Engaging High-School Students in Building Prefabrication (Resource Exchange)

Luciana Debs, Purdue University Programs

Luciana Debs, is an Assistant Professor of Construction Management in the School Construction Management Technology at Purdue University. She received her PhD from Purdue University Main Campus. Her previous degrees include a MS from the Technical Research Institute of Sao Paulo (IPT-SP), and BArch from the University of São Paulo (USP), in Sao Paulo, Brazil. Prior to her current position she worked in design coordination in construction and real estate development companies in Brazil. Her research interests include team work and collaboration in construction, effective communication in spatial problem solving, and design - field team interaction.

Dr. Yunfeng Chen, Purdue University Programs

Dr. Yunfeng Chen is an Assistant Professor in the School of Construction Management Technology at Purdue University. She is the founder/director of Construction Animation, Robotics, and Ergonomics (CARE) Lab. Her lab covers research in (1) Building Information Modeling (BIM)/Infrastructure Information Modeling (IIM); (2) Ergonomics and Human Factors; (3) AR/VR and Game; (4) Automation and AI; (5) Construction and Transportation Safety. She has been awarded one locally funded project from Local Technical Assistance Program (LTAP), two state funded projects (Georgia Department of Transportation and Indiana Department of Transportation), and one National Science Foundation (NSF) project as a PI and Co-PI.

Prof. Jiansong Zhang

Dr. Jiansong Zhang earned his Bachelor of Construction Management from Huazhong University of Science and Technology in Wuhan, China (2009) with top grade in his department, his M.Sc. in Civil and Environmental Engineering from Carnegie Mellon University (2010), and Ph.D. in Civil Engineering from the University of Illinois at Urbana-Champaign (2015). He worked in the Civil and Construction Engineering Department at Western Michigan University as an Assistant Professor for two years before joining the School of Construction Management Technology at Purdue University as an Assistant Professor in Aug. 2017. Dr. Zhang's professional experience includes working for Jiuzhou Engineering Consulting company in China. He is a member of American Society of Civil Engineers (ASCE), American Society for Engineering Education (ASEE), Construction Research Congress (CRC), and a member of ASCE Data Sensing and Analysis (DSA) Committee, Visualization, Information Modeling, and Simulation (VIMS) Committee, and Technical Council on Computing and Information Technology (TCCIT) Education Committee. He was recently elected Member-at-Large (term starts October 2017) of the ASCE DSA committee. He is also a member of the buildingSMART linked data working group and regulatory interoperability working group. He serves as a reviewer of Journal of Computing in Civil Engineering (since 2015), Journal of Construction Engineering and Management (since 2015), Journal of Management in Engineering (since 2017), Journal of Construction Engineering (since 2016), Journal of Automation in Construction (since 2017), Journal of Building and Environment (since 2017), and several international/national conferences (CRC 2016, CRC 2018, CIB W78 2018, ICSDEC 2016, ICCCBE 2016, WTC 2017, IWCCE 2017, ASC 2017). For example, he has been the session chair of Augmented & Virtual Reality session at IWCCE 2017, one of the session chairs of Data Sensing, BIM, Simulation Track, a program committee member of the Automation and Robotics Track, as well as a reviewer in both tracks of CRC 2018. He is an active member in Transportation Research Board (TRB) and was the TRB AFH10 2016 Straight-to-Recording Webinar Series panelist and moderator. Some of his honors include receiving the technology development award (2017) from Western Michigan University, conference travel awards (2012; 2013; 2014) from the University of Illinois, top three paper award (2013) from ASCE International Workshop on Computing in Civil Engineering, Chester P. Siess Award (2012) from the University of Illinois, Pokrajac Fellowship (2011) from the University of Illinois, CEE Department Scholarship (2009) from Carnegie Mellon University, and National Scholarship (2007; 2008) from China. Dr. Zhang has research interests in developing and leveraging advanced technologies to support construction engineering

©American Society for Engineering Education, 2020

and management, construction automation, and sustainable infrastructure, including building information modeling (BIM), artificial intelligence (AI) [i.e., natural language processing (NLP), machine learning, and automated reasoning], virtual reality (VR), and construction robotics. His research has been supported by Federal and State agencies such as Transportation Research Center for Livable Communities and Michigan Office of Highway Safety Planning. He has been awarded two National Science Foundation (NSF) research projects to study BIM interoperability scientifically and develop an interoperable BIM prototype system for automating building code compliance checking and modular construction analysis, respectively, through collaborations with experts in Civil and Construction Engineering, Mechanical and Aerospace Engineering, Civil and Environmental Engineering, Engineering Technology, Computer and Information Technology, Construction Management Technology, and industrial partners.

