Real-Time Evaluator to Optimize Installation of Prefab Retrofit Panels

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Project Summary

Objectives

Develop digital tools that provide real-time feedback to

- Reduce installation time and cost of prefabricated components so that overclad retrofits are more affordable
- Enhance installation quality and hence envelope airtightness and watertightness

Outcome: Prefabricated component installation time and cost is reduced by at least 25%.

Team and Partners

OAK RIDGE National Laboratory

PCI Precast/Prestressed Concrete Institute

Tindall

BENSONWOOD

GATE

METROMONT

Stats

Performance Period: 10/1/21 to 9/30/24

DOE budget: $900K

Milestone 1: Develop software to track and record position

Milestone 2: Develop software to compare real-time position and location in digital twin

Milestone 3: Conduct demonstration of RTE

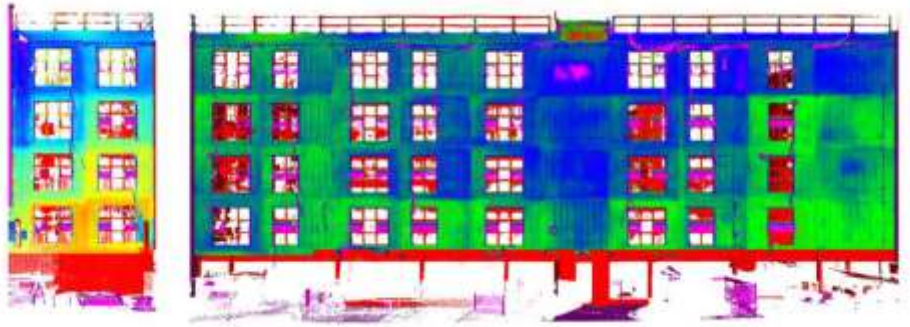
Problem

- ≥50% of existing residential and commercial buildings were built before 1980*; hence, lack modern energy efficient technologies
- <2% of buildings undergo energy retrofits each year
- Opaque envelopes affect ~25% of building energy use or ~10% of total US primary energy use**
- Retrofits with prefab overclad panels
  - Include most envelope components
  - Less disruptive to occupants than typical retrofit practices
  - Need to reduce cost to facilitate adoption
  - Installation cost (~$2K per panel) is prime candidate

Overclad panel retrofits

Energiesprong

State of the art: verification of volumetric modules' uneven façade AFTER installation



Tocci B. 2020

*EIA, Residential Energy Consumption Survey 2015 (RECS) and Commercial Building Energy Consumption Survey 2012 (CBECS)
**DOE, Research and Development Opportunities Report for Opaque Building Envelopes

State of the Art

- Overclad panel installation
  - Crane-installed panels guided to location by workers
  - Workers manually measure panel position
  - Adjustments made by workers to accurately position
  - Overall quality is checked after installation
- Challenges
  - Installation time is ~30 to ~60 minutes per panel
  - Inaccurate dimensions of existing façade
  - Out of tolerance connections
  - Compounding installation error that leads to rework, downtime

Installation Error and Downtime During Overclad Panel Retrofit

Credit: Targo Kalamees, Tallinn University of Technology

Installation issue discovered at bottom of panel

Panel is lifted

~2 hr to fix issue

Panel is reset

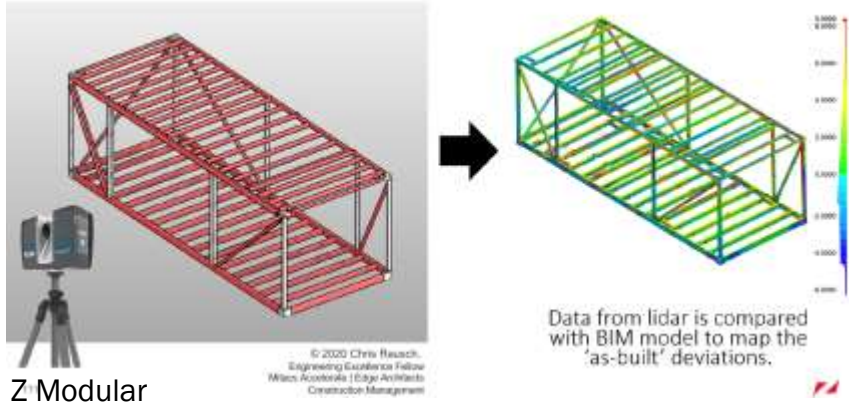
Goals

- Develop a Real-Time Evaluator (RTE) that provides real-time feedback to installers
  - Easy to use
  - Automated
  - Low capital cost using mostly available hardware and a single tracker
  - Accuracy of ±1/8” based on industry tolerances
- Lower cost of RTE via wide prefab market applicability
  - Building retrofits with overclads or reclads
  - New construction
    - Buildings: panelized, volumetric
    - Infrastructure
  - Onsite/offsite assembly

Novelty: Real-time feedback makes onsite prefab assembly a proactive process instead of a reactive process

