Green Engineering in Beam Production Using Honeycomb Structures

Roumany C. Phan and Katherine Acton
Department of Mechanical Engineering
University of St. Thomas
St. Paul, Minnesota, 55105
Email: phan9676@stthomas.edu

Abstract

This presentation on designing new shapes for the webs of I-beams grew out of work performed through the *Excel!* Research Scholar Program at the University of St. Thomas. The *Excel!* Research Scholar Program is an integrating foundation that allows scholars from underrepresented groups to challenge themselves through eight weeks of rigorous work on a research project. Scholars are able to self-motivate through support within the cohort, and are mentored under faculty from various departments.

In the production of beams, minimizing material usage will increase sustainability. During this eight-week program, research was conducted to address the question: How can the shape of I-beams be modified to decrease weight and maintain or increase stiffness? The honeycomb structure is a type of multi-cellular solid, whose characteristics give it the advantage of low density, leading to the reduction of material usage. Computational results show a tradeoff between the beam volume and bending stiffness. A comparison of the deflection of beams with vertical and horizontal honeycomb orientation in the web shows that the vertical orientation is preferable.

Introduction

This paper describes a project that was completed as part of the University of St. Thomas *Excel!* Research Scholars Program in the summer of 2015. The *Excel!* Program is a competitive program that admits and encourages underrepresented and/or first-generation scholars to prepare for graduate school. The program admits scholars who are passionate to change the world through the imprint of their works. At its core, *Excel!* is a summer research institute where scholars are asked to conduct their personal research while attending professional development courses and seminars such as graduate school preparation training, professional research presentation training, and more. Upon the admission into the program, scholars will pair up with a faculty at the institution and, together, they decide on a research topic.

The undergraduate research project described in this paper seeks to address the question of how engineers can make structures more sustainable by using designs that require less material. As universal population levels continue rising, the inquiry to building development is rising as well[1-4]. Consequently, the building industry seeks solutions to meet the demand. This puts pressure on Planet Earth[3, 5, 6.] According to Morel *et al.*, "throughout the world the building industry is responsible for high levels of pollution as a result of the energy consumed during extraction, processing and transportation of raw materials."[1] The building industry should strive to minimize its negative effects on the environment as much as possible, because some human actions cause environmental deterioration.[7]

Beams are one of the support systems commonly used in steelworks and other structures.[8, 9] Energy use is detrimental to the environment, yet essential to the production of beams.[1] Developing a path to minimize material usage in the production of beams will decrease energy use and increase sustainability.[1, 2, 5] The goal of this *Excel!* program undergraduate research project is to examine how use of materials can be minimized by different designs of web geometries, and how different web geometries affect beam performance.

In this paper, the *Excel!* Research Scholars Program will be described in detail. The undergraduate research presented through in this program will then be summarized[10], including the methods used and the results obtained. This paper is about both the *Excel!* Research Scholars Program and the research results that came out of it.

The *Excel!* Research Scholars Program

Upon admission into the summer program, the scholars are asked to select their topic and construct their question. The researchers then proceed to developing a research paper starting with the introduction and literature review. After approval by the program coordinator and the scholar's mentor, the scholar proceeds to develop a methodology for addressing the research question. Results are obtained and interpreted, and the program concludes with a presentation and a publication.

Each scholar conducts a detailed literature review surrounding their question. The program coordinator holds a class detailing the methods used to conduct an effective literature review, and then the scholars are asked to draft their literature review section for a program writing specialist to review. The writing specialist reviews the work to make sure that it is grammatically correct and accurate to the individual's style for a particular academic field. In this study, a literature review was performed around the topics of sustainable development, green engineering, I-beams, and honeycomb structures; citations were written in an appropriate style for engineering. Other students in the program majoring in different fields, such as public health or pre-law, learn literature review techniques appropriate to their discipline.

As summer progresses, each scholar attends lectures on different types of research methodologies. The scholars and their mentors decide to pursue a quantitative, qualitative, or mixed research method. For this study, the authors used a quantitative method to gather the data. The quantitative method was most appropriate for an engineering research topic that involved both computational modeling and experimental testing.

Once the scholars have completed their experimentation and gathered their results, together with their mentor, they discuss different approaches best to present their results. For this study, two different types of results are presented: computational and experimental. Computational results were gathered first, and these results were analyzed and used to determine which beam structures were chosen to undergo experimental testing.

