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Teaching a Methodology towards a Sustainable, Affordable 3-D-printed House: Heat Transfer and Thermal-Stress Analysis

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In the future, the tendency is toward manufacturing housing based completely on 3D printing because it decreases labor costs, speeds the process of construction and reduces the number of accidents at a work site. Department of Energy (DOE), and laboratories such as Construction Engineering Research Laboratory (CERL) are spending a lot to prepare a pipeline in the area of advanced manufacturing. The concerns are related to research, education and outreach.

Sustainable housing is environmentally friendly housing, in terms of everything from construction to the use of the building. The house needs to be air-tight and highly efficient. It must use renewable energy. Our work will exhibit designing walls in ways that make them mechanically strong and thermally efficient. It will also feature ideas about stress analysis and energy-related problems such as heat transfer, moisture and condensation. With respect to housing, 3D printing creates the major parts that go into the assembling of a house, with blueprints showing all the 3D-printed parts and how to assemble them.

The objective of this paper is to describe the students' benefits when introduced to a methodology towards a sustainable, affordable 3D-printed house with emphasis on heat transfer and thermal-stress analysis, and how that knowledge can be integrated into a DOE project and outreach program. Most importantly, project methodology will be discussed. We discuss the project from the students' point of view, and their development in design, integration, and also in written and oral communication skills. The methodology used to evaluate the effectiveness of this design program in term of learning outcomes is also described.

Teaching Methodology:

Three-dimensional (3D) printing [1], known as additive manufacturing is an advanced manufacturing process that can produce complex shape geometries automatically from a 3D computer-aided design model without any tooling, dies, or fixtures. The geometries can be made from different materials, use different processes, and start from either powder (case of metal printers) or plastic filament. The parts are made layer by layer.

In his 2013 State of the Union Address, President Barack Obama declared, "3D printing technology has the potential to revolutionize the way we make almost everything". As a result, the impression is that three-dimensional (3D) printing will take over all manufacturing in the world in different regions [2].

Teaching middle school students advanced manufacturing, and applications related to 3D-printing is challenging, since they lack the background knowledge in several related areas, to fully comprehend and perform sophisticated study and analysis. In particular the math and science skills needed to perform modeling and simulation using sophisticated software are insufficient.

Mathematical and Computational Modeling and Simulation is a highly multi-disciplinary fields with abundant applications in science and engineering. Thus, understanding the application of specific methods, concepts, and theories to solve problems is a required skill. In our case, applying heat transfer principles and, understanding the mechanical and thermal stresses analysis are required in this project. In the framework of this project, a methodology has been developed to allow students to perform simulation and be able to understand and analyze the results. This methodology is based on the understanding of the physical phenomena, performing experimentation, and using software, such as Heat2 and Autodesk Inventor. Our approach is based on active learning strategies that emphasize comprehensive understanding, avoiding as much as possible all the complication of numerical and analytical mathematics needed for such level of study.

A collaboration with middle school/high school instructors has been carried out and a methodology has been developed based on a step-by-step learning method. At this moment, only two middle/high schools instructors are involved. They enthusiastically helped with the process, and at the same time, they learned with the students, since they have never been exposed to such projects. Their presence was very useful in terms of addressing the appropriate pedagogy, communicating with middle/high school students, and controlling them in certain circumstances. Their presence was also invaluable when instructions from a university faculty were not communicated to the students based on the students' level of understanding.

During the summer camp, our objective was to encourage the students to understand the topic, be creative, and be able to generate great ideas to solve real problems. The two week camp was part of a larger program that included research, education and outreach. Specifically, this program had multiple goals:

1) Train the students to use Inventor™ 3D CAD computer program to create engineering designs and teach them how to 3D print the designs using advanced 3D printers.
2) Teach students thermal and mechanical engineering
3) Introduce the students to applications of advanced manufacturing (AM) to enhance their interest in pursuing college degrees that would prepare them for careers in AM.
4) Improve students' communication skills.

