# ISBOE HERC-IGEM Project

Yr 3: Final Report

**Project Title:** Cellulosic 3D Printing of Modular Building Assemblies

**Principal Investigator:** Dr. Armando McDonald

**Institution:** University of Idaho (lead) with subcontract to Boise State University

**Grant Number:** IGEM 20-002

**Award Amount:** $349,900

**Fiscal Period:** July 1, 2021 – June 30, 2022

**Final Report Submitted to SBOE:** August 2022

**Reporting Period:** July 1, 2021 – June 30, 2022

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## 1) Summary of project accomplishments

The accomplishments and plans for the project objective identified in the original proposal are summarized. A summary of accomplishments for the overall project management and engagement activities are also summarized below.

***Objective:*** *Identify an Idaho, highly energy- and process efficient, scaled approach to residential and low-rise commercial modular construction using 3D printing methods.*

*Team:* Armando McDonald (UI – Forest & Sustainable Products, PI); Ken Baker (UI - Idaho Design Lab, PI); Michael Maughan (UI – Mechanical Engineering), Damon Woods (UI – Idaho Design Lab), Tao Xing (UI – Mechanical Engineering), Ralph Budwig (UI – Mechanical Engineering), Casey Cline (BSU – Construction Management), Kirsten Davis (BSU – Construction Management), and Ty Morrison (BSU – Construction Management).

*Team background and overall goals:* This new team was formed based on this project that required multidisciplinary experience to integrate resin formulation chemistry, composite materials, 3D printing, mechanical engineering, energy efficiency, manufacturing and building design, and construction management to develop a printing platform for construction. Research was focused on developing a 3D printing system which utilized wood residues and a low temperature cured resin (binder) to deposit an extrudate to form a printed modular construction product. In addition, concepts for modular construction design were created and assessed for their feasibility in construction. Ultimately, research will advance solutions that can be applied in manufacturing and construction sectors; producing economic value from waste to enhance Idaho-based industries.

***Accomplishments of this project:***

The following provides detail of progress over the 3-year project, towards the aims described in the original proposal plan.

1. The project will research design for identification of adhesive/binder, flow, and cure attributes for a wood fiber cold print process.

   (McDonald and Maughan). Investigations were done to identify and evaluate suitable low cost and low temperature cure resins that would be suitable for use in additive manufacturing (AM). Procedures to monitor resin cure were developed by thermal analysis and rheometry to evaluate various commercial resins. Two resin systems were finally identified that were suitable, sodium silicate (SS) and phenol-resorcinol-formaldehyde (PRF). Formulations of resin and wood fiber (sourced from sawmill residues and screened into different mesh size fractions) blends (wood-SS and wood-PRF) were assessed for their flow behavior (rheology) (Figure 1) and extrudability. Ultimately, several formulations were deemed suitable wood-SS (45:55 and 50:50) and wood-PRF (50:50). A high shear blender was required to fully mix the resin and wood fibers prior to rheological and extrusion studies. A <40 mesh wood fiber fraction produced composites with good surface finish. Various curing regimes were investigated (time and temperature) to obtain material with no surface checks (no defects). The cured wood-SS and wood-PRF composites were evaluated for their flexural properties and fire resistance. The composites had flexural properties better than particleboard and were fire resistant (Figure 1). In addition, we have investigated the use of $CO_2$ to accelerate the curing of the wood-SS composites with the benefit of sequestering carbon in the composite product. **This section of work was the foundation for developing a formulation that could be integrated into a 3D printing system based on wood fiber and fire resistant.** Ph.D. graduate student *Berlinda Orji* in Environmental Science is currently working on this project topic and expected to complete her studies in Spring 2023. One publication has been published (*European Journal of Wood and Wood Products,* DOI: 10.1007/s00107-022-01861-z) and another two will be submitted soon. In addition, two presentations at international conferences and one 3D-printing workshop have been given.

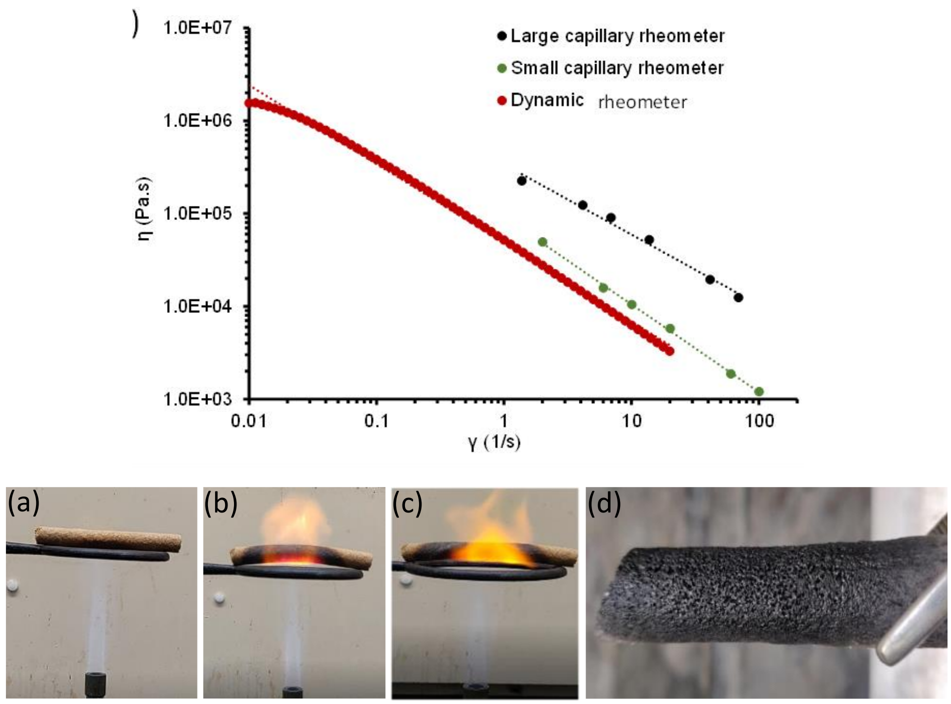



Figure 1. (Top row) viscosity versus shear rate (flow curves) plots of wood-SS (50:50) blend by dynamic and capillary rheometry at 22°C and (Bottom row) Photographs of the wood-SS (50:50) composite during a Bunsen burner flame test at (a) 0 min, (b) 2 min, (c) 4 min, and (d) after 5 min test completed.

2. <u>The project will develop a prototypical schematic design for a 3D printer that will print building sections (e.g., panels) from wood/natural fibers using a liquid-based chemical binder.</u>

(Maughan and McDonald). Complementing the wood-resin formulation was the development of a 3D printing platform. We conducted a literature review on 3D printing of biomaterials. The review revealed that 3D printing of environmentally friendly wood composites is a field that is newly emerging. Based on the mechanical properties of preliminary composite material samples (see above), we selected a plunger/barrel batch extrusion (e.g. syringe) approach as a preliminary test for extruding and depositing the composite mixture and this will require a high level of force which was achieved using a universal testing machine. The system was successful in extruding wood-resin mixture to produce a rod out of the nozzle at the bottom of the barrel and this validated our "proof of concept". Based on these findings a single screw extruder (35 mm dia. Screw with an 18 mm dia. nozzle) was purchased for continuous extrusion required for additive manufacturing (AM). To handle the required torque for extrusion a 1 hp motor was installed (original motor was 1/3 hp) and the screw flights modified for extruding the wood-resin mixtures as compared to molten plastic which it was designed for. Extrusion parameters, which are critical for producing smooth rods (Figure 2) and flow behavior (rheology) of this mixture,  govern how to produce defect free prints. We have refined the extrusion technique to eliminate surface defects (shark-skin). This defect is caused by friction and shear gradient within the flowing mixture. **Outcome: the extruder was successful in producing composite samples for evaluation** (see above). Graduate student *Conal Thie* worked on this section of the project and completed his M.S. in Mechanical Engineering thesis in Summer 2021 and is now employed as an engineer in Boise. In addition, one presentation at an international conference and one workshop on 3D-printing have been given as well as a published journal article (see above).