Prefab bridges

State of the art: verification of modules’ plumbness AFTER assembly



Z Modular

Alignment and Impact

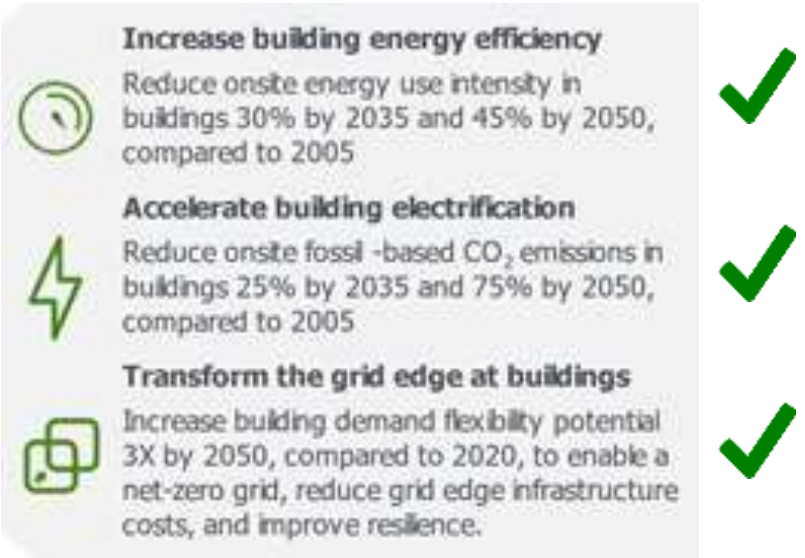
Successful RTE

- Reduces installation time and cost of prefab components by ≥25%
- Eliminates installation errors and downtime
- Meets maximum air leakage limits right after panels are installed

Contributions from faster and better overclad envelope retrofits to EERE/BTO goals

- ~0.6 quads decrease in energy use by 2030 from adding R12 to existing residential and commercial buildings*
- Lower operational energy and CO_2 emissions
- Smaller heat pumps
- Smaller thermal energy storage systems
- Accelerate building electrification

EERE/BTO's vision for a net-zero U.S. building sector by 2050



*2014 DOE Windows and Building Envelope Roadmap

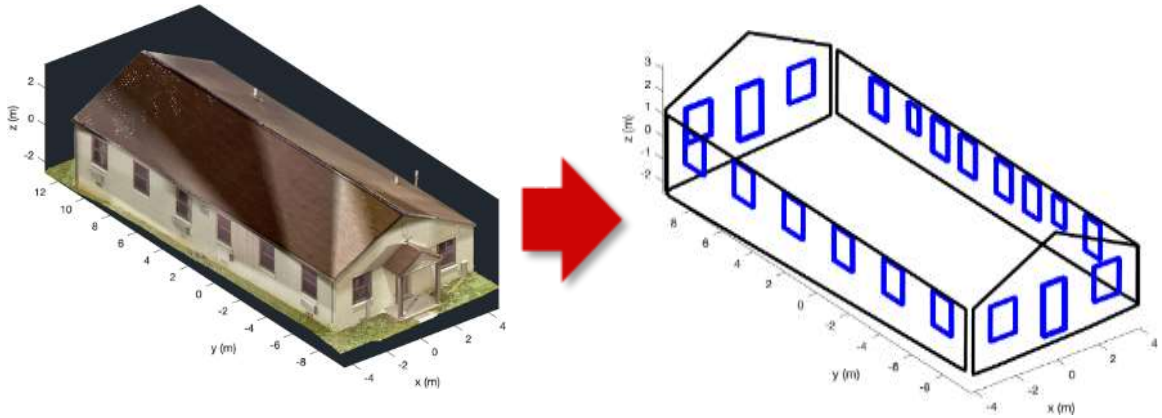
Real-Time Evaluator (RTE) Components

- Digital twin generation
- Connection positioning system
- Autonomous tracking system
- Installation assistant

Digital Twin and Connections

Digital Twin Generation

- Automated generation of existing façade measurements
- 1/8-inch accuracy
- Designer can use to size and locate panels



Point cloud scan data
(32M points)

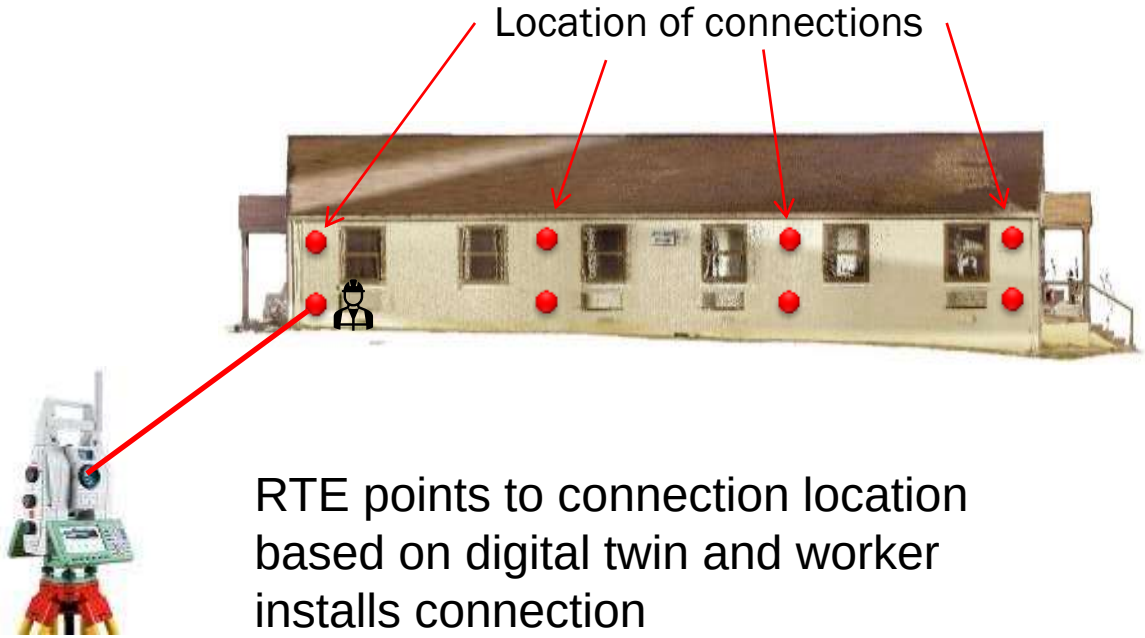
Dimensioned digital twin
(200 points)

