3D Block Printing: Additive Manufacturing by Assembly

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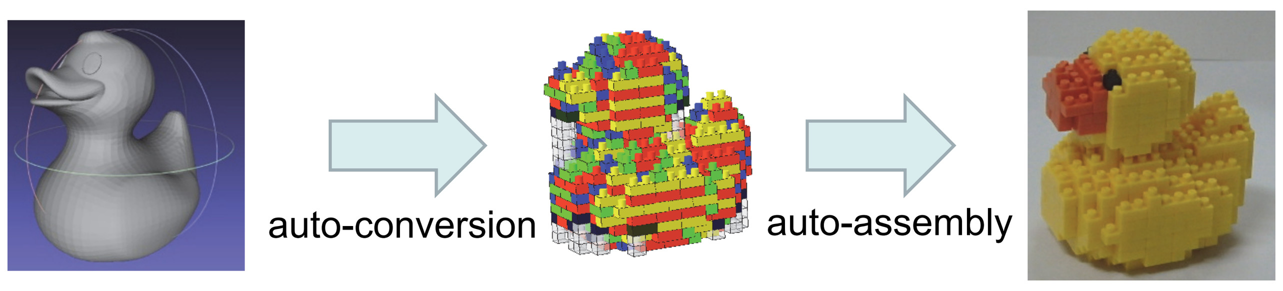
This paper overviews a robotic 3D block printer. It can fabricate 3D forms from their CAD models by assembling toy blocks as digital materials. It can achieve mass customization through the combination of mass-produced building blocks and automatic assembly planning for customized shapes. In this paper, we present mechanical analysis for assembly planning of toy blocks and ROS-based implementation of the system for high interoperability with various robots.

3D Block Printing [Maeda 2016 IROS] [Sugimoto 2017 CASE]

Additive manufacturing by assembly of digital materials

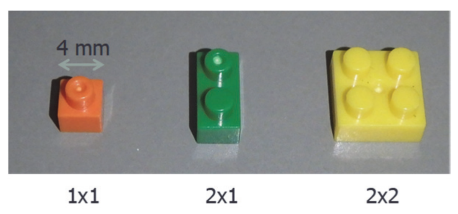


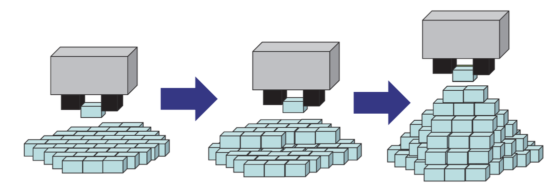
Potential Advantages

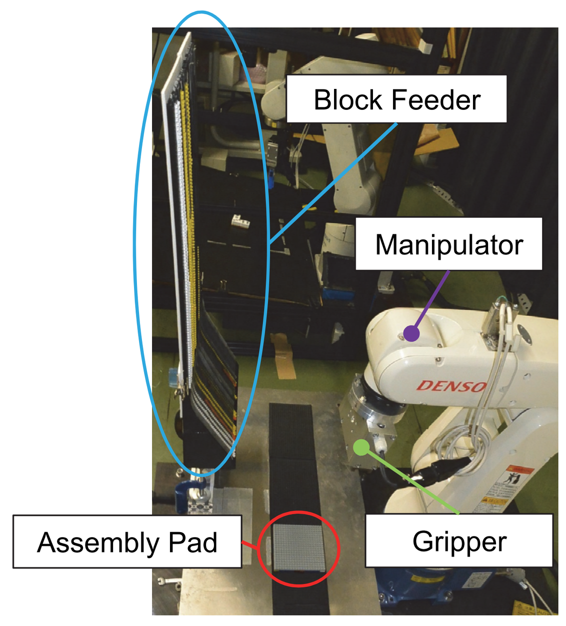
- Mass customization using mass-produced building blocks
- Multiple colors and materials
- High repeatability by using precision digital materials and their self-alignment
- Material reuse through disassembly
- Fabrication of shapes with function using functional blocks (e.g., electric circuits)

