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Developing Case Studies for a Repository for Resilient Infrastructure and Sustainability Education following a Natural Disaster

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Abstract

To preserve the stories of resiliency and document the infrastructure damages caused by Hurricanes Irma and María and the 2020 earthquakes in Puerto Rico, the timely collection of evidence is essential. To address this need, case studies of damages caused by the natural disasters and a repository of information aimed to keep record and centralize information regarding relevant cases that provide examples of evidence of infrastructure damages and processes worth preserving is needed.

To develop said case studies and a repository, a two-prong approach was used in this study. First, the case study methodology was followed. According to Yin, a case study is "an intense study of a single unit with the purpose of a larger class of (similar) units". Case studies are used in academia for both research and teaching purposes. Our research team advocates for the use of case studies as tools to inform both learning and decision-making. Secondly, the repository model was developed.

This paper presents the results of the development of the repository and includes sample case studies. The repository allows students, academics, researchers, and other stakeholders to understand the impact of extreme environmental conditions on the built environment. Faculty can use the repository in their courses to teach Architecture, Engineering and Construction students topics related to resiliency and sustainability in the build environment. Each case study developed and deposited in the repository, answers to research questions regarding what, how and when the damages happened, who were the stakeholders involved in the processes, what were their actions, and what are the lessons learned. The case studies have the potential of becoming responses to hypotheses for those mining the repository. The paper contributes to the body of knowledge by presenting the results of the development of case studies and a database that can be used for both research and teaching purposes. These can be replicated in the US and other countries, in need of recording and systematizing information after natural events.

Introduction

Preserving information that documents the infrastructure damages and reconstruction actions that affect the built infrastructure after catastrophic environmental events is core to the improvement to potential future mitigation and rebuilding actions. Following the devastation caused by Hurricanes Irma and Maria in Puerto Rico in 2017, there was an increased awareness regarding the importance of preserving the nature of extension of the impact of those events in the island's infrastructure, as well as the role that professionals, government and community-based communities had in the pre- and post-hurricane situations associated with the performance of those infrastructural elements in the context of sustainability and resiliency [1].

In alignment with these concerns, our research team received funding from the National Science Foundation for a project titled ¨Resilient Infrastructure and Sustainability Education – Undergraduate Program (RISE-UP). RISE-UP includes the development of a case study database to preserve the nature of extension of the impact of the damages caused by the hurricanes, in the context of the academic project. The project is aimed to carry out research and developing case studies of real scenarios related to infrastructure, starting with the damages caused by the 2017 hurricanes in Puerto Rico, in the context of an interdisciplinary academic project involving three Campuses at the University of Puerto Rico.

The University of Puerto Rico consists of eleven campuses, each offering different academic programs. Rio Piedras Campus, in the San Juan metropolitan area, houses the School of Architecture; Mayaguez Campus, in the west part of the island, houses the College of Engineering; and Ponce Campus, in the south part of the island, offers two-year associate and articulated degrees in Engineering and Construction. Prior to the implementation of this initiative, the Architecture/ Engineering/ Construction (AEC) curriculum had students developing in silos, without the required interaction and learning experience of work with other infrastructure-related disciplines [1]. Commonly, the academic preparation of scholars on infrastructure-related disciplines takes place in disjunct professional domains as the one described [2], [3] rarely tackling interdisciplinary problem-solving, nor focused on a systematic understanding of research results and lessons learned from previous disaster experiences.
To provide a solution to this important split, we designed RISE-UP as a collaborative platform among the three campuses, to allow Faculty from the three Campuses to develop an integrated curriculum that is currently offered as a minor degree. Providing a shared academic space for the interdisciplinary, students from Architecture/ Engineering/ Construction (AEC) fields exposed to common learning experiences fosters their ability to collaborate as professionals and foresee the importance of their contributions as integrated multidisciplinary teams.
The RISE-UP curricular sequence consists of four courses that are part of a minor degree that is complemented by internship and undergraduate research opportunities. The courses are taken sequentially in a process that builds on previous courses to deepen the level of knowledge as students advance in the curricular sequence [4].