©American Society for Engineering Education, 2020

Engaging High-School Students in Building Prefabrication (Resource Exchange)

Contact Information: Dr. Luciana Debs (ldecresc@purdue.edu); Dr. Yunfeng Chen (chen428@purdue.edu); and Dr. Jiansong Zhang (zhan3062@purdue.edu)

Activity Overview

The proposed activity was originally designed as an outreach activity for student recruitment into the School of Construction Management, at Purdue University, which offers two undergraduate majors in the field of construction. The university is a large land-grant university, with recruitment activities happening several times in a year. The goal of the activity is to introduce high-school students (grades 9-12) to modular and prefabricated construction while using mathematical (area and weight calculations) and technology concepts (make informed decisions about construction transportation and hoisting logistics) in an open-ended, model eliciting activity [1].

Modularization and the use of prefabricated elements in construction require a higher level of coordination among designers, manufacturers and contractors than traditional on-site assembly does. With this activity, students take the role of an integrated team (designer, manufacturer and contractor), proposing not only the design, but also reviewing transportation and hoisting logistics. During the activity, the students propose and revisit the design of their modules based on information phased in three parts (initial prompt, second iteration, and third iteration) to guide them through the process. By the end of the activity students will understand the implications of the module design for the construction management process and how design choices affect construction decisions.

Activity Information

Time: 2 hours (grade 12, lower grades may need additional time)

Learning Goals and Related Academic Standards:

- Students will propose a modular building façade for a small commercial building, taking into consideration size and weight constraints due to fabrication, transportation and hoisting - (ITEEA Standard 5.11 (Students will develop abilities for a technological world – apply the design process);
- Students will understand how size and weight of prefabricated pieces related to the selection of transportation and hoisting equipment - ITEEA Standard 6.20 (Students will develop an understanding of the designed world – selecting and using construction technologies);
- Students will calculate the volume of concrete and weight of the proposed prefabricated modules (Common Core Standards High School: Modelling)

- Students will use the weight of prefabricated modules to select transportation and hoisting equipment (Common Core Standards High School: Modelling)

Required Materials:

- 11'x17' handouts with initial prompt (including not-to-scale building elevations and perspective) – at least three, one for each iteration per group;
- Blank sheets for sketching and annotations;
- At least three take-off sheets (one for each iteration per group) – see appendix A
- Handouts with options for (a) semi-truck transportation; (b) routes from prefabrication factory to construction site; and (c) site hoisting equipment for on-site assembly. Handouts (a) and (b) are for the second iteration, and hand out (c) is for the third iteration (one hand-out per group).

Summary of activity procedures:

Students are given a short presentation on prefabrication and modular construction and then asked to work in pairs during the activity. If a mixed age group is present for the activity, it is suggested to pair students so that older students work with younger students to help them through the process.

- *Initial prompt*: with site plan and elevations in hand, students are asked to provide a proposal for how the building façade where the panels are located will be divided. In this first iteration, students focus on optimization of the pieces to have the least number of pieces, while optimizing to obtain pieces of the same or similar sizes. Students are also asked to provide a quantity take off, in terms of size, weight and quantities of the prefabricated panels.
- *Second iteration*: after the first iteration, they are provided with information about transportation logistics, including limitations of the transportation equipment and the potential routes. During a second iteration, students review their design and select their transportation equipment and route. Again, the students provide a revised quantity take off.
- *Third iteration*: then, a final iteration takes place. Students are given options for hoisting equipment on site. With that, they have to refine their modular design and select a hoisting equipment. A final table with quantities, weight and size of pieces is prepared by students. At the end of the activity, pairs show their design to peers.