The process that we developed was mostly oriented toward the middle school students and it was formed from three steps:

- Teaching the heat transfer phenomena,
- Teaching energy, and the conservation of energy,
- Learning the use of heat transfer software.

The integrated science approach [3] has been used, in which the contents of the three disciplines (physics, heat transfer, and energy) were reconstructed focusing on four basic aspects of energy (forms, transfer, transformation, and conservation) and using active learning teaching methodologies.

The module was assessed with few middle school students (aged 11–14) using straightforward and easy to understand explanations, labs, and menu-driven software. Analysis of students' outcomes (students participated into 2017 Appalachian Energy Summit Poster Competition, as shown in Figure 1) suggests an understanding of the energy concept, supporting the effectiveness of an interdisciplinary approach in the teaching of energy in physics and science in general.

The active learning method has been used in which students solve problems, answer questions, form questions, participate in class discussion, give their own interpretation, debate, or brainstorm during class. In our case, with such a small group, think-pair-share activities and short written of oral exercises [4] were used. A think-pair-share activity is when learners take a minute to ponder a previously discussed topic and later to discuss it with one or more of their peers. Finally, they share it with the instructors and the other group. These discussions are centered on an open-ended topic. A small group (2 to 3 students) discussion is encouraged after each topic and activity. A short written exercise used is the "one minute paper." In this exercise, students are asked to summarize the day's discussion in a short paper to be turned in before the end of class. This is a good way to review materials.

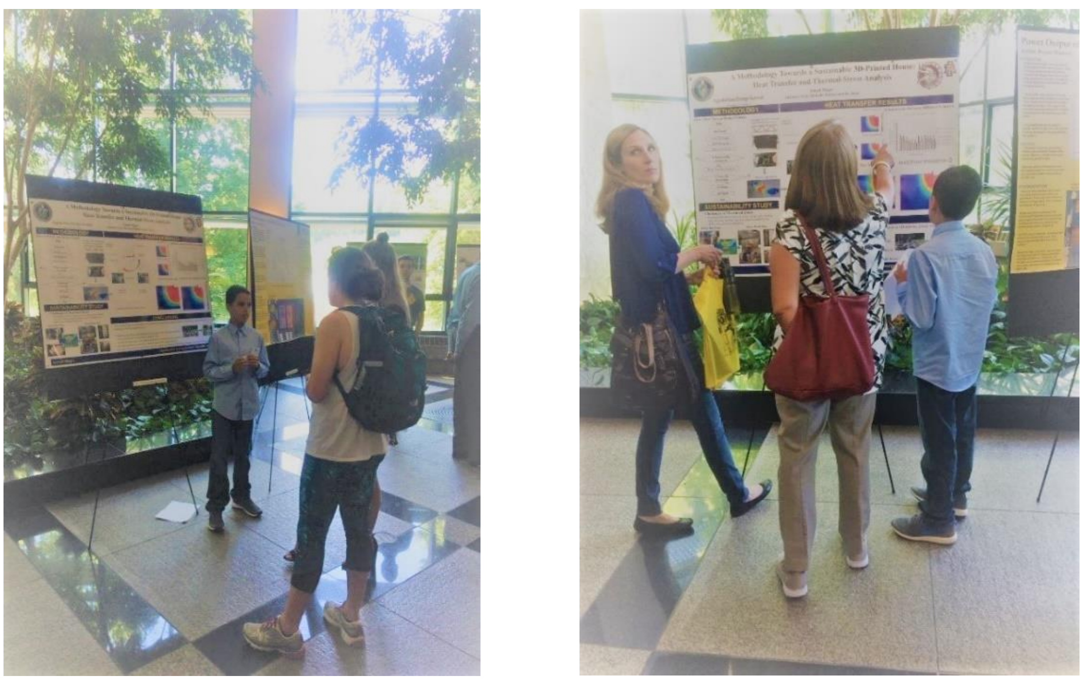

Figure 1: Student’s participating in 2017 Appalachian Energy Summit Poster Competition, (mainly designated to undergraduate and graduate university students)

1. *Teaching the heat transfer phenomena to middle school students*:

Usually, middle school students already have some knowledge about heat transfer phenomena and mechanisms. Our objective is to emphasize such topics and extend the knowledge to several applications in an integrated way [5-6].

