University of Idaho Colleges of Engineering, Natural Resources, Art & Architecture

HERC-IGEM
Cellulosic 3D Printing of Modular Building Assemblies

SECOND MID-YEAR REPORT
FISCAL PERIOD – JULY 1 TO DECEMBER 31, 2020

SUMMARY OF PROGRESS
December 31, 2020

Prepared for:
State Board of Education
Mr. TJ Bliss Ph.D.

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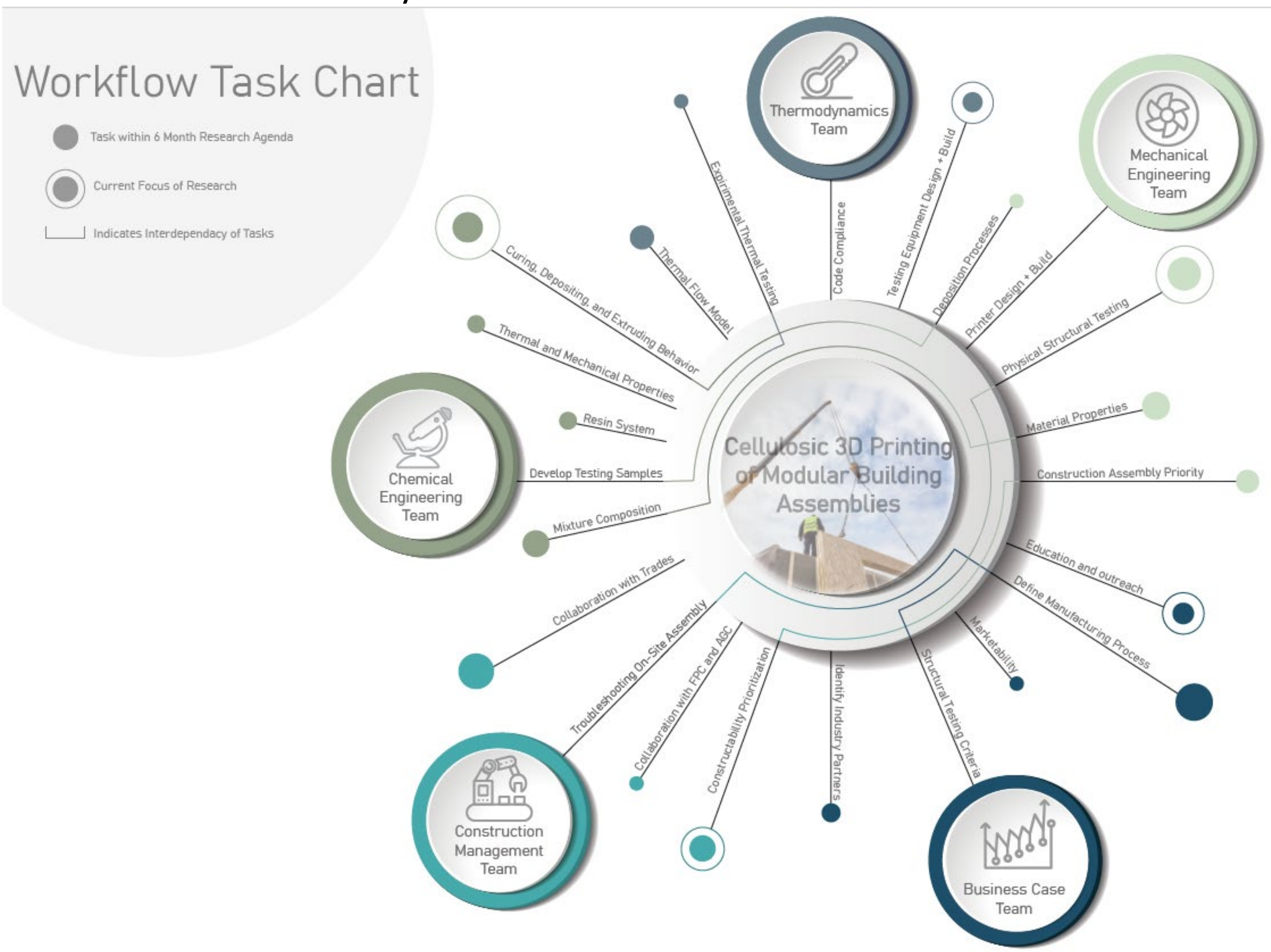
Acronyms and Abbreviations

3D printing	Three-dimensional printing
AM	Additive manufacturing
IDL	Integrated Design Lab
UI	University of Idaho

1. Introduction

The project objective is to identify the methodology, process, and materials necessary to three-dimensional cold print (3D print) building assemblies utilizing, to some maximum extent, wood products. Moving a significant portion of construction into a factory setting where labor and work is organized and executed more efficiently will have the following benefits: 1) increase the quality and energy efficiency of buildings; 2) lower overall construction costs; 3) provide appropriate compensation for a more skilled labor force and, 4) assist in mitigating the current construction skilled labor shortage challenge in Idaho.