Finally, instructors and students debrief the activity and discuss how manufacturing, transportation and assembly information has changed their design and the importance of coordination.

Activity Introduction

The activity is introduced by a 10-minute presentation on prefabrication, which stresses the need for an integrated approach among designers, engineers, manufacturers and contractors for a successful project. References of prefabricated façade elements and architectural precast concrete panels can be obtained on the internet to show students what could be done with prefabricated panels. During the activity introduction, it is important to stress the following factors, which will then be used during the activity:

- Modularization of panels – the ability to distill the design in smaller and simpler pieces that can then be combined to form more complex design – helps to bring the cost of panel production down, by increasing repetition;
- The design does not need to be constrained to a certain shape, though rectangular shapes are most common;
- The size and weight of the pieces is influenced by the manufacturer's machinery capability, transportation and hoisting equipment limitations and transportation regulations and route limitations, among others;
- The construction schedule is influenced by the quantity and size of pieces in a prefabricated façade.

Initial Prompt (Figures 1 and 2, not to scale)

You are an Integrated Design firm and you need to propose the design for the Precast panels to be used in the Grocery Store (see areas in gray in Figures 1 and 2).

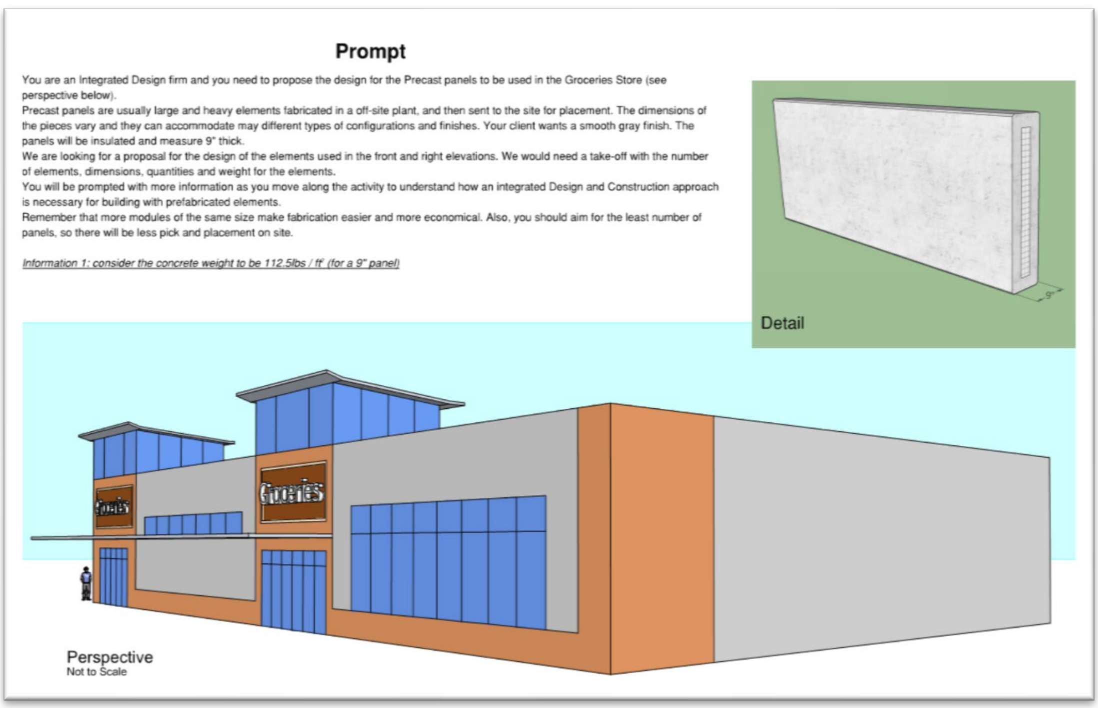

Figure 1 – Initial Prompt Front

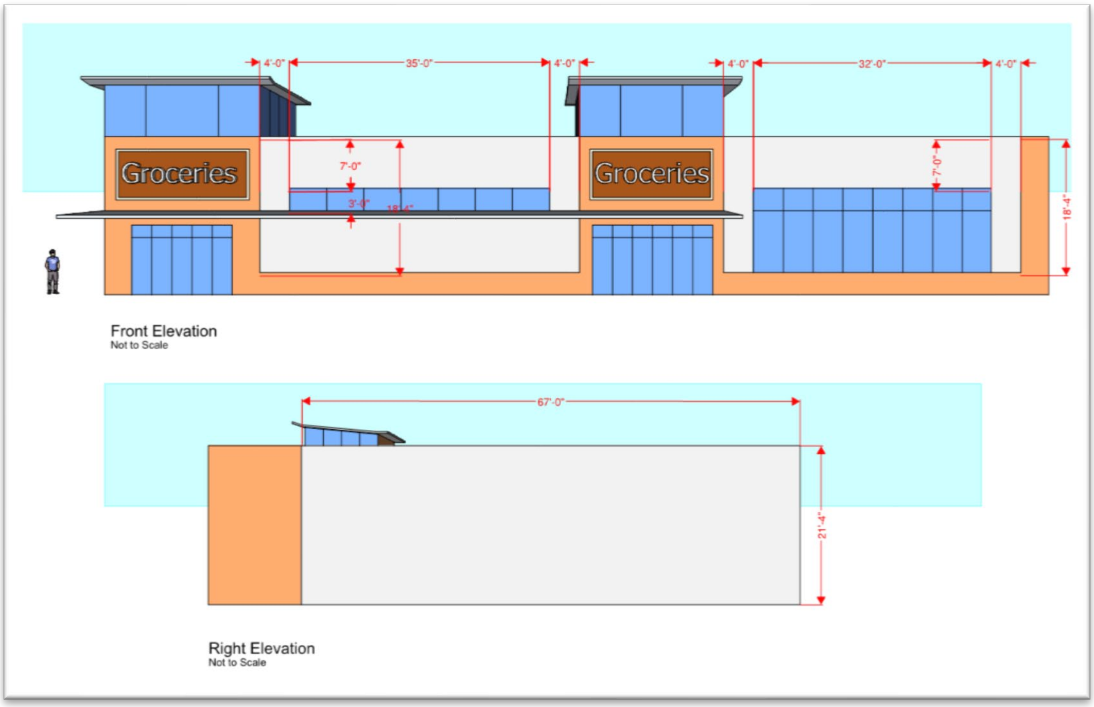

Figure 2 – Initial Prompt Back