Conduction:

- Define conduction, through examples from life, mechanics, and building. Discuss how the heat transfers from high temperature (warmer object) to low temperature (the cooler object), such as touching a boiling pot.
- Divide the class into groups around a table and each group is given items that can be used for the experiment.
- Have students experiment activate learning about situations where the conduction is identified clearly. One of the cases is to measure the temperatures, using an infrared temperature meter, of wall room surfaces from inside and outside on a sunny day. Encourage students to think about how their hands feel when they touch hot vs. cold items (such as stainless steel pot).
- Have students draw or write about how their hands feel when in contact with a hot surface vs. in contact with a cold surface.
- Discuss with students how the heat from a hot surface is transferred to their hands when their hands are in contact with such surface.
- Explain how some materials let heat through more easily than others. These are called good 'conductors' of heat. The heat travels or 'conducts' through the material. The glass should have felt the hottest because it is the best conductor of heat. Insulation materials, such as polystyrene felt the coolest, because it is a poor conductor of heat.

Convection:

- Define convection. Discuss how currents in the air can transfer heat, such as air in contact with a radiator under a window. Discuss the difference between natural and forced convection.
- Divide the class into small groups around a table in an active learning environment and give students items needed for the study, such as a temperature meter or thermometer (PT probe).
- Provide each group with a fan and two hot objects.
- While one group is measuring and recording the temperature of a hot object exposed to the fan airflow, the other group is measuring and monitoring the temperature of the second hot object far away from the fan (within the same room).
- The measurements are recorded each minute, over 5 to 15 minutes and both results are compared.
- Have students observe the operations and write or draw about it.
- Return to each group and reverse the experiment.

- Discuss with students how to explain why one object drops its temperature faster than the other. Discuss other similar situations, where similar phenomena are observed.

Radiation:

- Define radiation. Discuss how electromagnetic waves can transfer radiation from one object to another one (we discuss the surface facing each other's or partially facing each other's), both in vacuum or through medium, can transfer heat, like when sun radiation cross all atmosphere layers.
- Divide the class into groups around tables and provide each group with a table lamp (preferably with incandescent lamp) and other items, such as an infrared temperature meter.
- Have students experiment with the heat feeling, when the lamp is positioned downward and upward. Students should express what they observe over a 5- to 15-minute period. Using an infrared temperature meter, the students measure and each minute monitor the surface temperature of an object exposed to the lamp, in both lamp positions, upward and downward.
- Students should draw or write about what happened to the object as the lamp's rays heat their objects.
- Discuss with students how radiation from the sun transferred heat and light to an object. The difference between light and heat is discussed.

Discussion Questions:

Complementary and comprehensive discussion questions are discussed after the three phenomena are introduced. Example of such questions are:

- What are some real-world examples of conduction, convection, and radiation?
- How are conduction, convection, and radiation similar and different?
- Explain situations, where all these phenomena: conduction, convection, and radiation are discussed.
- Discuss the very basics of the fundamental equations and explain that numerical methods (computer program) are needed to solve them, so that we can access the thermal stresses within an object.
- Discuss quickly the boundary conditions, and how we can use them to solve a real situation. Different types of boundary conditions are barely described.

2. *Teaching energy, and conservation of energy*:

Energy is defined as the ability to produce change or do work, and that work can be divided into several main tasks we easily identified: energy produces light, heat, motion, sound, and so on. Explain the many forms of energy, and how, they all fall into two categories– potential or kinetic.

We first explain to students what conservation may means for laymen, for example when you try to "turn off the lights," and reduce the electrical bill. To scientists, "energy conservation" is not just about saving energy. Mainly, the "Law of Conservation of Energy" expresses that energy is neither created nor destroyed. When we use energy, it doesn't disappear. We change one form of energy into another, such as from mechanical to electrical or vice versa. A car engine burns gasoline, converting the chemical energy in gasoline into mechanical energy (motion energy). Likewise, solar cells change radiant energy into electrical energy. So, energy changes form, but the total amount of energy in the universe stays the same.

