Lessons Learned from Participating in a Virtual Interdisciplinary Undergraduate Research During the COVID-19 Pandemic

Elmer M. Irizarry Rosario, Undergraduate Student[1], Henry M. López De León, Undergraduate Student[2], Edwin E. Santana Caraballo, Undergraduate Student[1] and Dem Ele III Santiago Santiago, Undergraduate Student[1]

[1]University of Puerto Rico – Mayagüez, Puerto Rico, elmer.irizarry@upr.edu, edwin.santana2@upr.edu, dem.santiago@upr.edu

[2] University of Puerto Rico – Río Piedras, Puerto Rico, henry.lopez2@upr.edu

Mentors: Luis E. Suárez, PhD[3], Aidcer Vidot Vega, PhD[3], Luis A. Montejo, PhD[3], Luis G. Daza, PhD[4]

[3]University of Puerto Rico – Mayagüez, Puerto Rico, carla.lopezdelpuerto@upr.edu , luis.suarez3@upr.edu, aidcer.vidot@upr.edu, luis.montejo@upr.edu

[4] University of Puerto Rico – Río Piedras, Puerto Rico, humberto.cavallin1@upr.edu, luis.daza1@upr.edu

Abstract– Undergraduate research experiences and internships enhance student learning in undergraduate programs. Due to the worldwide COVID-19 pandemic, many summer research experiences and internships were canceled or postponed to future summers. The Resilient Infrastructure and Sustainability Education Undergraduate Program (RISE-UP) at the University of Puerto Rico consists of a curriculum that is composed of four courses and an experiential learning experience (internship or undergraduate research). Due to the lack of alternatives for students to fulfill the experiential learning experience in summer 2020, RISE-UP developed a summer virtual undergraduate research experience which focused on developing basic research skills and to apply them to develop interdisciplinary solutions for real problems. We collaborated with students from several disciplines and two campuses to analyze and address the seismic vulnerability of several structures. This experience allowed us to have a better understanding of seismic vulnerability, as well as finding interdisciplinary solutions to upgrade our infrastructure. It also provided us the opportunity to experience an internship without the risk of exposure to COVID-19. In this paper we share our experience and tools that aided us in our research to show that conducting virtual research is a viable and effective option for undergraduate students.

Key Words: Engineering Education, Online Summer Research, Earthquake Engineering, Case Studies

I. Introduction

Undergraduate research experiences enhance student learning in their undergraduate programs. These experiences also have a positive impact on student retention, build student confidence and develop critical thinking skills by introducing students to open-ended problems that may have multiple solutions [1]. Undergraduate research also contributes to the National Science Foundation (NSF) goal of developing an engineering and science workforce who is diverse, internationally competitive, and globally engaged [2].

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To understand the nature and motives of our summer research, it is important to know the background of our research group. We are all part of the Resilient Infrastructure and Sustainability Education Undergraduate Program (RISE-UP) composed of undergraduate students from the University of Puerto Rico Mayagüez and Río Piedras campuses. The program's purpose is to provide an intellectual and academic space for us to generate case study research and turn them into hands-on interdisciplinary solutions for real problems and projects starting with the ones generated by Hurricane María in September 2017. The program's curriculum is composed of four courses and experiential learning experience (internship or undergraduate research) where we can apply the knowledge acquired in the courses. Figure 1 shows the RISE-UP course sequence [3].

Level	RISE-UP Courses	Credits
4	INCI 5036: Design-Build Project Delivery	3
3	INCI 5010: Resilient and Sustainable Design and Construction	3
	Internship / Undergraduate Research	
2	INCI 5996: RISE-UP Seminar Series	3
1	ARQU 4147: Fundamentals of Integrated Practice for Resilient and Sustainable Infrastructure	3