Precast panels are usually large and heavy elements fabricated in an off-site plant, and then sent to the site for placement. The dimensions of the pieces vary and they can accommodate may different types of configurations and finishes. Your client wants a smooth gray finish. The panels will be insulated and 9" thick.

We are looking for a proposal for the design of the elements used in the front and right elevations. We would need a take-off with the number of elements, dimensions, quantities and weight for the elements.

You will be prompted with more information as you move along the activity to understand how an integrated Design and Construction approach is necessary for building with prefabricated elements.

Remember that more modules of the same size make fabrication easier and more economical. Also, you should aim for the least number of panels, so there will be less pick and placement on site.

Information 1: consider the concrete weight to be 112.5lbs / ft2 (for a 9" panel)

Prompt #2 (Figures 3 and 4, not to scale)

Now you have received updates on the location of the factory and transportation options. There are three routes you can choose from to transport the panels from the factory to the jobsite (Figure 3) and there are three truck options you can choose from to make the trips (Figure 4). Some of the routes are shorter, others are longer; some of the routes have weight and hour restrictions for transportation, and may pass through highly populated areas. You should consider the impact of your decision on the safety, cost and time to transport the pieces.

Taking all into consideration you may find that you need to re-evaluate your original proposal to see if there is a better way to divide the façade into prefabricated panels.