From the beginning to the end, the *Excel!* Research Scholars Program plays a significant role in the scholar's research. In addition to providing support through the faculty mentor, the program also supports a writing specialist. As the researchers complete their research paper, the program writing specialist edits the scholar's writing for grammar and usage, which is particularly important for students writing in English as a second language. The culminating event occurs at the end of the summer, when the researchers present their work at the *Excel!* Research Scholar Program Summer Research Symposium. This event is attended by faculty mentors, program facilitators, the scholars and their families. At this event, the president of the University of St. Thomas provided introductory remarks, which emphasized the importance of encouraging students from underrepresented groups to pursue research opportunities at the college level.

Although the research project concludes at the end of the summer, the scholars continue their participation in the program through their graduation. The program continues to provide support, including review of graduate school applications. The program also sponsors a Journey for Justice travel study program, through which scholars learn about historic sites important to the civil rights movement. This experience provides inspiration for the scholars to succeed with their post-graduate education goals.

Excel! Research Scholars Undergraduate Project: Green Beam Design

For this research project, the engineering topic that engaged the interest of the authors was how to help the building industry become more sustainable. The building industry is responsible for high levels of pollution as a result of the energy consumed during extraction, processing and transportation natural materials. As the population continues to grow, the demand for building supplies will also increase.[1-4] Government officials, scientists and engineers have begun to develop concepts that fight climate change through minimizing global energy consumption.[11, 12]

The I-beam is commonly used in steelworks and other structures.[8, 9, 13] An I-shaped beam is constructed of two parallel flanges connected by the web, usually making up 25 % to 40% of the entire beam.[9, 14] The bending stiffness of a beam is a quantification of its resistance to bending. The larger the bending stiffness a beam has, the larger its resistance to bending.[9, 14, 15] Bending stiffness is a function of the geometric properties of a material's cross-section. It would be advantageous to minimize material usage in the production of I-beams. Previous studies have examined the effects of changing the geometry of the web area. [9] It has been found that corrugated webs with various geometries can reduce the beam's weight up to 13.6% while increasing its load-carrying capacity. [18]

The goal of this work is to redesign the web area of I-beams so that the I-beam is more "green" due to minimized material usage. This goal can be achieved with the use of the honeycomb structure. The honeycomb structure is a type of multi-cellular solid made up of a collection of walls of cells nested together filling a given space.[17, 20] Honeycomb's characteristics give it the advantage of low density.[14, 15, 20] Therefore, as in earlier studies, embedding honeycomb structure into the web area of the I-beam in this study could not only aid in minimizing the use of natural resources, but also maintain or improve I-beams' moment of inertia and/or bending stiffness.

Research Methodology

The aim of this study is to impose green engineering concepts onto the production of I-beams, redesigning I-beams so their material usage is minimized. In order to approach this goal, a quantitative method will be used to examine the effects that different honeycomb web geometries have on the bending stiffness of modified I-beam type structures through a three-step process: design, computational testing and mechanical testing. The design process consists of 3D models of I-beams and modified beam structures created through the use of SOLIDWORKS. Case 1 is comprised of a rectangular web I-beam. Case 2 has a web geometry comprised of horizontally oriented honeycomb structures (Fig. 1a). Case 3 has a web geometry comprised of vertically oriented honeycomb structures (Fig. 1b). Computational testing is carried out using SOLIDWORKS simulation to evaluate beam deflections under a three point bending test. The material properties used are those of Acrylonitrile Butadiene Styrene (ABS) thermoplastic. In computational modeling, the material was considered only in linear elastic range.

