

engineering in action

using *Aladdin* as a tool to empower engineering learning

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With the publication of the Framework for P-12 Engineering Learning, engineering will hopefully become more prominent and equitable across secondary education in the coming years.

Introduction

Engineering learning, a three-dimensional construct that includes Engineering Habits of Mind, Engineering Practices, and Engineering Knowledge, has been well established and defined at the post-secondary level (Reed, 2018). Meanwhile, engineering within pre-kindergarten through 12th grade (P-12) classrooms continues to grow steadily. Changes introduced by *A Framework for K-12 Science Education* (National Research Council, 2012) and *Next Generation Science Standards* (NGSS Lead States, 2013) have started to place engineering within secondary science education, just as the inclusion of engineering design in *Standards for Technological Literacy* did within technology education classrooms at the turn of the century (International Technology and Engineering Educators Association, 2000/2002/2007). More and more students are now exposed to engineering learning prior to graduating from high school in a variety of courses like technology, science, and career/technical education classrooms, as well as informal learning programs. Nevertheless, engineering in its own right often remains a missing or minimal component of the learning experience for many students (Change the Equation, 2016; Miaoulis, 2010). To include engineering in a more prominent manner, the *Framework for P-12 Engineering Learning* (2020) has recently been published as a practical guide for developing coherent, authentic, and equitable engineering learning programs across schools. This guidance includes a definition of the three dimensions of engineering learning, principles for pedagogical practice, and common learning goals. The framework can support the development of in-depth and authentic engineering learning initiatives and provide building blocks toward the 2020 *Standards for Technological and Engineering Literacy*. As a component of the framework, engineering practices are detailed by describing core concepts that can support performing these practices with increased sophistication over time. Examples include making data-informed design decisions based on material properties and employing computational tools to analyze data to assess and optimize designs. In this *Engineering in Action* article, we introduce a freely available, open-source computer-aided design (CAD) software called *Aladdin* and discuss how it can support authentic engineering practice within secondary classrooms. Earlier works have suggested that *Aladdin* is an effective tool for implementing *Next Generation Science Standards* (e.g., Chao et al., 2018; Goldstein, Loy, & Purzer, 2017). Similarly, we make a case for using

Aladdin in secondary engineering education and discuss how recommendations of the *Framework for P-12 Engineering Learning* map to specific features of the software.

What is *Aladdin*?

Aladdin (formerly known as *Energy3D*) is a freely available, open-source CAD program that has been developed specifically to help students learn about designing energy-efficient buildings and renewable energy solutions (Xie, Schimpf, Chao, Nourian, & Massicotte, 2018). It also allows education researchers to study actions that students perform within the platform (e.g., Seah & Magana, 2019; Vieira, Seah, & Magana, 2018). Since the software is easy to use and has built-in tutorials, students can quickly learn how to model a simple building (e.g., see Figure 1). They can then start to do analyses to understand if their designs meet their needs (e.g., being within a certain budget and being an energy-neutral building). *Aladdin* can be downloaded for free on both Mac and Windows computers from the following website: <https://intofuture.org/aladdin.html>. The development of a cloud-based version is currently underway to make it even more powerful and accessible.

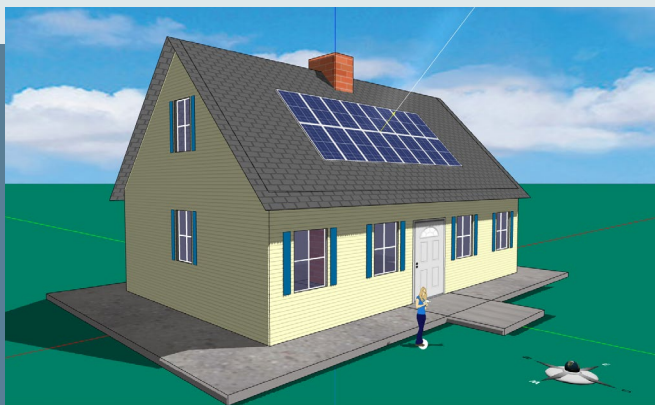


Figure 1.
An example house in *Aladdin*

Is *Aladdin* an Effective Teaching Tool?