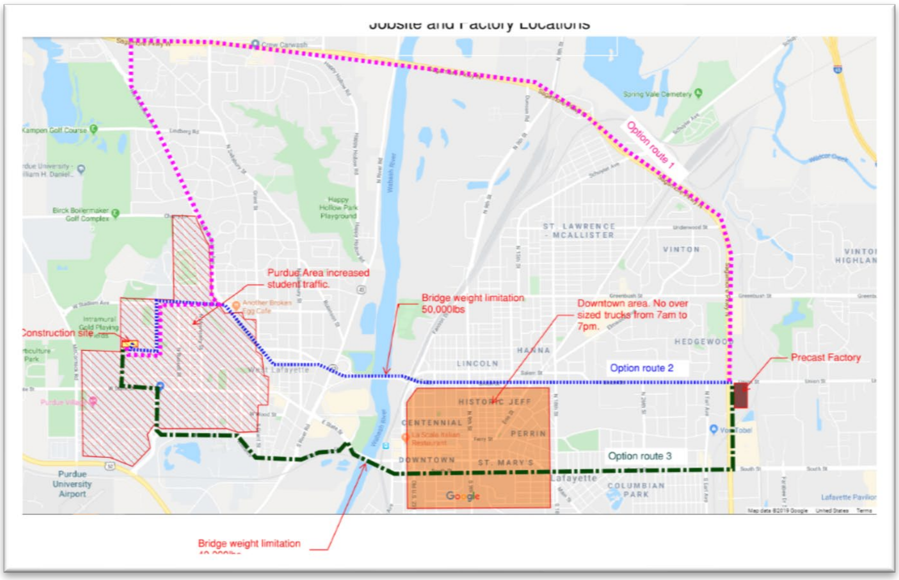

Figure 3 – Route options

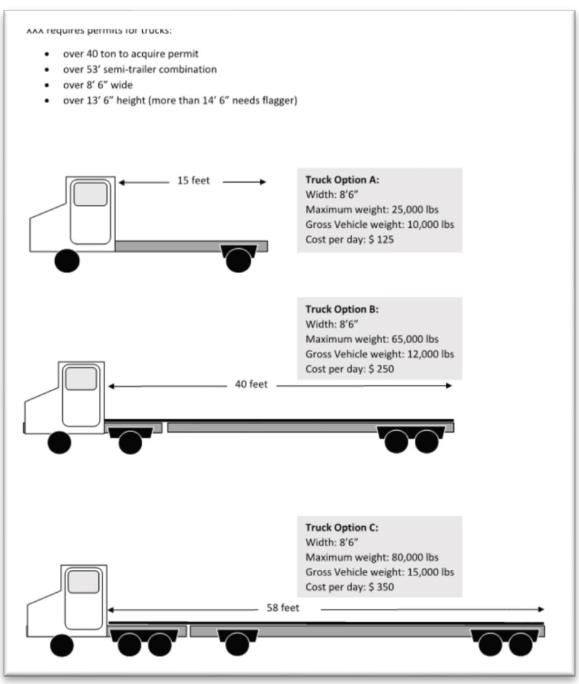

Figure 4 – Truck options hand-out

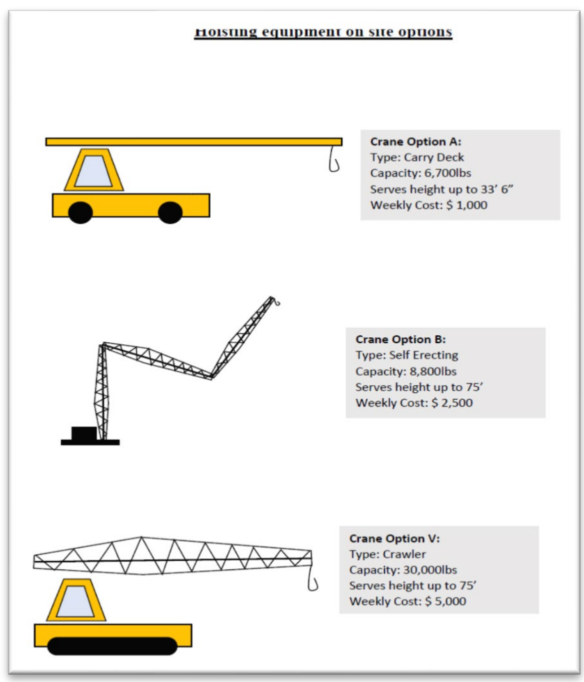

Figure 5 – Hoisting equipment options hand-out

Prompt #3 (Figure 5)

Finally, on site, the contractor informs that three different types of hoisting equipment can be used in this job (Figure 5). Select the one you think will best meet the needs of the project. Taking this new information into consideration you may find that you need to re-evaluate your original proposal to see if there is a better way to divide the façade into prefabricated panels.