Figure 2. Photographs of (a) smooth extruded wood-SS (50:50) rods and (b) extruded wood-SS showing sharkskin.

(Xing and Maughan) A multi-core processor computer was purchased for conducting computational fluid dynamics simulations (CFD). We conducted additional testing and used this as a comparison to validate CFD flow simulations of the composite mixture. The flow simulations allowed us to develop a model of the continuous flow extruder which is necessary for component sizing and determining mixture compression. Mixture compression is a key variable dictating mechanical properties such as bending strength and stiffness. Figure 3 shows CFD-generated pressure and temperature plots representing flow within the extruder. The pressure results show a good agreement with experimental data; however, the temperature results couldn't predict the experimental data. Therefore, we employed a discrete element method (DEM) to model the wood fibers during the extrusion process using ROCKY DEM software which overcome the CFD model limitations (Figure 4). Ph.D. student *Anas Nawafleh* in Mechanical Engineering was working on this project topic and expected to complete his studies in 2023-2024.

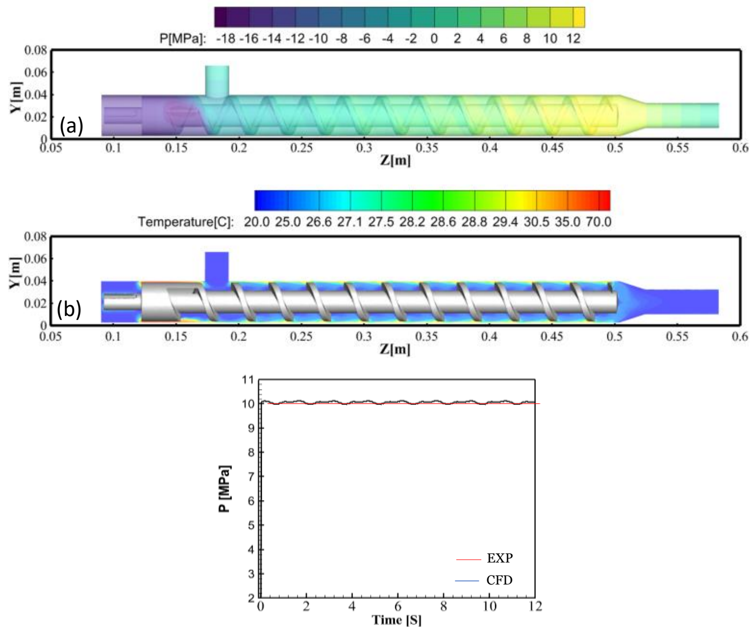
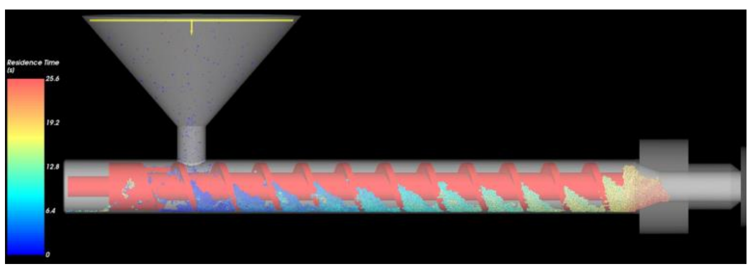
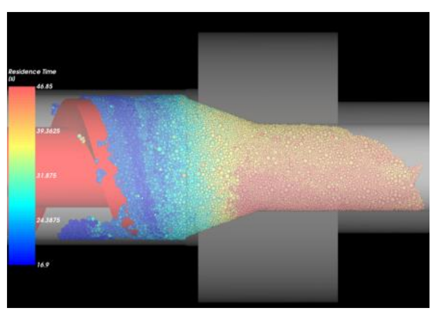



Figure 3. Single screw extrusion CFD simulation: (a) Contours of pressure, (b) Contours of temperature, and (c) Comparison between CFD and experiment.



(a)



(b)

Figure 4 – Single screw extrusion DEM simulation: (a) Contours of particles' residence time at 25.6 s, and (b) contours of particles' residence time at 46.85 s in the die.

(Maughan and McDonald). A 3D printer-frame was designed for additive manufacturing (AM) wood composite materials by an undergraduate researcher for a 2' x 3' x 2' build envelope. The printer gantry was then refined and built by a graduate student utilizing stepper motors for position control (Figure 5). The 3D printer uses a Smoothie Board CNC controller and Pronterface software. Extrusion was determined to be necessary for sustained 3D printing using a single screw extruder (discussed above). The challenge was connecting the extruder (~75 lbs) to the print head without putting too much strain on the gantry system. A high-pressure flexible hose with compression fittings was identified as an attachment method to convey the wood-resin (SS) mix from the extruder barrel to the print head nozzle (Figure 5). This eliminated the dead weight on the printer gantry. A rectangular nozzle was designed to produce a continuous ribbon in support of project goals to print a wall panel. Also identified during printing large structures was the extruder barrel heated up, due to friction, which prematurely cured the resin and the extrudate hardened impeding interlayer bonding. A heat exchanger cooling system was then fabricated on the extruder barrel to maintain temperature (~72$^{o}$F). This cooling system helped maintain good flowability of the wood-resin mix and improve interlayer adhesion. In addition, a rotating print head was developed to print cross-beam sections (e.g. stud wall) as well as panels. Code was developed to print panels. **This section of work proved our "proof of concept" in AM of a wood composites panel using low temperature cure resins.** Graduate student *Robert Carne* worked on this section of the project and completed his M.S. in Mechanical Engineering thesis in Summer 2022 and has now started his Ph.D. on 3D printing of wood composites.

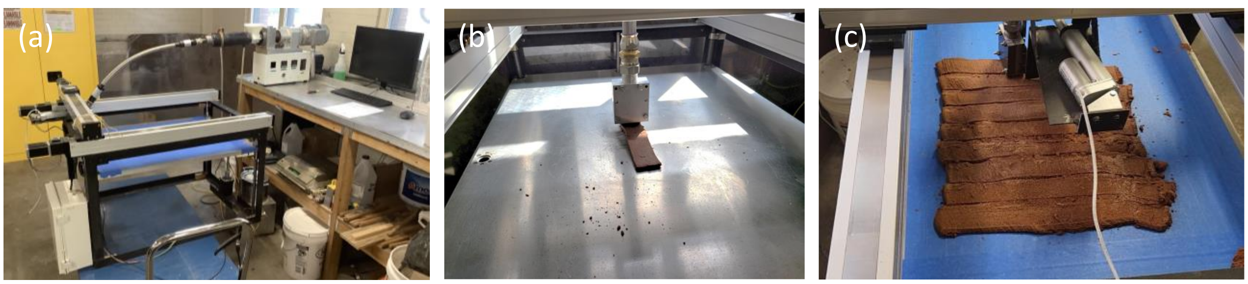



Figure 5. Photographs of (a) 3D-printer, (b) starting a ribbon print, and (c) panel print showing the rotatable nozzle.