Previous education research suggests that *Aladdin* is an effective tool for helping secondary education students specifically to learn important engineering concepts. Goldstein, Omar, Purzer, & Adams (2018) found that middle school students benefited by working on a design project using *Aladdin*; importantly, even if their projects were relatively simple. Furthermore, in their study, also with middle school students, Dasgupta, Magana, & Vieira (2019) showed that *Aladdin* helped students to learn principles of thermodynamics and heat, and allowed them to perform systematic experimentation to create better building designs. Magana et al. (in press) demonstrated different learning activities enabled by *Aladdin* within middle school, high school, and pre-service teacher classrooms. They found that students in all classrooms increased their conceptual understanding of thermodynamics. Students in those classrooms also produced feasible designs (i.e., met the design criteria and were energy efficient).

How Can *Aladdin* Be Used With the New Engineering Framework?

The *Framework for P-12 Engineering Learning* describes *engineering learning* as being composed of three areas: *Engineering Habits of Mind*, *Engineering Practice*, and *Engineering Knowledge*. We will illustrate how *Aladdin* can be used to teach students each of these areas within *engineering learning*.

Engineering Habits of Mind

Engineering Habits of Mind consist of *optimism, persistence, collaboration, creativity, conscientiousness, and systems thinking*. While *Engineering Habits of Mind* should be modeled through specific teaching practices, *Aladdin* can still help promote these habits. Specifically, students can learn about *systems thinking* by modeling buildings within *Aladdin*. They can understand how designing a building requires both identifying important components of a building system (e.g., location, size, and energy) and quantifying how those components interact with one another. Considering that almost all contemporary engineering now relies on the extensive use of CAD tools, early introduction of CAD concepts and usage in P-12 education may foster engineering habits of mind in an even more practical sense.

Engineering Practice

Engineering Practice involves *engineering design, material processing, quantitative analysis, and professionalism*. Each of these components of *Engineering Practice* involves a number of skills. Here we will demonstrate how *Aladdin* can help students learn skills for each component listed above.

Engineering design involves a number of skills such as problem framing, information gathering, ideation, engineering graphics, design communication, and decision making. We will particularly focus on decision making, as *Aladdin* has built-in analysis tools to help students make better design decisions. After students have modeled a building, they can quickly perform an annual energy analysis to determine the net energy usage of their building. Figure 2 shows an example annual energy analysis with net energy shown in circular orange markers and connected by a thick black line. The annual energy analysis tool allows students to quantify which months of the year require more energy. They will additionally be able to identify components of their building that require significant energy and try to mitigate that energy use. Since the annual energy analysis tool only takes a few seconds or a few minutes to run, students can easily explore how changes to their building design affect the energy use of the building.

In real-world engineering projects, engineers need to account for material properties such as thermal, mechanical, and electrical characteristics. The *material processing component of Engineering Practice* involves a number of skills such as manufacturing, measurement and precision, fabrication, casting/molding/forming, separating/machining, joining, conditioning/finishing, safety, and