A B

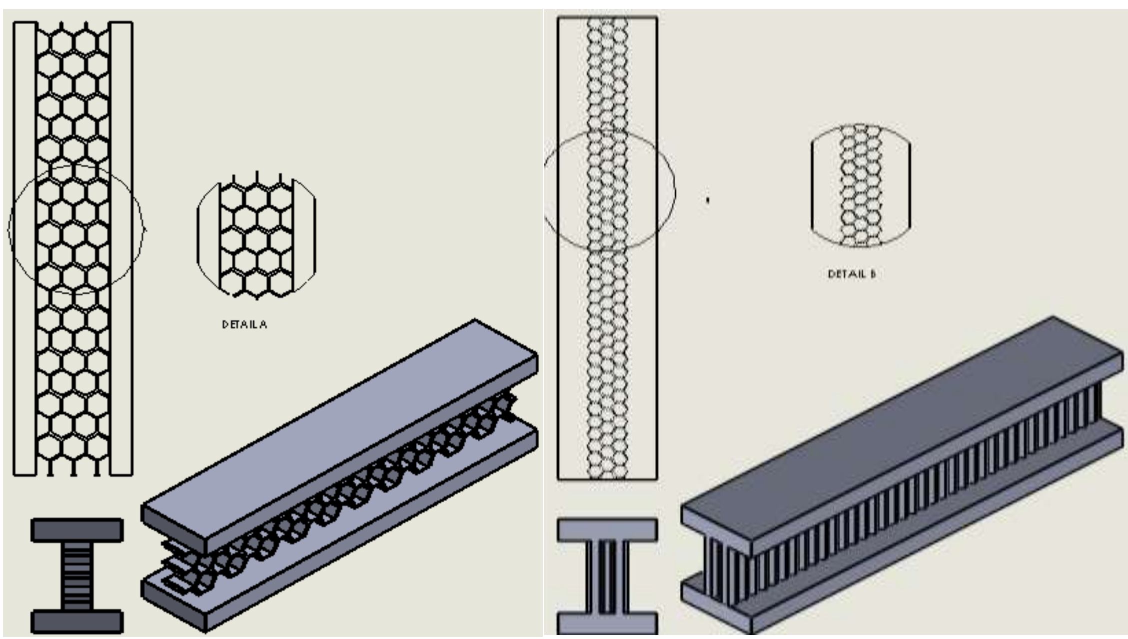

Fig. 1 (a) A Hexagon honeycomb web beams design with cell wall 0.5 mm thick and orientated horizontally to flanges. (b) A hexagonal honeycomb web beams design with cell wall 0.5 mm thick and oriented vertically to flanges. The web thickness of both beams is 50 mm and the web high of both beams is 20 mm.

Computational Results

The computational results of this study consist of data from computer simulation of Case 2 and Case 3 with different honeycomb wall thicknesses. Sixteen models of Case 2 and eight models of Case 3 were created and tested for their deflections. This study investigated beam deflection as a function of beam volume for each case. The beam deflection in the Y-direction at mid-span of each model was investigated when each beam was subjected to a 1-newton load in a 3-point bending test. The selected honeycomb models were compared with I-beam models of the same volume. Results are presented below for each case. Through this analysis, one model from each case was selected for further analysis by experimental methods.

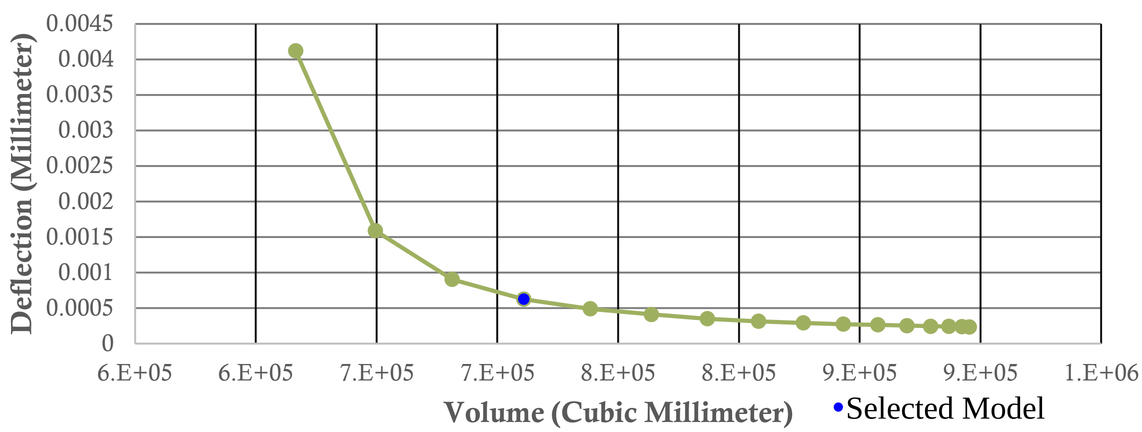

Fig. 2: Beam deflection as a function of beam volume for Case 2 (horizontal honeycomb structure).

A graph showing beam deflection as a function of beam volume for beams with geometry given by Case 2 is shown in Fig. 2. This plot shows an exponential relationship between beam deflection and beam volume. This curve shows that for the models in Case 2, the deflection decreases exponentially as the honeycomb wall is thickened and the volume increases. A model in Case 2 was selected (in blue) for further analysis. The model selected offers a relatively low deflection, while also offering a relatively low volume. A comparison between the deflection of the selected beam and a rectangular shaped I-beam of the same volume was also performed. These results are shown in Fig. 3.