3. <u>The project will develop a business case for the proposed printing process to market.</u>

(Woods, Baker, and Budwig). The Integrated Design Lab team developed an instrument and method based on ASTM C177 to evaluate the thermal properties of wood composite panels (wood-SS). The results showed that the wood-SS formulations had thermal conductivity values which ranged from 0.08-0.15 W/mK and were largely dependent on panel density. The thermal properties were comparable to other wood-based composites currently used in construction. In addition, a preliminary life cycle assessment (LCA) was performed on a wall section of the 3D-printed wall assembly, as well as for other common residential wall types (Structural insulated panels (SIPS)), wood frame, steel frame, concrete masonry units (CMU), and 3-layer cross-laminated timber (CLT)). The 3D-printed wall design is shown in Figure 6. The main factor under consideration was the total energy impact. It was found that the proposed 3D-print wall had the best performance in the materials stage and was a close runner up in the building energy usage and end of life stages (Figure 6). The 3D wall design has potential to decrease energy usage in the residential and light commercial building types. If additional incremental improvements are achieved in the envelope performance and manufacturing stages, the 3D-printed wall could become one of the lowest energy consuming wall types available. Graduate student *Tais Mitchell* worked on this section of the project and completed his M.S. in Mechanical Engineering thesis in Fall 2021 and is now employed as an engineer in ID.

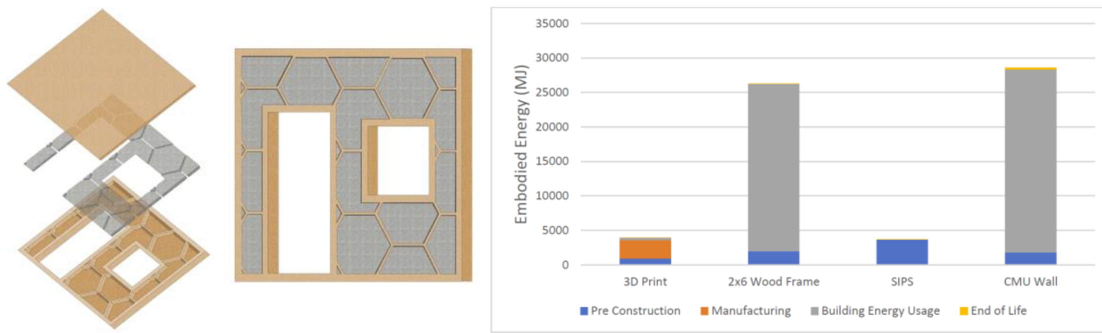



Figure 6. (left) 3D-printed wall design and (right) total energy impact comparison

(Woods). A 3D "weaving" printer was designed and developed at IDL.  The goal was to reinforce the structures with continuous natural fibers (jute and cotton) using an AM process. The weaving machine built in the same design framework as a 3D printer (Figure 7) which included a fiber spool and a fiber and resin placement nozzle. The nozzle "deposits" the resinated fiber along the pin bed. Using a modified program designed for a CNC machines, the G-code was created to produce desired "weft and warp" patterns (Figure 7). The tension of the pin beds allowed the fiber to weave upwards in the Z-direction. MS student in Architecture, Joseph Sedillo, worked on the design and fabrication of the unit and expected to graduate spring 2024.

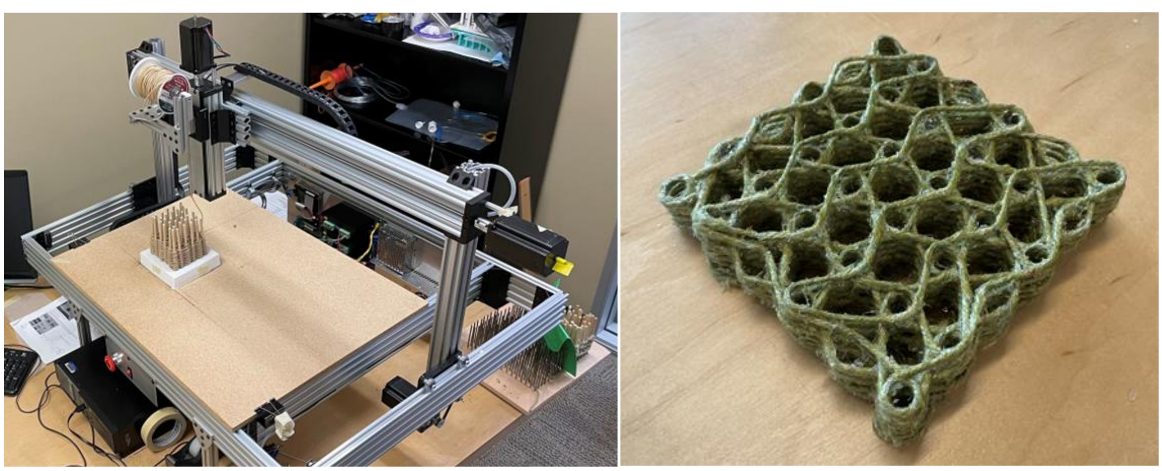


Figure 7. (left) 3D-weaving printer and (right) jute fiber-resin printed composite weave

(Baker) The IDL team together with BSU and UI Moscow campus utilized a gift from the Northwest Energy Efficiency Alliance to support two women architectural students (Lyndsay Watkins and Kelsey Ramsey MS in Architecture graduated in May 2022) who conducted a literature review, business case development, and graphic presentations of grant accomplishments. A business case was developed – *Our goal is to develop a reliable, cost-effective, and environmentally friendly process for the additive manufacturing of modular panels (wall, floor, and roof assemblies) predominantly from wood waste, utilizing a novel cold-setting print media*. An overview of the business case is shown in Figures 8 and 9.

