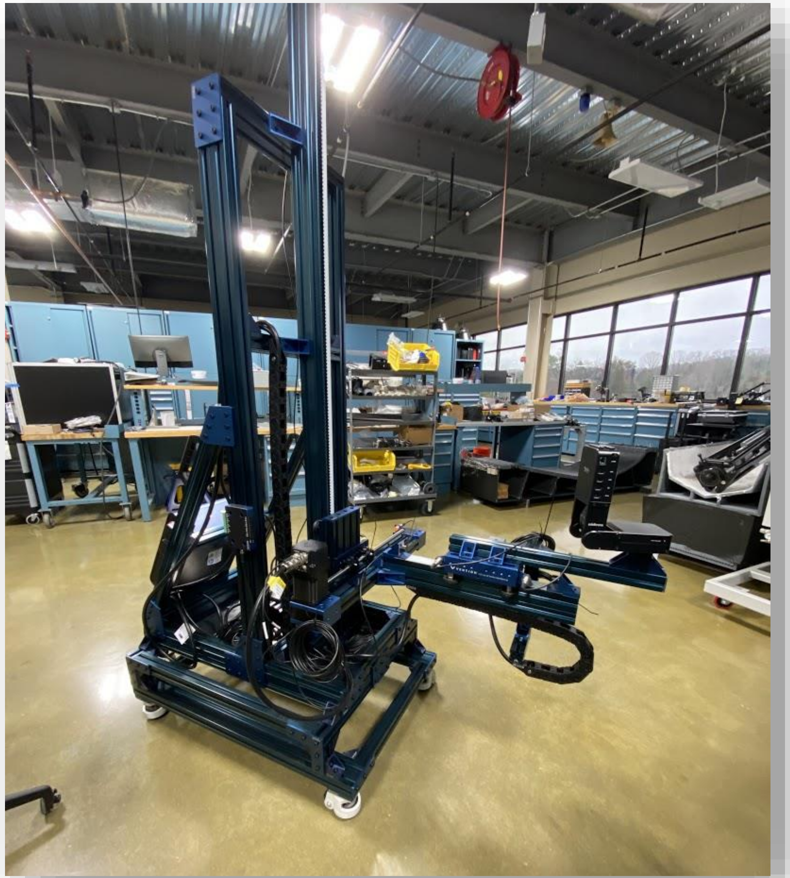
Robotically and Autonomously Installed Wall Interior Spray Foam



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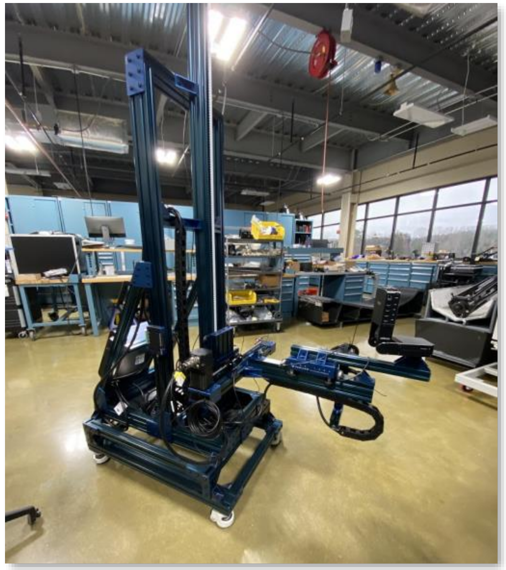
WBS 03.01.03.12.19

Image from: https://www.powerblanket.com/blog/spray-foam-insulation-properties-and-benefits/

Project Summary

Objective and outcome

Develop an innovative robotic system that completes the installation of interior spray foam to reduce labor costs by 50%, improve installation safety, increase the yield of installed insulation by 10%, and reduce the overall cost by 20%. The automated control and feedback system will guarantee consistent quality and achieving the target R-values.



