Quarterly Progress and Performance Indicators Report:
Project Number and Title: Project 2.4 - Thermoplastic Composites by 3D Printing and Automated Manufacturing to Extend the Life of Transportation Facilities
Research Area: 2 - New Materials for Longevity and Constructability
PI: *Roberto Lopez-Anido, University of Maine*
Co-PI(s): *James Anderson, University of Maine*
Reporting Period: *10/1/2021-12/31/2021*
Submission Date: *12/31/2021*

******IMPORTANT: Please fill out each section fully and reply with N/A for questions/sections with nothing to report. For ease of reporting to the USDOT, please do not remove, or change the order of, any sections/text. You may remove/add each rows in tables as needed. Thank you! ******
The report is due on the last day of the reporting period in .doc format to tidc@maine.edu.

Overview:

*Provide **BRIEF** highlights of activities performed during the reporting period. This summary should be written in lay terms for a general audience to understand. This should not be an extensive write up of findings (those are to be included in the final report), but a high-level overview of the activities conducted during the last three months **no more than 3 bullet points at no more than 1 sentence each** ….*

- Designed and manufactured precast concrete formwork using large scale 3D printing to minimize life-cycle cost.
- Large-scale 3D printing in combination with CNC machining used to manufacture relatively complex formwork for concrete casting operations.
- Biobased wood/PLA and conventional carbon fiber/ABS composite materials were used to manufacture 3D printed formwork sets for Unistress Corp., Pittsfield, MA, to assess durability.
- Large 3D printed formwork system was manufactured for precast concrete railroad bridge ballast retainer for American Concrete Industries, Veazie, ME.

Meeting the Overarching Goals of the Project:

How did the previous items help you achieve the project goals and objects? Please give one bullet point for each bullet point listed above.

- Evaluate the performance of 3D printed formwork through repeated cycles of concrete casting/demolding.
- Assess longevity and establish the useful fatigue life for 3D printed formwork.
- Investigate the cost/benefit of 3D printed formwork, which will be realized provided the material is durable and dimensionally stable.

Accomplishments:

List any accomplishments achieved under the project goals in bullet point form…

- Designed a cellular pattern for the formwork to minimize material use, reduce manufacturing time, and decrease costs.
- Deployed 3D printed formwork prototype at precaster plant to assess longevity during cycles of casting and demolding.

Task Progress and Budget:

Complete the following tables to document the work toward each task and budget (add rows/remove rows as needed, make sure you complete the Overall Project progress row and include all tasks even if they have ended or have not been started)…

Table 1.1: Phase 1 - Task Progress			
Task Number	**Start Date**	**End Date**	**% Complete**
Task 1.1: Review of the state-of the-art	01/01/2019	06/30/2019	100%
Task 1.2: Study the feasibility of using large-scale 3D printed forms for casting precast concrete structures	07/01/2019	12/31/2019	100%
Task 1.3: Select thermoplastic composite materials and surface finishing for 3D printed forms	01/01/2020	03/31/2021	100%
Task 1.4: Design and analyze large-scale 3D printed forms for precast concrete operation requirements	04/01/2020	06/30/2021	100%
Task 1.5: Design additive manufacturing, machining and assembly process for large-scale 3D printed forms	07/01/2020	12/31/2021	100%
Task 2.1: Manufacture large-scale 3D printed forms for precast concrete construction	10/01/2020	06/30/2021	100%
Task 2.2: Monitor concrete casting and demolding operations using 3D printed forms	07/01/2021	09/30/2022	10%
Task 2.3: Disseminate large-scale 3D printed form technology for precast concrete construction	01/01/2021	09/30/2022	5%
Task 2.4: Evaluate durability of 3D printed forms after reuse cycles of casting and demolding concrete operations	10/01/2021	09/30/2022	0%
Task 2.5: Facilitate large-scale 3D printed technology deployment and adoption by specifying material, manufacturing and operational requirements.	07/01/2022	12/31/2022	0%
Phase 1 Overall	01/01/2019	12/31/2021	100% Complete
Phase 2 Overall	10/01/2020	12/31/2022	20% Complete

Table 2: Budget Progress		
Project Budget	**Spend – Project to Date**	**% Project to Date (include the date)**
Enter Phase 1 Full Budget: $149,912	Enter Phase 1 Full Spend Amount (Federal + Cost Share)	Enter Phase 1 % Spent
Enter Phase 2 Full Budget: $158,467	Enter Phase 2 Full Spend Amount (Federal + Cost Share)	Enter Phase 2 % Spent
Enter Phase 3 Full Budget	Enter Phase 3 Full Spend Amount (Federal + Cost Share)	Enter Phase 3 % Spent

Is your Research Project Applied or Advanced?

