Enhancing Student Preparedness Through Experiential Learning: Lessons Learned from Assessing Building Structural Damages after the January-May 2020 Earthquakes in Puerto Rico

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Abstract*– Puerto Rico is exposed to multiple hazards including hurricanes, earthquakes, and floods. The Resilient Infrastructure and Sustainability Education Undergraduate Program (RISE-UP) at the University of Puerto Rico aims to introduce students to interdisciplinary problem-solving related to real challenges, especially those associated with the occurrence of natural disasters. The objective of this work is to share our experience with experiential learning related to structural engineering. The lessons learned from this experience, from the student´s perspective, could encourage faculty members to develop similar undertakings in their programs and students to participate when opportunities arise. During the 2019 fall semester, we enrolled in a course which covered the relationship between design and natural disasters, with an emphasis on rapid response to recover during the aftermath. The course combined lectures and in-class exercises on basic structural analysis, classifications of structures and the use of the FEMA Rapid Visual Screening (P-154) form. This was complemented with field visits of structures affected by Hurricane Maria where we developed several case studies. From December of 2019 to February 2020, Puerto Rico suffered an earthquake swarm reaching magnitudes as high as 6.4, which caused structural damages throughout the South West of the island. Following these events, we were able to use the training acquired during our course in a real-life, post-disaster situation. At the University, we participated in visual inspection brigades, where we aided professional engineers and faculty members in data collection and categorizing building damages. Our involvement helped streamline efforts as we provided additional support in report writing and organization of the data collected using GIS and other tools. The results of the visual inspections indicated that in many cases pre-existing conditions were aggravated by the earthquakes. Furthermore, we also witnessed firsthand the complexities of assessing infrastructure damage during and following high seismic activity. This experience enhanced our awareness of the significance of our profession in ensuring the safety of others both immediately after an earthquake and in the face of future disasters.

Keywords: Experiential Learning, Resiliency, Structural Damages, Engineering Education, Information Technology

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I. Introduction

In the 2019 Global Climate Risk Index Puerto Rico was listed as the most affected country by climate related events. In the period between 1998 and 2017 more than 2000 deaths were recorded to have occurred as consequence of these events [1]. As a tropical island, Puerto Rico is highly exposed to weather-related hazards like coastal erosion, hurricanes, floods and landslides. Additionally, its unique position among several fault lines also makes the island vulnerable to earthquakes and tsunamis.

The majority of Puerto Rican infrastructure was built in the 20th century during an economic boom brought on by rapid industrialization. During this time, the local government underwent large expansions on public infrastructure including the electrical grid, the aqueduct system and the roads. As a Commonwealth of the United States of America, for many years the island received federal tax exemptions that prompted manufacturing industries to set up factories on the island. However, in 1996, the federal government repealed these tax incentives and the island began an economic decline. The 90s marked the final major governmental investment in public infrastructure. Puerto Rico has been in a recession for over a decade, after GDP growth began to decline in 2005 [2], and the government began shifting towards authority measures. By the 2000s, the island's infrastructure already was in a decaying state due to a severe lack of maintenance and oversight. In 2016, the federal government instated a Federal Oversight Board to manage the island's finances and ensure payment to bondholders which has resulted in more severe authority measures [3].

In 2017, Puerto Rico was hit by two subsequent hurricanes, Irma and María, heavily affecting the already vulnerable infrastructure. This caused a near total collapse of the electrical grid's distribution system [4] as well as an interruption in water distribution services and collapse of mayor public infrastructure like roads and communication towers. Reinstating functioning basic utilities like power to nearly 97% took over seven months after the passage of the hurricane [5]. The resulting damage totaled an estimated $90 billion (USD), making it the third costliest tropical cyclone in modern US history [6]. A delayed and haphazard response by state and federal government authorities also triggered a humanitarian crisis that caused more than 4000 deaths [7].

The aftermath of María highlighted the need for resilient and sustainable infrastructure on the island. With the intensity of weather-related events expected to rise due to the climate crisis, the level of exposure and danger that events like María pose is even greater [1]. There is now an urgent demand for resilient practices in STEM professions. Considering this, the Resilient Infrastructure and Sustainability Education Undergraduate Program (RISE-UP) was developed at the University of Puerto Rico and is funded by the National Science Foundation (NSF). The program aims to prepare the next generation of architects and engineers for the climate realities they may face when designing and building infrastructure. To achieve this, it combines students from the School of Architecture, and the College of Engineering, including Electrical Engineering, Civil Engineering and Surveying across three campuses of the University of Puerto Rico (UPR). These three participating campuses are: UPR-Mayagüez (UPRM), located in the west of the island; UPR-Ponce (UPRP), located in the south of the island; and UPR Río Piedras (UPRRP), located in the San Juan metropolitan area. The curriculum is ambitiously interdisciplinary with a core team of professors representing each faculty and guest speakers from multiple disciplines. This allows the program to combine multiple learning perspectives and strategies aiming to optimize student learning.