Team and Partners

Oak Ridge National Laboratory

- Building Envelope Materials Research
- Manufacturing Demonstration Facility

SprayWorks
Spray Foam & Coatings **Equipment, Parts, Training, Material**

Stats

Performance Period: 10/1/2022 – 09/30/2025

DOE budget: $1050k, Cost Share: -

Milestone 1: Conceptual design

Milestone 2: Fabrication and in-lab testing

Milestone 3: Automated system’s field test

Problem

- Skilled construction workforce shortage ≥ half a million in 2023*
- Low-carbon net-zero buildings
  - Must have airtight and well-insulated envelopes
  - Cost is increased by having air sealing and insulating as separate tasks
- Closed-cell spray foam contributes to air tightness and high R-values per thickness in a single application
- Spray foam must be installed properly
  - Meet the required properties
  - Avoid costly repairs and uncured insulation with health concerns
- Installers must wear extensive protective gear
  - Makes installation difficult
  - Increases installation time

*https://www.abc.org/News-Media/News-Releases/entryid/19777/construction-workforce-shortage-tops-half-a-million-in-2023-says-abc

State-of-the-art

- Spray foam installation
  - Foam is installed manually, often in multiple passes
  - Robotic spray foam systems available are controlled remotely by an installer
- Difficulties
  - Manual spray foam installation is labor-intensive and requires extensive safety precautions to avoid health risks for installers
  - The manual installation is often inconsistent, not providing the targeted thermal and airtightness performance or resulting in overspray that requires shaving off excess insulation
  - Installation conditions can be strenuous for workers increasing fatigue
- Technical gaps
  - Current robotic systems are manually controlled and do not monitor the quality (e.g., spray thickness) or conditions

SprayBot for roof SPF install by SprayWorks

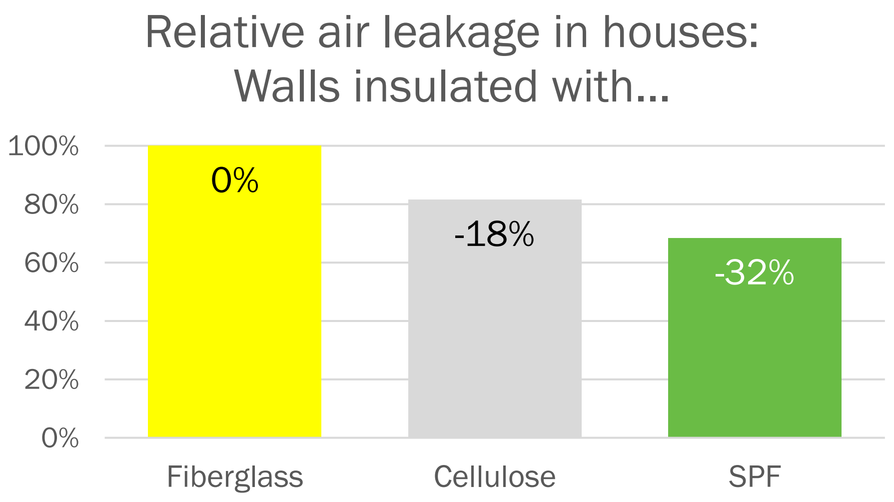
Q-Bot for crawlspace SPF install

Goals

- Increased efficiency
  - Robotic systems can work faster and more consistently than humans reducing time and costs
- Improved safety: Operator is not exposed to chemicals
- Improved quality and consistency
  - Precisely control the amount and location of foam insulation
  - Reduce waste by improving yield
- Reduced labor costs