- *From point cloud to digital twin in minutes*
- Reduce by ≥75% human effort to clean point cloud data from 3D scanners
- Part of Advanced Building Construction (ABC) Phase 2 project

Connection Positioning System

- Aids installers in positioning connections

  OR
- Checks the quality of position of connections after installation

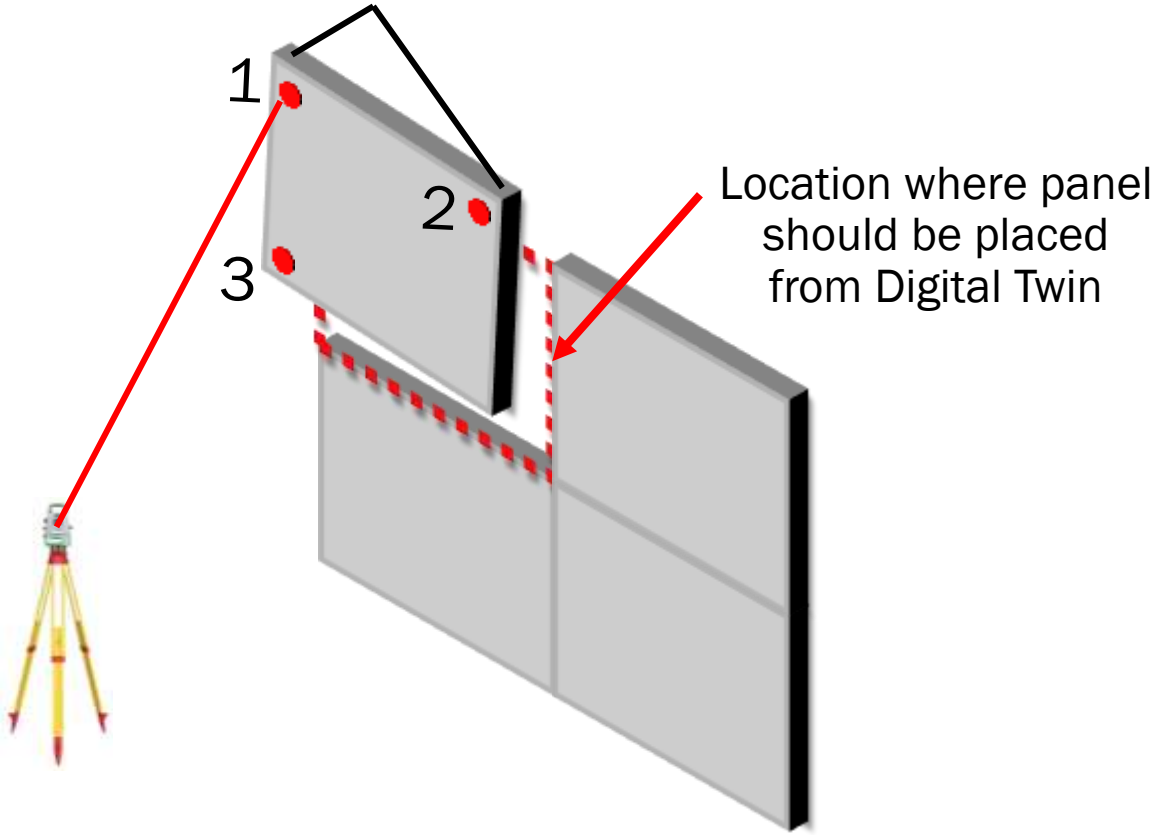


RTE points to connection location based on digital twin and worker installs connection

