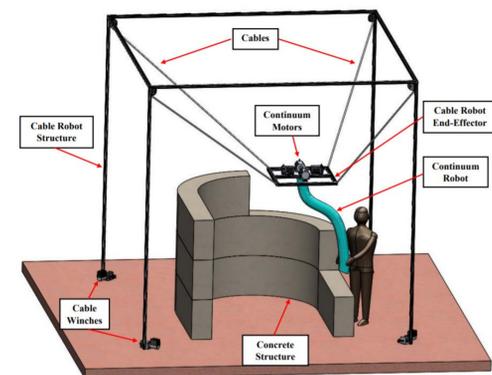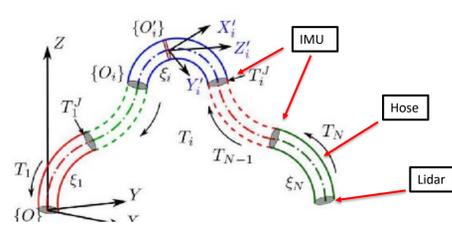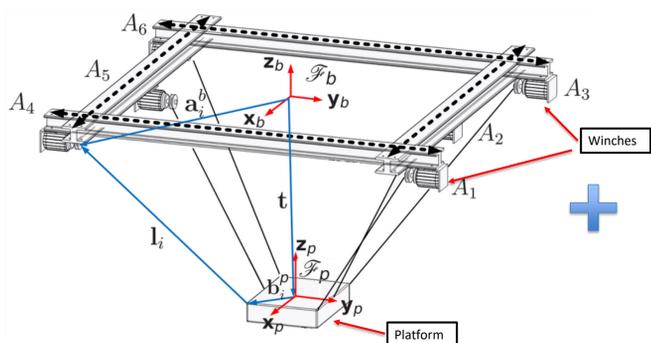# NRI: FND: 3D Concrete Printing with Macro-Micro Robots

Ian D. Walker, Venkat N. Krovi, Prasad Rangaraju, and Matthias J. Schmid, Clemson University

Ph.D. students: Haripriya Nekkanti, Adhiti T. Raman, Manu Srivastava; REU: Peter Sterckx; M.S. student: Bhooshan Deshpande

Project URL: https://cecas.clemson.edu/armlab-cuicar/research_1/cavs-in-manufacturing

Challenge: Interactively assist construction workers to dexterously deploy concrete-delivery hoses in congested spaces for 3D printing of concrete