Project Approach

The research design for this project consists of a quasi-experimental approach because it does not provide full control of potential confounding variables [1]. For RISE-UP we used a combined models' approach, by modeling the courses on a Project Based Learning (PBL) based on case studies. With PBL, we expect that students in the program will learn through their own experience, by dealing with real life situations. The exposure to these situations is reported via Case Studies [5][6]. A case study is an intense study of a single unit with the purpose of a larger class of (similar) units [7]. Case studies are used in academia for both research and teaching purposes. Our research team advocates for the use of case studies as tools to inform both learning and decision-making.

Results

During the first two years of the project, the following outcomes related to the case studies have been achieved: 1) development of case studies on situations associated with disaster and interdisciplinary responses; 2) development of the case study cloud-based repository.

Development of case studies on situations associated with disaster and interdisciplinary responses.

RISE-UP students, as part of their course assignments, have developed case studies. Below are two examples of case studies developed to date.

Initial Approach to Case Studies: Seismic Vulnerabilities of Schools in Puerto Rico

To achieve the goal of developing encouraging students to bring their different individual and professional approaches to the case studies starting with the first course of the curricular sequence, the students were assigned to teams based on their programs of study. Table 1 shows a sample of an interdisciplinary team composition. Student teams were asked to write a report which consisted of the outline structure shown in Table 2.

Table 1: Sample interdisciplinary student team for case study development.

Student Team by Discipline Student´s Program of Study
Environmental Design
Environmental Design
Civil Engineering
Civil Engineering
Surveying
Electrical Engineering

Table 2: Case study outline.

Case Study Outline
Title
Description
Actors involved
Location
Environmental condition studied (earthquake, landslide, liquefaction, etc.).
Narrative (what happened, evidence (photos, etc.), lessons learned, courses of action)
References
Acknowledgement

One of the assignments in the first course of the RISE-UP curricular sequence consisted of using the case study approach to study the impact of the earthquakes that occurred in the Southwest area of Puerto Rico between the months of December to February 2020. A total of 34 students, divided into 6 interdisciplinary teams, completed the case study assignments. The overarching topic for the case studies was the impact of the earthquakes in schools. Interdisciplinary teams of students were allowed to select the focus of their study based on their interests. Each student team selected a different approach to address the challenge, for example, a team included the assessment of the impact to specific structures and communities, another team focused on recycling materials from a collapsed school, etc. The initial case studies developed as part of the Fundamentals in Resilient and Sustainable Infrastructure course provided students with the necessary tools and skills to be able to develop in-depth case studies in the advanced courses.

In-depth Case Study: Structural Assessment and Proposed Solution for the Elvira Vicente School in Yauco, Puerto Rico

This case study is linked with the initial RISE-UP course where an interdisciplinary team was focused on learning how to perform structural assessments of buildings using technical tools such as those from Federal Agencies (FEMA) or Research Institutes (Applied Technology Council). The different teams of students and professors were assigned based on their programs of study but having in mind not only each personal interest but the benefit to have interdisciplinary learning experiences. Table 3 shows the interdisciplinary team composition. For this learning and research case study project four (4) students and one (1) professor were assigned. One student from Civil Engineering, two students from Architecture and one student from Electrical Engineering. Two University Campuses were involved: Mayaguez and Rio-Piedras.

Table 3: Interdisciplinary student team for case study

Student Team by Discipline **Student´s Program of Study**
Civil Engineering
Architecture
Architecture
Electrical Engineering

The first activity for all teams was a series of virtual conferences prepared by each professor assigned as a team mentor. The topics covered were related with natural hazards, seismic vulnerability in Puerto Rico and structural behavior of buildings and civil infrastructure. After these conferences, each professor assigned group work where each team was able to select a topic to explore and expand their knowledge based on their preferences. Table 4 describes the first conference offered by the mentor's group and the themes that each group selected as a working topic to present the first document to be evaluated. Each theme was developed using documentation, bibliographic references, and internal coordination among the students to produce a document that helps to understand concepts, references and organize students into the main theme to be developed in this course.