Tracking System and Installation Assistant

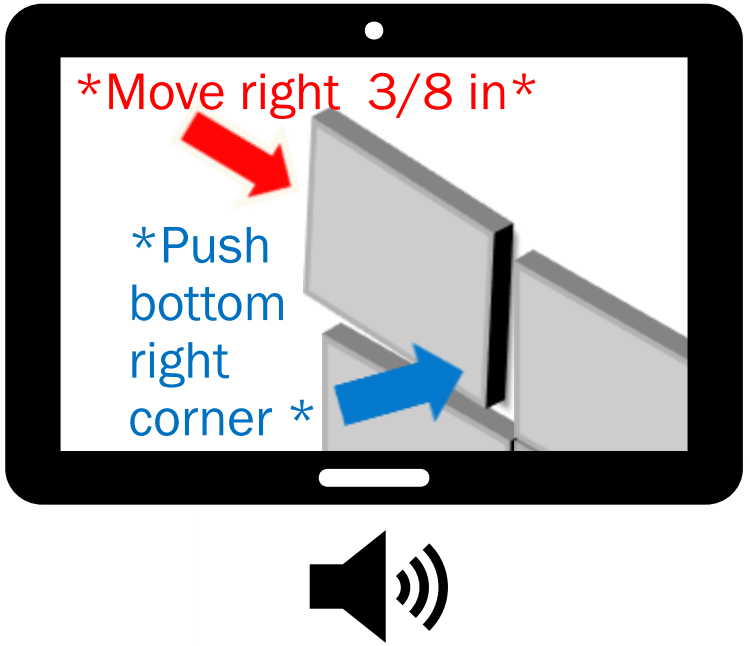
Automated Tracking System

- Monitors real-time position of component in 6 Degrees of Freedom (translation/rotation about each axis)
- 1/8-inch accuracy



Installation Assistant

- Serves as interface between RTE and installer
- Gives visual and auditory cues to installation crew on where to move panel to meet tolerances
- Updates digital twin with as-built component locations



Challenges, Risks, Commercialization, Demonstration

Technical challenges

- Adding new functions to off-the-shelf hardware
- Development of algorithms for automation of monitoring tasks

Risks and mitigation strategies

- New construction technologies have low adoption
  - Continually consulting with end users, including installers, surveyors, erectors, and designers on value proposition
  - Collaboration with prefab manufacturers will demonstrate and document faster installation times and fewer errors
  - Using off-the-shelf hardware and a single tracker to keep cost low

Stakeholder engagement

- Advisory group
  - Manufacturers
  - Installers
- Advise on relevance and requirements
- Ensures meeting end users' needs

Demonstration and validation

2024 – 2025 full-scale demonstration in ABC Phase 2 retrofit project

Progress: Specifications

Advisory Group

Jared Brewe

PCI
Precast/Prestressed Concrete Institute

Steve Brock

Nate Brooks

GATE

Chris Winfield

Gary Lentz

METROMONT

Mike Milkovitz

Tindall

Hans Porschitz

Jay Lepple

BENSONWOOD

Initial Specifications

- Measurement accuracy: ±1/8 inch
- Speed
  - 1 sec tracking position
  - 15 sec to measure orientation
- Tracking targets
  - Easily removable or disposable
  - Installable on a wide variety of materials
  - Accommodates limited access to panel sides and surfaces

