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Optimal Adaptation of Building Portfolio considering Climate Change Effects

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Considering the increased intensity and frequency of hurricanes, buildings in the coastal regions are exposed to significant risk associated with climate-related hazards. It is of great importance to ensure satisfactory structural performance under the impending climate change scenarios and seek for the optimal adaptation considering different constraints (e.g., budget, structural performance). Thus, the importance of recognizing and identifying adaptation strategies under climate change in a life-cycle context should be stated and more research is needed in this area. However, there have been really limited studies on optimum adaptation planning of buildings under hurricane at a large scale considering uncertainties and climate change effects. In this paper, several of these aspects are addressed. Overall, the main purpose of this paper is to conduct the performance assessment and optimization process of buildings under hurricanes by incorporating possible climate scenarios and to propose a decision-making tool to determine the optimal structural adaptation.

Keywords: Climate Change, Adaptation, Optimization, Life-Cycle.

1 Introduction

Due to the effects of climate change and population growth, the damage of buildings in the coastal areas has the potential to increase significantly under hurricanes. Considering sea level rise and increased intensity of hurricanes, the buildings in these regions are exposed to significant risk associated with climate-related hazards (van de Lindt and Dao 2012). Thus, it is of great importance to investigate and ensure satisfactory structural performance under the impending climate change scenarios and seek for the optimal adaptation considering different constraints (e.g., budget, structural performance) (Frangopol *et al*. 2017). Thus, the importance of recognizing and identifying adaptation strategies under climate change in a life-cycle context should be recognized and additional research is needed in this area (Dong and Frangopol 2016). However, there have been really limited studies on optimum adaptation planning of residential buildings under hurricane at a large scale considering uncertainties and climate change effects. In this paper, several of these aspects are discussed and addressed.

Nowadays, temperature, precipitation, sea level, and coastal storms are all rising at elevated rates, which are related with the greenhouse gas (GHG) emissions. According to Emanuel (2005), the increase in temperature of 1°C can result in an increase of the peak wind speed of a cyclone by 5%. Along with changes in climatic conditions, the earth faces irreversible and catastrophic consequences. Therefore, climate change is an issue that should be recognized worldwide and increased attention must be placed on strategies to design and maintain infrastructure systems that are damage tolerant and safe.

The optimal adaptation actions are investigated herein to improve structural performance under changing climate considering conflicting objectives. Relatively little attention has been addressed to quantify the costs and benefits of climate adaptation strategies (e.g., adaptations to reduce vulnerability of new and existing infrastructure). The importance of recognizing and identifying efficient adaptation strategies under climate change in a life-cycle context is addressed in this paper by using optimization at a large scale considering climate change effects.

The main purpose of this paper is to conduct the performance assessment and optimization process of buildings under hurricanes by incorporating possible climate scenarios and to propose a decision-making tool to determine the optimal structural adaptation. This paper assesses the damage risk, life-cycle loss, cost-effectiveness of adaptation measures, and optimal adaptation plans for residential buildings in a life-cycle context.

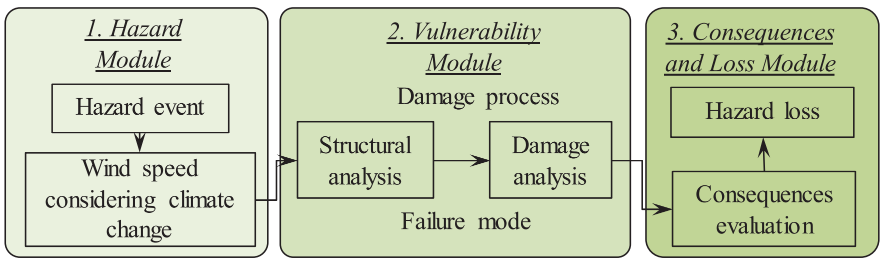

Figure 1. Computational flowchart of performance-based assessment of structural systems under hazard considering climate change

2 Structural Vulnerability Analysis and Loss Assessment under Changing Climate

2.1 *Climate Change*

Climate change can increase the climate-related hazard frequency and intensity; in turn, this can cause an increase of structural damage under hazard effects. In order to investigate the building performance under changing climate, the first step is to identify the possible future warming climate scenarios. In the United States, the majority of the residential buildings is associated with light-frame structures, which are vulnerable to the wind-related hazards (ASCE-7; Li and Ellingwood 2009). The wind speed associated with the investigated location of the buildings should be determined to account for the uncertainties. The probability density function (PDF) of the wind speed under the changing climate is considered. To describe a non-stationary wind process due to climate change, the parameters associated with wind are treated as time-variant. The time-varying Cumulative Distribution Function (CDF) of the wind speed during a hurricane is (Bjarnadottir and Stewart 2011)

$$F_V(v,t) = 1 - \exp[-(\frac{v}{u(t)})^{\alpha(t)}] \tag{1}$$

where $u(t)$ and $\alpha(t)$ are the two site-specific parameters for the Weibull distribution with time considering climate change. Given the investigated wind speed (e.g., hazard intensity), the structural vulnerability and probability of being in different damage states can be computed based on the limit state functions. Then, given the consequences of a structure being in different damage states, the relevant loss can be computed. The computational flowchart of the structural performance and loss under hurricane effects considering climate change is shown in Figure 1.