☒ **Applied** (*The systematic study to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.)*

☐ **Advanced** *(An intermediate research effort between basic research and applied research. This study bridges basic (study to understand fundamental aspects of phenomena without specific applications in mind) and applied research and includes transformative change rather than incremental advances. The investigation into the use of basic research results to an area of application without a specific problem to resolve.)*

Professional Development/Training Opportunities:

Describe any opportunities for training/professional development that have been provided. Did you provide a training to a State DOT/AOT or industry organization? What was the training? When was it offered? How many people attended? Did you meet with a State DOT/AOT or industry organization to inform them of your findings and how these findings could help their organization? When? How many attended the meeting?

- *N/A*

Technology Transfer:

Complete all of the tables below and provide additional information where requested. Please provide ALL requested information as this is one of the most important sections for reporting to the USDOT. ***ONLY provide information relevant to this reporting period.***

Use the table below to complete information about conference sessions, workshops, webinars, seminars, or other events you led/attended where you shared findings as a result of the work you conducted on this project:

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events

Type	Title	Citation	Event	Location	Date(s)
i.e. Conference, Symposium, DOT/AOT presentation, Seminar, etc.	Presentation Title	Full Citation	Name of event (i.e. TIDC 1st Annual Conference) or who was the presentation given to?		
Seminar	Thermal and Mechanical Numerical Modeling of Extrusion-Based 3D Printed Reinforced Polymers for Manufacturing Process Improvement	Bhandari, S. "Thermal and Mechanical Numerical Modeling of Extrusion-Based 3D Printed Reinforced Polymers for Manufacturing Process Improvement," Ph.D. Dissertation Defense, Dept. of Civil and Env. Engineering, University of Maine, 2021.	Dissertation Defense of Sunil Bhandari	Orono, ME	Oct. 20, 2021
Conference paper presentation slides	Design and manufacture of precast concrete formwork using polymer extrusion based large scale additive manufacturing and postprocessing.	Bhandari S., Lopez-Anido, R., Anderson, J. and LeBihan, A. ICAM 2021, ASTM International Conference on Additive Manufacturing, Nov. 1-5, 2021.	ASTM International Conference on Additive Manufacturing	Anaheim, CA,	Nov. 1-5, 2021

Symposium	Large Scale 3D Printing of Precast Concrete Tooling for Transportation Infrastructure	2021 Symposium on New England Railroad Infrastructure: Challenges, Solutions, and Opportunities, University of Maine, https://www.tidc-utc.org/events/2021-new-england-rr-symposium/	New England Railroad Symposium	Virtual	Nov. 10, 2021
Conference	Large Scale 3D Printing for Construction: Formwork for Precast Concrete Production and Culvert Outlet Diffusers	Lopez-Anido, R. "Large Scale 3D Printing for Construction: Formwork for Precast Concrete Production and Culvert Outlet Diffusers," Changing Course – A Virtual Gathering, Maine Transportation Conference, Dec. 2, 2021.	Maine Transportation Conference	Virtual	Dec. 2, 2021

Use the table below to report any publications, technical reports, peer-reviewed articles, newspaper articles referencing your work, graduate papers, dissertations, etc. written as a result of the work you conducted on this project. Please list only completed items and exclude work in progress.

Table 4: Publications and Submitted Papers and Reports

Type	Title	Citation	Date	Status
i.e. Peer-reviewed journal, conference paper, book, policy paper, magazine/newspaper article	Publication title	Full citation		i.e. Submitted, accepted, under review
Peer-reviewed journal	Design and Manufacture of Precast Concrete Formwork Using Polymer Extrusion-Based Large Scale Additive Manufacturing and Postprocessing	Bhandari, S., Lopez-Anido, R.A., Saavedra Rojas, F., and LeBihan, A. "Design and Manufacture of Precast Concrete Formwork Using Polymer Extrusion-Based Large Scale Additive Manufacturing and Postprocessing," STP1644 on ASTM International Conference on Additive Manufacturing (ICAM 2021).	Dec. 1, 2021	Submitted
Dissertation	Thermal and Mechanical Numerical Modeling of Extrusion-Based 3D Printed Reinforced Polymers for Manufacturing Process Improvement	Bhandari, S. "Thermal and Mechanical Numerical Modeling of Extrusion-Based 3D Printed Reinforced Polymers for Manufacturing Process Improvement," Ph.D. Dissertation, Digital Commons, University of Maine, 2021.	Dec. 15, 2021	Accepted

Answer the following questions (N/A if there is nothing to report):

1. Did you deploy any technology during the reporting period through pilot or demonstration studies as a result of this work? If so, what was the technology? When was it deployed?