Our 3D Block Printer

- Using nanoblocks (LEGO-like, but smaller)
- Layer-by-layer assembly from bottom to top
- Automatic assembly planning from a CAD model

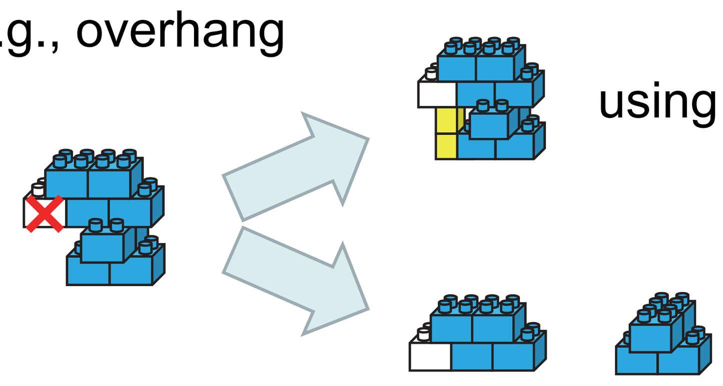






Dealing with unprintable shapes

- e.g., overhang



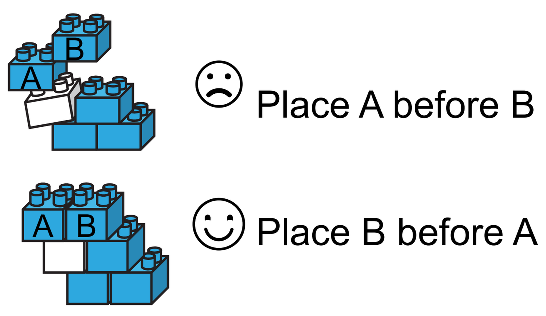
using support blocks

decomposing into subassemblies

Mechanical Analysis of Block Assembly

Block assemblability test is necessary for assembly planning

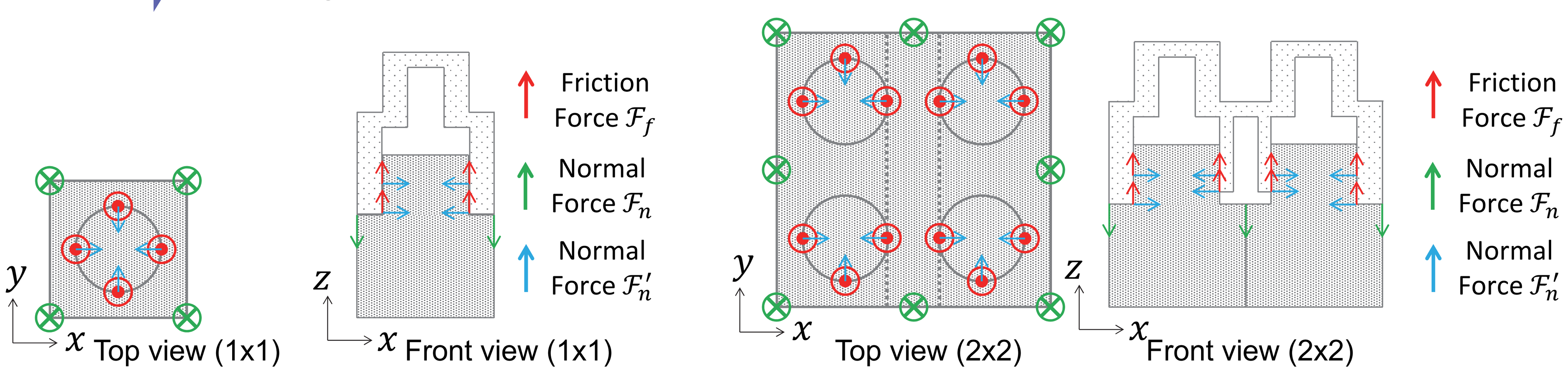
- Our previous study: empirical assemblability test
- Using variously-sized blocks was difficult