2.2 *Loss Assessment of Building Portfolios*

Given the building damage analysis, the next step is to assess the loss of the building portfolio within the investigated time interval and monetary discount rate. The losses estimated should include losses caused by both structural damage and property (e.g. contents and nonstructural components). The annual total loss associated with a spatially-distributed building portfolio under a given hurricane event can be computed as the sum of the loss of the buildings within the investigated region and can be expressed as (Dong and Frangopol 2017)

$$RL = \sum_{i=i}^{n_{bu}} l_i \tag{2}$$

where n_{bu} is the number of buildings within the investigated region and l_i is the loss associated with building *i*. Then, the expected total life-cycle loss of buildings within an investigated region can be computed as (Dong and Frangopol 2017)

$$E[TLC(t_{\text{int}})] = \frac{\lambda_f \cdot E(RL)}{\gamma} \cdot (1 - e^{-\gamma \cdot t_{\text{int}}}) \tag{3}$$

where γ is the monetary discount rate; t_{int} is the investigated time interval; and λ_f is the occurrence rate of the hurricane.

3 Optimization Procedure

Under budgetary constraints, the optimization process can be used to determine the optimal adaptation strategy considering both the performance and the cost associated with structural adaptation. The total cost of adaptation actions for an investigated region can be expressed as the sum of all costs. The benefit is assessed by subtracting the total loss considering no adaptation from the total loss with adaptation actions. The outcome of the performance module is the expected total life-cycle loss during the investigated time interval, considering the hazard probability, structural vulnerability, damage, and loss. As indicated in Figure 2, the cost module of the optimization process is used to compute the total structural adaptation cost within the investigated region. Genetic Algorithms (GAs) are adopted with an adequate number of generations to obtain the set of Pareto optimum solutions associated with the multiple objectives problem (Dong *et al.* 2014). The multi-objective optimization problem is formulated as follows:

Given:

Representative hurricane scenario; Configuration of the investigated building portfolio; Effects of structural adaptation on the building performance; Consequence evaluation of building failure; Climate change projection models; and investigated time interval and monetary discount rate.

Find:

Type of structural adaptations within the investigated region

Objectives:
Minimize the total life-cycle loss associated with all the buildings within the investigated region during the investigated time interval and minimize the total structural adaptation cost.

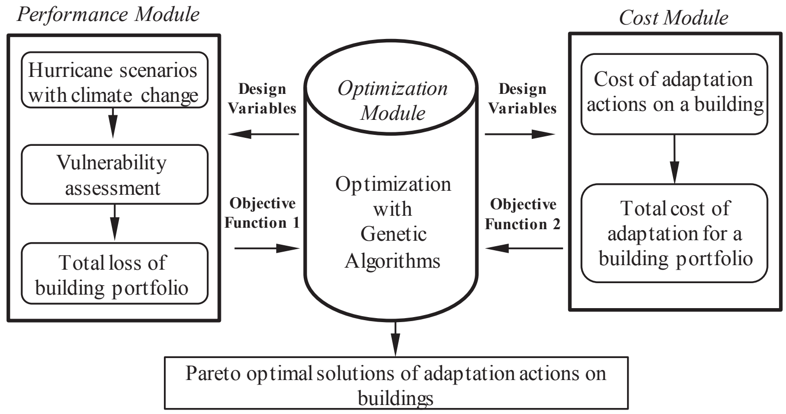

Figure 2. Computational process of the optimization

4 Illustrative Example

As indicated previously, the majority of the residential buildings in the United States is associated with light-frame structures, which are vulnerable to the wind-related hazards. The proposed approach was applied to a portfolio of residential buildings located in Pinellas County, Florida. The portfolio of structures considered herein is a group of residential buildings, which have similar characteristics, such as the number of floors, material types, and geometrical pattern. The single-story building is the most common residential building type. The annual loss of the single building and building portfolio under a given hurricane event is investigated. In order to compute building performance under hurricane, the characteristics of wind speed at the locations of building should be identified. The wind speed associated with a given hurricane event is derived from existing data by fitting a Weibull distribution as indicated in Eq. (1). Based on the recorded hurricane wind speed data in the investigated region, the parameters associated with the Weibull distribution can be determined (Li *et al.* 2016). The investigated time interval has a large effect on the expected value of the life-cycle loss of the buildings. Additionally, as indicated in Dong and Frangopol (2017), the monetary discount rate can also affect the expected value of the life-cycle loss significantly.

Given the cost of adaptation actions, the total loss of investigated building portfolios associated with different adaptation plans of the buildings in a life-cycle context is investigated using Eq. (3). The structural adaption actions considered herein are strengthen the buildings to other updated types of buildings that were constructed later (Dong and Frangopol 2017). Subsequently, by using GAs, the Pareto optimum solutions associated with the multiple objectives are obtained using an adequate number of generations.

5 Conclusion

This paper presented a computational procedure for the buildings adaptation under hurricanes considering climate change. This study fills the gap in the way optimal adaptation of portfolio of structures can be achieved in a life-cycle context considering climate change effects.

Acknowledgments

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