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Robots in the Built Environment: Workflows for AEC at the Autodesk Technology Centers

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Learning Objectives

- Discover various software approaches being used to program robots at the Autodesk Technology Centers
- Learn about the challenges involved when contending with the physical constraints and material properties in robotic workflows
- Imagine how research at the Autodesk Technology Centers can inform future workflows at construction sites
- Learn about the resources and opportunities at the Autodesk Technology Centers

Description

This course will present case studies of resident projects that were fabricated at the Autodesk Technology Centers. These case studies will focus on the robotic workflows for AEC, describing both the robotic software (examples include Autodesk Maya, Machina, ABB RobotStudio, PowerMill) and the challenges overcome from troubleshooting physical constraints. Attendees will gain knowledge in various approaches to robotic fabrication and how this informs the move to automate fabrication at the construction site.
Case studies examples:

- Perkins and Will's Mass timber pavilion fabrication utilizing workflow of suction grippers, drills, saws and nail guns
- AI SpaceFactory's MARSHA -a 15 ft structure made from biopolymer basalt composite utilizing additive workflow
- Apis Cor's 3-D printed 2-story, 12,000 sq. ft concrete building.
- Mad Workshop's Arroyo Bridge- a 80 ft pedestrian bridge utilizing a robot to position 600 steel members in unique places for a manual welding process

Speaker

Stefanie Pender is a Senior Shop Supervisor at the Autodesk Technology Center Boston, a research and development workspace where Autodesk invites startups, colleges and universities, and industry experts to explore ways to advance the building industry. The center focuses on industrialized construction, digital fabrication, automation and robotics in construction, and other ideas that are transforming the built world. Stefanie supports residents utilizing robotics at the technology center in applications that range from milling, welding, 3D printing, cutting, and material handling.

Perkins and Will: Robotic Fabrication of Nail Laminated Timber

- Workflow utilizes robotics, mass timber and parametric design
- Cross-laminated timber (CLT) has grown in popularity due to its ability to be prefabricated off-site and assembled on-site.
- International Code Council adopted new standard for 2020 that would permit high-rise construction with CLT (and other mass timber assemblies) up to 18 stories.

Robotic Setup

- 6-axis ABB IRB 4600-40/2.55 mounted on an ABB IRBT 4004 linear track
    - 7 degrees of freedom
    - Maximum reach of robot is 2.55 m from base of robot
    - When mounted on external linear axis, the range is extended across 9 meters
    - Position repeatability (RP) of .06 mm
    - Path repeatability of .28mm
- 5 tools with ATI automatic tool changers
    - Custom spring-actuated suction gripper for gripping wood
        - Max payload 20kg
    - Modified Fasco Lignoloc Coil Nailer shooting a magazine of 150 nails
        - Tool not used throughout the entire process)
    - Modified Dewalt Pneumatic Nail gun with a 300-nail magazine shooting 63.5 mm nails.
    - An air-cooled milling spindle equipped with a 12.7 mm end mill with a max rpm of 24000.
    - A modified Dewalt Circular saw with 177.8mm Diameter Blade.
- Workholding
    - Alignment slide constructed to serve as a constant reference obtaining the physical gripping center of each piece of lumber
    - A Schunk pneumatic gripper with stepped grips was floor mounted to function as vise as each lumber is processed.

There were limitations of tooling that required specific technical operations guidelines within the process, for example when using the pneumatic nail gun, the nozzle had to be fully pressed and perpendicular to the lumber.

Robot Work Cell

- Work Envelope measures 4.26 meters wide by 12.22 meters long

Design Scripting

- Rhinoceros 3D – modelling
- Grasshopper – scripting
- Machina Plugin - robot communication
- ABB RobotStudio – verified simulation

Results

- Final pavilion measured 4.26 meters tall and 6 meters wide
- 2,451 individual pieces of wood and 10,828 nails fabricated in modules
- 54 hours of robotic fabrication
- Assembled in Chicago at the Greenbuild Expo
- “Relational nature of the digital model allowed for large amount of data to be flexible, changing as real-world tests affirmed or rejected our initial assumptions.”
- “In the robot script, Machina was a useful tool to seamlessly compile fabrication instructions from Grasshopper to robot-readable code, simulate robot movement in ABB RobotStudio and subsequently sending that data in real time to the robot for execution.”
- This workflow allowed for real-time modifications to the design as changes arise.
- “The use of wood allows for a renewable, widely available material to displace steel or concrete and reduce a building’s carbon footprint.”
- The robotically constructed modules were accurate to 1mm precision, while the completed assembly, done by hand, were accurate to within 75 mm.