The main theme of this RISE-UP course consisted in assessing the actual seismic risk of the public-school buildings in Puerto Rico, having in mind that many of them were designed and constructed several decades ago and are still in use. In this case, the mentor made the contact with the local Government Office in charge of the maintenance and improvements of school buildings in PR (OMEP), to obtain original construction documents, including architectural and structural plans. At least five school construction documents were available. The selected building had a typical structural system observed in many local schools and it was known that this school was affected by the seismic activity in the south area of Puerto Rico on January 7, 2020.

Table 4: Conference case study outline.

Case Study Outline
Title: Seismic Vulnerability in Puerto Rico
Description: Seismic hazard in PR including Tsunami and Liquefaction risks
Participants: All the teams
Location: Puerto Rico
Environmental condition studied: earthquake risks, building fragility, code compliance, tsunami risks, liquefaction maps, power plants risks, methods for structural retrofitting.
Reaction: The conference helped student understand the real seismic risk of structures. Many of them were not aware of the geomorphological conditions of the Island of Puerto Rico and the poor governmental planning, in particular the location of important public infrastructure in zones with higher risks of tsunamis and liquefaction. As consequence of this conference, four themes were selected by each team, these were: 1- The Reliability of the PR Power Plants under the seismic risk. 2- Advanced Methods to improve the seismic response of buildings. 3- Areas of Puerto Rico with high risk of Tsunamis. 4- Seismic vulnerability of urban downtowns of PR municipalities.
References for the students, regarding other similar studies (provided in the class): • Mazzei, Patricia, et al. "With Earthquakes and Storms, Puerto Rico's Power Grid Can't Catch a Break." The New York Times, The New York Times, 10 Jan. 2020, www.nytimes.com/2020/01/10/us/puerto-rico-electricity-power-earthquake.html. • Null, Null, and Anshel J. Schiff. "Guide to Improved Earthquake Performance of Electric Power Systems." Books, American Society of Civil Engineers, 21 Mar. 2013, ascelibrary.org/doi/book/10.1061/9780784404140. • Philippe Roux, Dino Bindi, Tobias Boxberger, Andrea Colombi, Fabrice Cotton, Isabelle Douste-Bacque, Stéphane Garambois, Philippe Gueguen, Gregor Hillers, Dan Hollis, Thomas Lecocq, Ildut Pondaven; Toward Seismic Metamaterials: The METAFORET Project. Seismological Research Letters; 89 (2A): 582–593. doi: https://doi.org/10.1785/0220170196 • Información Sísmica (Terremoto del 1918), Red Sísmica de Puerto Rico. http://redsismica.uprm.edu/Spanish/informacion/terr1918.php • Presentación Plan de Uso de Terrenos, Junta de Planificación de Puerto Rico. http://jp.pr.gov/Portals/0/Plan%20de%20Usos%20de%20Terrenos/Presentaciones/Presentaci%C3%B3n%20Plan%20de%20Uso%20de%20Terrenos_Para%20p%C3%A1gina%2 0web.pdf?ver=2017-05-10-160439-963 • Mapas de Desalojo, Red Sísmica de Puerto Rico. http://redsismica.uprm.edu/Spanish/tsunami/programatsunami/prc/maps/todos.php • Ciudades Más Pobladas de Puerto Rico, Geodatos. https://www.geodatos.net/poblacion/puerto-ricoProject. Seismological Research Letters; 89 (2A): 582–593. doi: https://doi.org/10.1785/0220170196

The first task between the faculty mentor and the students was to familiarize themselves with the construction drawings, mechanical properties of materials, inadequate construction details, lack of modern code compliance, etc.
The students learned how to model a building structure using specialized software. During various sessions they were trained to understand and use ETABS structural software. The team was able to model and run the software applying the load cases and combinations, using the applicable seismic forces for the location of the building. Figure 1 depicts the 3D model of the school under evaluation (Figures 1 to 5 from [8]).