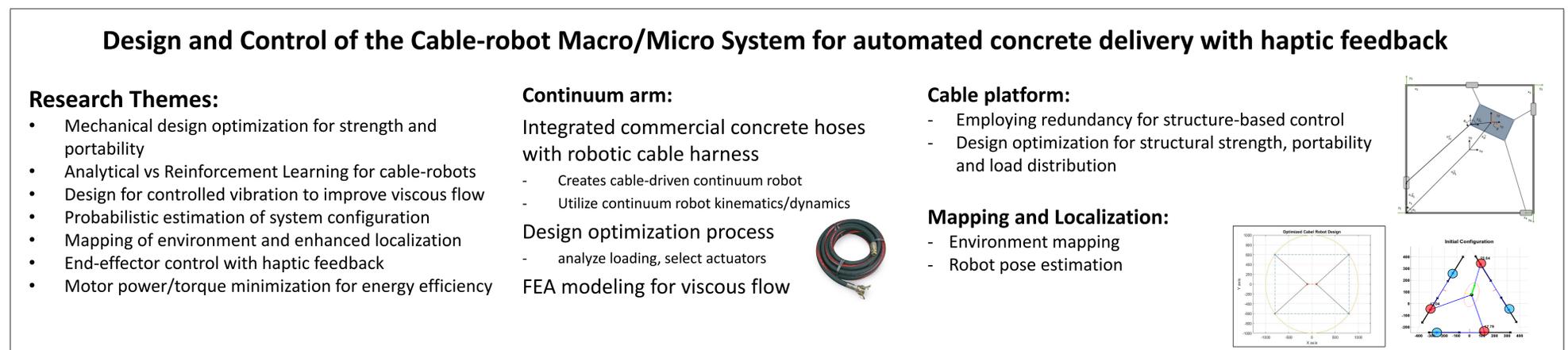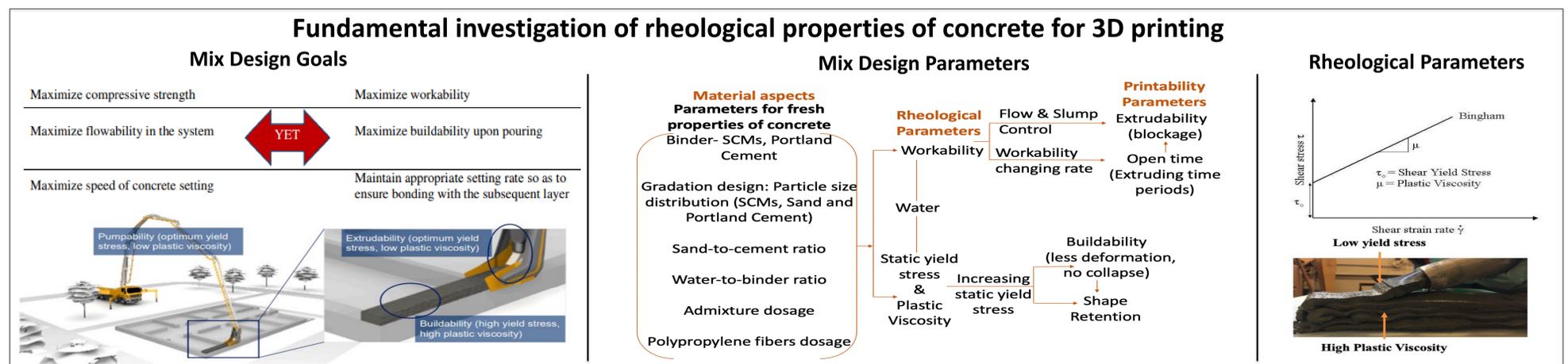**Background:** Construction industry is vital for national economy:
- ~ 5% of US Gross Domestic Product (GDP)
- $1.463 trillion, 6.7 M workforce (in 2017)
- Construction is one of the least automated industries in the world
- Productivity hindered by lack of automation tools
- Within construction, concrete operations are a foundational element

Proposed solution: Intelligent co-robot: novel cable-driven macro/micro design:
- Cable-robot acts as the macro-base
- Cable-driven continuum robot (integrated with concrete delivery hose) serves as micro-unit
- Field Intelligence: Situational awareness and physical-assist
- Field-deployable with large workspace/load carrying capability

Impact of solution:
- Fundamental research in rheology of 3D-printable concrete
- New generalizable modeling of coupled cable-driven macro-micro robot systems
- Intelligent assist for concrete delivery in construction industry

Fundamental investigation of rheological properties of concrete for 3D printing

Design and Control of the Cable-robot Macro/Micro System for automated concrete delivery with haptic feedback

Research Themes:
- Mechanical design optimization for strength and portability
- Analytical vs Reinforcement Learning for cable-robots
- Design for controlled vibration to improve viscous flow
- Probabilistic estimation of system configuration
- Mapping of environment and enhanced localization
- End-effector control with haptic feedback
- Motor power/torque minimization for energy efficiency

Continuum arm:

Integrated commercial concrete hoses with robotic cable harness
- Creates cable-driven continuum robot
- Utilize continuum robot kinematics/dynamics

Design optimization process
- analyze loading, select actuators

FEA modeling for viscous flow

Cable platform:
- Employing redundancy for structure-based control
- Design optimization for structural strength, portability and load distribution

Mapping and Localization:
- Environment mapping
- Robot pose estimation

Broad impact: Fall 2019: 2 Female Ph.D. students and 1 REU student hired; Industry and conference (ACI, ACerS, TRB) presentations; Spring 2020: 1 additional Ph.D. student hired; Outreach seminars to high-schools and industry and REU hires planned for summer