Task and Motion Planning for Robotic Assembly

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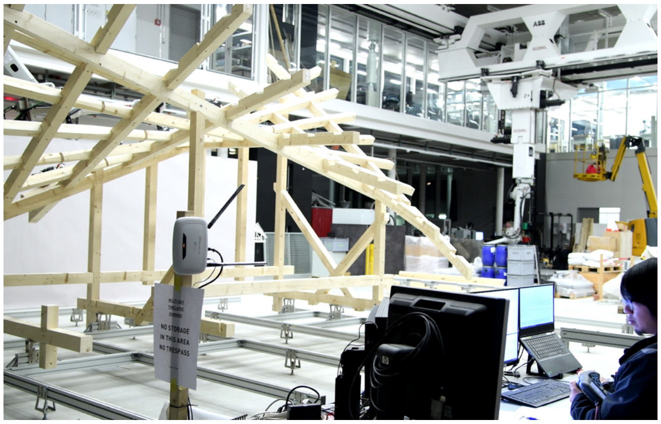
1 Robotic Motion trajectory created for timber aseembly process (Pok Yin Victor Leung, 2021, © Gramazio Kohler Research).

Task and Motion Planning

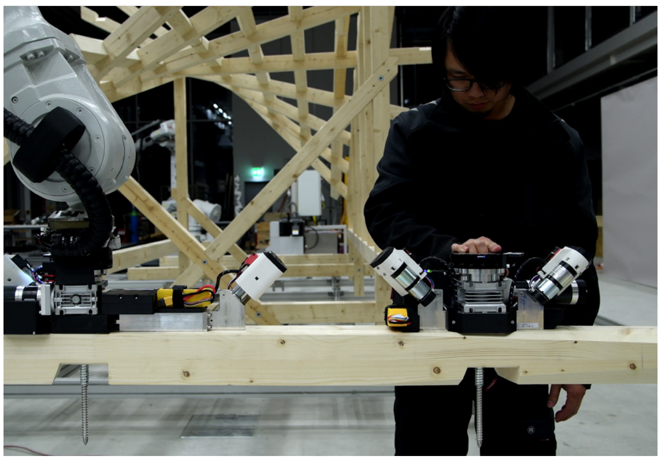
When programming robotic assembly processes, it is often necessary to create a sequential list of actions. Some actions are robotic motions (requiring motion trajectory), and some are for controlling external equipment, such as grippers and fastening tools. The act of planning these actions and motion trajectories is called Task Planning and Motion Planning. Existing literature in robotics explored many different planning algorithms for planning a single trajectory to planning a complete sequence of tasks where continuity is maintained [Garrett et al, 2021]. Many application literature focused on the TAMP for service robots, medical robots, and self-driving cars, while there are few examples for architectural applications. For digital fabrication and automated construction, the planning method has to be adapted to the needs of architectural assemblies and the scale of construction [Leung et al, 2021]. Some of the unique challenges are the highly bespoke workpiece and assembly geometry, the large workpiece (e.g., long beams), and a dense collision environment.

This three-day hybrid workshop addressed the needs of the architectural robotics community to use industrial robotic arms to assemble highly bespoke objects. The objects do not have any repetitive parts or assembly targets. The workshop leaders shared their experiences using industrial robots to construct large-scale timber structures. One of the most useful techniques is the recently published "Flowchart Planning Method," where task sequence is planned using a flowchart, and motion trajectories are planned in a second pass [Huang et al, 2021].

The workshop began with a deep understanding of robot kinematics, tool space, joint



2 Robotic Process that is pre-planned can be executed with minimal human supervision and surprise error such as singularity and collisions.