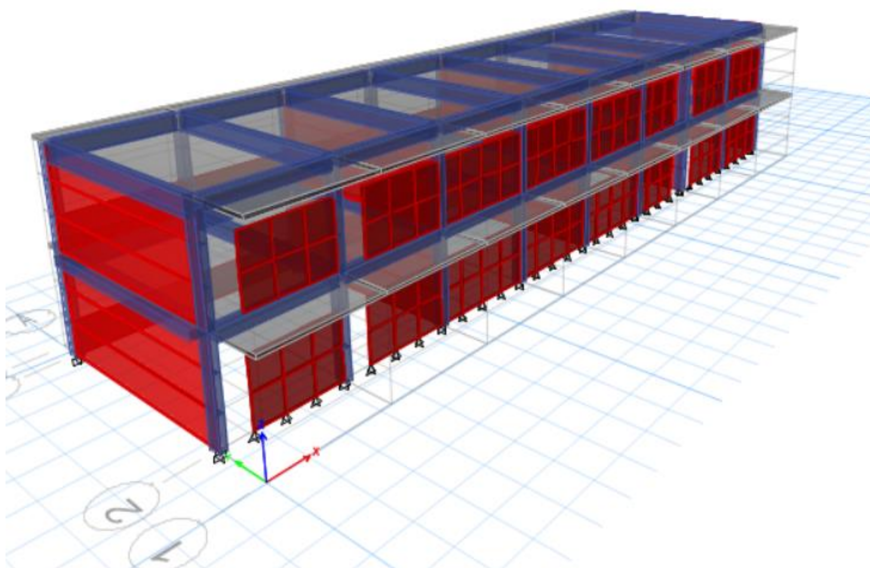

Figure 2- Structural Modeling by students using ETABS software. From [8].

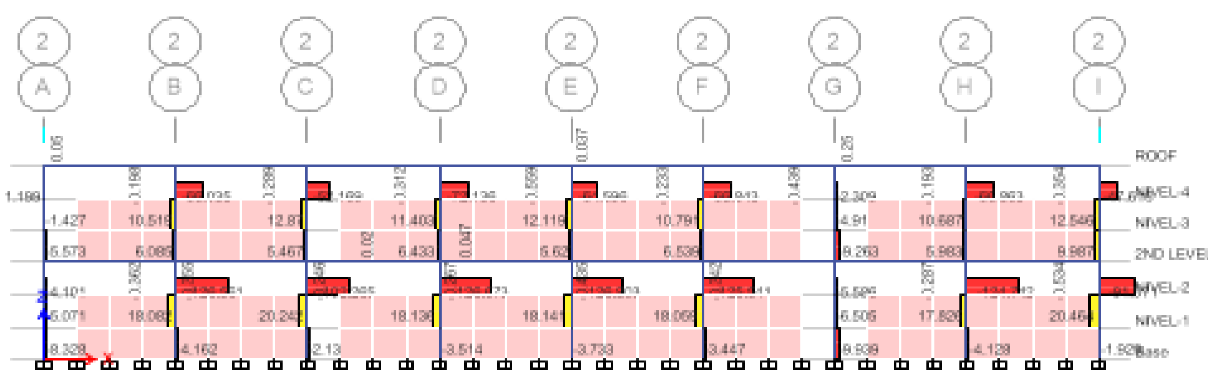

Figure 1- Short-column effect on columns. From [8]

Once the team had specific results, they analyzed and interpreted the internal forces developed by main structural components. The students were instructed on how to verify the actual strength of reinforced concrete elements such as columns and beams. Using the mechanical properties of these materials they would be able to detect structural problems such as: “short-column effect”; “insufficient development length of steel reinforcement”, “pounding”, “excessive building displacement”, among others. Figure 2 shows a frame elevation with forces on columns with “short-column effect”.