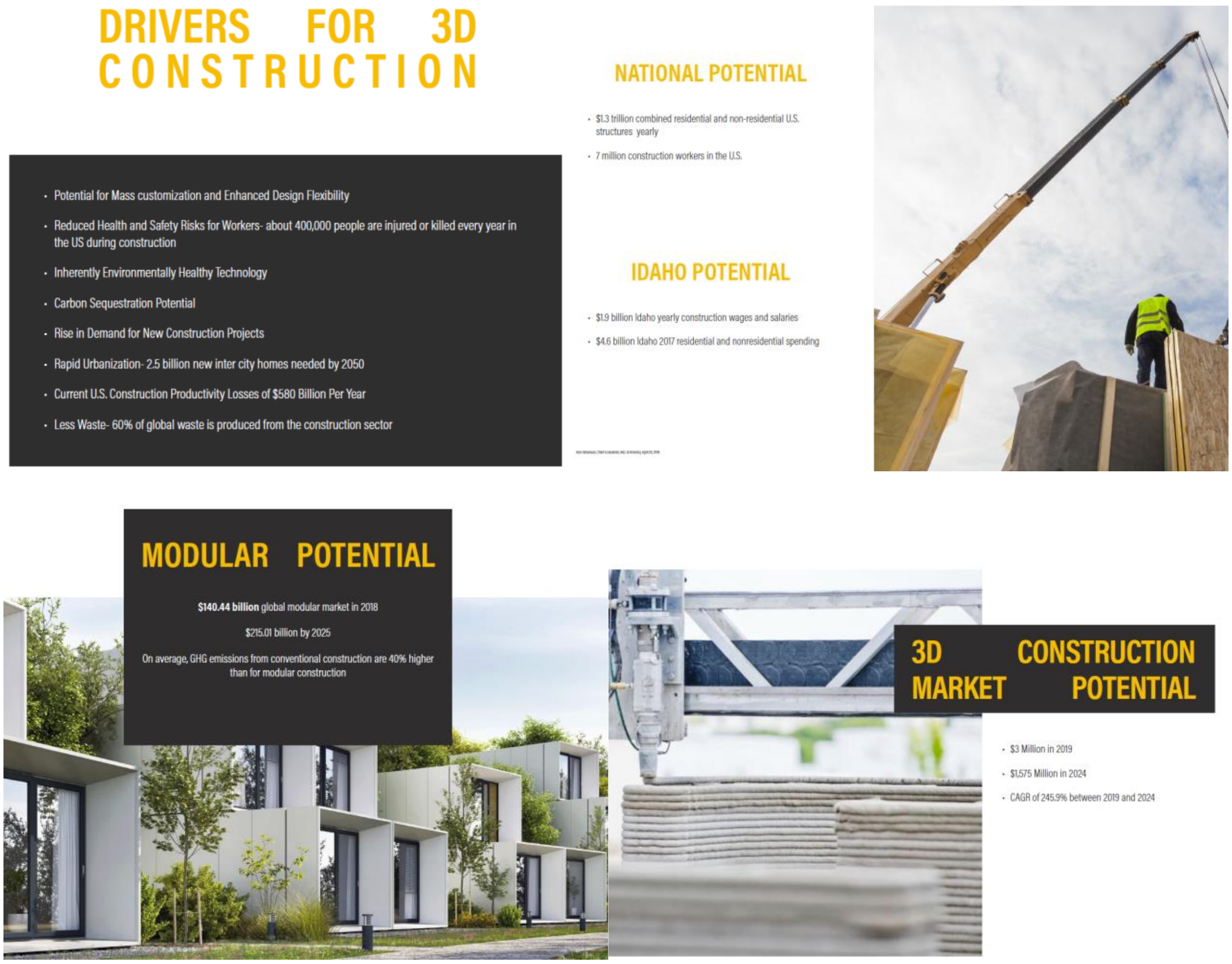



Figure 8. Drivers and markets for 3D construction

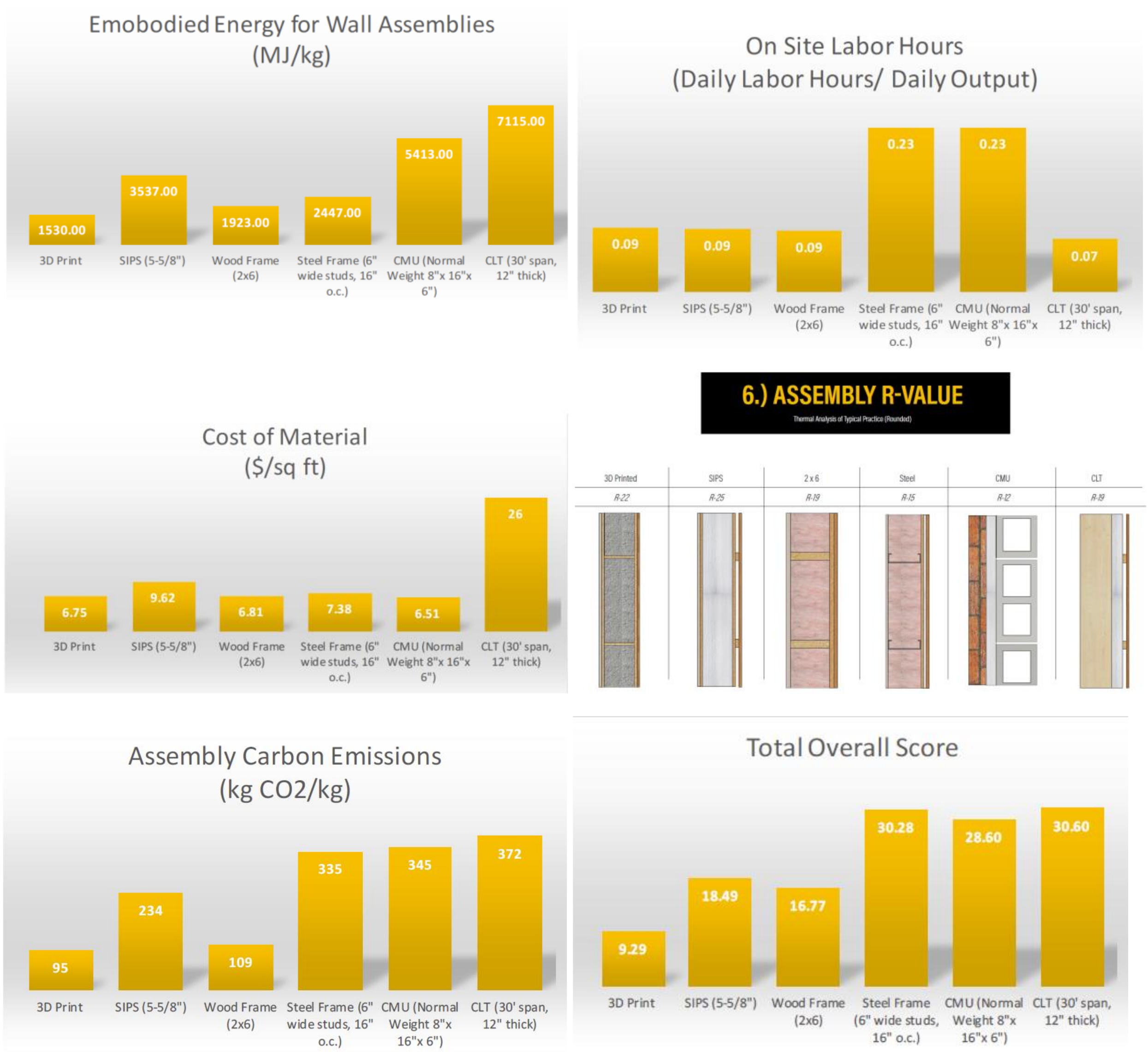



Figure 9. Comparison of embodied energy, labor costs, material costs, R-values, $CO_2$ emissions and overall score of six different wall construction types.

(Cline, Davis and Morrison). The BSU team worked with two undergraduate students in Construction Management on how to use 3D printed panels in construction. Printed panels (10” x 10”) were provided by UI for assessment. The outcomes were:

- *Analyzed constructability for the planned panels*. This analysis provided an overview of the site issues with modular construction such as panel construction, transportation, and connections, as well as thoughts about end user expectations.
- *Assisted in development of the business case for the 3D printed panels*. Evaluation of the best market (residential, light commercial, etc.) for printed panels like this based on constructability was also provided.

- *Developed a construction sequencing model*. 3D modelling and video editing software was used to develop models and a video to begin determining optimal panel configurations and ideal construction sequencing of panels. This work included a simulation of full-size panel printing, proposed panel shapes, and a possible construction sequence.
- *Assisted with prioritization of desirable features to improve constructability*. Provided troubleshooting on the project and developed priorities based on constructability aspects. Examples of these priorities include items such as: water resistance, durability, ability to modify panels at job site with commonly available construction tools.
- *Evaluated 3D printed panels* for connection options, machining, nailing, fasteners, caulking and suitability for finishes.
- *Investigated how constructability analysis might be taught to students*. An initial framework for teaching students' construction related aspects that should be considered in the design of new construction materials was developed. This initial framework for teaching constructability analysis on the modular panel development can later be expanded to help teach students working in a broader array of construction materials development projects.

The team presented two poster presentations on their work at (i) 58th Annual Associated Schools of Construction International Conference (2022) and (ii) American Society for Engineering Education (2022).

