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Training Teachers to integrate a Sustainability Assessment for Green Building and Retrofitting Project into a K-12 Classroom

Victoria C. P. Chen, Erick C. Jones Jr.
Industrial, Manufacturing, and Systems Engineering Department
University of Texas at Arlington

Vishnu Sharma, Suman Gudikandula
Data Science MS Students
University of Texas at Arlington

Rahsirearl Smalls
Project Lead the Way STEM Teacher
Charles Baxter Jr. High School, Everman ISD

Jocelyn Sigler
Advanced Biology and Environmental Systems Teacher
Lamar High School, Arlington ISD

Abstract

We present a collaborative research process for building an Industrial Engineering (IE) analytics process to train non-engineering K-12 teachers to conduct sustainability assessment in green building. One important goal of this engineering experience is for these teachers to bring research into their classrooms. Buildings play a vital role in society, and the construction industry is one of the largest consumers of natural resources. Sustainability assessment of building design must analyze a variety of decision variables, both qualitative and quantitative, and must address the three pillars of people, planet, and prosperity, corresponding to social, environmental, and economic performance objectives. Our IE analytics process enables K-12 teachers to perform meaningful research without overwhelming them with technical components outside of their backgrounds and in a way that could be translated to the K-12 classroom. This work is part of a National Science Foundation Research Experiences for Teachers project (EEC-2055705), and our IE analytics process is used to study a tiny home and a primary school.

Introduction

For the 2022 National Science Foundation Research Experience for Teachers program, Jocelyn Sigler and Rahsirearl Smalls worked on the Sustainability Assessment for Green Building and Retrofitting project under the guidance of Dr. Victoria Chen and Dr. Erick Jones Jr. The research objective of the project was to evaluate if using experimental design rather than expert intuition to select buildings materials and design would yield improvement in sustainability goals. The instructional goal was to train the pair of teachers in the summer, so they could translate this research experience into the classroom[1,3].

Buildings, commercial and residential, comprise 39% of U.S. energy consumption. This drives the question: What green building technologies are most important in achieving desired sustainability objectives? Constructing sustainable buildings and improving energy efficiency in buildings is critical for sustainability efforts due to the long-life cycle of buildings. Decisions in the early design phase have a long-lasting impact on every pillar of sustainability: people, planet, & prosperity.

Our research project investigated how the choice of building materials and technologies affected performance metrics for annual energy cost (prosperity), global warming potential (planet), and human health particulates (people). Building simulation tools were employed to estimate performance for different building types. An experimental design was used to identify combinations of materials and technologies to simulate, and the Pareto front of nondominated combinations was visualized as a 3D graph of the three performance metrics.

Methods

We utilized two programs: eQUEST, a building energy simulation program to simulate the amount of energy used by a designated structure, and Athena Impact Estimator for Buildings (ATHENA), which assesses the life cycle of a building based on its materials and assemblies. Domain expertise in building design was provided by Mr. Anthony Robinson, President of Axis Design-Build, Inc., Dallas, TX, and Dr. Charles MacBride, Assistant Professor in the School of Architecture at the University of Texas at Arlington. To prepare for the arrival of the teachers Drs. Chen and Jones had the MS students Mr. Sharma and Gudikandula learn eQuest and ATHENA and develop instruction manuals and training videos. While these were helpful to the teachers, due to the technical nature of the software, the students still had to provide hands on support to help the teachers download the software, run the software, and interpret the results.

The teachers chose their own buildings to evaluate. Ms. Sigler chose to assess a single-story primary school with data retrieved from baseline specifications provided by the Department of Energy's Commerical Reference Buildings [7]. Mr. Smalls had access to blueprints from Dr. MacBride's tiny home project in the University of Texas at Arlington School of Architecture. The teachers then had to model their chosen buildings in the software tools.

Next, Dr. Chen developed an experimental design with 48 runs using orthogonal arrays to systematically evaluate different building characteristics limited by the parameters that could be modeled in the software [5,6]. This design of experiment was the checklist needed to run simulations that would allow us to determine if our IE analytics process could produce improvement in the three selected performance metrics, compared to expert guidance provided by Mr. Robinson and Dr. MacBride [2,4].

After the teachers modeled their buildings in the software, they used the 48-run experimental design to organize simulation runs and conducted these runs over the course of 6 weeks. ATHENA was used to calculate global warming potential and human health particulates, and e-QUEST was used to calculate the electric (kw/h) and natural gas (BTU) consumption. Several modifications were made to the types of materials being used to determine the ideal solution that would be most efficient, most cost effective and the least harmful to the environment. All modifications were compared to a construction baseline created prior to the adjustments.