Progress: Hardware

Survey-Grade Laser Scanner/Tracker

Leica Geosystems MS60

Photo credit: Leica

Targets

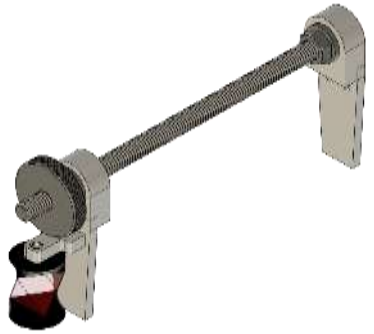
Reusable, Trackable

Photo credit: Leica

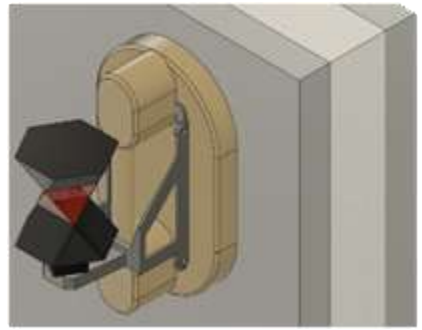
*Approximate Relative Scale

Preliminary Fixture Prototypes

Mechanical clamp for new construction



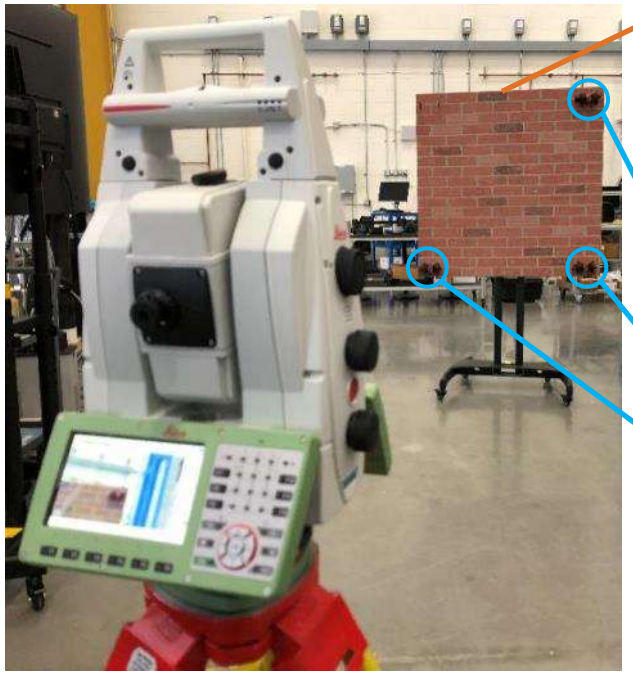
Mechanical clamp for overclad panels

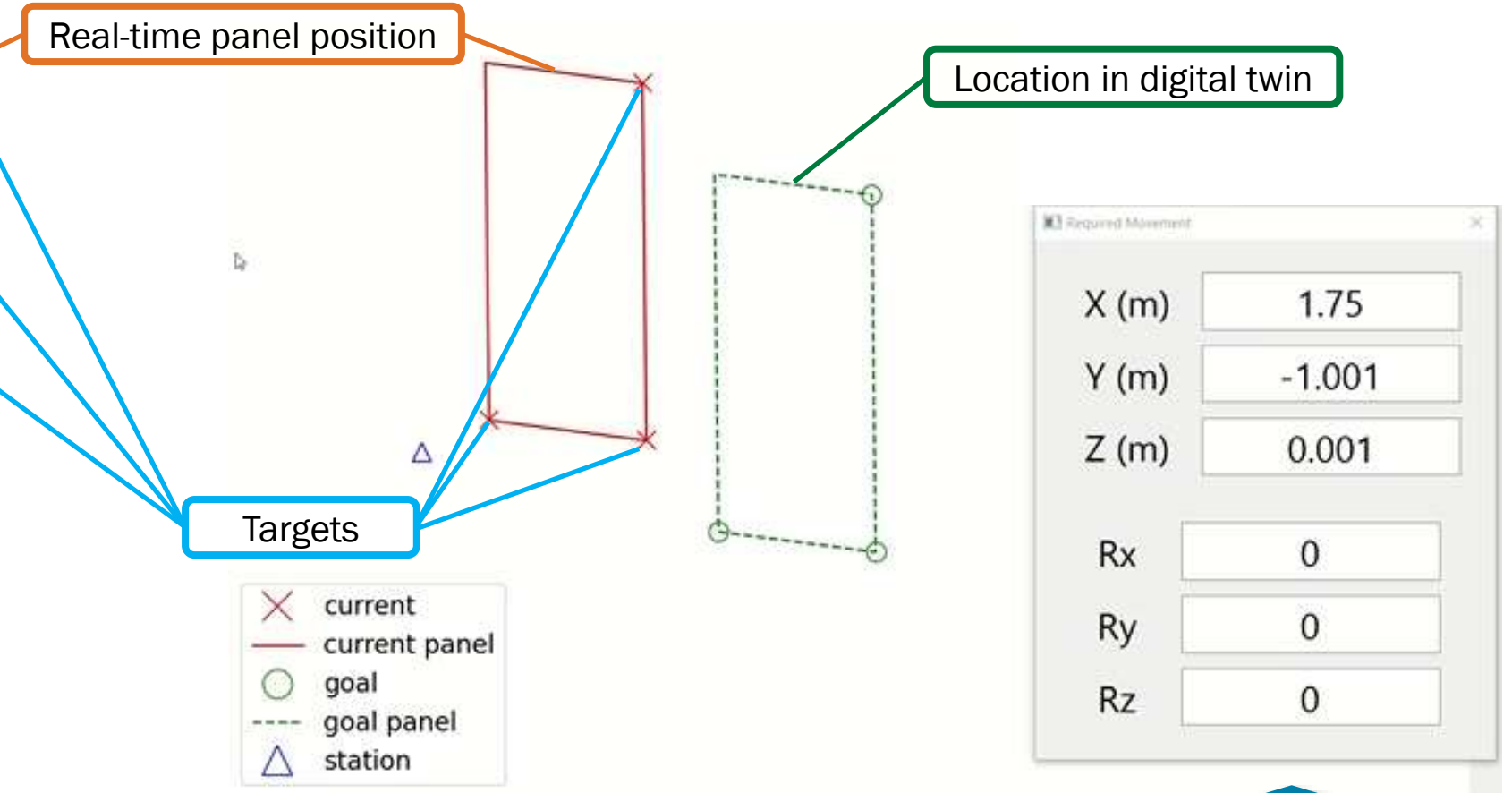


Vacuum fixture

- Modular design for easy part interchangeability
- Design varies with accessibility and required robustness

Progress: Software and Proof of Concept





Proof of concept: Real-time feedback on difference between actual location and location in digital twin

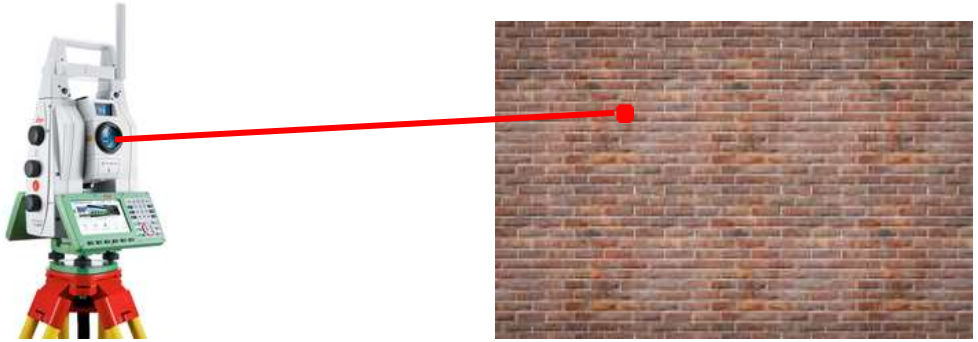
Provisional patent application #63/425823