**2. Summary of budget expenditures for Y 3 (July 1, 2021 – Jun 31, 2022)**

A detailed expenditure report is provided in Appendix A. The table below summarizes the spending in the major budget categories, relative to the budgeted amounts for Year 3. The expenditure report was run on August 2022. The average "burn rate" for the entire grant (including BSU subcontract) was $21.7k/month (or 6.2%). A total of 25.38% of the budget remains which is $88,807.33 returned to SBOE.

| | Budget | Funds Expended | Difference |
|---|---|---|---|
| Salaries/Hourly/Fringe | $ 194,100.00 | $136,563.19 | $ 57,536.81 |
| Travel | $ 7,400.00 | $ 3,037.43 | $ 4,362.57 |
| Other Expense | $ 19,000.00 | $ 20,006.80 | $ (1,006.80) |
| Capital Equipment | $ - | $ - | $ - |
| Small Equipment | $ - | $ - | $ - |
| Overhead | $ - | $ - | $ - |
| Trustee Benefits | $ 51,600.00 | $ 50,228.00 | $ 1,372.00 |
| BSU Subcontract | $ 77,800.00 | $ 51,257.25 | $ 26,542.75 |
| | | | |
| Total without Subcontract | $ 272,100.00 | $209,835.42 | $ 62,264.58 |
| Total With Subcontract | $ 349,900.00 | $261,092.67 | $ 88,807.33 |

**3. Demonstration of economic development/impact**

- Patents, copyrights, Plant Variety Protection Certificates received or pending

Drs. McDonald, Maughan and Baker submitted an invention disclosure to the UI Technology Transfer office. They provided feedback and were not willing to support submission to the Patent Office.

- Private sector engagement

This project work involves considerable engagement with stakeholders. The additive manufacturing of wood composites has received considerable interest from the Forest Products sector (Boise Cascade Corp. (contact Dann Briscoe) and the 3D printing industry (Massivit 3D Printing Technologies Ltd. (Contact - Ben Arnold); Continuous Composites (contact - Nathan Stranburg); and Alquist 3D (contacts - Aaron Hackett and Aiman Hussein)). These companies have been selected to be part of our stakeholder advisory board on the wood composites additive manufacturing program. Boise Cascade is an affiliate member of the wood composites additive manufacturing program by contributing $10,000. In addition, Drs. McDonald and Maughan were contacted by the US Army and USDA-Forest Products Laboratory to discuss our wood composites AM research at two virtual meetings and were interested in moving forward on a collaborative project. This resulted in submitting a preproposal to the Department of Defense "*Wood-composite structures by additive manufacturing*".

- Jobs created

Several of the research assistant and all of student research assistantship positions described in the next section were newly created during this grant.

**4. Numbers of faculty and student participation**

The numbers of faculty, students and other researchers participating are as follows:

| | |
|---|---|
| Faculty: | 10 (7 UI and 3 BSU) |
| Graduate Students: | 8 (6 UI (2 whom are from groups underrepresented in STEM) |
| Undergraduate Students: | 6 (4 at UI (3 from groups underrepresented in STEM), 2 at BSU) |

***More details on staffing:***

McDonald staffing: 1 PhD student in Environmental Science. 1 woman.
Baker staffing: 2 undergraduate women students in Architecture
Woods and Budwig staffing: 1 MS student in mechanical engineering, 2 MS students in architecture and 1 undergraduate student in Architecture. 2 women.
Maughan staffing: 2 MS students in mechanical engineering, 1 undergraduate student in mechanical engineering
Xing staffing: 1 PhD student in mechanical engineering
Cline, Davis and Morrison staffing: 2 undergraduate students in construction management

**5. Description of future plans for project continuation or expansion**

- PI Armando McDonald is actively working in wood composites and additive manufacturing. Dr. McDonald was recently awarded a $136K grant from Sun Grant Program Western Region "*Toward production of lignin-based bioplastics and biocomposites*". Also, he was awarded a $200k contract from Idaho National Laboratory "*Characterization of Solvent Extracted Plastics from Municipal Solid Wastes and Alloying to Form Composite Materials*". Drs. McDonald (PI) and Maughan also submitted a preproposal (together with Dr. Maughan, May 2022) to the Department of Defense for $300k titled "Wood-composite structures by additive manufacturing". Drs. McDonald (PI) and Maughan are working on a $650k proposal to USDA-NIFA (planned submission 28 September 2022) on optimization of our current 3D printing system platform.

- CoPI Michael Maughan is actively working in additive manufacturing. Dr. Maughan (PI) was awarded a $3.96 million grant from NSF titled "*RII Track 2 FEC: Developing a Circular Biobased Framework for Architecture, Engineering and Construction Through Additive Manufacturing*". Drs. McDonald and Woods are also senior personnel on this project. This is a multidisciplinary project Between UI and Auburn University. This project has provided the impetus to expand this wood composites additive manufacturing research to include biobased resins and natural fibers. Furthermore, this project includes a rigorous testing program for the AM structures as well as architectural design on how to use AM in construction and built environment.

- CoPI Tao Xing is continuing his work on fluid dynamics and additive manufacturing. He was recently awarded $250k from the M.J. Murdock Charitable Trust for the project "*An Integrated 3D Imaging and Printing System for Studying Biofluid and Biomechanics*". Dr. Xing was also awarded $252k from NSF Major Research Instrumentation for the project "MRI: *Acquisition of a 3D Printer for Studying Biofluids and Biomechanics*". These awards help support our ongoing research activities in additive manufacturing.

- CoPI Damon Woods is continuing his research on thermal/energy behavior in buildings. Drs. Wood (PI) and McDonald (coPI) were awarded $206k in 2021 (plus $106k supplemental in 2022) for an Idaho Department of Commerce IGEM grant titled "*Testing new manufacturing methods of natural fiber insulation batts".* This award helps support research activities in wood/natural fiber composites and construction.

**6. Expenditure reports**

The expenditure reports presented in Appendix A detail the expenditures at the University of Idaho, including the amounts for paid invoices from Boise State University that totaled $51,257.25.

**7. Commercialization Revenue**

None to report yet.

**Publications:**

Orgi, B.O., Thie, C., Baker, K., Maughan, M.R., McDonald, A.G. (2022) Wood fiber - sodium silicate mixtures for additive manufacturing of composite materials. *European Journal of Wood and Wood Products*. DOI: 10.1007/s00107-022-01861-z

**Theses:**

Tais Mitchell. (2022) Thermal Characterization of Printable Wood Composite and Life Cycle Assessment of a Novel Wood-Based 3D-Printed Exterior Wall. M.S. thesis in Mechanical Engineering, University of Idaho, December 2021, Boise, Idaho.

Conal Thie. (2022) Wood and Resin Composite Extrusion for Additive Manufacturing. M.S. thesis in Mechanical Engineering, University of Idaho , August 2021, Moscow, Idaho.

Robert Carne. (2022) 3D Printing of Wood-Sodium Silicate Composites. M.S. thesis in Mechanical Engineering, University of Idaho, August 2022, Moscow, Idaho.