AI SpaceFactory: Marsha, Additive Habitat Construction

- Team won the finale of NASA's 3D Printed Habitat Challenge in May 2019
- Contest was designed to advance autonomous additive construction, structural and architectural concepts
- Team successfully printed a 1:3 scale alpha prototype of the Marsha design of 15 ft – becoming the tallest ever polymer-based monolithic 3D print.
- Final product included three prefabricated wall penetrations placed autonomously.

Robotic Setup

- 6-axis ABB IRB 6700-245/3.00 mounted on a modified forklift
    - Maximum reach of robot is 3.0 m from base of robot
    - Maximum payload is 245 kg
- To expand the work envelope horizontally, the team fabricated a counterweighted 1-meter extension arm which linked the extruder with the tool changer on axis 6
- Hydraulic lift – caterpillar GC70K (modified)
- To expand the work envelope vertically, the team acquired a modified forklift to lift robot – added approximately 3.5 meters of vertical reach.
- Extruder – Stranpresse Model 30 (modified) + Rockwell controller
- Pellet Dryer – ConAir MDCW Carousel Plus Dryer
- Conveying system – ConAir TL Model TubeLoader

Material

- Team formulated a novel polymer that could one day leverage Martian (or lunar) ISRU (In-situ resource utilization) technologies: a fiber-reinforced thermoplastic.
- Material is a blend of approximately 40% chopped basalt fiber and 60% PLA (polylactic acid), a polymer produced by bacteria (biopolymer).
- Basalt – a kind of volcanic rock is abundant on parts of Mars and the Moon.
- PLA – "could be upcycled from trash PLA generated during a mission or "grown" biologically from agricultural food stuffs and other nutrient-rich biowaste".

Design Scripting

- Rhinoceros 3D – modelling
- Grasshopper – scripting
- Machina Plugin - robot communication
- ABB RobotStudio – verified simulation

Results

- 30 hour total print time
- "Autonomy was the most important scoring basis for Phase 3 of the 3D Printed Habitat Challenge…Based on time spent printing vs. time spent intervening, the team achieved a 91.5% autonomy score. Interventions were either remote (teleoperations) using only controls or physical which required setting foot into the printer's work envelope and shutting off operations for safety reasons".
- "In slabs and floors, a standard printing sequence produces unrecoverable distortion. The team invented a process that mostly mitigates this."
- Other issues were cold bonding and slumping; please see attached white paper for elaboration of these issues.

Apis Cor: Additive concrete in construction

- Team printed 2-story 12,000 sf administrative building for Dubai Municipality.
- Team utilized their own custom printer and software to print walls of building.
- In addition, Apis Cor is also working with Thornton Tomasetti and University of Connecticut to test samples of their 3-D printed wall structures to see if it meets the minimum requirements of US code.
  - Designing and prototyping 3D printed wall structures. These printed walls are compared to the well-documented concrete masonry unit (CMU) wall.
  - Have demonstrated similar results in compressions testing
  - Writing a report on the viability of Apis Cor's product for US Building codes.

Robotic Setup (for testing 3D printed walls).

- 6-axis ABB IRB 6700-245/3.00
  - Maximum reach of robot is 3.0 m from base of robot
  - Maximum payload is 245 kg
- Custom concrete extruder and mixing system

Design Scripting (for testing 3D printed walls)

- Fusion 360 – modelling
- PowerMill Robot - programming
- ABB RobotStudio – verified simulation

Results

- Apis Cor's product has surpassed minimum requirements for Building Codes in the US.

MadWorkshop: Arroyo Bridge

- The Martin Architecture and Design Workshop (MADWORKSHOP) supports students, makers, artists, and architects in the realization of socially valuable design projects.
- The Arroyo Bridge project is an 80 foot pre-fabricated sculptural steel span. This asymmetrical pedestrian bridge is designed to be broken down into nodes for transport to its final installation in Southern California.
- Owing to the complex geometry of the structure, construction would utilize robotic arms to precisely pick and place steel members in position to allow a human fabricator to weld and/or fix each component in place.
- To meet the tight constraints of the site and structure, they will use computer vision and 3D scanning to verify correct placement of each node in shop during fabrication and in field during installation.