The only exception to this law is when a small amount of matter is converted into energy during nuclear fusion and fission.

We explain to the students that conservation is expressed by equations of conservations. We have conservation of mass, conservation of energy and other types of conservation, such as conservation of momentum. The equations are very complex and solving them numerically allows us to discover the behavior of the materials, such as thermal and mechanical stresses that show different states and behavior of the material.

3. *Learning the use of heat transfer software*:

Heat transfer is governed using the heat transfer equation, in addition to initial and boundary conditions. The heat equation is a partial differential equation that describes the distribution of heat, or variation in temperature, in a given object over time. Solving the heat transfer equation can be done either analytically or numerically, but both solutions need mathematical background knowledge, that middle school students may not have. The solution is to use existing software with a menu-driven interface that facilitates the use of such software.

Our choice was the use of the European software HEAT2. HEAT2 is a PC-program for two-dimensional transient and steady-state heat transfer. The program along with the three-dimensional version HEAT3, is by more than 1,000 consultants and 100 universities and research institutes worldwide. The program has been validated against international ISO standards.

We discuss heat transfer from home through the ground (conduction), but the surface will be convection and radiation. The heat transfer is happening through the floor of the basement and crawlspace, as well as through the walls of the basement and crawlspace. To reduce such heat transfer, we put insulation either at the floor level, wall level, and/or both surfaces. From that, multiple configurations will take place. For economic and sustainability reasons, we select the use of plastic waste as insulation material.

Plastic waste contributes significantly to the growing waste problem in the United States and other industrialized countries. The use of multiple layers of plastics for packaging is increasing in building construction, industry, hospital sterility, household waste, automotive parts, and agricultural sectors. The disposal of clean plastics from these applications is also growing. Plastic waste comprises approximately 11.3% of the weight of today's municipal solid waste in the United States. About 5.2% of the plastics were recycled, constituting 1.39 million tons from a total generated of 26.7 million tons (EPA, 2003). Nearly 9% of plastic containers and packaging were recycled, mostly soft drink, milk, and water bottles. Plastic milk bottles were the most recycled materials, accounting for roughly 32%. Plastic soft drink bottles were recovered at a 25% rate (EPA, 2003).

Thus, the use of Advanced Manufacturing (AM), an innovative technology to improve products or processes, plastic waste will be recycled and 3D printed into major parts used to assemble houses. Additive Manufacturing, including 3D printing [1-3], derives from the field of rapid prototyping developed during the late 1980s and 90s. The 3D printing process begins by digitally preparing a blueprint of the object using software such as Autodesk Inventor and PTC Creo that is to be printed using 3D printing hardware and software. The 3D-printer program “slices” the object into layers and sequentially sends this information to the 3D-printer that constructs the object by making repeated passes each time a head deposits a thin layer of material onto the material previously deposited.

Design Methodology Developed and Case Study:

This automated manufacturing process has been applied to multiple industrial applications, specifically for complex parts, such as automotive, aerospace, and medical, with less human intervention and minimum material wastage. However, a more recent application of this technology towards affordable housing seems to be more sustainable, and cost-effective, while maintaining a comfortable indoor environment. Research interest in employing 3D printing for building and construction has increased exponentially in the past few years [1].

The 3D-printing fabrication is well-established for small object needed in manufacturing. Consequently, great improvements are expected in the construction industry. The use of additive manufacturing in construction (AMC) was suggested by Pegna in the late 1990s [4]. He proposes a new production system in layers of small masonry structures, consisting of depositing a layer of Portland cement, a reactive material on a layer of matrix material (silica), activated by water vapor. The first efforts to apply this new technology date back to the beginning of the year 2000, with the experiences of a large-scale automated extrusion and construction system called Contour crafting [7-13]. Contour crafting is a building printing technology being researched by Behrokh Khoshnevis of the University of Southern California's Information Sciences Institute (in the Viterbi School of Engineering) that uses a computer-controlled crane or gantry to build edifices rapidly and efficiently with substantially less manual labor.