During the 2019 fall semester, we took the first course of the RISE-UP curricular sequence titled *Fundamentals of Resilient and Sustainable Infrastructure.* In this course we explored the relationship between design and natural disasters, with an emphasis on rapid visual response to recover during the aftermath. In the course, we were introduced to the complexities of assessing infrastructure damage following natural disasters and were trained in using the Federal Emergency Management Agency (FEMA) Rapid Visual Screening (P-154 form) [8].

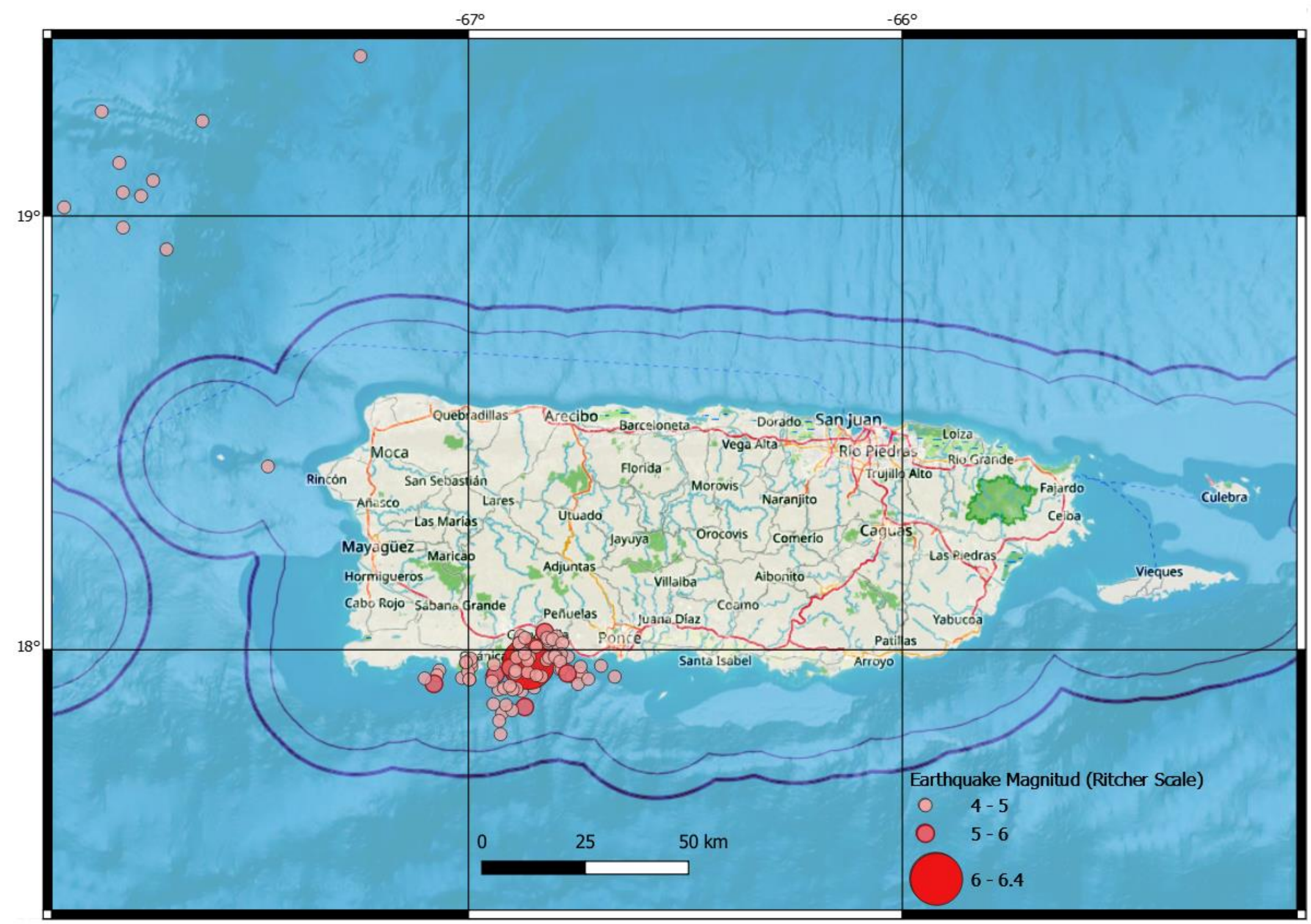

Figure 1. Map illustrating the hypocenter of earthquakes with magnitudes greater than 4 on the Richter Scale registered in the period from January to May 2020, figure adapted from Puerto Rico Seismic Network.