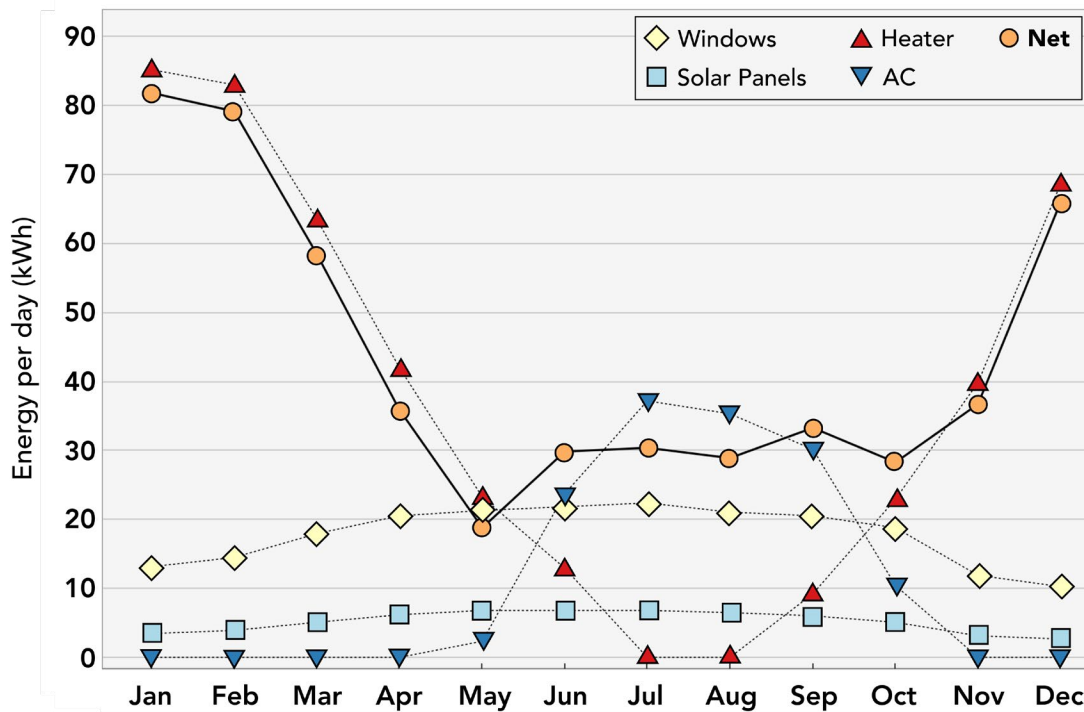


Figure 2. The *Aladdin* built-in annual energy analysis tool showing energy use (in kWh) for various components of a modeled building as a function of time (in months). The figure has been modified from the *Aladdin* output to improve readability by increasing the marker and font sizes and by using colorblind safe colors (electronic version only).

material classification. While it is a CAD software, presently *Aladdin* does not easily allow fabrication, for example, by sending CAD designs to a 3D printer (though it supports printing out 2D pieces for assembling into 3D structures). Nevertheless, students can still use the software to learn about material classification. Students can explore how changing material properties (e.g., thermal insulation of building walls) may affect the overall building design. *Aladdin* allows students to set either the U-value or R-value for one or more walls of a building (see Figure 3). The U-value is the overall heat coefficient of a material and has units of $W/m^2 \cdot ^\circ C$. In the case of a hot summer day or a cold winter night, an ideal house should have low U-values for its walls to minimize thermal energy transferring through them. A low U-value will keep the inside of the building insulated, thus allowing it to be cooler inside in the summer and warmer in the winter. Alternatively, instead of setting the U-value, students can set the R-value. The R-value is a measure of the resistance to heat conduction and has units of $h \cdot ft^2 \cdot ^\circ F/BTU$. As part of their building design, students can explore setting different insulation values (either U- or R-values), they can look up typical insulation values for real building construction materials, and they

can explore the consequences of setting different insulation values for different walls to factor for solar irradiance.

Quantitative analysis involves a number of skills such as computational thinking, data collection, analysis and communication, system analytics, modeling and simulation, and computational tools. By the nature of the CAD software, *Aladdin* is ideal for teaching all of these skills, but here we will particularly focus on how it can help teach students to use computational tools. *Aladdin* allows students to model buildings in a specific location (e.g., Indianapolis, Indiana). Students can use the heliodon feature to visually study the Sun's path through the sky as a function of time (see Figure 4). In the case of Indianapolis, since the city is located nearly 40 degrees north of the equator, students will notice that the Sun's path is lower in the sky in the winter and higher in the summer. They can,



Insulation Value of Wall(11)

Examples:
US R13 (cellulose, 3.5"), US R16 (mineral wool, 5.25"), US R31 (fiberglass, 10")

Apply to:

