecting sensors)
6. **Timing of maintenance activities** can create system destabilization

Comparison with Traditional Analysis

STPA Advantages:

- Identifies interaction failures between subsystems
- Reveals control system vulnerabilities
- Addresses socio-technical factors
- More comprehensive hazard identification

Monte Carlo Results:

- Traditional RC Buildings: Mean risk score 9.47/15
- VF-integrated structures: Mean risk scores 9.72-11.41/15
- Higher risk profile requires enhanced monitoring

Conclusions

- VF systems introduce unique risks requiring specialized monitoring and control
- Safety constraints must address interconnected nature of biological/structural systems
- Implementation requires:
 - Specialized design codes
 - Integrated monitoring systems
 - Standardized maintenance protocols
 - Enhanced control systems

**THANK YOU
FOR YOUR ATTENTION !**

QUESTIONS ?

CHECK THIS OUT

Vanian, V., Rousakis, T., Fanaradelli, T., Voutetaki, M., Macha, M., Zapris, A., Theodoridou, I., Stefanidou, M., Vatitsi, K., Mallinis, G., Kytinou, V., & Chalioris, C. (2025). Performance-Based Damage Quantification and Hazard Intensity Measures for Vertical Forest Systems on RC Buildings. Buildings, 15(5), 769. <https://doi.org/10.3390/buildings15050769>