In December of 2019, Puerto Rico began experiencing an earthquake swarm which has extended until the present. Approximately, 92 earthquakes with a magnitude greater than 4 on the Richter scale have been registered in a period of six months (Figure 1) [9]. These reached magnitudes of up to 6.4 on the Richter scale, causing structural damages throughout the South West of the island. Due to this, classes were delayed temporarily at UPRM until building safety could be assessed. A Visual Inspection Committee was assembled on campus. The team was comprised of Professional Engineers (P.E.s), Professors, Graduate and Undergraduate Students from the Department of Civil Engineering and Material Science and Engineering. The Committee conducted over 60 campus building inspections and provided recommendations on repairs and improvements.

II. Methodology

The learning process was divided into four main phases, which correspond to the primary learning strategy experienced. The first phase included lectures, the second phase included field visits to conduct case studies, the third phase included a real-life application, and the fourth phase included reflecting on the experience and the lessons learned. Figure 2 shows the methodology.

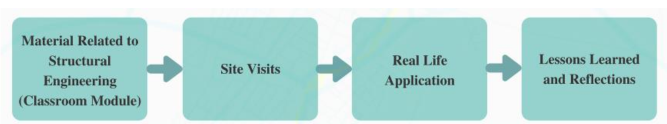

Figure 2: Methodology

III. Results

The results of the first three phases are shown below. The reflection on the experience and the discussion of the lessons learned are presented in the discussion and conclusions section.

A. *Lectures*

Given the multidisciplinary approach to our course, the lectures related to structural engineering were given by two professors from different campuses, both experts in the field of structural engineering and seismic design. We first received an introductory lecture giving an basic structural analysis of earthquake loads, different types of structures, earthquakes sciences and the use of the Rapid Visual Screening (RVS) method (P-154 form).The objective of this particular lecture was to present how structural safety can quickly be assessed utilizing this method and also how the form was created, its purpose and how to fill out each individual section. Subsequent lectures were focused on in-depth structural analysis; these covered the 2018 Puerto Rico Building Code (PRBC), possible hazards and common design flaws that make structures more vulnerable to earthquakes.

B. *Field Visits to Conduct Case Studies*

After completing the lectures, we participated in several field visits to assess the safety of the structures at the site.

The first visit was to UPR campus at Ponce. Here teams were divided into groups and assigned one building each. The main purpose of this exercise was getting students acquainted with identifying the structure type of buildings and clarify doubts related to structural system classification.

The second and third visits were planned in sites which had been severely affected by María. The first of these was a basketball court and the second a baseball field, both in the municipality of Peñuelas. At each site, teams were prompted to carry out the RVS Method and determine the safety level of each structure. Afterwards, we reported our findings in case studies through a cloud collaboration software. Figure 3 shows a sample completed RVS form.

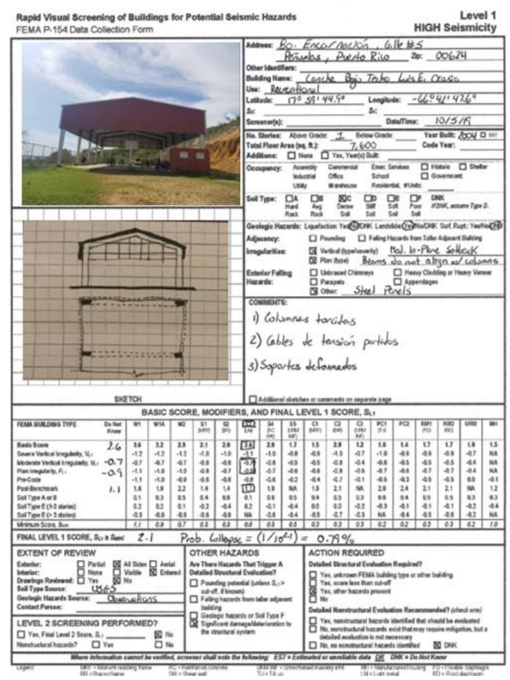

Figure 3: Sample of Completed RVS form

C. *Real-Life Application*

After the earthquake of magnitude 6.4, we began collaborating with the Visual Inspection Committee at UPRM. The Committee divided into teams, and each team was assigned several buildings to inspect each day. After the inspections, the findings were comprised in a collaborative report that was then shared with the University Administrators. In the report, we categorized damage in the following categories: structural (damages such as cracks or fissures in structural elements like beams and columns), nonstructural (damages in architectural or decorative elements) and pre-existing conditions (damages caused by wear such as moisture related problems, not caused