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Salaries

| | | | | |
|---|---|---|---|---|
| E4105 Faculty | | | | |
| Woods, Lindsay | | | | 12096.63 |
| 286.04 hours | | | | |
| Zhang, Wei | | | | 1615.60 |
| 40.00 hours | | | | |
| E4106 Staff | | | | |
| Baker, Kenneth | | | | 13760.61 |
| 341.20 hours | | | | |
| E4108 Summer Salary | | | | |
| Budwig, Ralph | | | | 3234.80 |
| 2.50 hours | | | | |
| Maughan, Michael | | | | 3195.92 |
| 52.00 hours | | | | |
| Woods, Lindsay | | | | 1240.58 |
| 29.32 hours | | | | |
| Xing, Tao | | | | 3493.88 |
| 52.00 hours | | | | |
| E4109 IA/GA Salary | | | | |
| Carne, Robert | | | | 16504.80 |
| 780.00 hours | | | | |
| Mitchell, Tais | | | | 5920.00 |
| 320.00 hours | | | | |
| Nawafleh, Anas Mohammad Hussein | | | | 16497.00 |
| 780.00 hours | | | | |
| Orji, Berlinda Oluebube | | | | 20234.24 |
| 988.00 hours | | | | |
| Ramsey, Kelsey | | | | 1665.00 |
| 90.00 hours | | | | |
| | | | | ---------- |
| | | | | $ 99459.06 |

Temporary/Irregular Help

| | | | | |
|---|---|---|---|---|
| E4135 Temporary Student | | | | |
| Carne, Robert | | | | 4441.50 |
| 210.00 hours | | | | |
| Mitchell, Tais | | | | 2368.00 |
| 128.00 hours | | | | |
| Nawafleh, Anas Mohammad Hussein | | | | 2707.20 |
| 128.00 hours | | | | |
| Sedillo, Joseph | | | | 7774.00 |
| 428.50 hours | | | | |
| | | | | ---------- |
| | | | | $ 17290.70 |

Fringe Benefits

| | | | | |
|---|---|---|---|---|
| E4280 Faculty CFR Benefit Expense | | | | 7334.70 |
| E4281 Staff CFR Benefit Expense | | | | 5624.51 |
| E4282 Student CFR Fringe Expense | | | | 2319.22 |
| | | | | ---------- |
| | | | | $ 15278.43 |

Travel

| | | | | |
|---|---|---|---|---|
| E5365 Personal Vehicle - Out-of-State | | | | |
| 14-OCT-21 | Z1024220 | Parking 08062021 | | 36.00 |
| E5371 Motor Pool Vehicle - In-State | | | | |
| 17-AUG-21 | Z1021426 | A Mcdonald: trip 8718 | to pick up wo | 35.45 |
| 17-MAR-22 | Z1031041 | A McDonald: trip 9091 | Meeting with | 57.31 |

| | | | |
|---|---|---|---|
| E5372 Motor Pool Vehicle - Out-of-State | | | |
| 25-FEB-22 | J1305132 | 2-1-22 to 2-15-22 MotPool-arwenb | 60.00 |
| E5381 Airfare - Out-of-State | | | |
| 14-OCT-21 | I2201487 | McDonald, Armando Gabriel. | 448.80 |
| 22-MAR-22 | Z1031178 | Airfare 12132021 | 336.39 |
| E5392 Ground Transportation-Out-of-State | | | |
| 22-MAR-22 | Z1031178 | lyft in LA | 34.14 |
| 22-MAR-22 | Z1031178 | lyft in LA area | 36.81 |
| E5397 Lodging & Per Diem ? Out of State | | | |
| 14-OCT-21 | Z1024220 | McDonald, A: lodging for travel to | 995.05 |
| 22-MAR-22 | Z1031178 | Hotel 02272022 | 188.37 |
| 22-MAR-22 | Z1031178 | hotel expenses (second charge) hote | 565.11 |
| 22-MAR-22 | I2224406 | Maughan, Michael | 40.00 |
| 22-MAR-22 | I2224406 | Maughan, Michael | 74.00 |
| 22-MAR-22 | I2224406 | Maughan, Michael | 56.00 |
| 22-MAR-22 | I2224406 | Maughan, Michael | 74.00 |
| | | | ---------- |
| | | | $ 3037.43 |

Operating Expenses

| | | | |
|---|---|---|---|
| E5023 Express Mail | | | |
| 11-NOV-21 | Z1025599 | McDonald, A: FedEx shipping of samp | 11.56 |
| 11-NOV-21 | Z1025599 | McDonald, A: shipping samples for r | 26.17 |
| 18-JAN-22 | Z1028581 | McDonald, A: FedEx shipping of rese | 11.67 |
| 18-JAN-22 | Z1028581 | McDonald, A: Shipping research samp | 16.24 |
| 26-JAN-22 | Z1028940 | McDonald, A: UPS shipping of sample | 14.22 |
| E5070 Conference/Registration Fees | | | |
| 03-SEP-21 | Z1022134 | McDonald, A: SWST conference regist | 650.00 |
| 22-MAR-22 | I2224406 | Maughan, Michael | 695.00 |
| E5199 Other Professional Service | | | |
| 11-OCT-21 | J1296434 | mech engr shop chrgs 3d prntr wrk | 341.00 |
| E5320 Software/Applications - Individual | | | |
| 28-JUL-21 | J1292993 | CT 500.01 from 849997 to 849989 | 500.01 |
| 04-NOV-21 | TC102721 | TDX190117 Adobe Acrobat Pro 2020 | 107.88 |
| 04-NOV-21 | TC102721 | TDX190117 Microsoft Visio Prof. | 33.94 |
| 04-NOV-21 | TC102721 | TDX191661 Adobe Acrobat Pro 2020 | 107.27 |
| 04-NOV-21 | TC102721 | TDX191661 Microsoft Visio | 33.94 |
| E5350 Other Technical Services | | | |
| 23-SEP-21 | J1296645 | DDE/CT from 849997 | 1050.00 |
| 03-MAR-22 | J1305423 | DDE/CER Basham Lab Services | 2400.00 |
| 23-MAY-22 | J1310305 | SB; Basham Hrs CER Lab Services | 525.00 |
| E5410 Office and Administrative Supplies | | | |
| 23-SEP-21 | Z1023283 | Doorstops IDL labs | 9.99 |
| E5724 Research Supplies | | | |
| 06-AUG-21 | J1292558 | machine shop chrgs for IGEM prntr | 120.00 |
| 06-AUG-21 | J1292557 | machine shop work for MechEngr | 194.00 |
| 03-SEP-21 | Z1022134 | McDonald, A: Bipee round cover slip | 9.80 |
| 03-SEP-21 | Z1022134 | McDonald, A: Sodium silicate for re | 48.34 |
| 03-SEP-21 | Z1022134 | McDonald, A: conductive adhesive ta | 43.10 |
| 03-SEP-21 | Z1022134 | McDonald, A: refund from shipping c | -24.22 |
| 10-SEP-21 | Z1022370 | Calibration Materials ordered for I | 78.46 |
| 20-SEP-21 | Z1022903 | McDonald, A: DSC aluminum sample pa | 476.81 |
| 20-SEP-21 | Z1022903 | McDonald, A: Sodium silicate soluti | 111.36 |
| 22-SEP-21 | Z1023158 | Expense for a breadboard (DIY circu | 6.99 |
| 22-SEP-21 | Z1023158 | Expense for a few resistors so that | 9.63 |
| 28-OCT-21 | Z1024848 | Purchase Tecplot for research. Inde | 1156.66 |
| 01-NOV-21 | Z1024941 | Purpose: Steel tubing necessary for | 73.52 |
| 01-NOV-21 | Z1024941 | Purpose: Supplies for heat exchange | 42.64 |
| 11-NOV-21 | Z1025599 | McDonald, A: chemicals for research | 45.81 |
| 11-NOV-21 | Z1025599 | McDonald, A: chemicals for research | 35.73 |
| 01-DEC-21 | J1300511 | JKD/ Phys Shp Wrk: McDonald | 543.50 |