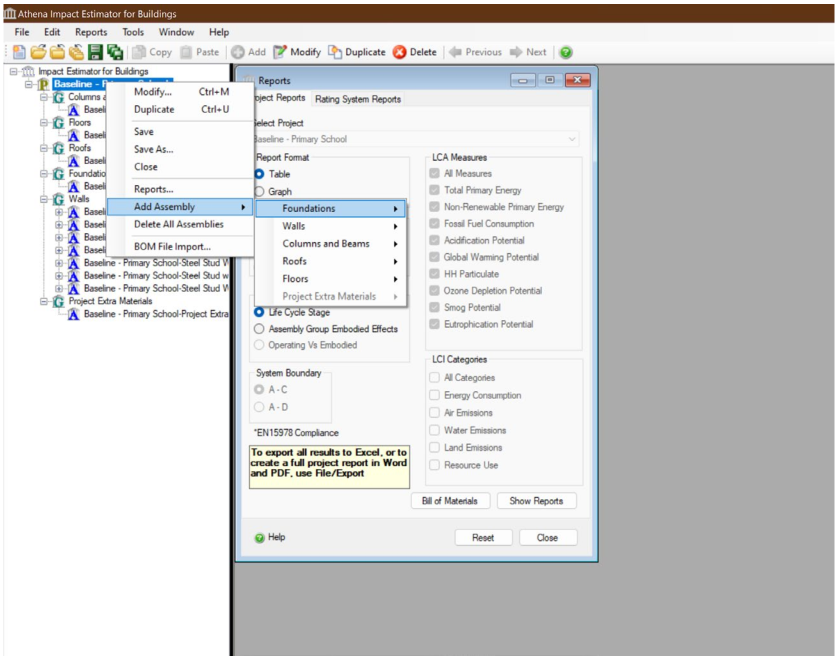

Figure 1- ATHENA Drop Down Menu

Research Summary and Conclusions

Tiny Home Study

As shown in Figure 2, the results showed that the baseline run was not a Pareto point, and therefore, the experiment provided valuable insights beyond domain expertise on what types of building design settings could improve performance. The Pareto points identify settings that outperform (or match) all others in one or a combination of metrics. With this definition, a Pareto point is nondominated, even though it may not be optimal for all metrics. However, the Pareto front provides decision makers with multiple choices, and they must still decide which metrics to prioritize. A decision maker could choose a slightly more expensive option that had better environmental or social impacts or could choose to balance all pillars equally.

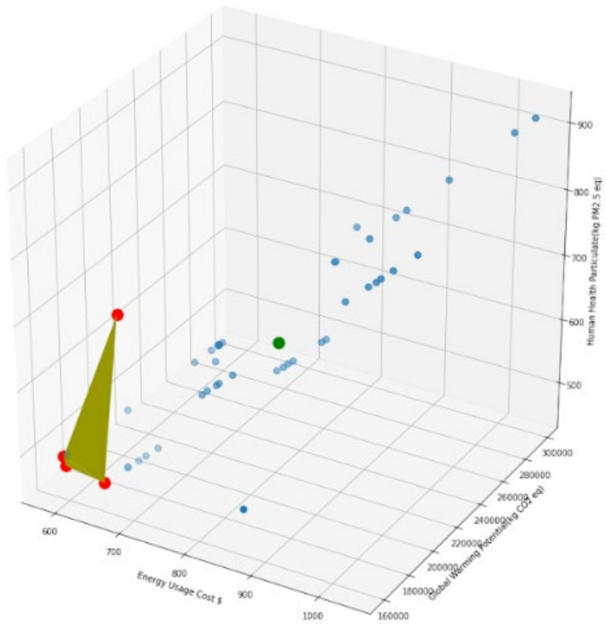

Figure 2 - Tiny Home Simulations Runs The x-axis shows energy usage in units of cost ($) with higher values being worse, the y axis shows global warming potential in units of CO_2 -eq , and the z axis shows human health particulates in PM 2.4 – eq. For all axis higher values are worse. Red dots on the yellow plane indidcate the Parteo frontier. The green dot is our baseline point. The other blue dots are dominated simulation runs.

School Study

Our first step was deciphering the blueprints and building the structure in the software. Once entered, the simulations were run based on the blue print settings to obtain a baseline reading.
Next, we identified 17 input variables, with the help of Mr. Robinson, to vary in our simulations to study alternate combinations of materials and technologies.
As shown in Figure 3, the Pareto front provided building design settings that outperformed the baseline across three pillars of sustainability. Even though there was not a single “answer” in the data, it provided a foundation that could be used to approach building specifics with their main focus in mind, whether it is lowering cost, decreasing an environmental footprint, improving overall human health, or any combination of the three.