Progress: Connection Positioning System

Option 1: Real-Time Guidance during Connection Installation

Process

1. Digital twin has as-designed connection locations
2. RTE laser points to fastener location
3. User installs connection



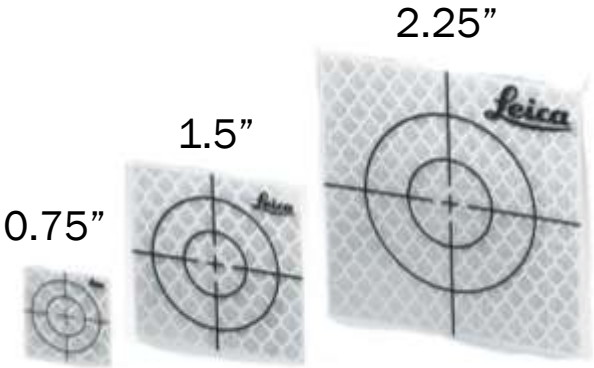
Surface measurement is accurate to 2 mm + 2 ppm.

Option 2: Post-Installation Positioning and Analysis

Process

1. Tape reflectors/targets attached to connections
2. RTE measures locations of connections
3. RTE assesses quality of installation

Accuracy:
2 mm (5/64 in) + 2 ppm



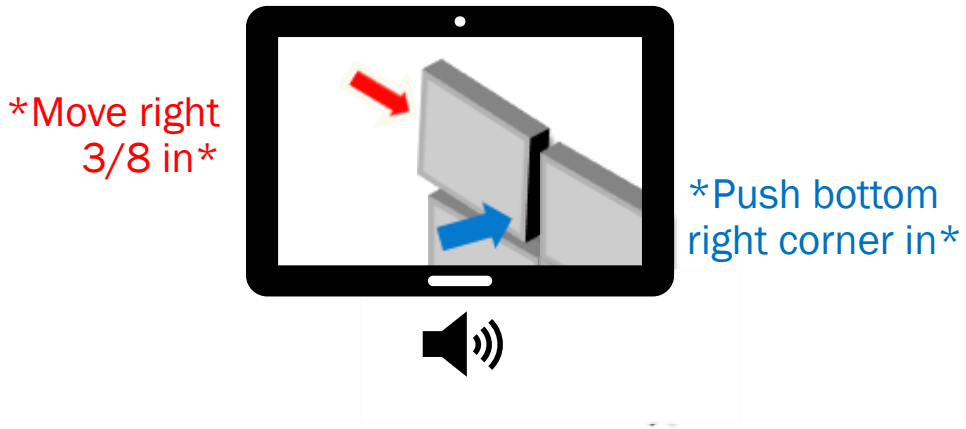
Disposable Tape Reflectors

Cost per piece: $0.10 – $3

Future Work: Installation Assistant and Lab-Scale Testing

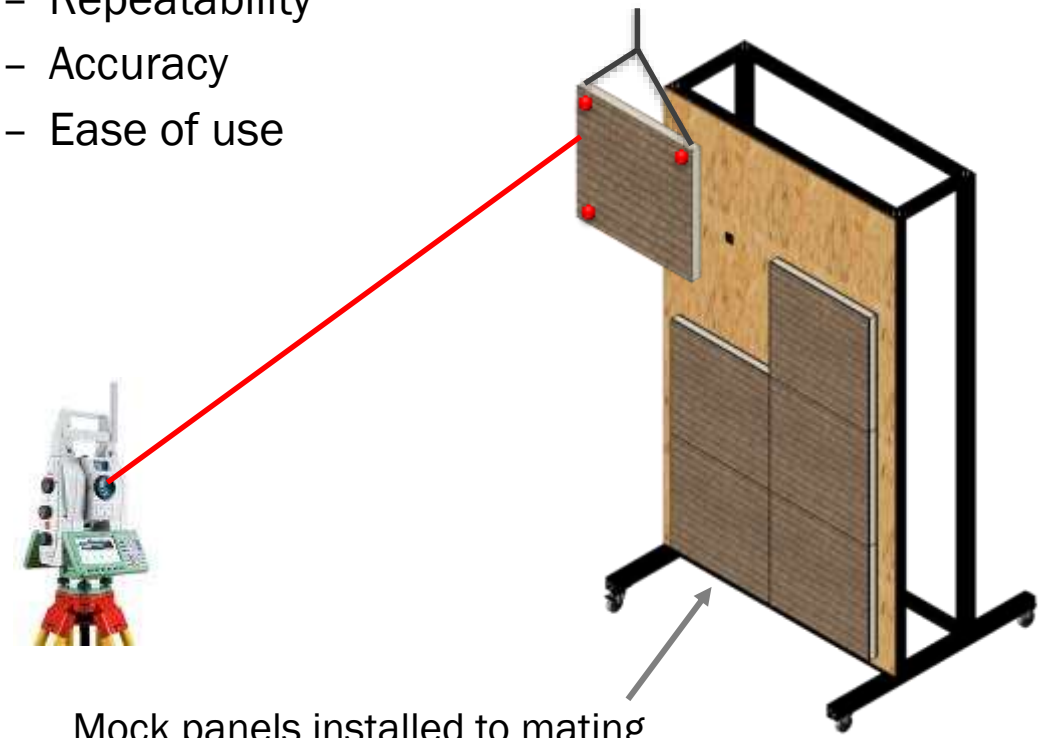
Design of installation assistant system

- Design algorithms to:
  - Compare real-time component position to digital twin
  - Generate installation commands
  - Update digital twin with final position of component
- Test interaction between system and installer
- Gather feedback from stakeholders