Fig. 1 RISE-UP Course Sequence

The experiential learning experience (undergraduate research or internship) is especially important for our RISE-UP curriculum in two ways; it counts as the 3-credit hours needed to complete the program, and it gives us the opportunity to participate in a research or work group and put into practice the different skills acquired in our interdisciplinary environment. The experiential learning experience required in the RISE-UP curriculum can be satisfied by participating in internships or summer research experiences at our university or at other universities in programs such as NSF´s Research Experiences for Undergraduates (REUS). Due to the ongoing COVID-19 Pandemic, many internships and summer research experiences were canceled. The cancelation of research and internship opportunities led our professors to design and offer a summer interdisciplinary research course at our university specifically designed for RISE-UP students. An additional motivation for us to participate in the research course was the ongoing seismic sequence that prompted us to apply the concepts that we were learning in our courses to propose interdisciplinary solutions to infrastructure challenges generated by the earthquakes. The seismic sequence opened many possibilities for potential case studies around structural and seismic engineering. This paper contains information about our experience participating in the course including how our research was structured, techniques and methods used by us to overcome the challenges of online communication and external factors in our research groups, our lessons learned and reflection on completing an online interdisciplinary summer research project.

II. METHODOLOGY

Our research experience was divided into four phases. As shown in figure 2, the first phase included lectures on introduction to research and structural engineering. The second phase was the case study selection. The third phase consisted of developing interdisciplinary solutions to the infrastructure challenge that was selected. Finally, the fourth phase reflects our experience participating in the research and the lessons learned. Each of the phases will be explained in detail in the results section.

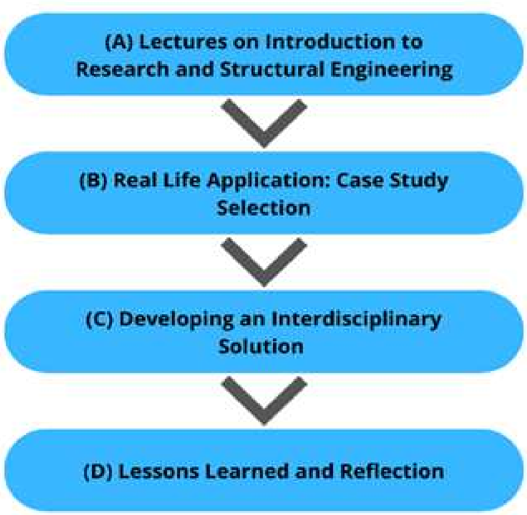

Fig. 2 Main Research Phases for Summer 2020

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III. RESULTS

The results of the first three phases (A, B and C) are shown below. The reflection on the experience and the lessons learned (phase D) are presented in the conclusions section.

A. Lectures on Introduction to Research and Structural Engineering

Our summer experience was divided into 2 major components: (1) An introduction to scientific research and (2) earthquake engineering lectures and projects (Figure 3). The purpose of the introduction to research component was to discuss supplementary topics covered in regular summer research programs, such as technical writing, creating research posters, displaying data and the process of applying to graduate school. We had the opportunity to apply this knowledge when we wrote our midterm and final reports for the structural engineering course. Furthermore, the skills acquired in this course are very useful for us in our university courses and future research projects that we may pursue.

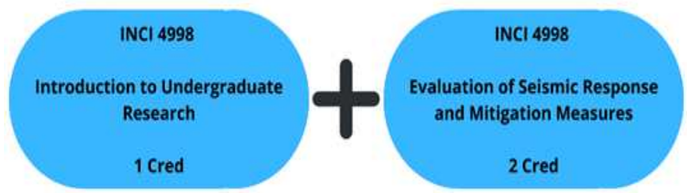

Fig. 3 Structure of Summer Research Class and Project

In the structural engineering component, we had four professors who co-taught the course and discussed the importance of vulnerability and resilience of civil infrastructure in Puerto Rico. The lectures centered around topics such as natural hazards, structure dynamics, numerical models for seismic response of structures and an introduction to performance-based design. These lectures were critical for the success of our research projects. The interdisciplinary nature of the groups guaranteed a holistic approach to the problems tackled.