Alignment and Impact

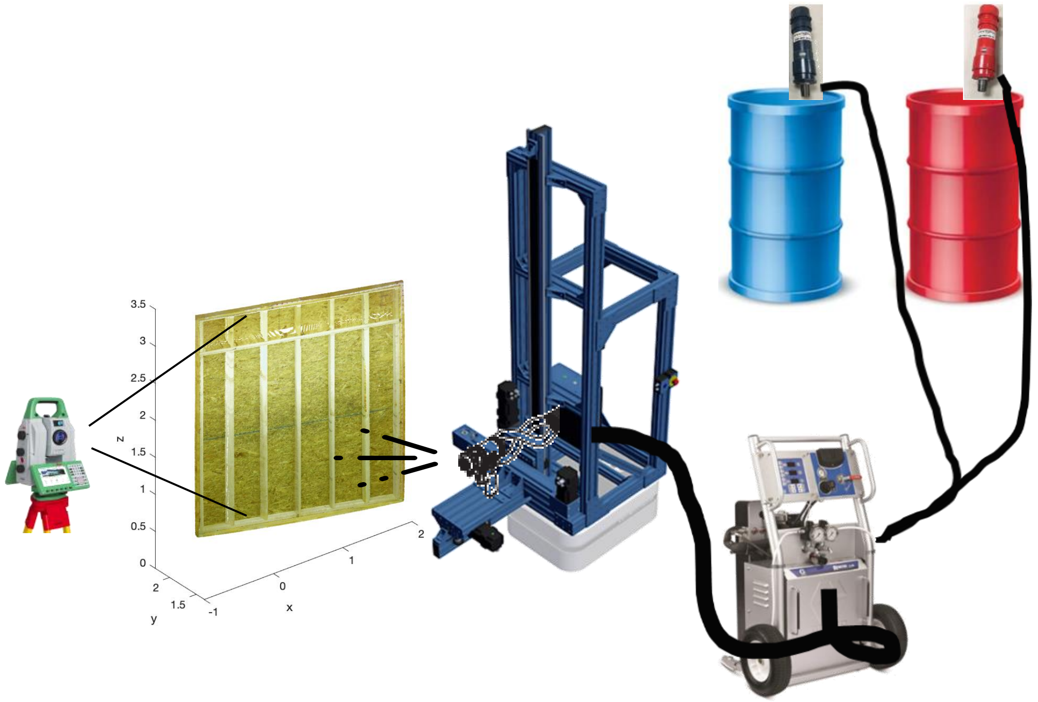
- 50% reduction in labor and trades on the jobsite compared with traditional methods
- 20% savings in total cost
- Higher overall R-value than manual installation and fewer repairs due to better control of spray foam consistency and quality
  - Improves energy efficiency, reduces waste, and consumer energy burden
- Autonomous foam sprayer can be tailored to prefab factories and exterior building applications
  - Accelerates energy-efficient building construction in tight labor markets
  - Sprayed foam reduces defects in prefab construction after transportation to the jobsite



Bruce Harley in "Energy Design Update, April 2005".

Tasks for the Robotic System to Perform

- Scan wall geometry, develop spray path, and send it to the AutoFoamBot
- The robotic system finds and moves to its location
- The bot applies spray foam autonomously on the wall cavities, avoiding structural irregularities and protrusions like windows, vent openings, and doors
- The bot monitors the substrate conditions and spray thickness continuously to adjust settings and help ensure quality and achieve the target R-value



Scan Locate
Automatic spray Monitor/Control
Deliver product

Challenges, Risks, Commercialization, Demonstration

Technical Challenges

- Spray mist may cover sensors and moving parts
  - Curtain shields, operable covers
- Handling climatic conditions on job site
  - Automatic monitoring and temperature controls

Commercialization

- Spray foam trade shows and training events with SprayWorks
- Prefabricated housing/component manufacturers
- Larger companies with sizable jobs

Risks

- Equipment malfunction, loss of position
  - Perform location checks
  - Monitor performance, stop and inform the controller person if not performing