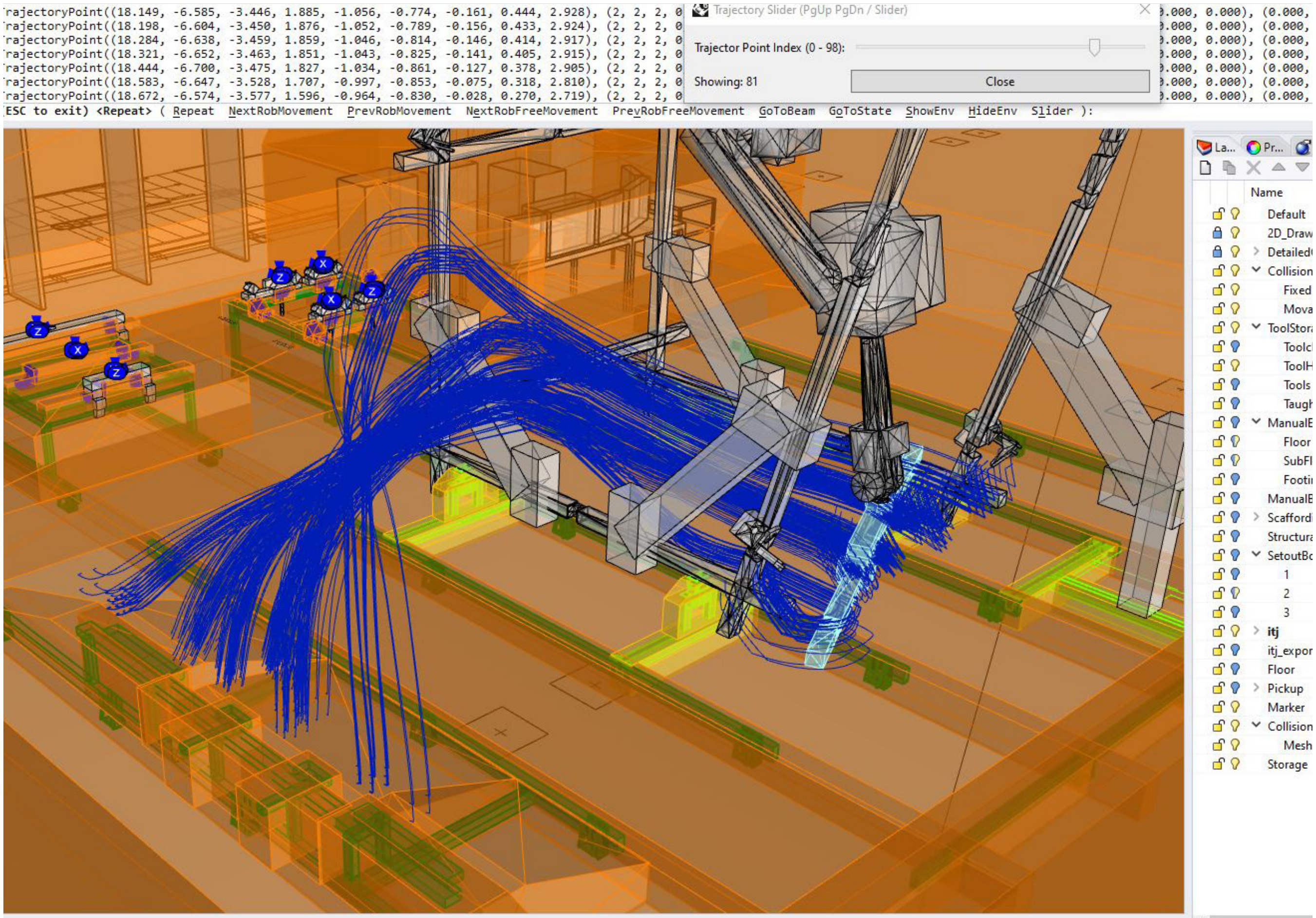


3 The offline planning approach is compatible with manual operations

4 One major robotic assembly challenge is accurate alignment

space, and how computational models are used to describe various robotic systems. Examples of 6R, 6R1P, 6R2P and 6R3P robots are shown, including the famous 34 joints gantry robot in the Robotic Fabrication Laboratory (RFL) in ETH Zurich. Discussion included how robotic kinematics related to the assembly properties and how to make quick assessment regarding reachability.
Students learn the theory (mathematic background) and the practical knowledge (software libraries) to solve forward kinematics, inverse kinematics, collision checking, and motion planning for Cartesian linear and free motion. Students use compas, an open-source framework, for design modeling, geometrical computation and to access the software libraries for planning. One of the most convenient planning libraries is compas_fab [Rust et al, 2018], a plug-in for the compas framework that provides access to state-of-the-art motion planning libraries. The software workflow allows students to design a bespoke assembly in Rhino (with the help of Grasshopper) and to design the robotic process that assembles the object from its constituent parts. The trajectories for the robotic process are planned sequentially using scripts written in Python using compas and compas_fab. The resulting trajectories can be simulated in a virtual environment such as PyBullet or Rhino. Students who participated in person could also execute the planned trajectory with a 6R ABB GoFa robot to validate that the trajectories are collision-free.
Other topics such, assembly sequence, geometrical blocking, sweep (continuous) collision checking, neighbor detection, allowed collision matrix, and trajectory smoothing are also discussed. Students can identify the planning technique and planner features required for their future applications.

Finally, the instructors shared their experience in setting up a workflow for creating large scale experiments. This include hardware preperations such as preparing the ground connections, scaffolding, robot calibration, gripper and tool design; Software preperation include modeling custom robot and tools features and tuning the parameters of the motion planner to balance planning speed, accuracy and optimality of the trajectory.



5 Planned trajectory visualized in Rhino. The image depicts a robotic arm in the RFL manpulating a piece of timber (cyan) in the middle of an assemble process. The robot, its gripper and the attached timber workpiece can be seen nevigating around a dense collision scene to reach its destination.

ACKNOWLEDGMENTS

The theoretical and technical bases of this workshop is developed during the doctoral research of the instructors [Huang, 2023] [Leung, 2023]. The continued development of this work is supported by the currently affiliated instutites of the instructors.

Many thanks to all the researchers for sharing the algorithms we used for task and motion planning, openly and freely.