Debrief

After finishing the calculations for prompt 3, the students should have three 11’ x 17’ pages with proposal for the façade division into smaller prefabricated panels (an example prepared by the authors of a possible outcome can be seen in figure 6) along with three take-off spreadsheets. The students are asked to share the last proposal with a summary of the three iterations and provide the following information: (1) how many panels there are in total in their final proposal; (2) what the smallest and largest panel sizes are; and (3) how they have used the information to up with the best proposal for their client.

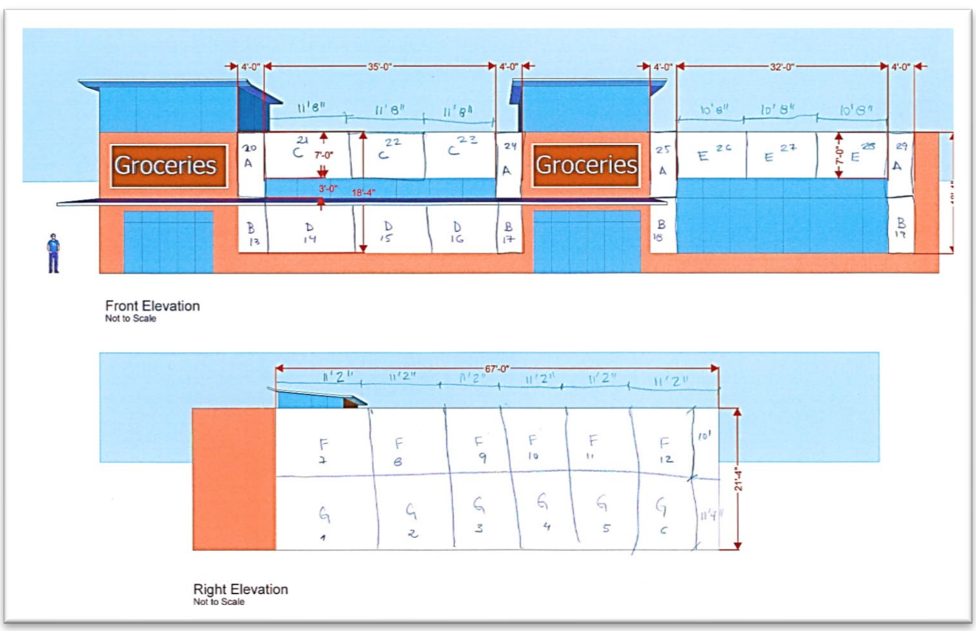

Figure 6 – Example of final output prepared by the authors. Panels with the same size are represented with the same letter and each panel as a unique number identification

At the end of the activity, the group can start a discussion about how factors mentioned in the activity can impact the total construction schedule and cost, safety and the aesthetics of the final product, the importance of mathematics for quantity take-off and weight modeling of prefabricated pieces, and the benefits and challenges of using prefabricated panels on construction projects.

Acknowledgement

The authors would like to thank the National Science Foundation (NSF). This material is based on work supported by the NSF under Grant No. 1827733. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the NSF.

References

[1] Diefes-Dux, H. A., Moore, T., Zawojewski, J., Imbrie, P. K., & Follman, D. (2004, October). A framework for posing open-ended engineering problems: Model-eliciting activities. In *34th Annual Frontiers in Education, 2004. FIE 2004.* (pp. F1A-3). IEEE.

Appendix A – Take-off Chart

Panel Number	Dimensions	Weight for 1 panel	Quantity of equal Panels