Capacity [Luo 2015]

- A force margin of inter-block connection
- Applicable to evaluation of the physical stability of LEGO-like block sculptures
- Only for assembled block sculptures

Must be extended for the physical stability of block sculptures *during* the placement of each block



Assemblability test for block placement

Check whether the minimum capacity is positive by solving the following linear programming problem:

$$
\begin{aligned}
&\underset{C_{\mathrm{M}}, C_i, f_{f_i}, \boldsymbol{F}, \boldsymbol{F}_k, a_k}{\text{maximize}} \quad C_{\mathrm{M}} \\
&\text{subject to} \begin{cases}
C_{\mathrm{M}} \le C_i = T - f_{f_i} & (i = 1, 2, \cdots, m) \\
\boldsymbol{W}_j \boldsymbol{A} \boldsymbol{F} = \boldsymbol{Q}_j & (j = 1, 2, \cdots, N) \\
\boldsymbol{F} = (\boldsymbol{F}_1^T, \cdots, \boldsymbol{F}_n^T)^T & \\
\boldsymbol{F}_k = \begin{cases} a_k \boldsymbol{t}_k & (k \in \mathcal{F}_f) \\ a_k \boldsymbol{n}_k & (k \in \mathcal{F}_n) \end{cases} & (k = 1, 2, \ldots, n) \\
a_k \ge 0 & (k = 1, 2, \ldots, n) \\
a_k \le T_{2\times 2} \quad (k \in \mathcal{F}'_{n, 2\times 2}) & (k = 1, 2, \ldots, n) \\
f_{f_i} = \sum_{k \in \mathcal{F}_{f_i}} a_k & (i = 1, 2, \ldots, m),
\end{cases}
\end{aligned}
$$

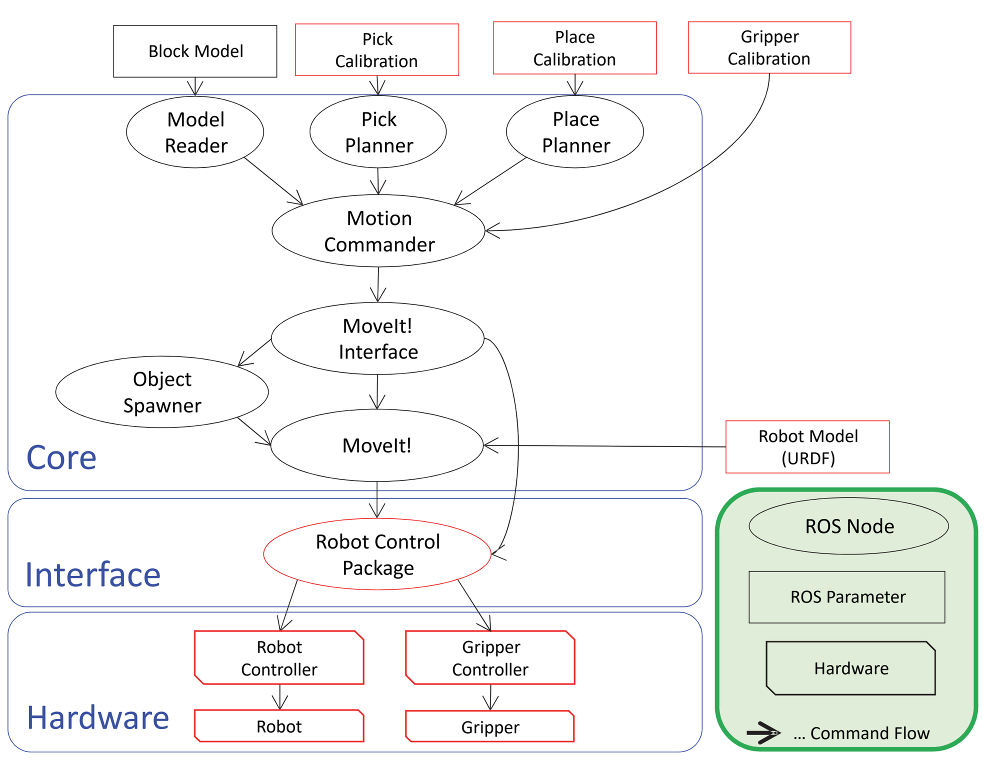
- C_{M}: minimum capacity
- C_i: capacity at the *i*-th connection
- $\boldsymbol{Q}_j$: external wrench exerted to the *j*-th block including insertion force