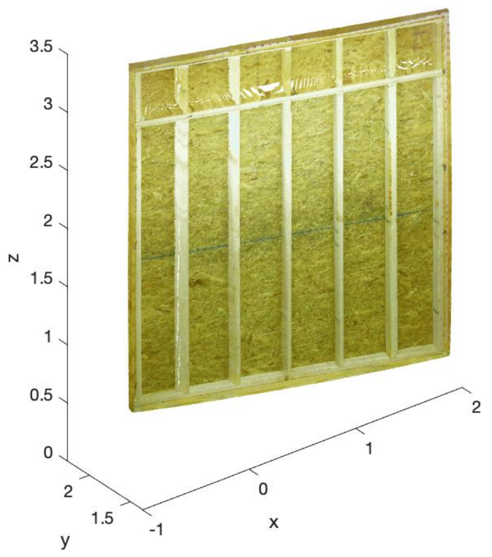
Demonstration

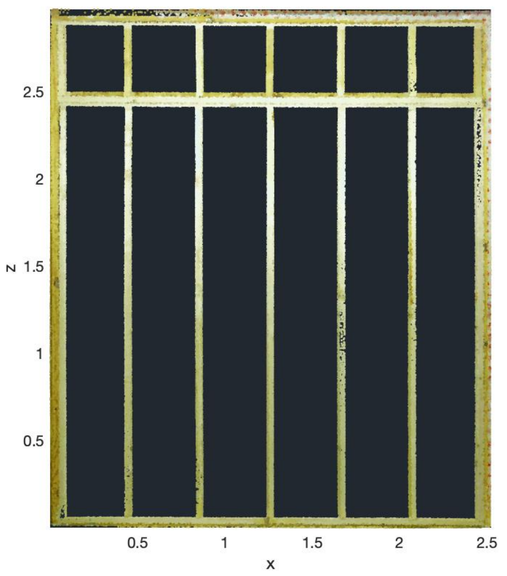
- Field demonstration with comparison to manual installation

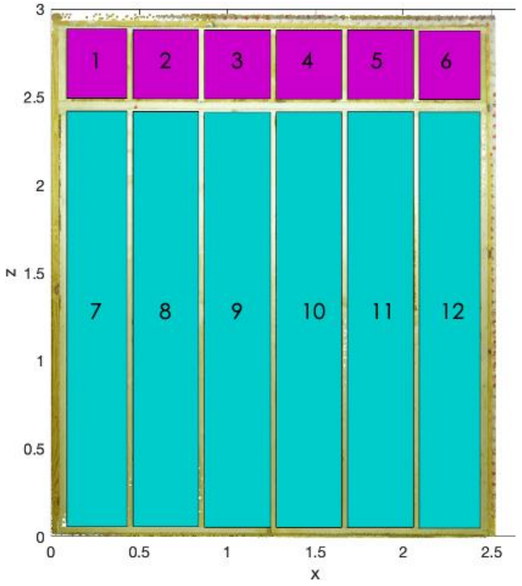
Progress: Technical Boundaries and Specifications

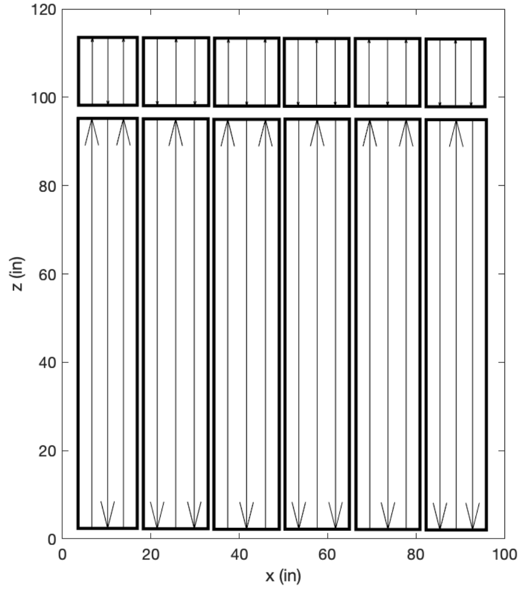
- Ability to fit through doorways and step over door sills and debris
- Autonomously locate and fill wall cavities using LIDAR and Vision systems
  - Scanning and spray path accuracy, ½” resolution
- Omnidirectional base motion to allow free motion
- Five-degree-of-freedom robotic system
- Monitor substrate, environment, and spray temperature to optimize foam composition and improve quality and installation consistency
- Monitor foam thickness to ensure adequate thickness without overfill, no spots >1” off the specified thickness
- Fill standard height 8-foot-tall wall with extendable design