B. Real Life Application, case study selection

One of the factors that motivated us to participate in the summer research experience was the nature of the projects themselves. The ongoing seismic sequence that started in January 2020 in Puerto Rico allowed us the opportunity to work on real case studies that were both timely and relevant not only to our academic fields but also to our daily lives. Our professors selected four projects, each of them centered around a structure or type of structure that suffered severe damage or failed during the earthquakes. Each group collected information of the structure and damage suffered during the earthquakes, developed a numerical model to perform a seismic assessment and designed a retrofitting plan. Group A studied an important power plant in southern Puerto Rico that was damaged causing power interruption in the area. Group B focused on soft-story residential houses which were the type of structures most affected by the earthquakes and are unfortunately quite common in Puerto Rico. Group C analyzed the failure of a reinforced concrete bridge pier on a main road near the University of Puerto Rico, Mayagüez campus (Figure 4). Finally, Group D investigated the damage sustained in schools, using a school in the municipality of Yauco as base model. Each team consisted of three to four students which included one or two environmental design (architecture) students and the rest were engineers (civil, electrical, surveyors). This allowed teams to have an integrated and interdisciplinary approach to the problems faced. Since every team had to design and analyze at least one rehabilitation measure for their case study, the diverse flow of ideas was important in the creative process. Once the projects were selected, the assigned mentor worked with the team to analyze the project requirements including the software to be used and analysis to be performed to assess and seismically retrofit the structures.

Fig. 4 Earthquake Damages to Viaduct Bridge Column in Mayagüez, Puerto Rico (source: Vidot, A. & Montejo, L.)

C. Developing an interdisciplinary solution

The completion of our online research experience was influenced by the constraints of having to work during the pandemic [4], but we were still focused on completing successful projects and obtaining valuable results. Some compromises had to be made when handling meetings, presentations, and overall interactions between our groups, but we managed effective communication to complete our tasks.

The meetings with the mentors and other team members were held via virtual meeting platforms such as Google Meet due to the pandemic lockdowns and the fact that the team members were composed of students from all over the island. The primary tools to communicate with the mentors were virtual meetings and emails. Within our teams, the primary forms of communication were group chats and video conferences. The team dynamic was similar in all the groups. Each teammate would gather information and process data individually but when it came to running simulations, changing structural designs, and writing reports, we would all have a meeting with all the members to coordinate.

Some of the difficulties we overcame were a short timeframe, technical limitations, software limitations and loss of power or Wi-Fi. Not all of us had a top-of-the-line computer to run simulations, most of us had modest computers just for online classes. Some simulations would take longer to run and consume a substantial portion of our time. One group had a limited software license that could only run a certain number of loads on a model, meaning that they had to run each load individually instead of all at once adding more complexity to the simulation. This was later fixed by one of the mentors who managed to obtain a license for one student to use for the rest of the summer. As demonstrated by hurricane Maria in 2017 and the earthquakes in 2020, Puerto Rico's electrical system is not the most reliable [5]. We experienced blackouts in some areas of the island and internet outages which hindered participation in virtual meetings. To overcome these challenges, some of us used data hotspot from our phones to rejoin the virtual meetings if power or internet went out.

Even though we faced all these challenges we were still able to complete valuable research results. Groups presented detailed results from different structural analyses, some of them involving nonlinear models like the Viaduct Bridge analysis in Mayagüez [6] and the soft-story residential houses [7]. The results of these analyses were presented using techniques learned in the introduction to research course at the beginning of the summer, such as creating and editing graphs that are easy to read. Each of the projects also had a category where we presented possible rehabilitation or damage prevention techniques for every structure studied. The Viaduct Bridge Group investigated ways of permanently repairing the bridge's columns [8] because the repairs made by the city were temporary solutions. The project consisted of modeling the section of bridge with Seismostruct® software (Figure 5), performing a series of tests to determine the performance levels of the structure, running the earthquake's time history, and analyzing the results in comparison to the proposed rehabilitation methods. The results were later graphed for easier understanding (Figure 6) and the rehabilitation method chosen was a fiber-reinforced polymer (FRP) jacket for the columns.