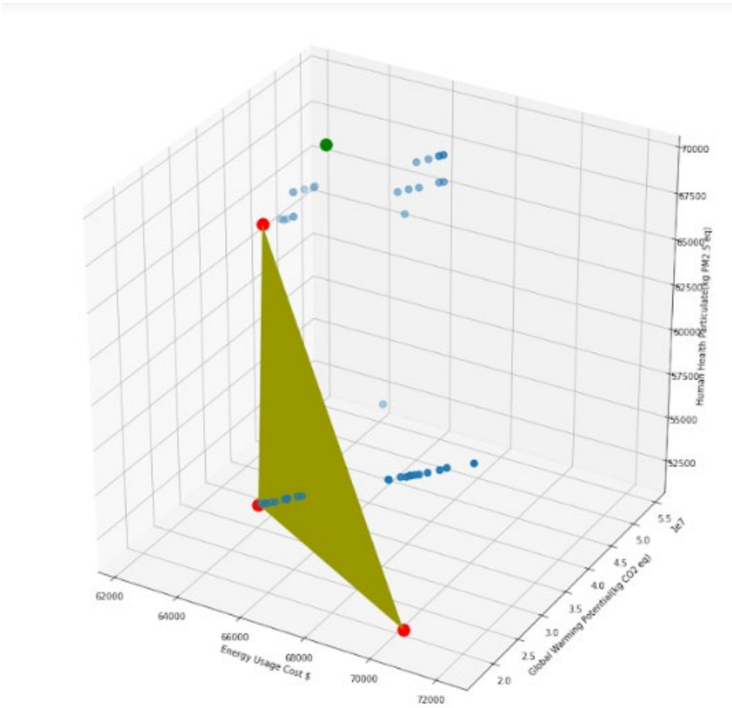

Figure 3 – School Building Simulations Runs The x-axis shows energy usage in units of cost ($) with higher values being worse, the y axis shows global warming potential in units of CO_2 -eq , and the z axis shows human health particulates in PM 2.4 – eq. For all axis higher values are worse. Red dots on the yellow plane indidcate the Parteo frontier. The green dot is our baseline point. The other blue dots are dominated simulation runs.

Plans for Implementation in K-12 Classroom

To implement this lesson into Mr. Smalls' classroom, Mr. Smalls will have the students participate in a green tiny home building challenge. Project Lead the Way/Science of Technology is a course that introduces middle school students to topics in engineering as well as exposes them to possible engineering careers. One of the major themes in the course is the Engineering Design Process. In this lesson, students will design the tiny home in a city of their choice that is as environmentally friendly as possible while staying on budget. This project will evaluate the students' understanding of the Engineering Design Process, as well as increase their awareness of their impact on the environment.

Mrs. Sigler plans to incorporate this into her lesson plan by having students use the software Floor Planner to design buildings with reduced environmental impact and while focusing on health concern & building implications. Furthermore, plans to have them research alternatives to common system materials to provide rational decisions.

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ERICK C. JONES JR

Dr. Professor currently serves as an Assistant Professor of Industrial, Manufacturing, and Systems Engineering at the University of Texas at Arlington. His research interests include investigating how communities, companies, and countries can allocate their limited resources in a way that maximizes their desired outcomes in a sustainable, equitable, and resilient but also elegant way. He assesses these problems by combining physical experimentation, data analytics, and stochastic systems optimization to provide actionable decisions and create scalable prototypes.

VICTORIA C. P. CHEN

Dr. Chen currently serves as Professor and Director of Doctoral Studies for Industrial, Manufacturing, and Systems Engineering and Director of the Center on Stochastic Modeling, Optimization, & Statistics at the University of Texas at Arlington. She has expertise in the design of experiments, statistical modeling, and data mining, particularly for computer experiments, adaptive dynamic programming, surrogate optimization, and stochastic optimization. She has studied applications in sustainability and energy, smart cities, transportation, health care, law enforcement, and chemical analysis.

SUMAN GUDIKANDULA

Mr. Gudikandula is a recent graduate of the Masters of Data Science program at the University of Texas at Arlington. He has recently started working at ADP in New York.

VISHNU SHARMA

Mr. Sharma is a graduate student in the the Masters of Data Science program at the University of Texas at Arlington.

JOCELYN SIGLER

Ms. Sigler is an advanced biology and environmental systems teacher at Lamar High School in the Arlington Independent School District.

RAHSIREARL SMALLS

Mr. Smalls is a Project Lead the Way STEM teacher at Charles Baxter Junior High School in the Everman Independent School District.