Progress: Automatic Spraying Path Generation









Wall cavity LiDAR scan → Automatic stud identification → Identification of wall cavities to be sprayed → Automatic spray path generation

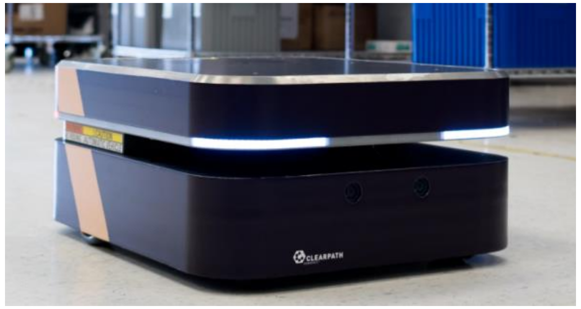
LiDAR scanner

Point cloud

Spray foam gun specs

Progress: Robotic spray system

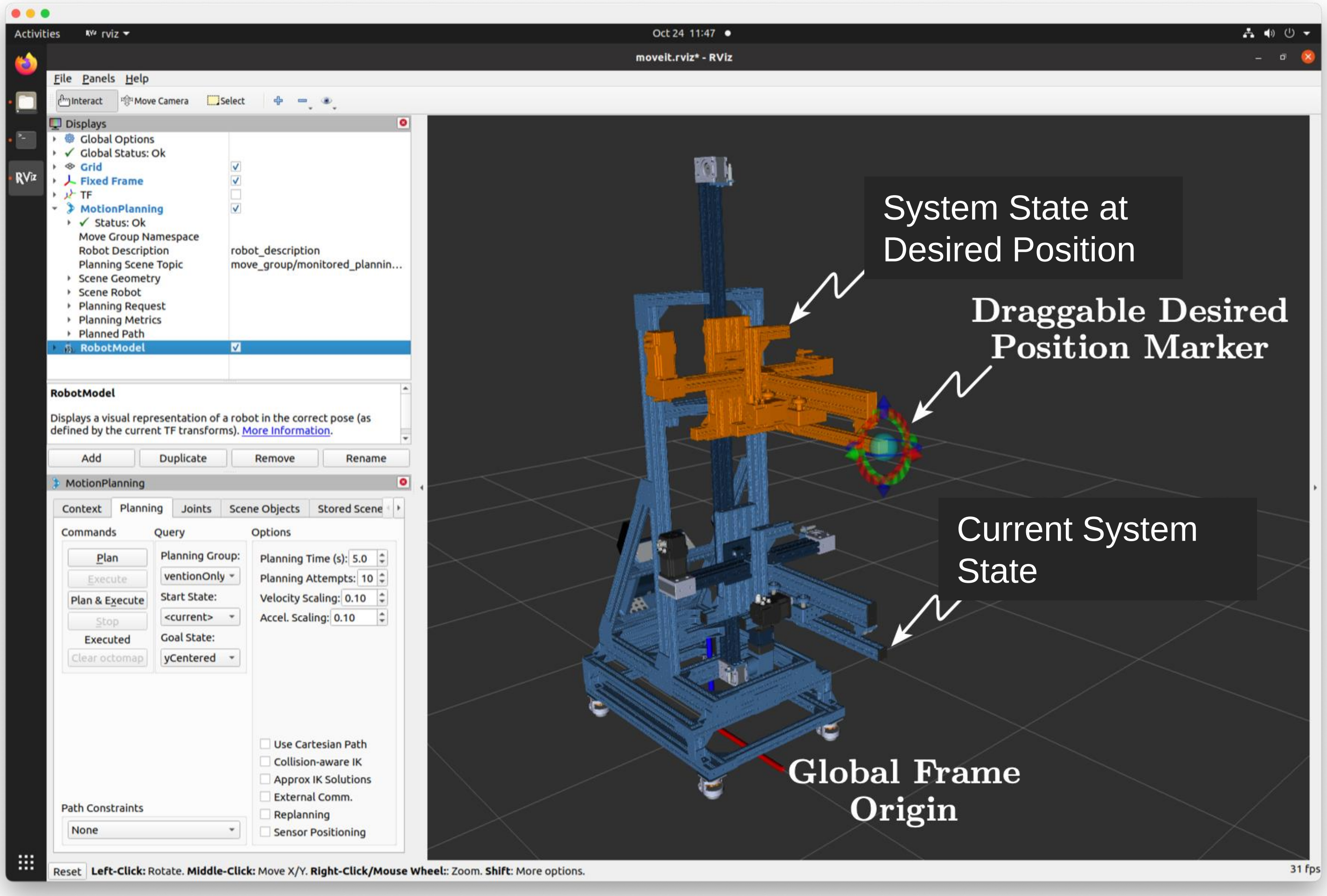
- Mechanical and Electrical Assembly has been completed
  - Components from Vention.io
  - Testing has begun
- Successful motion on X & Y axes
- Clear Path robot platform (Boxer)
  - Scheduled completion of manufacturing March 31st, 2023
  - Delivery 1-2 weeks after