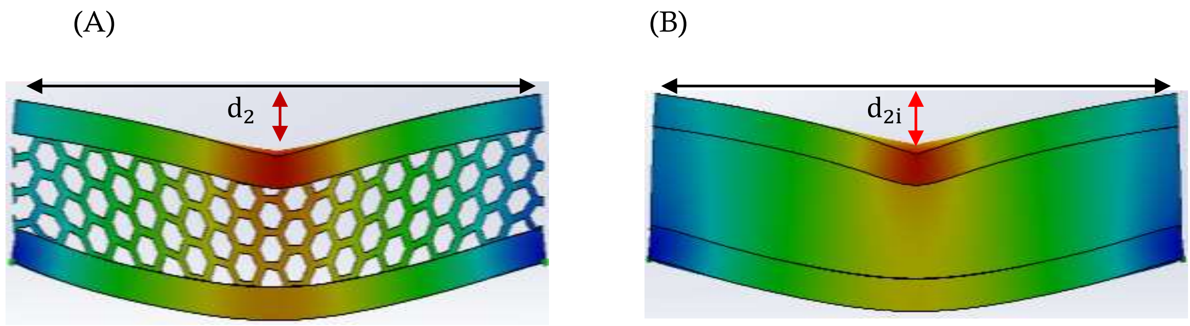

Fig. 3 A comparison of models from Case 3 with I-beams of same volume. (A) An I-Beam with honeycomb web geometry in the horizontal orientation with the deflection (d1) value of 6.205930e-4 millimeters. (b) A rectangular web geometry I-Beam with the same volume as (a) with the deflection (d2) value of 3.5941e-4. The percentage difference (the significant value) in deflection values of beam with honeycomb structure and I-beam of the same volume is 72.67%.

The percentage difference in deflection values of the beam with honeycomb structure and an I-beam of the same volume is 72.67%. In other words, the horizontally oriented honeycomb structure is much less stiff than the rectangular web structure.

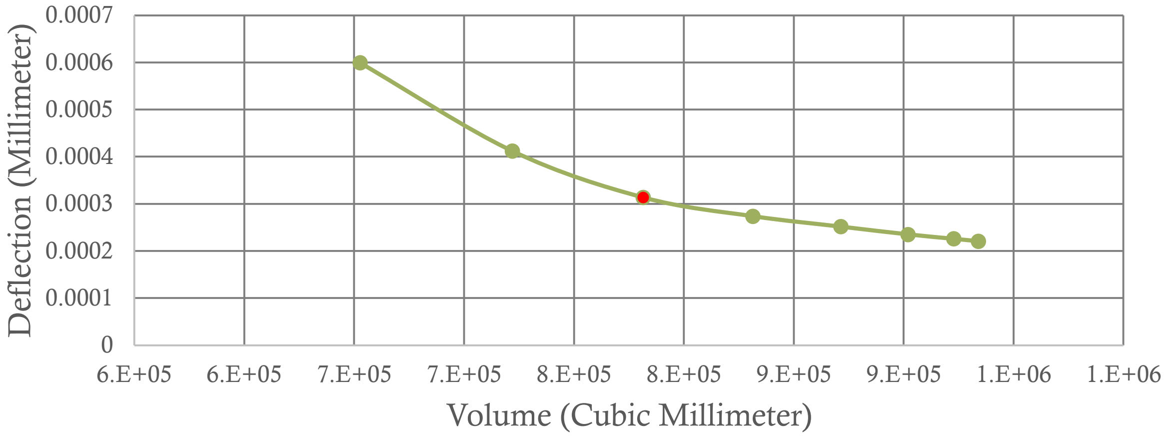

Fig. 4: Beam deflection as a function of beam volume for Case 3 (vertical honeycomb structure).

A graph showing beam deflection as a function of beam volume for beams with geometry given by Case 3 is shown in Fig. 4. This plot shows an exponential relationship between beam deflection and beam volume. This curve shows that for the models in Case 3, the deflection decreases exponentially as the honeycomb wall is thickened and the volume increases. There is a corresponding gain in stiffness as the deflection values decrease. A model in Case 3 was selected (in red) for further analysis. The model selected offers a relatively low deflection, while also offering a relatively low volume. A comparison between the deflection of the selected beam and a rectangular shaped I-beam of the same volume is also performed. These results are shown in Fig. 5.

