# Hybrid Planning for Challenging Construction Problems: An Answer Set Programming Approach

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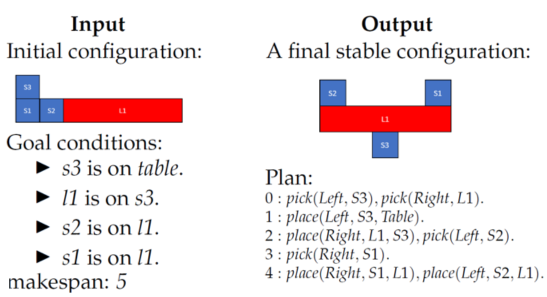
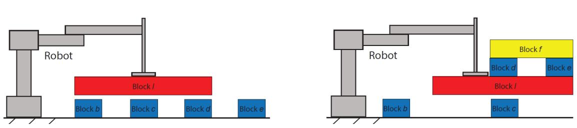
We study construction problems where multiple robots rearrange stacks of prefabricated blocks to build stable structures. In these problems, we are given an initial configuration of blocks of different sizes on a table, some goal conditions (e.g., build a bridge) for the robots, and an upper bound on a makespan. The objective is to find a final stable configuration of blocks stacked on each other that satisfy some specified goal conditions, and a feasible stack rearrangement plan to obtain that final configuration from a specified initial configuration of the blocks. It is desirable that these plans make sense in the spirit of (Fahlman 1974), e.g., to allow concurrency and subassembly construction and manipulation (instead of manipulating one block at a time) and temporary counterweight and scaffolding (for stability of intermediate configurations). Here is an example:



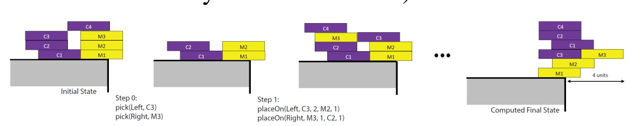

Robot construction problems involve several challenges from the perspective of planning, knowledge representation and reasoning, and robotics. These challenges include

- representation of sophisticated ramifications of actions,
- reasoning about global constraints to eliminate spurious structures during planning,
- integrating low-level feasibility checks into planning to ensure stability of constructions and feasibility of plan executions, and
- elaboration tolerant representation of variations of robot construction problems.




For instance, the left figure above shows a robot placing a large block $l$ on top of a small block $b$. As a direct effect of this action, $l$ becomes placed on $b$. As a ramification of this action, $l$ is located on top of other small blocks close to $b$, such as $c$ and $d$. The right figure shows a robot moving a subassembly of blocks $d$, $e$ and $f$ from one location $b$ to another location $c$. As a direct of effect of this action, the base block $l$ becomes placed on $c$. As ramifications of this action, block $l$ is not on $b$ anymore, none of the blocks included in the subassembly are supported by $b$ anymore, and all blocks in the subassembly are supported by $c$ now. Representing these ramifications require concepts that are recursively defined. In the left figure, to identify which blocks are close to $b$ and will become placed under $l$, we need to define the global positions of blocks from their relative positions; such a definition is recursive. In the right figure, we need to define which blocks are supported by which other blocks in a construction, like a subassembly being carried; such a definition is recursive as well. The capability of defining recursive concepts, like the transitive closure of "being immediately on top of another block", is needed for representing sophisticated ramifications. This is challenging, e.g., for PDDL-based planning (Thiébaux, Hoffmann, and Nebel 2005).

Robot construction problems ask for not only a feasible plan but also a feasible goal state. They require not only reachability checks but also stability checks, and not only for preconditions of pick and place actions but also for states. For a feasible construction plan, stable goal configurations should be determined for planning, and the structure being constructed and the subassemblies carried by the robot should be ensured to be stable at every state reached during the execution of a plan and during each transition from one state to another. The figure below shows an instance with the goal of finding a maximum overhang from a given initial state, and its output (a stable final state and a feasible plan to reach it executed by a bimanual robot).




Therefore, the robot construction problems cannot be addressed using solely a task planner, but necessitate proper use of feasibility checks together with the planner. While essential for real-life applicability, it is challenging to combine task planning studied over discrete domains, with feasibility checks performed in continuous domains (Erdem et al. 2011; Nouman, Patoglu, and Erdem 2021).

We propose a general elaboration tolerant method to solve a wide range of construction problems, addressing the challenges above. Our method is based on the knowledge representation and reasoning paradigm of Answer Set Programming with external atoms (Eiter et al. 2005) (i.e., semantic attachments (Weyhrauch 1980)) that utilize the state-of-the-art feasibility checkers and physics engines. We prove the soundness and completeness of our method, introduce a set of challenging construction benchmark instances, perform experiments to investigate the computational performance of our hybrid method, and demonstrate the applicability of our method using a bimanual Baxter robot.

We refer the reader to our article (Ahmad, Patoglu, and Erdem 2023) for further information, including links to our benchmark instances, and examples of dynamic simulations and physical implementations with a bimanual robot.

## References


Ahmad, F.; Patoglu, V.; and Erdem, E. 2023. Hybrid planning for challenging construction problems: An answer set programming approach. *Artif. Intell.* 319:103902.

Eiter, T.; Ianni, G.; Schindlauer, R.; and Tompits, H. 2005. A uniform integration of higher-order reasoning and external evaluations in answer-set programming. In *Proc. of IJCAI*, 90–96.

Erdem, E.; Haspalamutgil, K.; Palaz, C.; Patoglu, V.; and Uras, T. 2011. Combining high-level causal reasoning with low-level geometric reasoning and motion planning for robotic manipulation. In *Proc. of IEEE ICRA*, 4575–4581.

Fahlman, S. E. 1974. A planning system for robot construction tasks. *Artif. Intell.* 5(1):1–49.

Nouman, A.; Patoglu, V.; and Erdem, E. 2021. Hybrid conditional planning for robotic applications. *Int. J. Robotics Res.* 40(2-3).

Thiébaux, S.; Hoffmann, J.; and Nebel, B. 2005. In defense of PDDL axioms. *Artif. Intell.* 168(1–2):38–69.

Weyhrauch, R. W. 1980. Prolegomena to a theory of mechanized formal reasoning. *Artif. Intell.* 13(1):133–170.