Once this phase of the course was done, all the teams made a presentation showing their progress on each project. The presentation included open discussions, questions, and suggestions.
The last part of course consisted of exploring the retrofitting options to improve the seismic behavior of the building. These options not only were studied considering the structural practicability but also the cost and expected time to implement the solution. In this task, the collaboration between engineering and architecture students was evident as they made decisions on aspects related with facades, natural ventilation and illumination, accessibility issues, and aesthetics to understand what type of alternatives are possible. Figure 3 shows one of the final structural retrofitting options selected and Figures 4 and 5 depict the interior and exterior architectural modifications to the school based on the proposed solutions [8].

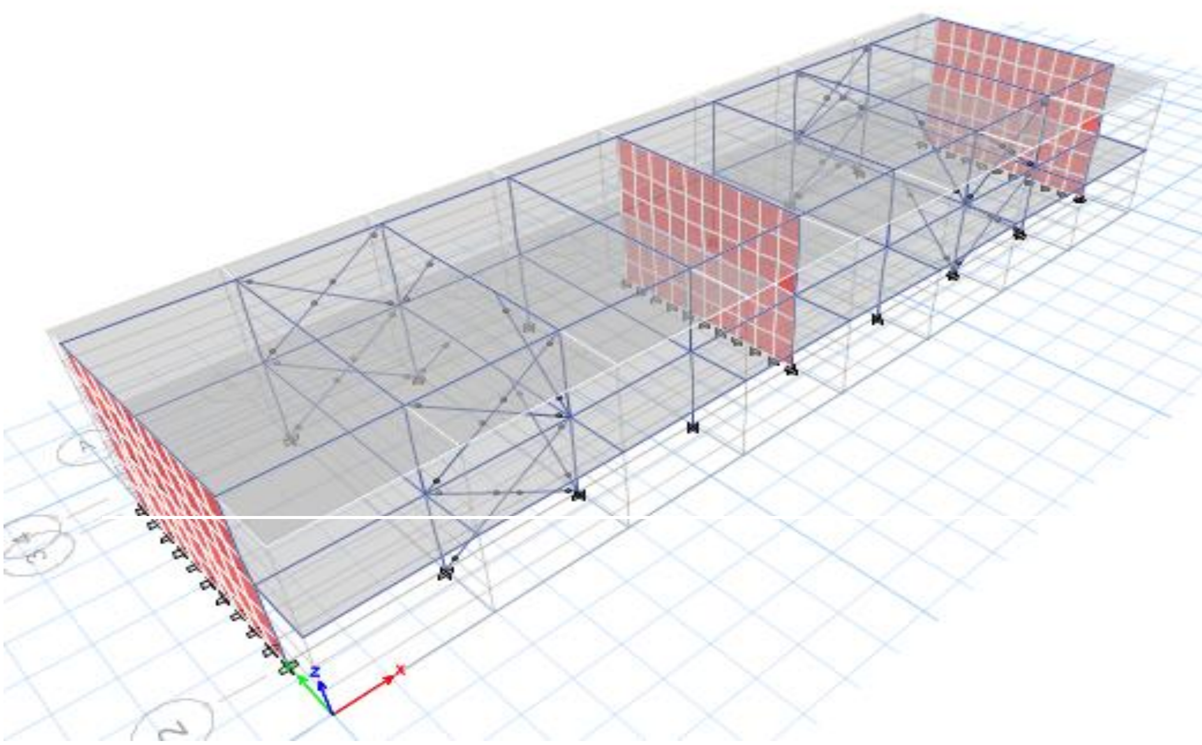

Figure 3- Cross bracing option. From [8]

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Figure 4- Interior view of retrofitted building. From [8]

Figure 5- Exterior view with facades modifications. From [8].