(A) (B)

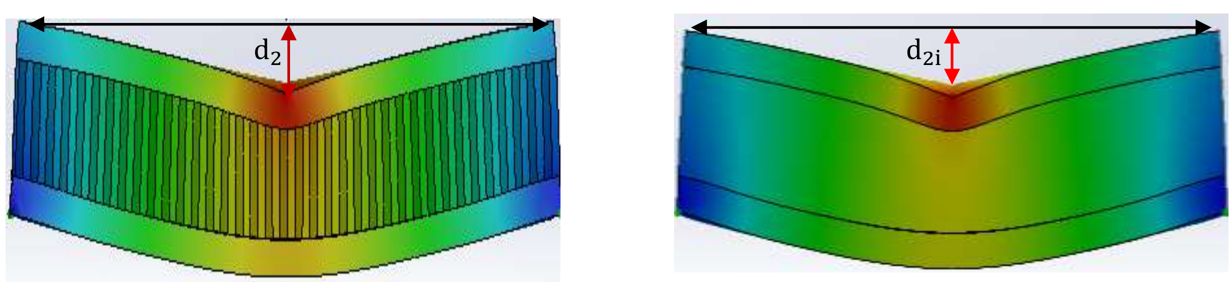

Fig. 5 A comparison of model from Case 3 with the I-beam of the same volume. (a) An I-Beam with honeycomb web geometry in the vertical orientation with the deflection (d1) value of 3.13284e-4 millimeters. (b) A flat web geometry I-Beam with the same volume as (a) with the deflection (d2) value of 3.76238e-4 millimeters. The percentage difference (the significant value) in deflection values of beam with honeycomb structure and I-beam of the same volume is -16.74%.

The percentage difference in deflection values of the beam with honeycomb structure and an I-beam of the same volume is -16.74%. In other words, the vertically oriented honeycomb structure is stiffer than the rectangular web structure.

Experimental Results

The experimental results were obtained using two 3D printed beam models tested on a tensile testing machine (Mechanical Testing System, MTS). This test again investigated the beam's stiffness, quantifying load as a function of deflection in a 3-point bending test. Results were compared for a rectangular web geometry I-beam and an I-beam with horizontally oriented web geometry. Results are presented below for the rectangular shaped web geometry (Fig. 6), and the horizontally oriented honeycomb web geometry (Fig. 7).

These plots demonstrate complex curves. In both, as the deflection increases, the load increases until a point at which there is a sudden decrease in load. This point corresponds with the permanent deformation and failure of the material. In the computational models, material behavior is considered only in linear elastic range. In experimental results, the model is tested to failure. The experimental results agree with the computational results; the beam with rectangular web geometry is significantly stiffer than the beam with horizontally oriented honeycomb web geometry.

Discussion

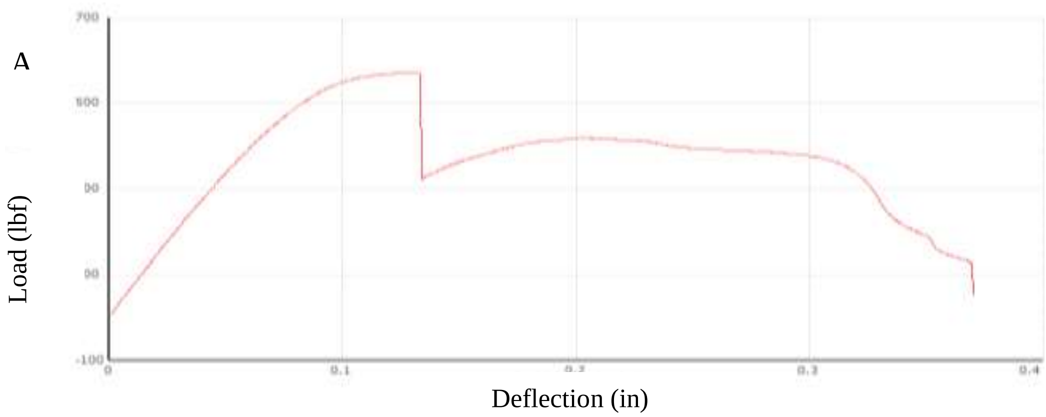

Fig. 6: Load (lbf.) as a function of deflection (in) for beam with rectangular web geometry