Lab-scale testing

- Tests on supporting structure w/ and w/o out-of-plane imperfections
  - Repeatability
  - Accuracy
  - Ease of use



Mock panels installed to mating connectors on supporting structure

Additional Scope of Work: Flat and Level Analysis Tool (FLAT)

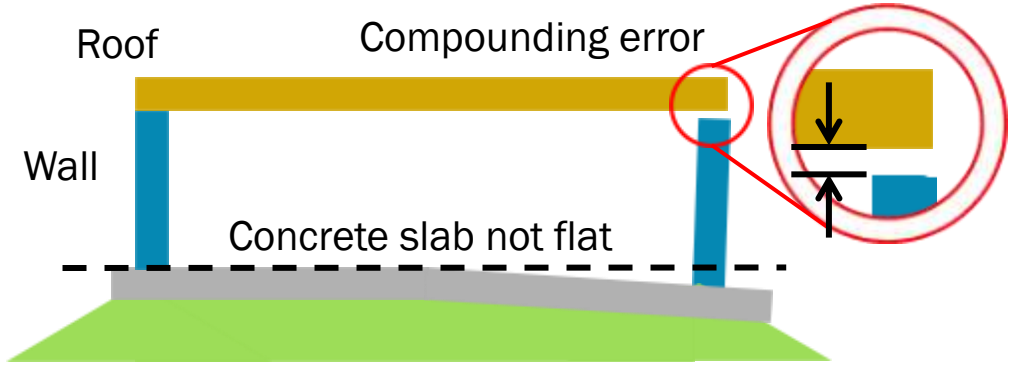
Background

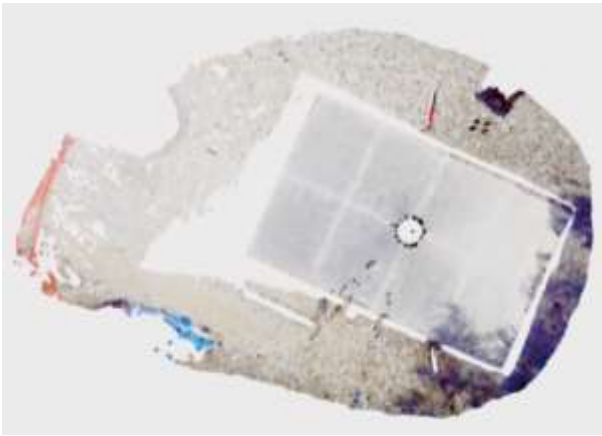
- Concrete slab-on-grade
  - Often not flat or leveled
  - Compounds errors when assembling envelope
- Measurement of floor flatness and levelness
  - Manual: Takes days and thousands of dollars
  - State-of-the-art: Laser scanning techniques require human input and hours to process

Goal: Reduce envelope installation time and improve quality by providing real-time feedback on flatness and levelness so slab is fixed while concrete is workable.

Outcomes

- **Reduce time and human effort** to measure floor flatness and levelness **by 80%.**
- **Reduce assembly time of envelope components** by reducing fixes.



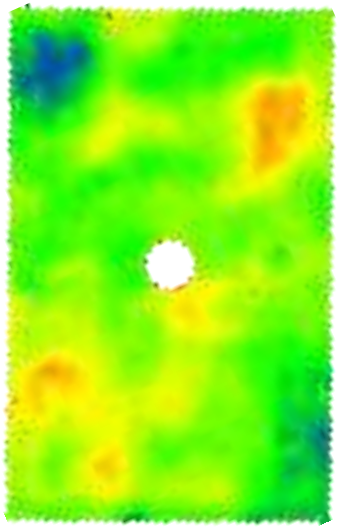


Laser Scan

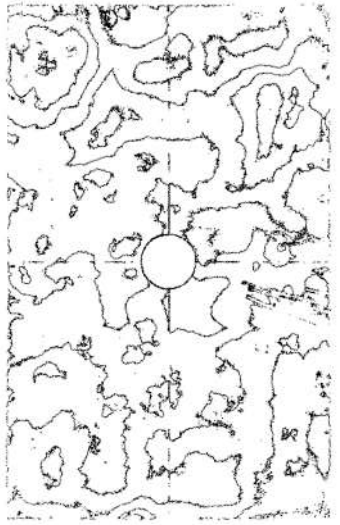
Automated Analysis <10 seconds

Invention disclosure #202305305

High spot
Low spot



Heatmap



Contour

Publications and Intellectual Property

- Publications
  - Real-time evaluator to optimize and automate crane installation of prefabricated components. 40th Int Symposium on Automation and Robotics in Construction. July 4 – 7, Chennai, India.
  - Future papers on
    - Automated segmentation and analysis of concrete floor slab flatness and levelness from point cloud data. To be submitted to *Automation in Construction.*
    - Demonstration and evaluation of a real-time evaluator to optimize the installation of prefabricated components. To be submitted to *Automation in Construction.*
- Intellectual property
  - *Real-Time Evaluator to Optimize Prefab Retrofit Panel Installation.* Provisional patent application #63/425823.
  - *Flat and Level Analysis Tool (FLAT)*. Invention disclosure #202305305.