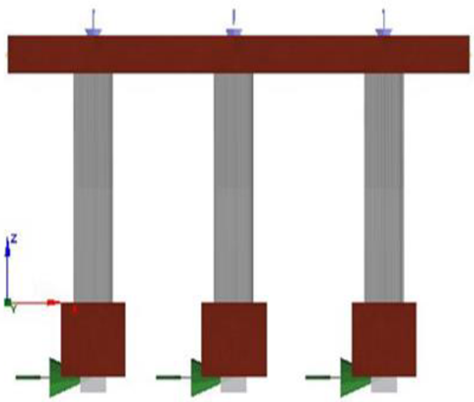

Fig. 5 Nonlinear Model of Viaduct Bridge Section

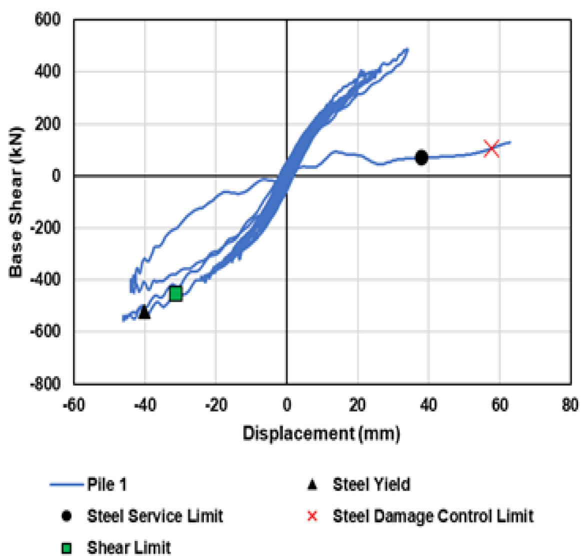

Fig. 6 Hysteresis Curve for Viaduct Bridge Column Model

The group who studied seismic vulnerability of schools in Puerto Rico [9] not only managed to test and analyze their designs, but also took other factors into consideration that were not required by the project such as cost, constructability, time frame, safety, and aesthetic. They predicted how the building would respond to a ground acceleration using ETABS® (Figure 7).

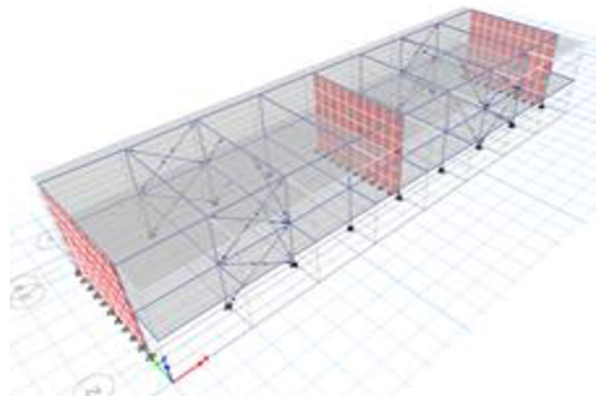

Fig. 7 Yauco School 3d Structural Model Using ETABS®

The results from the analyses performed pointed out the vulnerabilities of the school, many of which were expected since it was built in 1957 and designed using a building code from 1953. This code only focused on gravitational loads and did not consider lateral loads such as wind or earthquake. The group tested many rehabilitation designs until two were chosen [10]. One of the options offered a faster implementation but was costlier and the other one was cheaper, but it took more time to complete. For the least costing option, we would reenforce the columns of the structure, add three load-bearing walls of 10 inches (25.4 cm) on the ends off the school and in the middle and four structural steel bracings (Figure 8). Meanwhile in the faster option we would still use the same number of Load-bearing walls, but a more considerable amount of structural steel bracing since is faster to implement compared to reenforcing the columns, we also considered plates and fabrics made from carbon fiber which have a faster implementation but are too costly. Besides the structural aspect, the group also focused on giving the middle school a more appealing look for students with more vibrant colors, windows that permit more airflow and sunlight to reduce energy consumption and made more doors for a safer way to evacuate in case of an emergency (Figure 9).