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by the earthquakes). To aid in the inspection process, special attention was given to buildings built prior to 1968 (pre-code in FEMA P-154 form), structures showing maintenance problems and building with apparent short columns or heavy overhangs [10]. After the results were published, we used the information to develop a GIS, which has been used by the university to streamline repair efforts at UPRM. Figures 4-6 show the results of the inspections.

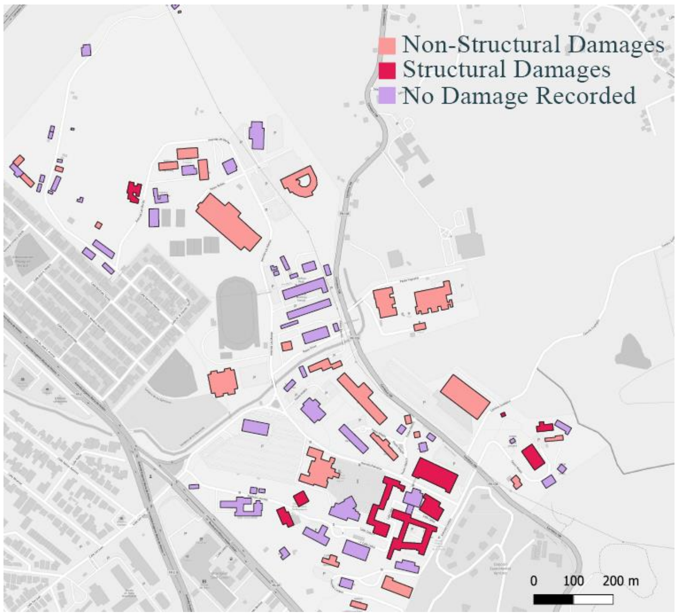

Figure 4: Map of structural and nonstructural damage

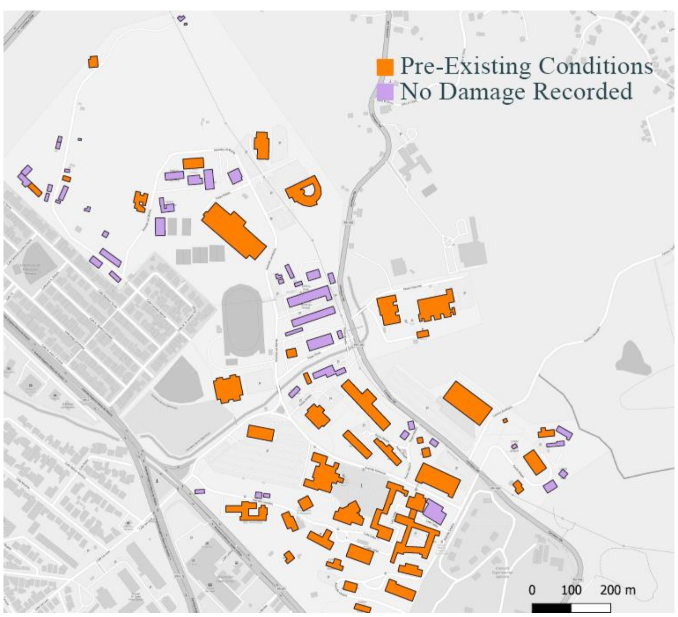

Figure 5: Map of buildings with pre-existing conditions

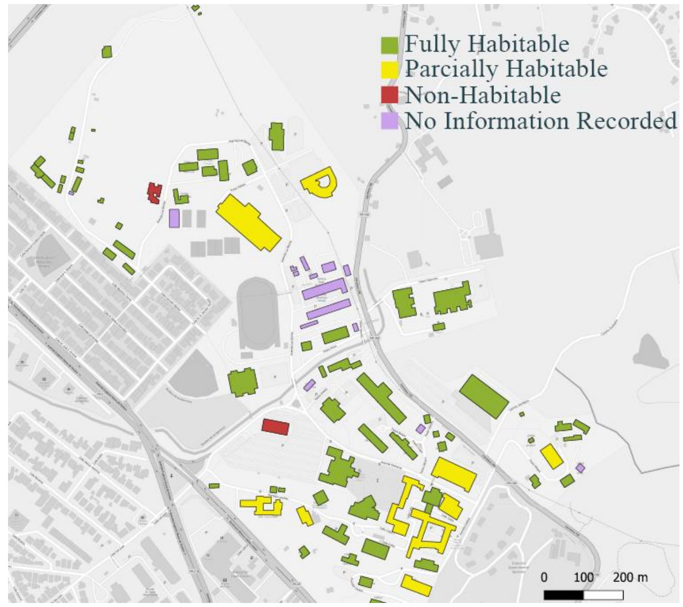

Figure 6: Habitability map of UPRM Buildings

IV. Discussion

The class exercises and case studied allowed us to gain greater understanding of post-disaster safety assessment. Our participation in post-earthquakes inspections provided a real-life experience to apply the knowledge gained in the course. Here we helped accelerate the inspection process by readily integrating into the RVS Committee. With the reports published by the Visual Inspection Committee, we created a GIS to help visualize building damages on campus. Using GIS, we were able to determine that most buildings on the campus met full habitability criteria. Two buildings were categorized non-habitable; one sustained heavy damage following the earthquake swarm, while the other was deemed non-habitable following María. By including pre-existing conditions, we were also able to determine that most buildings which sustained damages following the earthquakes also had deteriorated conditions which most likely made them more vulnerable during seismic events. The reports included several repair recommendations to address damages from the earthquakes and to address potential future vulnerabilities of the buildings.

V. Conclusions

Through the learning experiences provided in the introductory course we were able to gain dominion over methods rapidly applicable in the wake of a natural disaster. Being exposed to diverse leaning environments allowed us to gain practical knowledge related to concepts studied in the course and participate in relief efforts following the events of the earthquakes. Participating in a real-life post-disaster recovery scenario allowed us to witness firsthand the complexities of assessing infrastructure damage following high seismic