- 588 parts uniquely placed and calibrated by robot
  - 297 pipes
  - 234 gussets
  - 50 connectors and 4 backers
  - 3 solid bars
- Decking
  - 80 stanchions
  - 960 guardrail rods
  - 590 Board feet of IPE
  - 40 custom fit standoffs

Robotic Setup

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    - When mounted on external linear axis, the range is extended across 9 meters
    - Position repeatability (RP) of .06 mm
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- 4 tools with ATI automatic tool changers
    - Teach spike
    - QA paddle
    - Gusset magnetic gripper
    - Pipe magnetic gripper

- Workholding
    - Fixture cart
    - 198 slats

Robot Work Cell

- Work Envelope measures 4.26 meters wide by 12.22 meters long

Design Scripting

- Rhinoceros 3D – modelling
- Grasshopper – scripting
- Mimic for Maya – scripting, simulation and generating robot code
- ABB RobotStudio – verified simulation

Resources and Opportunities at the Autodesk Technology Centers

Autodesk Technology Centers

The Autodesk Technology Centers are where the future of making takes shape. With locations around the world, we invite industry, academic, and entrepreneurial communities to reimagine what it means to design and make and create a shared vision of the future that will enable people to do more and make better things with less negative impact.

Autodesk provides the facilities, technology and equipment, training, and expertise for these communities to explore ideas that will shape the future. Each location—San Francisco, Boston, Toronto, and Birmingham, UK—explores different aspects of the future of making, from construction to advanced manufacturing to artificial intelligence. But all the spaces are designed to foster open innovation and advance the industries that help imagine, design, and make the world around us.

The Autodesk Technology Centers exist to create a shared vision of the future of making with a community of innovators and thought leaders, and the Residency Program is a vital part of bringing that vision to life.

Residency Program

The Autodesk Technology Centers in Boston, San Francisco, and Toronto offer a Residency Program that provides open workspaces for teams from industry, academic, and startup communities doing forward-looking work in the areas of construction, manufacturing, and design.

Residency proposals are reviewed on a rolling basis, and selected participants are provided with dedicated project areas in a technology center, access to advanced fabrication machinery, training, and connections to industry experts and the technology center community. The program can be tailored to meet individual goals and availability. Residencies can last anywhere from two weeks to a year or more.

Autodesk Technology Center Boston

The Autodesk Technology Center Boston is a research and development workspace where Autodesk invites startups, colleges and universities, and industry experts to explore ways to advance the building industry. The center focuses on industrialized construction, digital fabrication, automation and robotics in construction, and other ideas that are transforming the built world including architecture and engineering.

Located in Boston's Seaport Innovation District, the workspace offers teams access to large format fabrication equipment and project space, as well as training and expertise from Autodesk personnel. Resident teams test and develop solutions that will improve how we build the places where we live and work and the infrastructure we rely upon. More than just a workspace, the center fosters an open community where industry thought leaders can collaborate on a shared vision of the future of construction.

Autodesk Technology Center San Francisco

The Autodesk Technology Center in San Francisco is a hub for the exploration of the future of manufacturing. Focused on the concept of configurable microfactories, this technology center brings together forward-thinking startups, academic researchers, and thought leaders from industry to create a shared vision for the future of making.

Part of the global Autodesk Technology Center network, this center located on the Embarcadero at Pier 9 supports residents with a range of advanced manufacturing equipment, robotics, and general shop facilities and workspaces to explore the research and development of ideas pushing the boundaries of traditional manufacturing.

Autodesk Technology Centre Toronto

The Autodesk Technology Centre in Toronto explores technologies that will advance how we design across all industries. The centre is home to forward-looking research in areas such as generative design, artificial intelligence, and human-computer interaction, and is where research is applied to create solutions that help people do more, make better things, and with less negative impact on the world.

Located in Toronto's Discovery District, one of the world's largest urban innovation hubs, the centre is generatively designed to facilitate a collaborative community. It offers dedicated workspace, along with access to advance prototyping and validation tools, where Autodesk customers, industry experts, entrepreneurs, and thought leaders can come together to reimagine how we design the world around us.

Autodesk Technology Centre Birmingham, UK

The Autodesk Technology Centre in Birmingham, UK, specializes in demonstrating new additive, subtractive, and fabrication processes that are transforming the way things are made. Working with customers from a variety of industries, ranging from automotive and aerospace to consumer products and industrial devices, the centre provides a space to explore advanced manufacturing techniques and computer-aided manufacturing solutions, often through production work commissioned by customers. Here, teams examine how automation—enabled by new manufacturing processes—is unlocking a new era of design freedom where it's possible to manufacture increasingly complex designs.

This centre is part of Autodesk's global network of facilities that helps bring to life solutions aimed towards solving some of the world's most complex manufacturing and fabrication challenges, empowering our customers to make anything.

Residency proposal: https://form.jotform.com/technologycenters/proposal

References:

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