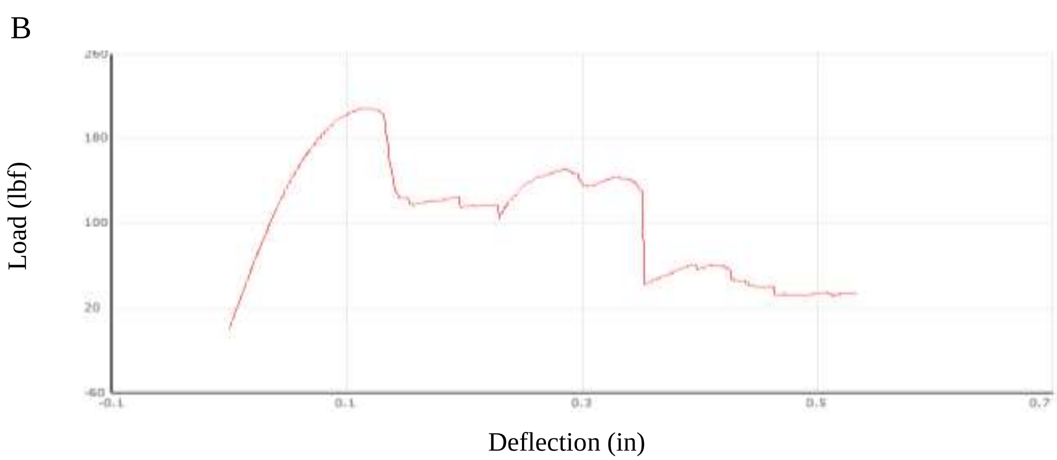

Fig. 7: Load (pound) as a function of deflection (in) for beam with horizontal honeycomb web geometry

Based on these results, change in deflection with volume in these beam structures exponentially decreases. It was expected that, as the volume increased by thickening the honeycomb cell wall, the deflection would decrease for both cases. Research showed that changing the web geometry could reduce the beam weight as well as alter the beam's ability to carry load.[9, 13] These results show vertical orientation of honeycomb cells is preferable to horizontal orientation, particularly at low material volume. Beam models with vertical cell orientation have lower deflection values under given load than beams in the horizontal orientation. Beam models with horizontal cell orientation also have higher deflection values under a given load than beams with rectangular web geometry, when volume is held constant. Beam models with vertical cell orientation also have lower deflection values under a given load than beams with rectangular web geometry, when volume is held constant.

Future studies will examine several other geometries such as corrugation, square honeycomb, or tetrahedral structure, because geometry such as corrugation has been found to increase stability for beams. If there are structures that show improved stiffness for low volume in the production of beams, as does the vertically oriented hexagonal honeycomb, then the results of this study could be potentially implemented for the building industry. It could be a solution that allows the building industry to work toward reducing negative impacts on the environment as well as reducing energy consumption. When material usage in the production of beams is reduced, the building industry can theoretically lower material cost. However, the intricacy of the vertically oriented hexagonal honeycomb web geometry could also cause difficulty and increased cost in fabrication and production. Through current enrollment in the course Manufacturing Processes and Statistical Control, the student researcher is gaining more insight into the fabrication and production process, and additional cost of producing these types of beam structures.

Through this process, the student author has learned how to conduct a literature review, to obtain and organize both computational and experimental results. The student author has also gained familiarity with computational tools, such as SOLIDWORKS and finite element methods, as well as experimental methods, such as 3D printing and the use of a tensile testing machine to perform a 3 point bending test. These skills will be beneficial in further coursework, senior design projects, and as a starting point for learning advanced skills in graduate school.

Conclusion

The *Excel!* Research Scholars Program is a rigorous and competitive program that supports students to seek to change and challenge the world. The Excel! Research Scholars Program encourages its scholars to pursue academic and professional developments, through training in research at the undergraduate level. In the summer of 2015 under the mentorship of Dr. Katherine Acton, and with many supports from the *Excel!* Research Scholar Program, this research on "green" beam design was conducted.

In addition to the rich educational opportunity that the *Excel!* program provided, the student was also given the chance to build skills in the field of engineering. *Excel!* allowed the student researcher to have a hands on experience. The student continues to build a network of support among scholars and faculty whose goals and research interests are aligned with his academic and professional goals.

This research illustrates the potential to use novel design to decrease material usage. The building industry should not only strive to meet the needs of the present, but also to ensure that its actions will not compromise the needs of the next generation.[5] Research conducted through the *Excel!* Scholars program has increased the author's understanding and interest in continuing this inquiry. For the sake of the planet and the nation's socioeconomy, this is an important topic for the next generation of engineers.

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