Invention disclosure: Robotically and Autonomously Installed Wall Interior Spray Foam, ID 202205217. Mikael Salonvaara, Peter Wang, Joshua Vaughn, Celeste Atkins, Bryan Maldonado, Diana Hun, Philip Boudreaux.

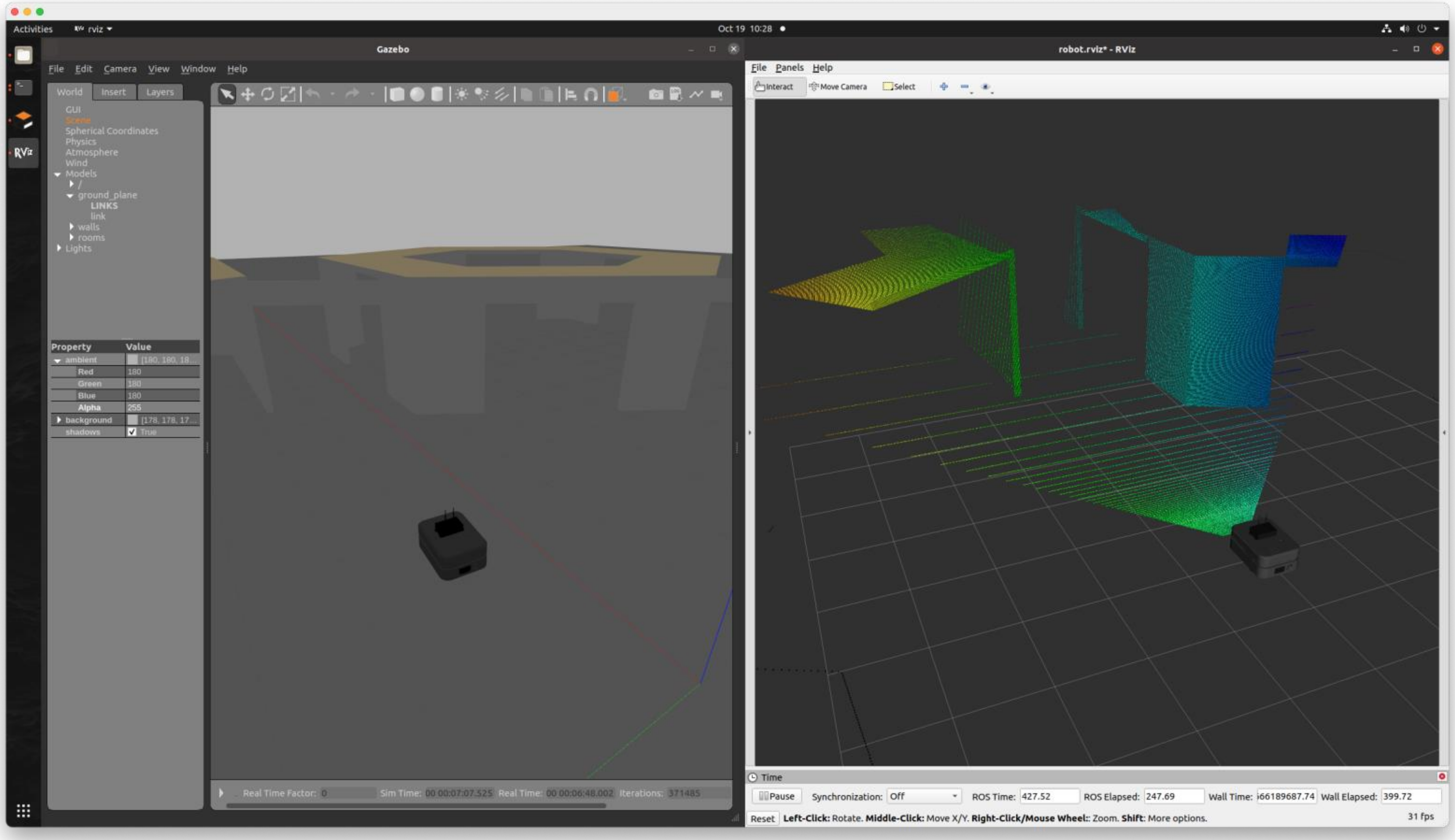
Progress: Vention System in ROS (Robot Operating System)