| | | | |
|---|---|---|---|
| 10-DEC-21 | Z1027024 | McDonald, A: DSC pans for research. | 480.52 |
| 10-DEC-21 | Z1027024 | McDonald, A: DSC pans for research. | 189.40 |
| 10-DEC-21 | Z1027024 | McDonald, A: Duracell batteries for | 10.97 |
| 10-DEC-21 | Z1027024 | McDonald, A: Extruder parts for res | 2556.53 |
| 10-DEC-21 | Z1027024 | McDonald, A: Flat steel bar for res | 12.08 |
| 10-DEC-21 | Z1027024 | McDonald, A: Replacement O-Rings fo | 7.25 |
| 10-DEC-21 | Z1027024 | McDonald, A: Submersible water pump | 13.99 |
| 10-DEC-21 | Z1027024 | McDonald, A: Ziplock bags for resea | 8.51 |
| 10-DEC-21 | Z1027024 | McDonald, A: replacement food proce | 28.62 |
| 10-DEC-21 | Z1027024 | McDonald, A: saw blade for table sa | 17.13 |
| 10-DEC-21 | Z1027024 | McDonald, A: table saw for research | 377.10 |
| 29-DEC-21 | Z1027787 | grains to build wood 3D printer ind | 10.59 |
| 29-DEC-21 | Z1027787 | supplies to build wood 3D printer i | 3.78 |
| 18-JAN-22 | Z1028581 | McDonald, A: 21X datalogger for res | 53.00 |
| 18-JAN-22 | Z1028581 | McDonald, A: 21X datalogger refund | -53.00 |
| 18-JAN-22 | Z1028581 | McDonald, A: Batteries for research | 12.74 |
| 18-JAN-22 | Z1028581 | McDonald, A: Brushes for research. | 22.67 |
| 18-JAN-22 | Z1028581 | McDonald, A: Campbell Scientific CE | 51.24 |
| 18-JAN-22 | Z1028581 | McDonald, A: Durometer for research | 28.00 |
| 18-JAN-22 | Z1028581 | McDonald, A: Lab supplies: Buchner | 47.97 |
| 18-JAN-22 | Z1028581 | McDonald, A: Lap supplies: 9 count | 23.62 |
| 18-JAN-22 | Z1028581 | McDonald, A: Thermogravimetric unit | 624.13 |
| 03-FEB-22 | Z1029276 | Parts for constructing 3D weaver ma | 854.96 |
| 03-FEB-22 | Z1029276 | Parts for constructing 3D weaver ma | 945.24 |
| 03-FEB-22 | Z1029326 | PLA Filament puchased for research | 31.48 |
| 03-FEB-22 | Z1029336 | Purpose: bearings to build wood 3d | 433.91 |
| 03-FEB-22 | Z1029336 | Purpose: padlock eyes to secure mat | 62.24 |
| 03-FEB-22 | Z1029336 | Purpose: padlocks to secure equipme | 51.36 |
| 03-FEB-22 | Z1029336 | Purpose: tools to build the wood 3d | 61.73 |
| 03-FEB-22 | Z1029336 | linear motion shaft: Purpose: suppl | 139.69 |
| 17-FEB-22 | Z1029869 | Purpose: Supplies build wood 3D pri | 37.98 |
| 17-FEB-22 | Z1029869 | Purpose: Supplies to build wood 3D | 27.06 |
| 17-FEB-22 | Z1029869 | Purpose: VFD for new extruder neces | 348.29 |
| 17-FEB-22 | Z1029869 | flat bar Purpose: metal to build wo | 17.60 |
| 17-FEB-22 | Z1029869 | heat shrink butt connectors kit Pur | 15.99 |
| 17-FEB-22 | Z1029869 | tools and supplies for research lab | 264.97 |
| 17-FEB-22 | Z1029869 | tools and supplies for research lab | 210.94 |
| 17-FEB-22 | Z1029869 | tools and supplies for research lab | 190.62 |
| 28-FEB-22 | Z1030257 | Keyboards purchased for use with la | 26.97 |
| 24-MAR-22 | Z1031286 | Parts for constructing 3D weaver. I | 112.28 |
| 30-MAR-22 | Z1031591 | HERC-IGEM purchases. I went to Home | 12.99 |
| 30-MAR-22 | Z1031591 | HERC-IGEM purchases. I went to Home | 7.99 |
| 30-MAR-22 | Z1031591 | HERC-IGEM purchases. I went to Home | 19.92 |
| 30-MAR-22 | Z1031591 | HERC-IGEM purchases. I went to Home | 49.51 |
| 30-MAR-22 | Z1031618 | Mcdonald, A; Ridgeyard Manual Sugar | 256.99 |
| 06-APR-22 | Z1031921 | From Cardholder E-mail: A receipt | 47.40 |
| 12-APR-22 | J1307690 | JKD/ Phys Shp Wrk: McDonald | 365.00 |
| 14-APR-22 | Z1032353 | 691636 ? Supplies to build wood 3D | 10.27 |
| 14-APR-22 | Z1032353 | 691636 ? Supplies to build wood 3D | 41.01 |
| 14-APR-22 | Z1032353 | 691636 ? Supplies to build wood 3D | 1564.36 |
| 14-APR-22 | Z1032353 | electric linear actuator - then ful | 44.19 |
| 14-APR-22 | Z1032353 | filament, 691636 ? Supplies to buil | 69.97 |
| 14-APR-22 | Z1032353 | full refund for 44.19 expense 69163 | -44.19 |
| 14-APR-22 | Z1032353 | fully refunded 3d printer supplies | -1564.36 |
| 14-APR-22 | Z1032353 | shrink tubing, stepper motor 691636 | 96.95 |
| 15-APR-22 | Z1032416 | Mcdonald, A; 4-port USB 3.0 purchas | 15.99 |
| 15-APR-22 | Z1032416 | Mcdonald, A; Fielect 24V Brushless | 11.84 |
| 15-APR-22 | Z1032416 | Mcdonald, A; Pipe fittings and meta | 41.30 |
| 25-APR-22 | Z1032930 | mounting brackets Purpose: supplies | 8.85 |
| 25-APR-22 | Z1032930 | semiconductors, diodes, etc Researc | 23.31 |

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|---|---|---|---|
| 17-MAY-22 | Z1034317 | Mcdonald, A; 8oz Gorilla Glue purch | 12.49 |
| 17-MAY-22 | Z1034317 | Mcdonald, A; Book on wood adhesives | 28.30 |
| 17-MAY-22 | Z1034317 | Mcdonald, A; Electrical connectors | 10.92 |
| 17-MAY-22 | Z1034317 | Mcdonald, A; Lab supplies purchased | 22.25 |
| 17-MAY-22 | Z1034317 | Mcdonald, A; Panel outlets purchase | 8.99 |
| 17-MAY-22 | Z1034317 | Mcdonald, A; Pipette bulb filler fo | 14.18 |
| 17-MAY-22 | Z1034317 | Mcdonald, A; Switches purchased for | 7.99 |
| 17-MAY-22 | Z1034317 | Mcdonald, A; Thermocouple plug purc | 31.30 |
| 17-MAY-22 | Z1034317 | Mcdonald, A; Unit instruments UFC-1 | 32.49 |
| 06-JUN-22 | Z1035606 | o Research supplies this is a micro | 380.00 |
| 06-JUN-22 | Z1035606 | o Research supplies. A radiator to | 38.99 |
| 06-JUN-22 | Z1035606 | o Research supplies. Bearings to re | 10.50 |
| 06-JUN-22 | Z1035606 | o Research supplies. Bearings to re | 12.99 |
| 06-JUN-22 | Z1035606 | o Research supplies. Hose connector | 131.00 |
| 17-JUN-22 | Z1036922 | McDonald, A; Fuses purchased for us | 19.30 |
| 17-JUN-22 | Z1036922 | McDonald, A; Spigots purchased for | 17.98 |
| 17-JUN-22 | Z1036922 | Mcdonald, A; Connectors purchased f | 12.99 |
| E5741 Med Lab & Tech Supplies | | | |
| 10-NOV-21 | J1299491 | jkm/ct from 691678 to 691649 | 18.35 |
| 11-FEB-22 | U0139717 | Chemstores/McDonald | 119.06 |
| 17-MAY-22 | U0140367 | Chemstores/MaDonald | 45.68 |
| | | | ---------- |
| | | | $ 19921.21 |