Tasks for First Half of Year 2 – July to December 31:



2. Summary of Project Accomplishments for the reporting period just completed

1) Research and identify the printing mix of wood/natural fibers, binders and adhesives;

6 Month reporting Dr. McDonald staffing: 1 Ph.D. student in Environmental Science. 1 woman. Salary expenditures and student tuition in the McDonald lab have focused on supporting the research efforts of one Ph.D. student. Operational expenses are in line with ongoing and projected research activities on wood-resin curing research. Appropriated funds will be expended by the end of year 2.

6-month report overview

Three thermoset resins with wood fiber were evaluated using the custom-built capillary rheometer using a variety of die diameters (Figure 1). Capillary extrusion was performed at different shear rates to determine flow-curves of the resin-wood fiber mixtures. Comparisons between the capillary and dynamic rheometers flow curves were obtained and show good agreement (Figure 1). We are determining the cure characteristics (chemistry and kinetics) of the resins by a combination of dynamic rheology, differential scanning calorimetry (DSC) and infra-red (IR) spectroscopy to establish parameters for printing.

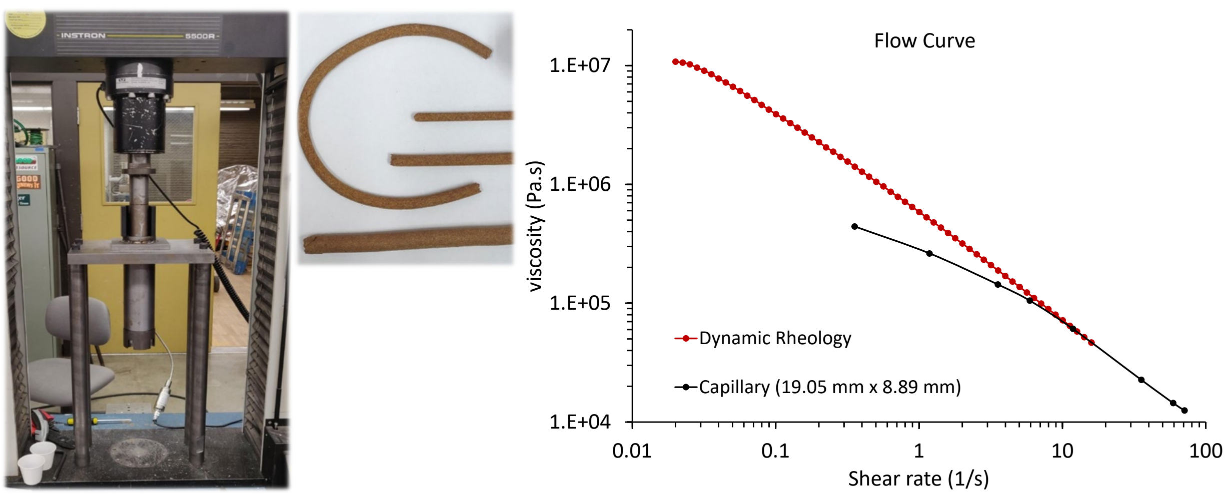


Figure 1. (left) large capillary rheometer, (middle) extruded rods, and (right) flow curves

2) Develop the technical description design for a 3D fibrous wood wall printing process including prototype printer design and CFD extrusion modeling;

Prepared by: Michael R. Maughan, Ph.D., P.E. and Tao Xing, Ph.D.

The University of Idaho (UI) Mechanical Engineering (ME) team has the responsibility of developing a 3D printing process and printer for depositing a wood waste composite mixture developed by other researchers in the UI College of Natural Resources (CNR). The goal is to make bespoke composite building panels. UI ME is also responsible for thermal modeling and optimization of the 3D printed composite building panels. Extrusion has been identified as the preferred deposition technique. We have experimented further with an extrusion machine to develop a continuous flow process and have identified necessary upgrades to the equipment for higher throughput. Simulations of the material have been developed. A printer frame has been manufactured and assembled. Components for a computer control system have been purchased. Two Master of Science students have been employed on the project.

Figure 1. Extrusion test nozzles and sample wood composite extrudate.

Continuous flow extruder – We have used the continuous flow extruder to make cylindrical samples with varying size nozzles that were machined by students. Figure 1 shows the nozzles and a sample of extrudate used in conjunction with the SJ-35 described in the prior annual report.

Figure 3. 3D printer frame and gantry system

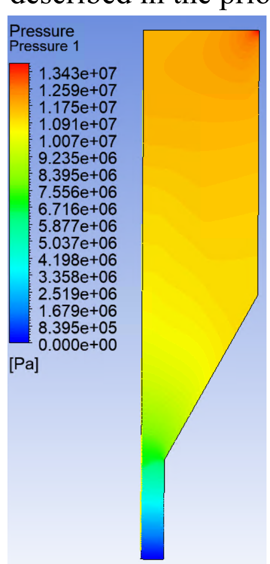


Figure 2. CFD simulation pressure plot.

Direct extrusion frame – With the direct extrusion frame described in the last report, we have conducted additional testing and used this as a comparison to validate computational fluid dynamics (CFD) simulations of the composite mixture. The flow simulations will allow 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 bend testing. Figure 2 shows a preliminary result of CFD on the generated pressure contour of flow within the direct extrusion frame.