After this layer-by-layer construction of whole structures in a non-stop working session [14], various innovations on automated additive manufacturing processes have been tested. Another way consists of printing different components separately, and incorporating them to form a complete assembly (e.g., emerging objects [15]), like molding hollow honeycomb elements filled and assembled from the Amsterdam Canal House [16]. The goal, stated by various manufacturers and researchers involved, is the sustainability of the built environment, in terms of economic, environmental and social benefits, such as the goals set in Khoshnevisk's "houses of the future" [17].

Many questions need to be answered regarding the use of 3D-printing in housing, and if such solution is sustainable. The aim of this project is the attempt to give an answer to this question, through the identification of the main, experimental case studies and the analysis in terms of environmental benefits and potential problems.

The paper [1] reviews the latest research trends from 1997 to 2016. Multiple tentatives of printed 3D-houses were successful, but usually in small scale. Recently, the Construction Engineering Research Laboratory (CERL) in Champaign, Illinois, has successfully three-dimensionally printed the largest structure up-to-date structure (a 512 square-foot concrete structure) [18]. The structure, called a barracks hut or B-Hut, was printed as a result of a three year Army Program called the "Automated Construction of Expeditionary Structures." It uses an additive manufacturing process to "print" semi-permanent structures in a theater of operation. The ability to use concrete, for all the walls, in exception of the wooden roof sourced from readily available materials, reduces logistical requirements for the U.S. Army. Structural [19], and thermal [20] studies have been performed to predict the best mixture for the structure and the most energy-efficient building in terms of energy.

A methodology for building construction has been developed (Figure 2). This methodology is based on three steps:

- 3D CAD model preparation (figure 3)
- Mechanical stress analysis
- Thermal stress analysis

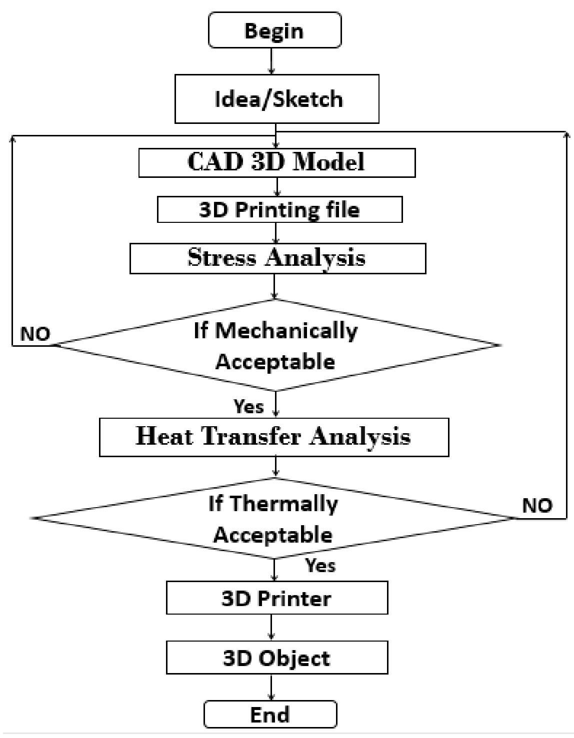

Figure 2: Flow chart for Design Process Developed

Students must go through these steps, where an object is sketched and designed, using a computer program (such as Autodesk Inventor). Students have the freedom in their design, in compliance with the constraints and criteria [21-22]. Before the 3D printing of the object, the students must study the stability, the resistance of this object under different conditions of temperature and pressure. The flowchart in Figure 2 shows the steps that students must follow for a complete analysis. As for analysis, students should check the effect of mechanical properties on temperature distribution, and the effect of temperature on mechanical properties.

In this work, we propose an integrated approach, where the 3D-printed concrete (figure 4) is associated with plastic waste (figure 5) for sustainable and affordable housing. Obviously, not all the materials found in the municipal waste stream can be recycled, nor can all consumer products be made from recycled materials. However, the United States is certainly far from those practical limits. A much higher percentage of materials now discarded in U.S. waste streams is recyclable and the environment would certainly benefit if many of the products now made from virgin resources were instead manufactured from recycled resources.