Subawards

| | | | |
|---|---|---|---|
| ES001 Subaward 1 Expenses | | | |
| 02-APR-22 | I2226130 | Boise State University | 21664.32 |
| 25-MAY-22 | I2235209 | Boise State University | 2348.67 |
| 16-JUN-22 | I2239086 | Boise State University | 27244.26 |
| | | | ---------- |
| | | | $ 51257.25 |

Tuition Remission and Training

| | | | |
|---|---|---|---|
| E7140 Tuition and Fees - Grad Assistants | | | |
| 09-AUG-21 | J1293588 | G1GB for V00705715 | 786.00 |
| 09-AUG-21 | J1293588 | SHI1 for V00705715 | 978.00 |
| 13-AUG-21 | J1293884 | G1GA for 181-71260 | 786.00 |
| 13-AUG-21 | J1293884 | SHI1 for 181-71260 | 978.00 |
| 13-AUG-21 | J1293884 | T1GA for 181-71260 | 4170.00 |
| 17-AUG-21 | J1294016 | G1GC for V00467497 | 786.00 |
| 17-AUG-21 | J1294016 | G1GC for V00758485 | 786.00 |
| 17-AUG-21 | J1294016 | JBB1 for V00467497 | 105.00 |
| 17-AUG-21 | J1294016 | RAP1 for V00467497 | 695.00 |
| 17-AUG-21 | J1294016 | T1GC for V00467497 | 4170.00 |
| 17-AUG-21 | J1294016 | T1GC for V00758485 | 4170.00 |
| 20-AUG-21 | J1294344 | bb move from 819989 | 4170.00 |
| 23-AUG-21 | J1293645 | G1GB for 172-63620 | 786.00 |
| 23-AUG-21 | J1293645 | SHI1 for 172-63620 | 978.00 |
| 23-AUG-21 | J1293645 | T1GB for 172-63620 | 4170.00 |
| 23-AUG-21 | J1293645 | VVSF for 172-63620 | 100.00 |
| 07-SEP-21 | J1294874 | ID1C for 172-63620 | 175.00 |
| 03-JAN-22 | J1301695 | G2GB for 172-63620 | 786.00 |
| 03-JAN-22 | J1301695 | T2GB for 172-63620 | 4170.00 |
| 03-JAN-22 | J1301695 | VVSF for 172-63620 | 100.00 |
| 05-JAN-22 | J1301967 | G2HC for V00788801 | 522.00 |
| 05-JAN-22 | J1301967 | RAG2 for V00788801 | 462.00 |
| 05-JAN-22 | J1301967 | T2HC for V00788801 | 2772.00 |
| 06-JAN-22 | J1302117 | G2GA for 181-71260 | 786.00 |
| 06-JAN-22 | J1302117 | SHI2 for 181-71260 | 978.00 |
| 06-JAN-22 | J1302117 | T2GA for 181-71260 | 4170.00 |
| 01-FEB-22 | J1302114 | G2GB for V00705715 | 786.00 |
| 01-FEB-22 | J1302114 | SHI2 for V00705715 | 978.00 |

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|---|---|---|---|
| 01-FEB-22 | J1302114 | T2GB for V00705715 | 4170.00 |
| 04-APR-22 | J1307150 | JAB2 for V00788801 | 105.00 |
| 01-MAY-22 | J1308750 | JBB2 for V00788801 | 105.00 |
| 19-MAY-22 | J1309824 | G3HB for 172-63620 | 87.00 |
| 19-MAY-22 | J1309824 | MP3 for 172-63620 | 35.00 |
| 19-MAY-22 | J1309824 | T3HB for 172-63620 | 462.00 |
| 14-JUN-22 | J1312128 | dls; refund V00618943 | -35.00 |
| | | | ---------- |
| | | | $ 50228.00 |
| | | | --------------- |
| | | Total Expenses | $ 256472.08 |

| | | |
|---|---|---|
| Salaries | | |
| E4105 Faculty | | |
| | Woods, Lindsay | 12096.63 |
| | 286.04 hours | |
| | Zhang, Wei | 1615.60 |
| | 40.00 hours | |
| E4106 Staff | | |
| | Baker, Kenneth | 13760.61 |
| | 341.20 hours | |
| E4108 Summer Salary | | |
| | Budwig, Ralph | 3234.80 |
| | 2.50 hours | |
| | Maughan, Michael | 3195.92 |
| | 52.00 hours | |
| | Woods, Lindsay | 1240.58 |
| | 29.32 hours | |
| | Xing, Tao | 3493.88 |
| | 52.00 hours | |
| E4109 IA/GA Salary | | |
| | Carne, Robert | 16504.80 |
| | 780.00 hours | |
| | Mitchell, Tais | 5920.00 |
| | 320.00 hours | |
| | Nawafleh, Anas Mohammad Hussein | 16497.00 |
| | 780.00 hours | |
| | Orji, Berlinda Oluebube | 20234.24 |
| | 988.00 hours | |
| | Ramsey, Kelsey | 1665.00 |
| | 90.00 hours | |
| | | $ 99459.06 |
| Temporary/Irregular Help | | |
| E4135 Temporary Student | | |
| | Carne, Robert | 4441.50 |
| | 210.00 hours | |
| | Mitchell, Tais | 2368.00 |
| | 128.00 hours | |
| | Nawafleh, Anas Mohammad Hussein | 2707.20 |
| | 128.00 hours | |
| | Sedillo, Joseph | 7774.00 |
| | 428.50 hours | |
| | | $ 17290.70 |
| Fringe Benefits | | |
| E4280 Faculty CFR Benefit Expense | | 7334.70 |
| E4281 Staff CFR Benefit Expense | | 5624.51 |
| E4282 Student CFR Fringe Expense | | 2319.22 |
| | | $ 15278.43 |
| Travel | | |
| E5365 Personal Vehicle - Out-of-State | | |
| E5371 Motor Pool Vehicle - In-State | | |
| E5372 Motor Pool Vehicle - Out-of-State | | |
| E5381 Airfare - Out-of-State | | |
| E5392 Ground Transportation-Out-of-State | | |

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|---|---|
| E5397 Lodging & Per Diem ? Out of State | |
| | ---------- |
| | $ 3037.43 |
| Operating Expenses | |
| E5023 Express Mail | |
| E5070 Conference/Registration Fees | |
| E5199 Other Professional Service | |
| E5320 Software/Applications - Individual | |
| E5350 Other Technical Services | |
| E5410 Office and Administrative Supplies | |
| E5724 Research Supplies | |
| E5741 Med Lab & Tech Supplies | |
| | ---------- |
| | $ 19921.21 |
| Subawards | |
| ES001 Subaward 1 Expenses | |
| | ---------- |
| | $ 51257.25 |
| Tuition Remission and Training | |
| E7140 Tuition and Fees - Grad Assistants | |
| | ---------- |
| | $ 50228.00 |
| | --------------- |
| Total Expenses | $ 256472.08 |