I. *Four 3D printed formwork sets with biobased Wood fiber/PLA and synthetic Carbon fiber/ABS were delivered to Unistress Corp. plant in Pittsfield, Massachusetts*
A system of 3D Carbon fiber/ABS forms for a railroad bridge ballast retainer were delivered to American Concrete Industries plant in Veazie, Maine.

2. Was any technology adopted by industry or transportation agencies as a result of this work? If so, what was the technology? When was is adopted? Who adopted the technology? *N/A*
Yes. American Concrete Industries, Unistress Corp. Ltd. and MaineDOT
3. Did findings from this research project result in changing industry or transportation agency practices, decision making, or policies? If so, what was the change? When was the change implemented? Who adopted the change?
N/A
4. Were any licenses granted to industry as a result of findings from this work? If so, when? To whom was the license granted?
N/A
5. Were any patent applications submitted as a result of findings from this research? If so, please provide a copy of the patent application with your report.
N/A
6. Were any industrial contracts awarded base on furthering planned research and development activities as a result of findings from this work? If so, when? How much was awarded? Who awarded the contract?
N/A

Please add figures/images that can be included on the website and/or in marketing/social media materials to further clarify your research to the general public.

Figure 1 – 3D printed formwork sets with three different polymer composites for Unitress Corp., Pittsfield, MA

Figure 2 – Railroad bridge ballast retainer 3D printed forms for American Concrete Industries, Veazie, ME

Describe any additional activities involving the dissemination of research results not listed above under the following headings:

Outputs:

Definition: Any new or improved process, practice, technology, software, training aid, or other tangible product resulting from research and development activities. They are used to improve the efficiency, effectiveness, and safety of transportation systems. List any outputs accomplished during this reporting period:

- Example: New sensing technology was developed. This technology will…

- Designed and manufactured 3D printed formwork for window screen system in Unistress Litewall precast concrete panel for parking structures.
- Designed and manufactured large 3D printed formwork system for railroad bridge ballast retainer.

Outcomes:

Definition: The application of outputs; any changes made to the transportation system, or its regulatory, legislative, or policy framework resulting from research and development activities. List any outcomes accomplished during this reporting period:

- Example: The developed sensing technology was installed in Bridge A in town, state on 1/1/2021. This installation will…

- This installation will demonstrate the feasibility of using 3D printed formwork for railroad bridge precast concrete ballast retainers at the American Concrete Industries plant in Veazie, ME.
- This installation will assess the longevity of 3D printed formwork prototypes deployed at the Unistress Corp. Ltd. plant in Pittsfield, MA

Impacts:

Definition: The effects of the outcomes on the transportation system such as reduced fatalities, decreased capital or operating costs, community impacts, or environmental benefits. The reported impacts from UTCs are used for the assessment of each UTC and to make a case for Federal funding of research and education by demonstrating the impacts that UTC funding has had on technology and education. NOTE: The U.S. DOT uses this information to assess how the research and education programs (a) improve the operation and safety of the transportation system; (b) increase the body of knowledge and technologies; (c) enlarge the pool of people trained to develop knowledge and utilize technologies; and (d) improves the physical, institutional, and information resources that enable people to have access to training and new technologies. List any outcomes accomplished during this reporting period:

- Example: The developed sensing technology's successful deployment resulted in the adoption of the technology by the StateDOT. The technology will be installed in all new bridge installments of this type.

- This adoption will increase the body of knowledge on large-scale 3D printing technologies for precast concrete formwork.