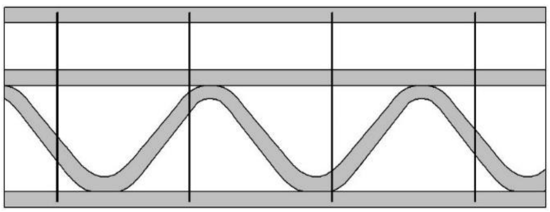

Figure 3: CAD design of the Wall

Figure 4 (a): Wall preparation testing (top view)

Figure 4 (b): Wall preparation testing (side view)

Figure 5: Plastic Waste

Challenges of 3D-printed House

Two major challenges, that need to be studied:

1. Finishing and problems related to codes: energy code (figure 6), building code, fire code, national electrical code.
2. Material workability, ability to be extruded, and buildability [19].
At the end of the summer camp, each student presents his/her work through a final presentation (figure 7).

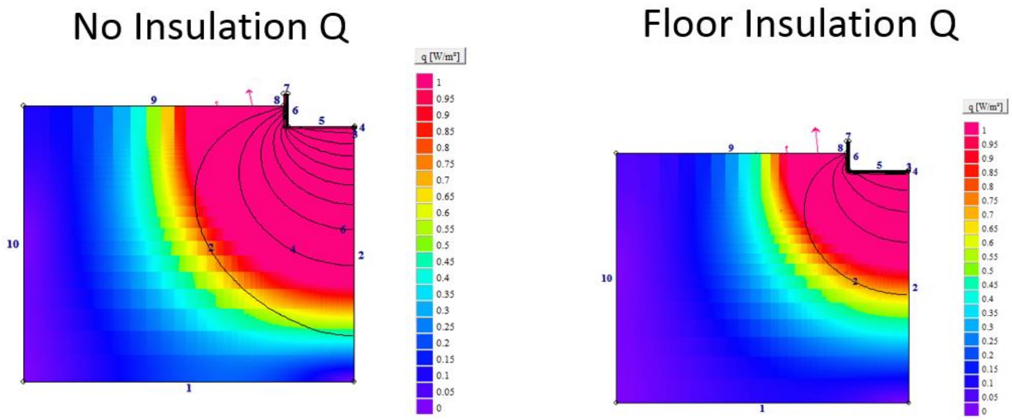

Figure 6: Heat transfer through the ground, (a) No Insulation, (b): Floor Insulation

Figure 7 (a): from the summer camp final presentation; (b) Price after the final presentation.

Indirect Assessment Results:

We conducted a course evaluation by students. The course objectives introduced earlier in the course were again provided to the students at the end of the semester. The students' provided input on two topics:

- The extent to which they feel competent in specific areas, as mentioned in Table 1.

- Motivations for program experience (Table 1).

Using the indirect course evaluation form, students were asked, anonymously, to self-assess their ability in specific areas identified by the instructor in connection with the course learning objectives, as well as the motivations for the program experience. The compilation of the results of the students' self-assessment of course learning objectives questions for this short course are presented in Table 1. The students responded with"5" (Extremely Competent) through "1" (Not Very Competent). In this way, an equivalent class was obtained for each question. The results of the students' assessments showed that for all the questions, students generally felt like they were able to perform the tasks requested. The next step is to check if the assignments performed by the students will show the same positive answers.

The instructor also conducted an evaluation of the performance of the students in the course as part of the Program Objectives (PO) and outcome assessment process. A summary report on the performance of students (to meet the program objectives) and compliance with the program outcomes was prepared and submitted to the funding agency (DOE). A more rigorous process in assessing the learning outcomes of this capstone course will be implemented, which will be in parallel with the program outcomes. The following outlines process will be used for this course assessment.