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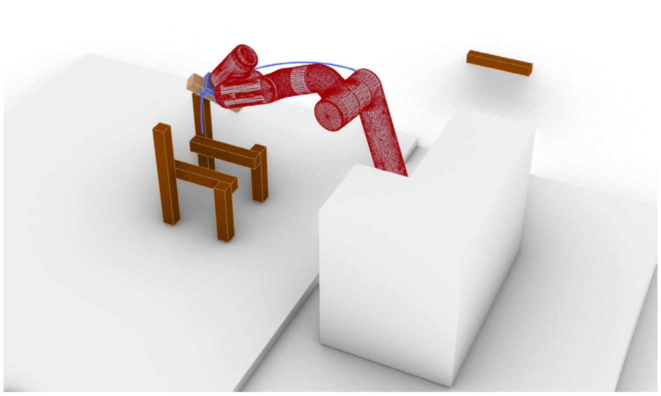
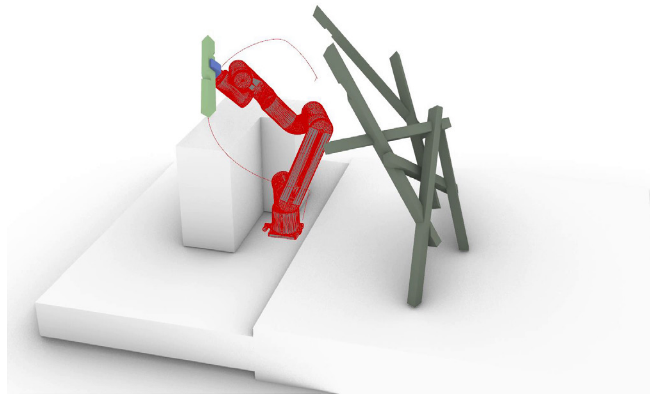
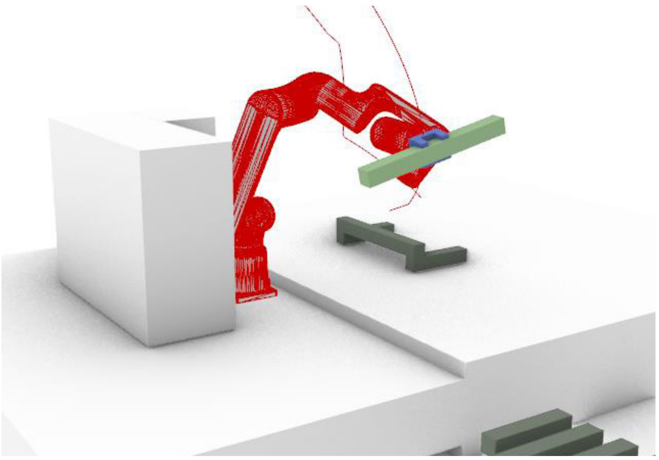


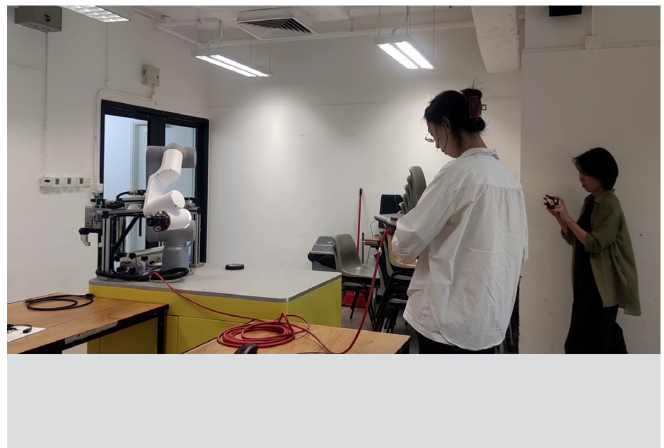
6 Student work by Jeremy Chen.



7 Student work by Lee Su Huang



8 Student work by Chenxiao Li



9 Students executing planned actions (Chenxiao Li and Namjoo Kim).

Ziqi Wang and Peng Song and Mark Pauly, 2021. State of the Art on Computational Design of Assemblies with Rigid Parts, in Computer Graphics Forum (Eurographics 2021)

Pok Yin Victor Leung is a researcher in the ETH Zurich investigating the use of Distributed Robotic Tools for assembling timber structures. He is obsessed with designing and making custom robots, machines and end effectors for digital fabrication. Victor has many years of experience in timber related topics, related to the digitization of the design-to-assembly workflow. This includes timber joint design, structural design, software development, mechatronics, robot control and motion planning. Victor also works as a consultant for digital artist and architects in the realization of kinetic installation, digital artwork, 3D printed structures, and various mechatronics project.

Yijiang Huang is a Postdoctoral Researcher in the Department of Computer Science at ETH Zurich. He researches at the intersection between Architecture, Computing, and Robotics to make design and construction more connected. Yijiang completed his Ph.D. in the Building Technology Program at MIT's Department of Architecture. Before MIT, he studied applied math and did research in computer graphics at the University of Science and Technology of China, where he received his Bachelor of Science.