Participants and Collaborators:

*Use the table below to list **all** individuals (compensated or not) who have worked on the project.*

Table 5: Active Principal Investigators, faculty, administrators, and Management Team Members

Individual Name	Email Address	Department	Role in Research
Roberto Lopez-Anido	rla@maine.edu	Civil and Environmental Engineering	P.I.
James Bryce	James.bryce@maine.edu	Advanced Structures and Composites Center	Project Manager

*Use the table below to list **all** students who have participated in the project during the reporting period. (This includes all paid, unpaid, intern, independent study, or any other student that participated in this project.) **ALL FIELDS ARE REQUIRED.***

Table 6: Student Participants during the reporting period								
Student Name	**Start Date**	**End Date**	**Advisor**	**Email Address**	**Level**	**Major**	**Funding Source**	**Role in research**
				Email is not included in the external report and is only used for internal purposes.	(i.e. Junior, Master's Ph.D)		(i.e. TIDC, University (non TIDC match i.e. study abroad program), unpaid intern, independent study student, etc.	What work are they conducting? Please be descriptive. Student research assistant is not enough info.
Sunil Bhandari	2019-02-01	2021-12-15	R. Lopez-Anido and D. Gardner		Ph.D. Candidate	Civil Engineering	TIDC	Design the 3D printed formwork, structural analysis and design
Felipe Saavedra	2021-01-01	present	R. Lopez-Anido		M.S. student	Civil Engineering	TIDC	Design and testing of connections. Surface finishing and assembly of forms

Use the table below to list any students who worked on this project and graduated or received a certificate during this reporting period. Include information about the student's accepted employment (i.e. the student is now working at MaineDOT) or if they are continuing their students through an advanced degree (list the degree and where they are attending).

Table 7: Students who Graduated During the Reporting Period			
Student Name	**Degree/Certificate Earned**	**Graduation/Certification Date**	**Did the student enter the transportation field or continue another degree at your university?**
			Please list the organization or degree
Sunil Bhandari	Ph.D. in Civil Engineering	Dec. 15, 2021	Postdoctoral Research Associate, TIDC-ASCC, University of Maine

Use the table below to list any students that participated in Industrial Internships:

Table 8: Industrial Internships			
Student Name	**Degree/Certificate Earned**	**Graduation/Certification Date**	**Did the student enter the transportation field or continue another degree at your university?**
			Please list the organization or degree

*Use the table below to list **organizations** that have been involved as partners on this project and their contribution to the project.*

Table 9: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
		List the amount	List the amount	Mark with an "x" where appropriate		
MaineDOT	Augusta, ME				x	
Precast/Prestressed Concrete Institute Northeast (PCI-NE)	Belmont, MA				X	
Unistress Corporation	Pittsfield, MA		40,000		X	
American Concrete Industries	Veazie, ME			X	X	

*Use the table below to list **individuals** that have been involved as partners on this project and their contribution to the project.*
*(**List your technical champion(s) in this table.** This also includes collaborations within the lead or partner universities who are not already listed as PIs; especially interdepartmental or interdisciplinary collaborations.)*

Table 10: Other Collaborators				
Collaborator Name and Title	**Contact Information**	**Organization and Department**	**Date(s) Involved**	**Contribution to Research**
	For internal use only			(i.e. technical champion, technical advisory board, test samples, on-site equipment, data, etc.)
Rita L. Seraderian, P.E., FPCI, Executive Director	rseraderian@pcine.org	PCI-NE	2019-02-01 present	Technical champion
Joseph Stilwell P.E., Fabrication Engineer	Joseph.R.Stilwell@maine.gov	MaineDOT-Bridge Program	2021-03-03 present	3D printed formwork for railroad bridge ballast retainer

Use the following table to list any transportation related course that were taught or led by researchers associated with this research project:

Table 11: Course List						
Course Code	**Course Title**	**Level**	**University**	**Professor**	**Semester**	**# of Students**
i.e. CE 123		Grad or undergrad?	Where was the course taught?	Who taught the course?	Enter Spring, Fall, Summer, Winter and the year	How many students were enrolled in the class?

Changes:

List any actual or anticipated problems or delays and actions or plans to resolve them (list no-cost extension requests here)…
The schedule has been affected by disruption of day-to-day laboratory and office work due to the University shutdown in response to COVID-19 health safety precautions.

List any changes in approach and the reasons for the change…

Planned Activities:

List the activities planned during the next quarter.

- Cast the concrete part using Wood fiber/PLA and Carbon fiber/ABS forms at Unistress Corp. plant in Pittsfield, Massachusetts
- Cast railroad bridge ballast retainer formwork at American Concrete Industries plant in Veazie, Maine.
- Monitor the temperatures and deformation in the forms during concrete casting operations.
- Assess and monitor the damage to the forms during repeated castings.
- Assess the durability of the WF/PLA and CF/ABS forms compared to traditional steel forms in terms of number of castings before failure.
- Further investigate the repair methods and their effects on durability of the 3D printed forms.