- MoveIt for motion planning and sensor visualization
- Can easily integrate:
  - Vention controller
  - Boxer mobile base
  - Vision, LiDAR, and other sensing



Progress: Boxer in Simulated Environment with LiDAR

- Tested controls in simulated environment
  - Developed trajectory-generation algorithms for Vention platform
  - Initial test of localization algorithms for mobile base
- Integration of controls with physical system
  - Tested baseline control of Vention system
  - Code for mobile base ready for testing once system arrives



Future work: Robotic Mechanical Systems

- Design mount for spray nozzle onto gimbal mechanism
- Design hose management system
- Design a shroud to protect equipment from the back spray
- Mount the Vention System to the Clearpath Mobile Platform
- Test the fully assembled system

Future work: In-Laboratory Spraying

- Spray foam installation on an 8’x8’ wall in laboratory conditions
- Evaluation of spray quality, the resulting thickness, and speed
- Test wall assembly for airtightness and thermal performance in the climate chamber

Ventilation enclosure with exhaust air to allow safe spraying in the lab

Future Work: Field Demonstration and Techno-economic Analysis

- Field evaluation
  - Test robotic installation under varying climatic conditions and on the job site surfaces (e.g., varying substrates, cleanliness)
  - Test samples for adhesion, insulation quality, and installed thickness
- Techno-economic analysis with SprayWorks Equipment Group
  - Determine
    - Typical costs for existing practice and drivers for significant costs
    - Yield, labor, and cost of robotic installation of spray foam
    - Product optimization steps
  - Evaluate the feasibility of scaling up, and gain customer feedback
- Trial runs with a sister project developing a biobased foam