- Individual instructor evaluation of the degree of learning achievement of individual students on a team, which includes consideration of the collective achievements of the team.
- Peer evaluation (optional by instructor).
- Grading of deliverables by the instructors (projects evaluation, oral presentation, team minutes, and web site if applicable)
- Teamwork survey
- Self-assessment
- Final presentation judging (with evaluation criteria explicitly indexed to the learning objectives and articulated via rubrics for all measures)

The survey assessment of the competence and motivations, before and after the class learning objectives, clearly showed the improvement in terms of competence of the students in modeling, data collection and analysis, and problem solving. The improvement touched all aspects.

Conclusions:

Teaching a high-level course during the summer for middle and high school students with limited mathematical background is always a challenge. Our approach was based on the use of generally considered hard topics to real applications where students needed to perform real engineering work. The main objective was to familiarize students with both advanced manufacturing and 3D-printing and demonstrate how we can use these topics to design and solve the new century challenges. The case study considered in this report is related to the integration of the 3D-printing in sustainable building and the use of plastic waste in building for insulation purposes.

The ultimate goal of this research is to perform a sustainable design based on 3D-printing while incorporating the use of plastic waste as building insulation. The benefits are multiple, including:

- Rapid construction, affordable housing, and the reduction of work site accidents
- Reduction in the United States' plastic waste
- Reduction in energy consumption and improvement of the environment
- Prevention of pollution caused by manufacturing from virgin resources

- Reduction of the need for land filling and incineration which helps avoid pollution produced by these technologies

Our objective is to extend the use of this prototype to other middle school students in different disciplines where mechanical and thermal analysis is needed: mechanical, electrical and industrial engineering.

Yet, down the line, the scientific community must develop ways to check 3D-printed housing for condensation, mold and other aspects of "sick-building syndrome" that can endanger the health of humans. In addition, building, electrical, mechanical and fire codes must change to make 3D-printed housing more feasible.

Table 1: Pre-Survey: Results of Indirect Assessment for this short course (12 students in the course)

Indirect Assessment						
Student Self-Assessment of Course Learning Objectives	Extremely Competent (5)	Very Competent (4)	Competent (3)	Becoming Competent (2)	Not Very Competent (1)	Equivalent
The extent to which you feel competent in the following areas:						
Computer Modeling	1	4	6	1		3.42
Laboratory Science	1	1	6	4		2.92
Collecting/Analyzing Data	3	6	3			4
Hypothesis Development	2	4	6			3.67
Problem Solving	3	6	3			4
Motivations for program experience						
Contributes significantly to field of interest	2	5	5			3.75
Desire to improve my skills working with people from diverse backgrounds	2	4	5	1		3.58
My academic advisor of faculty mentor	4	2	6			3.83
To be competitive for college	3	5	3	1		3.83
To be more competitive for the 21st century workforce	5	5	1	1		4.17
To enhance my analytical and research skills	3	7	2			4.08
Desire to learn more about the world	4	5	1	2		3.92
Prior interest	1	10	1			4
Personal Growth	4	4	4			4

Table 2: Post-Survey: Results of Indirect Assessment for this short course (12 students in the course)

Indirect Assessment						
Student Self-Assessment of Course Learning Objectives	Extremely Competent (5)	Very Competent (4)	Competent (3)	Becoming Competent (2)	Not Very Competent (1)	Equivalent
The extent to which you feel competent in the following areas:						
Computer Modeling	5	5	2			4.25
Laboratory Science	3	3	6			3.75
Collecting/Analyzing Data	3	6	1			4.33
Hypothesis Development	2	5	5			3.75
Problem Solving	5	6	1			4.33
Motivations for program experience						
Contributes significantly to field of interest	4	6	2			4.17
Desire to improve my skills working with people from diverse backgrounds	3	6	2	1		3.92
My academic advisor of faculty mentor	4	2	6			3.83
To be competitive for college	4	6	2			4.17
To be more competitive for the 21st century workforce	6	6				4.50
To enhance my analytical and research skills	4	7	1			4.25
Desire to learn more about the world	4	5	1	2		3.92
Prior interest	2	10				4.17
Personal Growth	5	6	1			4.33

References:

[1] Yi Wei Daniel Tay, Biranchi Panda, Suvash Chandra Paul, Nisar Ahamed Noor Mohamed, Ming Jen Tan & Kah Fai Leong, "3D printing trends in building and construction industry: a review", ISSN: 1745-2759 (Print) 1745-2767 (Online) Journal homepage: http://www.tandfonline.com/loi/nvpp20.