Modular 3D-printer frame and gantry system – Since June 2020, we have constructed the printer frame and motion gantry (Figure 3). The system utilizes stepper motors for position control. The target layer geometry is wide and thin which enables a large surface area to promote interlayer adhesion.

Graduate research assistant – UI ME has been staffed with two graduate research assistant (GRA) since June. GRA1 has focused on the deposition process and performance modeling of the material. The new GRA2 has manufactured and assembled the printer frame.

3) Refine the business case for private industry investment and, study the thermal properties of a prototype cured product.

Prepared by: Ken Baker, M. Arch

The Boise team is comprised of two Ph.D.'s, the PI and one engineering graduate student. Utilizing a gift from the Northwest Energy Efficiency Alliance we have been able to fund two architectural students, both women, for part time work under this grant to assist in literature reviews, business case development and graphic presentations of grant accomplishments.

The business case, in good draft form at the end of year 1, has been updated with better data on costs and embodied energy for the six construction types being compared. The following table highlights the research in this area. The 3D printed panel has the lowest (best) score of the six wall types studied.

Comparison Criteria	3D Print	SIPS (5-5/8")	Wood Frame (2x	Steel Frame (6" wide studs, 16"	CMU (Normal Weight 8"x 16"x	CLT (3-layer)
Assembly Embodied Energy **	1530.00	3638.00	1923.00	2447.00	5411.00	5086.00
Mileage to place of manufacture	5.00	380.00	478.00	424.00	11.00	436.00
Labor Cost* ($/sq ft)	1.26	4.04	3.83	11.85	11.09	3.97
On Site Labor Hours*	0.09	0.09	0.09	0.23	0.23	0.07
Cost of Material* ($/sq ft)	6.75	9.62	6.81	7.38	6.51	26
Overall O&P cost for assembly*	4.16	17.13	13.20	33.10	23.79	36.30
Assembly R Value****	22.44	25.34	19	15.6	11.66	15.81
Assembly Carbon Emissions (kg CO2/kg**)	95	224	109	335	345	261.8
Assembly Embodied Energy of key material**	1.00	3.17	1.41	1.95	5.00	4.67
Mileage to place of manufacture	1.00	4.17	5.00	4.54	1.05	4.64
Labor Cost* ($/sq ft)	1.00	2.05	1.97	5.00	4.71	2.02
On Site Labor Hours*	1.43	1.38	1.31	5.00	5.00	1.00
Cost of Material* ($/sq ft)	1.05	1.64	1.06	1.18	1.00	5.00
Overall O&P cost for assembly*	1.00	2.61	2.13	4.60	3.44	5.00
Assembly R Value****	1.85	1.00	2.85	3.85	5.00	3.79
Assembly Carbon Emissions (kg CO2/kg**)	1.00	3.06	1.22	4.84	5.00	3.67
Total Overall Score	**9.33**	**19.09**	**16.95**	**30.96**	**30.21**	**29.79**

To better align with thermal property testing methods widely used in literature, a guarded hot plate apparatus is being developed to meet ASTM standard C177. When completed, the apparatus will be able to determine the thermal conductivity of an 8-inch square section of material. The apparatus will be used to validate previous thermal conductivity experiments using a less regarded testing method and further characterize the thermal properties of the 3D printed wood material. It will also be used in preliminary thermal testing for different geometric wall variations to optimize the thermal performance of the full wall assembly. The expected completion date is estimated to be around early to mid-March of 2021.

Figure 2. Guarded Hot Plate used to examine the thermal properties and to set up a testing protocol for future samples based on ASTM standard C518

3. Summary of Budget Expenditures

The budget is on track for yearly expenditures. Permission for travel dollar reallocation was provided in November and numerous pieces of research equipment that will advance our research are being purchased.

Expenditure	Budget	First Half	Remaining
Salaries & Fringe	202700	89133	113567
Tuition	49014	22643	26371
Equipment & Supplies	49600	7698	41902
Travel	6800	0	6800
BSU	62700	20000	42700
			0
Total	370814	139474	231340

4. Demonstration of Economic Development/Impact

- Patents, copyrights
    - Two patents, one for the print media and one for the printer design are proposed by the end of year two.
- Technology licenses signed

- None currently

- Private sector engagement
  - Communications on industry partnership potential with the Associated General Contractors and the Idaho Forest Products Council.

- Jobs created
  - None at this time

- External funding
  - We are currently working on two proposals, one NSF and one DOE, that would fund development of a manufacturing plan for large scale production of panels.

- Other pertinent information
  - None currently

5. Numbers of Faculty and Student Participation

There are nine faculty participating in the grant, six from the U of I and three with BSU. There are four full time students working on the grant as of July 1, 2020.

6. Description of Future Plans for Project Continuation or Expansion

We are currently working on two proposals, one NSF and one DOE, that would fund development of a manufacturing plan for large scale production of panels. Both are due in late January 2021.

7. Commercialization Revenue

None to date.