Thank you

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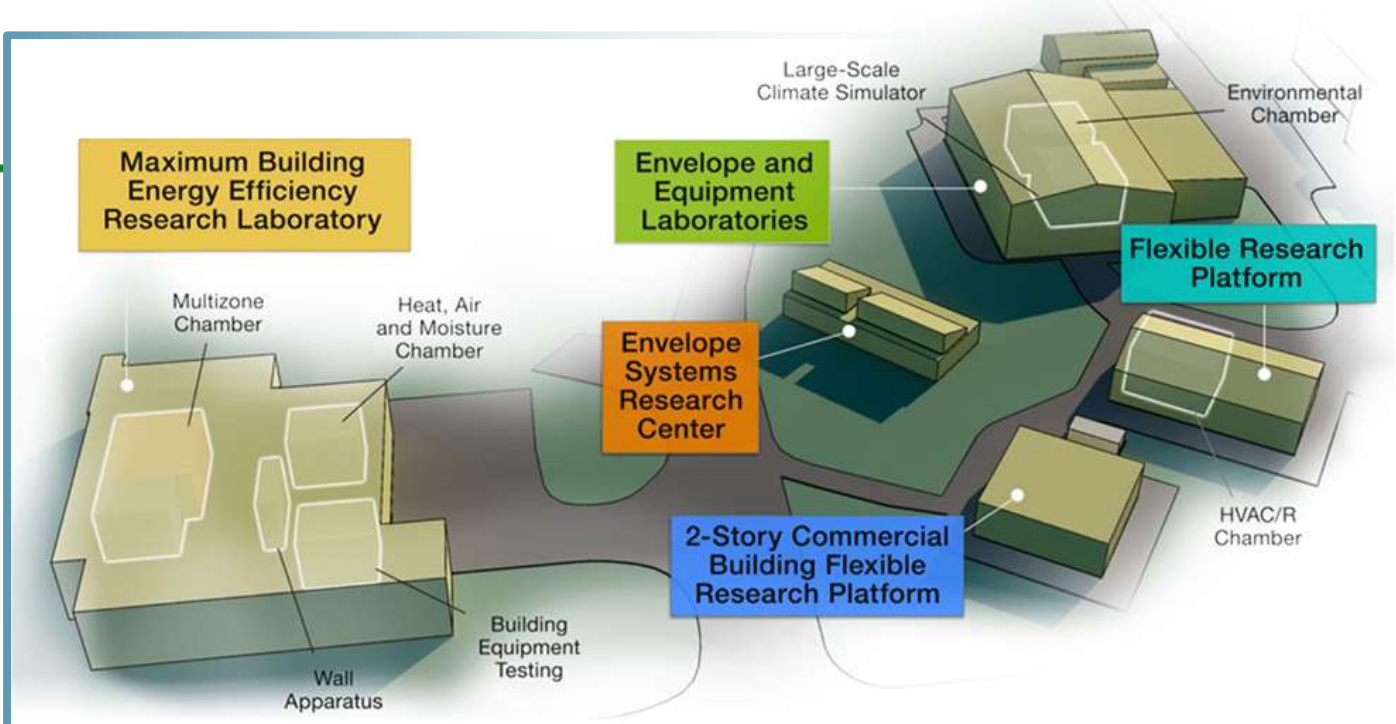

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Scientific and Economic Results

236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution

	FY2022				FY2023				FY2024			
Planned budget	$300				$400				$300			
Spent budget	$200				$130				$0			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
M1.1: Set tracking system requirements												
M1.2: Select tracking equipment and software to build system on												
M1.3: Develop retroreflector system												
M1.4: Develop software to track and record position data												
M2.1: Set requirements for low-cost connection locating system												
M2.2: Design low-cost retroreflector system (<$5)												
Current/Future Work												
M1.5: Develop software to integrate as-built panel data into digital twin												
M2.3: Build and test low-cost retroreflector system												
M2.4: Develop software that will collect as-built locations of connections and compare it with the digital twin												
M3.1: Develop software to compare panel positions from the digital twin with the real-time panel position												
M3.2: Develop software that provides guidance on how to adjust the panel placement												
M3.3: Design physical system and user interface for use in the field to provide guidance to the installation crew and crane operator												
M3.4: Build and test the positioning assistant system												
M3.5: Develop concepts for robotic installation aids												
M4.1: Design test wall panels												
M4.2: Design panel mounting system with integrated locating system												
M4.3: Construct test wall panels												
M4.4: Construct mounting system												

Team


Diana Hun


Nolan Hayes


Bryan Maldonado


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OAK RIDGE National Laboratory

System Design

Software development and software and hardware integration


Jared Brewe

PCI Precast/Prestressed Concrete Institute


Steve Brock


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Chris Winfield

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BENSONWOOD

Advisory Group

Manufacturers and installers of prefab panels