☒ Only this Wall

☐ All Walls of this Building

U-Value in SI Unit: $W/(m^2 \cdot ^\circ C)$

R-Value in US Unit: $h \cdot ft^2 \cdot ^\circ F/Btu$

Cancel OK

Figure 3. Wall insulation can be modified for buildings in *Aladdin*

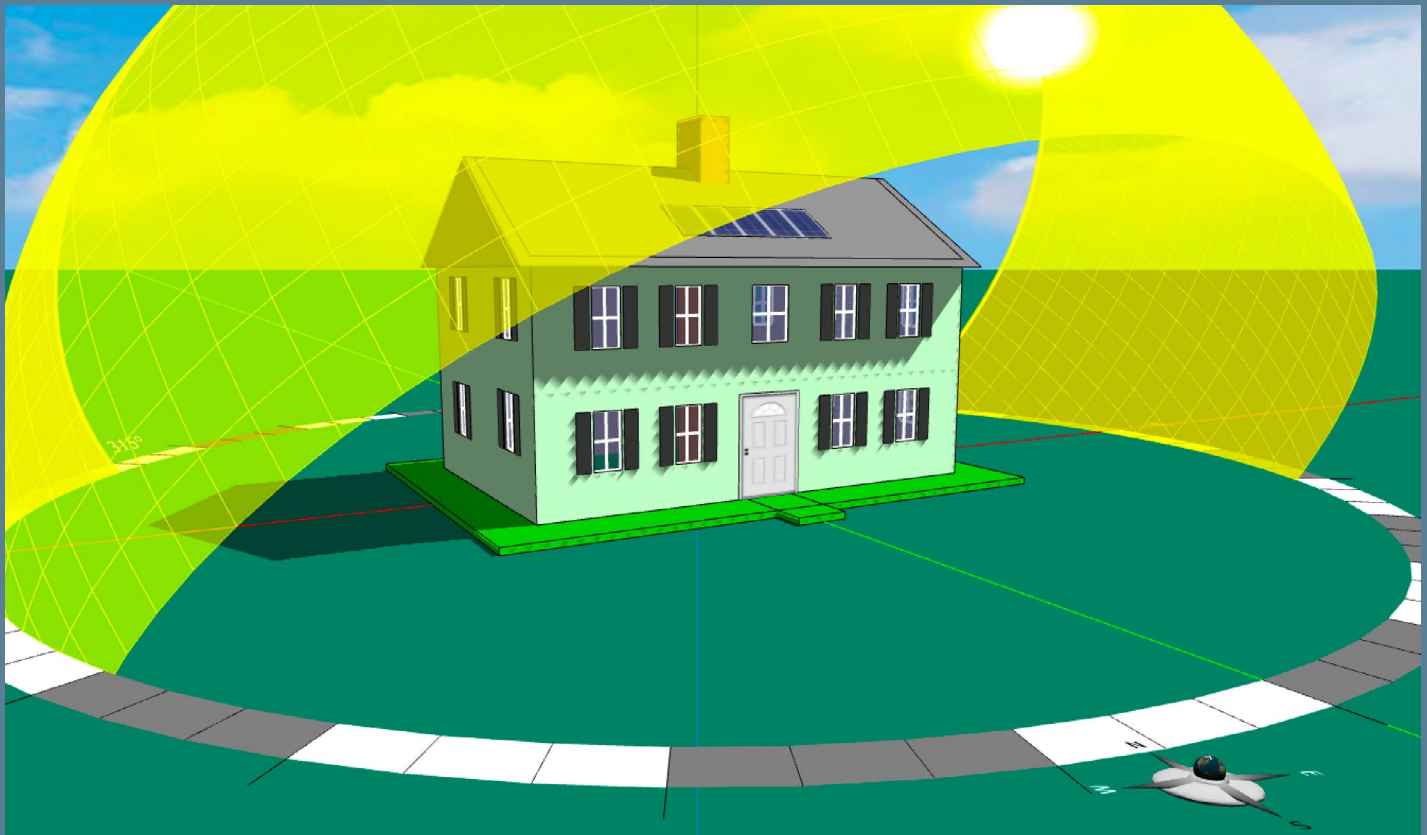


Figure 4. Heliodon feature in *Aladdin* allows students to analyze energy use based on the Sun's path across the sky

for example, then think about how their building designs can take advantage of the Sun's path to maintain a certain temperature throughout the year.

The final component of *Engineering Practice* is *professionalism*, which involves a number of skills such as professional ethics, workplace behavior/operations, honoring intellectual property, the role of society in technological development, engineering-related careers, and technological impacts. Since *Aladdin* allows students to model buildings and to analyze them for their energy efficiency, the software naturally lends itself to a discussion about technological impacts, particularly impacts on the environment. Constructing and operating buildings produces significant amounts of carbon dioxide emissions. In 2017, buildings accounted for 39% of the world's carbon dioxide emissions (Abergel, Dean, Dulac, & Hamilton, 2018). Given that buildings are a significant contributor to climate change, we need to both make current buildings more sustainable and improve future building designs. *Aladdin* can help teach our youth to be mindful of the impact that buildings have on the environment and to work towards mitigating those negative effects.

Engineering Knowledge

Engineering Knowledge involves engineering sciences, engineering mathematics, and engineering technical applications. We will focus here on engineering sciences and engineering technical applications.

Engineering sciences include statics, mechanics of materials, dynamics, fluid mechanics, mass transfer and separation, chemical reaction and catalysis, circuit theory, thermodynamics, and heat. *Aladdin* can help students learn concepts in both thermodynamics and heat. A lesson on the first law of thermodynamics would be a good introduction to students using *Aladdin*. Students would then use the software with the knowledge that maintaining a comfortable temperature inside a building (i.e., no change in its internal energy) means that the building needs to have no net heat (assuming of course, there is no thermodynamic work done on the building). Students can use the heat flux visualization tool in *Aladdin* (see Figure 5) to understand how certain parts of a building have higher heat fluxes (windows in this particular case) and can think about ways in which thermal energy exchange between the inside of a building and the outside environment can be minimized.