Thank you

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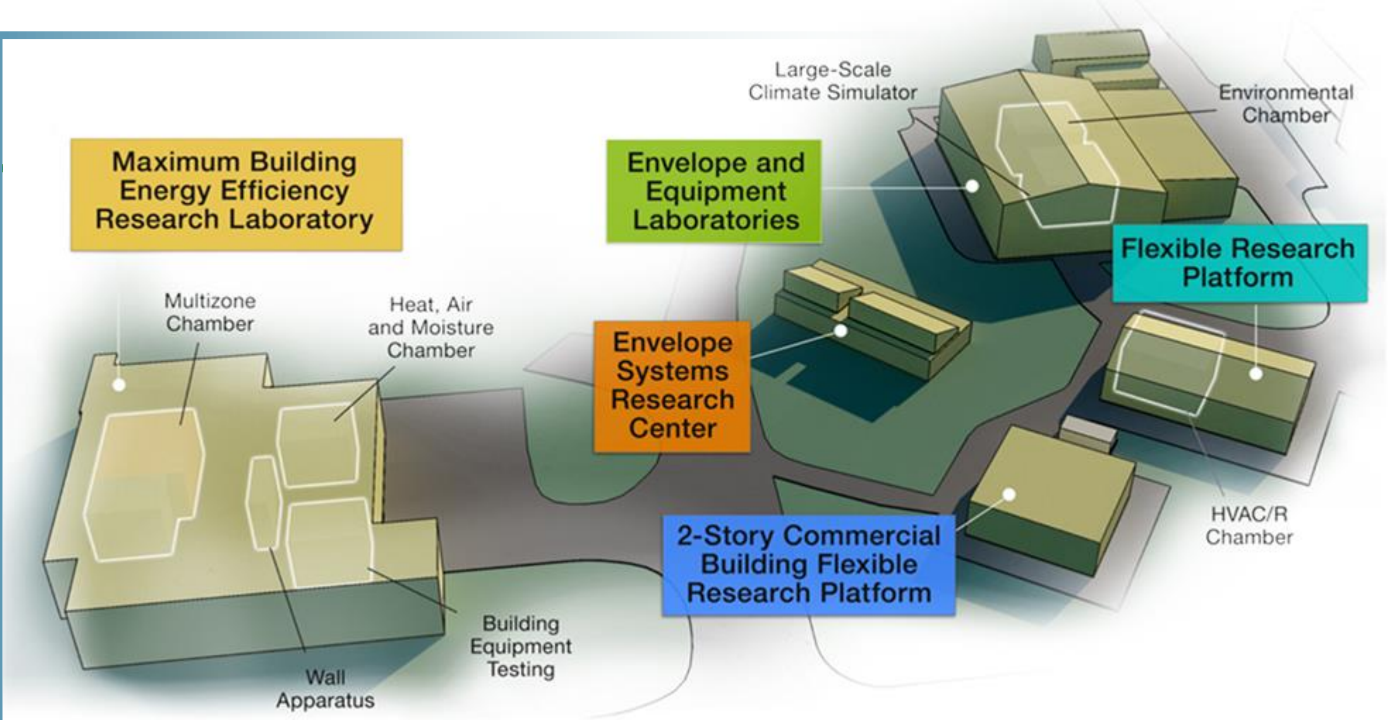

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Scientific and Economic Results
238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution

	FY2022				FY2023				FY2024			
Planned budget	$300,000				$450,000				$350,000			
Spent budget	$188,000				$91,000							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 MS: Technical boundaries defined for installation.												
Q3 MS: Select scanning and metrology tools.												
Q4 MS: Application of scanning tool on the robot refined												
Q4 MS: Conceptual design for complete system designed												
Q4 MS: Typical costs identified and quantified												
Q1 MS: Complete assembly of the system												
Q2 MS: Integrate controls into the spray system												
Current/Future Work												
Q3 MS: Integrate spray system with the motion platform												
Q4 MS: Fabrication and in-lab testing performed												
Q4 MS: Projected lifetime costs of the system quantified												
Q2 MS: Interior spray installed and passes standards												
Q4 MS: Automated installation in the field												
Q4 MS: Techno-economic analysis of the system												

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Team


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SPRAYWORKS
Spray Foam & Coatings Equipment, Parts, Training, Material

System Design

Advisors