activity. Most notably, the knowledge gained in the course allowed us to help streamline relief efforts and make notable contributions using Information Technology. The deterioration of structures observed during inspections highlighted the importance of efficient design and infrastructure maintenance. The combination of these experiences enhanced our awareness of the significance of our profession as future engineers in ensuring the safety of others both immediately after an earthquake and in the face of future disasters.

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REFERENCES

[1] Eckstein, D., Hutfils, M.-L., & Winges, M. (2018). Global Climate Risk Index 2019. Who Suffers Most From Extreme Weather Events? Weather-related Loss Events in 2017 and 1998 to 2017. https://germanwatch.org/files/Global%20Climate%20Risk%20Index%202019_2.pdf.
[2] The Perfect Storm: How Climate Change and Wall Street Almost Killed Puerto Rico, Rolling Stone. https://www.rollingstone.com/politics/politics-features/puerto-rico-hurricane-maria-damage-722570/
[3] The story of Puerto Rico's power grid is the story of Puerto Rico, The Economist. https://www.economist.com/united-states/2017/10/19/the-story-of-puerto-ricos-power-grid-is-the-story-of-puerto-rico
[4] Kwasinski, A. & Andrade, Fabio & Castro-Sitiriche, Marcel & O'Neill-Carrillo, E.. (2019). Hurricane Maria Effects on Puerto Rico Electric Power Infrastructure. IEEE Power and Energy Technology Systems Journal. PP. 1-1. 10.1109/JPETS.2019.2900293.
[5] Puerto Rico One Year After Hurricane Maria, Center for Puerto Rican Studies Hunter College. https://centropr.hunter.cuny.edu/sites/default/files/data_briefs/Hurricane_maria_1YR.pdf
[6] Costliest U.S. Tropical Cyclones Tables Updated, National Hurricane Center. https://www.nhc.noaa.gov/news/UpdatedCostliest.pdf
[7] Mortality in Puerto Rico after Hurricane Maria, The New England Journal of Medicine. https://www.nejm.org/doi/full/10.1056/NEJMsa1803972
[8] FEMA. (2015). Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook (P-154).https:// www.fema.gov/media-librarydata/1426210695633d9a280e72b32872161efab26a602283b/FEMAP-154_508.pdf.
[9] Sismos Significativos Más Recientes, Red Sísmica de Puerto Rico. http://redsismica.uprm.edu/Spanish/php/CatalogS/Mseismicity.php
[10] Jain, Sudhir K., et al. "A Proposed Rapid Visual Screening Procedure for Seismic Evaluation of RC-Frame Buildings in India." Earthquake Spectra, vol. 26, no. 3, Aug. 2010, pp. 709–729, doi:10.1193/1.3456711.