Engineering technical applications include concepts such as mechanical design, structural analysis, hydrologic systems, geotechnics, environmental considerations, and electrical power. Given that *Aladdin* allows students to easily add solar panels onto their model buildings, it is a convenient place to teach students about electrical power generation. This is also a relevant topic to students since we, as a society, will likely be using more solar power for our electrical power generation in the coming years and decades. When a student places a solar panel, they will have a number of options to alter properties such as the model of the solar panel (e.g., ASP-

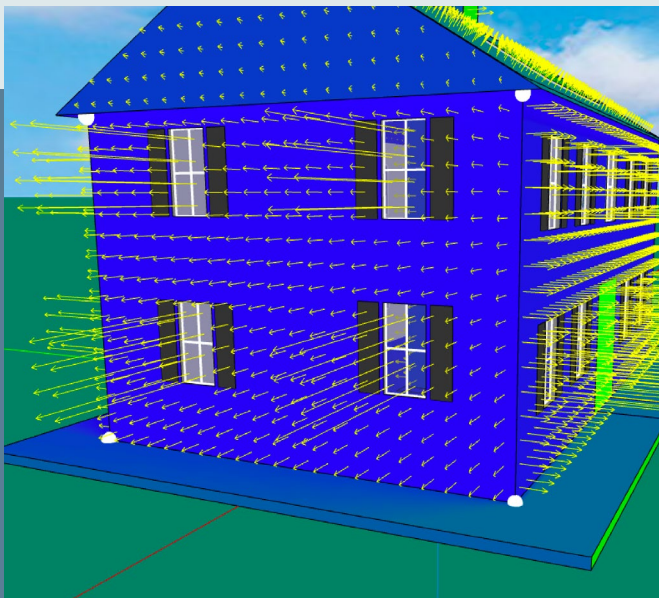


Figure 5.
Heat flux vectors demonstrating more energy loss through windows than walls of the building

400M, CS6X-330M-FG, and FS-275), size, cell type (e.g., polycrystalline, monocrystalline, and thin film), cell efficiency, and inverter efficiency (see Figure 6). Cell efficiency is defined as the fraction of incident solar energy that is converted by the cell to electrical energy. While solar energy is freely available, students may be interested to learn that a contemporary limiting factor for solar energy production is cell efficiency. Even today, the most efficient solar cells tend to be under 40% efficient (Green et al., 2020). While certain solar panel parameters are limited by current technology, students can explore ways to alter the number, size, and orientation of solar panels to increase electrical power production.

Conclusions

With the publication of the *Framework for P-12 Engineering Learning*, engineering will hopefully become more prominent and equitable across secondary education in the coming years. As this occurs, teachers will need effective tools to help them teach engineering concepts to students in an authentic manner. Here we demonstrate how a freely available, open-source CAD program can

Figure 6.
Options to change solar panel parameters in *Aladdin*

Model	Custom
Panel Size:	0.99m × 1.65m (6 × 10 cells)
Cell Type:	Monocrystalline
Color:	Blue
Solar Cell Efficiency (%):	18.33
Nominal Operating Cell Temperature (°C):	48
Temperature Coefficient of Pmax (%/°C):	-0.5
Shade Tolerance:	Partial
Orientation:	Portrait
Inverter Efficiency (%):	95

Apply Cancel OK

serve that purpose. By doing so, we hope that we have provided some examples and ideas for teachers to empower engineering learning within their classrooms in authentic and rigorous ways. In addition, this tool may provide options for teachers to continue their instruction virtually in times of interruption, such as during the COVID-19 pandemic.

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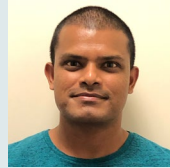
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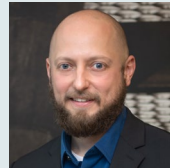
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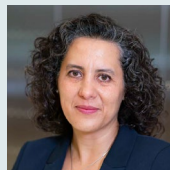
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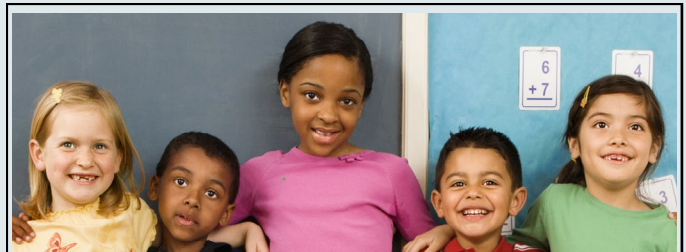


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