The final activity consisted of preparing a final report and presenting the case study for the scrutiny of other students and mentors. The students answered questions, reflected on the lessons learned including how this course contributed to their academic preparation.

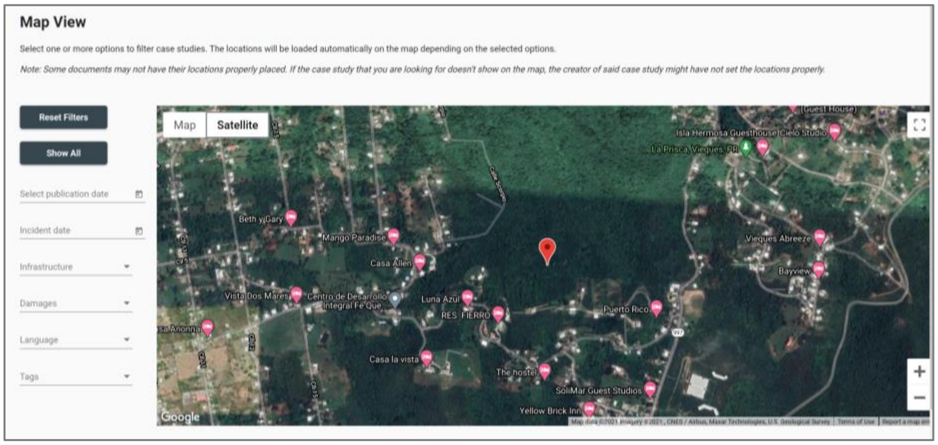

Figure 6- "Map" search screen of the case study repository.

Current state of development of the case study cloud-based repository

The cloud-based case study repository has been developed, it is already functional and allows users to input information and perform data mining. Users of the repository are provided with an interface that allows the development of visualizations, searches, filtering, and other activities. Figure 6 includes an example of the "Map" search screen of the case study repository. This screen allows to search and screen the cases based on location, type of infrastructure, environmental disaster type, date, and type of damage. Figure 7 provides an example of the plot comparison visualization.

The repository currently consists of two spaces that allows users to perform tasks: 1) TellSpace: This is the environment in which cases are reported. Here, information is introduced in the repository, and 2) SearchSpace: This one is the space in which the mining of the data takes place at. Users of the repository are provided here with an interface that allows the development of visualizations, searches, filtering, and other activities to enable the identification and creation of relationships between the cases, fostering the development of explanatory models, the exploration of commonalities between the stories, and elaborate and unveil narratives based on the stories initially reported via TellSpace.

Figure 7: Plot comparison visualization in the case study repository.

Conclusions

For the first two years RISE-UP has met its goals, as it has provided a mechanism for students to learn how to conduct case study research and to understand and document the impact of extreme environmental conditions on the built environment. The cloud-based case study repository is functional and used by RISE-UP students and faculty. The case studies developed have the potential of becoming responses to hypotheses for those mining the repository.

The case study examples presented in this paper focused on the seismic vulnerability of public schools in Puerto Rico, a timely and relevant topic. Currently, the seismic vulnerability of schools remains an unsolved problem. The interdisciplinary student team composed of engineering and architectural students offered a diverse perspective and experience about interdisciplinary collaboration, teaching strategies and learning effectiveness, using small teams. Considering that many technical aspects applicable to this project at the beginning of the course were unknown by the students, and despite the short time duration and different academic backgrounds, leads us to conclude that students were able to overcome the learning curve and could apply the new knowledge to successfully complete the research.

Although still in its development phase, we expect that in the future, the case study repository will become openly available to the local academic and professional communities of Puerto Rico and beyond. We also expect that its conceptual and applied developments will be replicable to other locations nationwide, therefore contributing to the preservation and systematizing of the infrastructural impact of after natural events and their dissemination.

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