[2] CMHC & SCHL (Home to Canadians) 3D Printing and the Construction Industry Article 3—December 2015.

[3] Valeria Poggi, Cristina Miceli and Italo Testa, "Teaching energy using an integrated science approach", Published 8 December 2016 • © 2016 IOP Publishing Ltd, Physics Education, Volume 52, Number 1.

[4] Bonwell, C. C., & Eison, J. A. (1991). Active learning Creating excitement in the classroom. Washington DC George Washington University.

[5] Jade Woodard, Ms Thesis "mechanical study of the feasibility of 3D-priting housing" (2017)
[6] Brandy Diggs, Ms Thesis "the study of heat transfer and energy efficiency for barracks hut or B-Hut" (2017).

[7] Khoshnevis, B.: Automated construction by contour crafting related robotics and information technologies. Automation in Construction, 13(1), pp 5-19, 2004.

[8] Khoshnevis, B. (2004). Houses of the Future. Construction by Contour Crafting Building Houses for Everyone. Urban Initiative policy Brief. USC-University of Southern California.

[9] Balinski, B. (2014). Chinese company 3D prints 10 houses in a day from recycled material. Architecture & Design; 22 April, 2014.

[10] Zhang, J., & Khoshnevis, B. (2013). Optimal machine operation planning for construction by Contour Crafting. Automation in Construction, 29(0), 50-67.

[11] Buswell, R. A., Gibb, A. G., Soar, R., & Thorpe, A. (2007). Freeform construction: Megascale rapid manufacturing for construction. Automation in Construction, 16(2), 224-231.

[12] Cesaretti, G., Dini, E., De Kestelier, X., Colla, V., & Pambaguian, L. (2014). Building components for an outpost on the lunar soil by means of a novel 3D printing technology. Acta Astronautica, 93(0), 430-450.

[13] Khoshnevis, B. (2004). Houses of the Future. Construction by Contour Crafting Building Houses for Everyone. Urban Initiative policy Brief. USC-University of Southern California.

[14] http://www.d-shape.com/index.htm

[15] http://www.emergingobjects.com/

[16] http://3dprintcanalhouse.com/

[17] Khoshnevis, B. (2004). Houses of the Future. Construction by Contour Crafting Building Houses for Everyone. Urban Initiative policy Brief. USC-University of Southern California.

[18] IS 3D PRINTED HOUSE SUSTAINABLE? Oberti I.; Plantamura F. Politecnico di Milano, Dept. Architecture, Built Environment and Construction Engineering (ABC), Via Bonardi 9, 20133, Milan. ilaria.oberti@polimi.it, francesca.plantamura@polimi.it

[19] Jade Woodard (2017), "Investigating Properties of High-Performance Printing Concrete", Master of Science at North Carolina A&T State University, 85 pages.

[20] Brandy Diggs (2017), "Clustering Analysis: Envelope Energy Performance, Moisture Control and Thermal Bridge of Military B-Huts", Master of Science at North Carolina A&T State University, 91 pages.

[21] Sissy S. Wong, Jonah B. Firestone, Lionnel G. Ronduen, EunJin Bang, "Middle School Science and Mathematics Teachers' Conceptions of the Nature of Science: A One-Year Study on the Effects of Explicit and Reflective Online Instruction", International Journal of Research in Education and Science Volume 2, Issue 2, Summer 2016 ISSN: 2148-9955.

[22] Joseph M. Furner and David D. Kumar, "The Mathematics and Science Integration Argument: A Stand for Teacher Education", Eurasia Journal of Mathematics, Science & Technology Education, 2007, 3(3), 185-189.