ROS-based Implementation of Block Printer

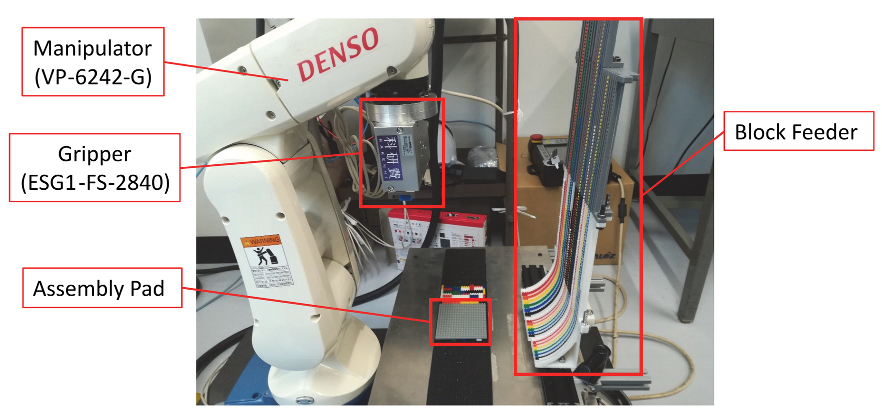
A new implementation of block printer based on ROS and MoveIt

- For higher interoperability with various robots
- Motion planning for collision avoidance

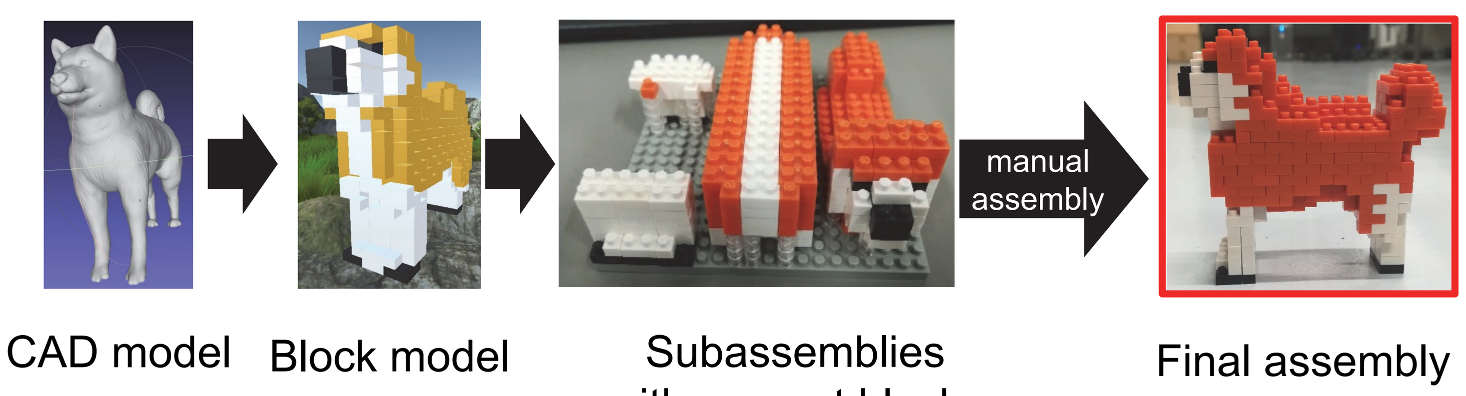
System Architecture



Experimental Setup



Assembly Example



CAD model | Block model | Subassemblies with support blocks | Final assembly

Interoperability with Various Robots