Fig. 8 Architectural Render of Classroom with Lateral Load Reinforcement

Fig. 9 Architectural Render of Yauco School After Rehabilitation

The group that studied the soft-story residential houses used the software Seismostruct® to develop a nonlinear model and characterized the seismic behavior of these structures through pushover and dynamic time history analyses (Figure 10). It was evident from the analyses that these structures suffer from soft story because of the lack of walls on the ground floor, damage is then rapidly accumulated on the first floor causing the premature collapse of the structure. It was also apparent that these structures had an axis much weaker than the other because all the columns were oriented in the same direction. Because of the large differences between the location of the center of mass and stiffness, torsion becomes the second dominant mode of vibration – amplifying the demand on the corner columns. Based on these results, the group concluded that the columns on the ground floor had to be reinforced, ultimately choosing column jacketing, a method in which the original column is enveloped in a new column to make it stronger (Figure 11). The results obtained after jacketing showed an increase on the strength and stiffness on both axes, but mostly on the weak axis. The damage was now better distributed along the structure avoiding the risk of a premature collapse and torsion is no longer a dominant mode [11].

Fig. 10 Architectural Render of Soft Story Home

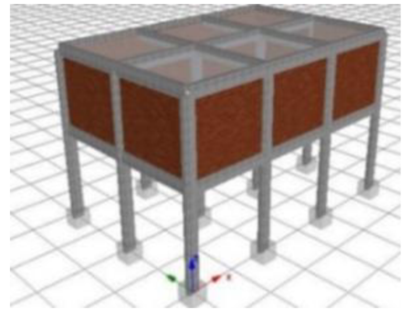

Fig. 11 Structural Model of Soft Story Home

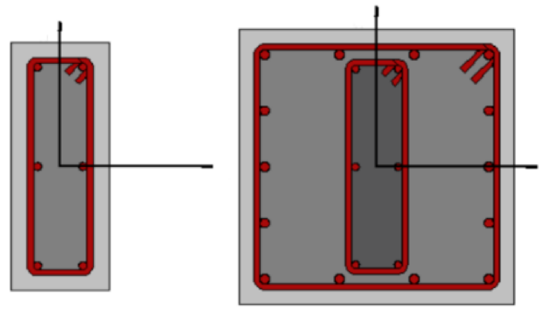

Fig. 12 Original column (left) and jacketed column (right)

IV. CONCLUSIONS

The last phase of our research (phase D) included a reflection on the experience, and the lessons learned. The entire process of completing summer research projects during a pandemic was a vast learning experience for us. We believe that the most crucial tool we had to our advantage during this research was the interdisciplinary and diverse approach that fueled our problem-solving skills. The research project made us realize the importance of having an open mind in an interdisciplinary team. Being from diverse backgrounds, each of us had different resources, points of view and experiences that we gathered throughout our student life. Working together we had a more holistic view of the project instead of focusing on just one factor. We also needed an open mind and to actively listen and understand our team member´s perspectives to be able to reach consensus on the design decisions. It became evident that we all had different skillsets that were needed on a day-to-day basis during this project. Combining these traits made it possible to form an effective team and to develop an interdisciplinary solution that is better than any solution that we could have developed individually or working only with team members of a single discipline.

Based on our experience, we believe that virtual research is a great option to continue finding solutions to our everyday challenges and advancing scientific knowledge during the pandemic. Virtual research experiences offer more flexibility for students and mentors to keep working from home. We acknowledge that virtual research experiences in some areas can be more challenging, for example when certain equipment is needed or when fieldwork and a laboratory are required to conduct experiments, but many research projects can be designed in a way that can be meaningful for both faculty and students without requiring in-person participation. One of the main lessons learned is the need for open and effective communication to face the avoidable hurdles that are common in research, particularly when in-person meetings are not possible. Weekly virtual meetings with our mentors allowed us to have a constant feedback loop and show them the progress that the team made during the week, which resulted in a better product.

In conclusion, we believe that we managed to find an effective and interactive way to execute a research project despite the limitations imposed by the pandemic. Even though we would have enjoyed our summer internships and research experiences in a more traditional manner; where we could have had in-person experiences, we are thankful for the experience of participating in this virtual research. We managed to communicate effectively with our team members, were able to generate effective simulations related to structural engineering and developed design solutions that can eventually be useful for future infrastructure projects. In terms of course requirements, every group in the RISE-UP Summer Research experience successfully completed a technical report and a final presentation discussing the findings. The challenges imposed by the lack of in-person meetings or ability to collaborate forced us to use our creativity, soft skills, and technical skills to overcome the challenges by having effective communication and an open mind which resulted in a rewarding learning experience.

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