Creating LEGO Technic Parts on Demand through Bimanual Interaction in VR

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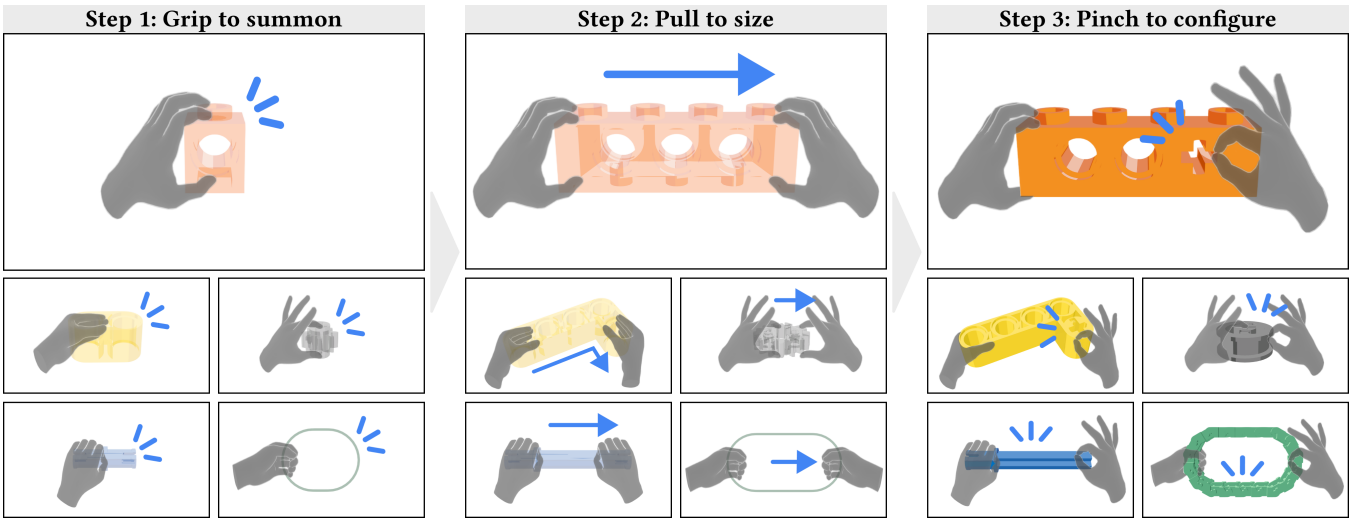


Figure 1: In this study, we propose a bimanual VR interaction technique to instantly create an essential set of universal LEGO Technic parts, which we identified through an analysis of a renowned textbook [6]. First, the user performs a hand gesture that resembles gripping a part to summon it (orange: brick/plate; yellow: beam/half-beam; gray: gear/pulley/wheel; blue: pin/axle; green: string/belt). Second, the user performs the same gesture with the other hand, grips the part, and pulls it, bending it if applicable, to size the part. Third, the user pinches the part to configure its holes or profile.

Abstract

LEGO Technic is a powerful tool for prototyping moving objects. However, physical assembly requires users to maintain a large inventory of parts and repeatedly search this inventory for specific parts. In this study, we identified an essential set of LEGO Technic parts through a literature analysis. Based on the geometric and functional characteristics of these parts, we designed an intuitive bimanual interaction technique to instantly create them in VR. Finally, we applied this technique to build various moving objects, demonstrating its applicability to LEGO Technic prototyping.

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CCS Concepts

• **Human-centered computing** → **Interaction techniques**.

Keywords

LEGO; virtual reality; bimanual interaction

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1 Introduction

Whereas standard LEGO sets focus on static scenes, the LEGO Technic series enables users to build moving objects from mechanical

parts such as beams, axles, and gears. Owing to this capability, LEGO Technic has evolved beyond a children's toy and is widely used as an educational tool for students and a prototyping tool for designers [7] and engineers [5]. However, physical LEGO Technic assembly presents two major constraints. First, users must acquire a large inventory of parts to realize their ideas. Second, users must search for specific pieces repeatedly during assembly.

To overcome these limitations, we propose a novel VR interaction technique to instantly create LEGO Technic parts as needed (Figure 1). Rather than automatically generating complete models from rough inputs [9], or to search for and assemble parts [2], our bimanual interaction technique leverages bare-hand gestures, which are effective for summoning and handling objects in VR [8, 10]. Through this approach, we aim to empower users to actively develop their ideas by assembling parts with their own hands.

2 Essential LEGO Technic Parts

We conducted a literature analysis to identify the essential parts for LEGO Technic prototyping and characterize their properties to inform our interaction design. We selected a textbook authored by a LEGO Robot Olympiad judge [6] that presents foundational assembly patterns used to construct complex mechanisms. We examined all examples within this book and classified the required parts according to their form and function (Figure 2).

The key finding from this analysis is that universal parts can be defined by sizing and configuring a shared primitive specific to their functional type (Figure 1). For example, all bricks share a cuboid primitive, and each individual brick is then defined by the number of unit cuboids pulled along given axes and the types of holes it contains. In contrast, non-universal parts have irregular shapes tailored to their mechanical or decorative functions, as demonstrated by a joint (Part ID: 61903), a turntable (Part ID: 50163), and a motor (Part ID: 8882).

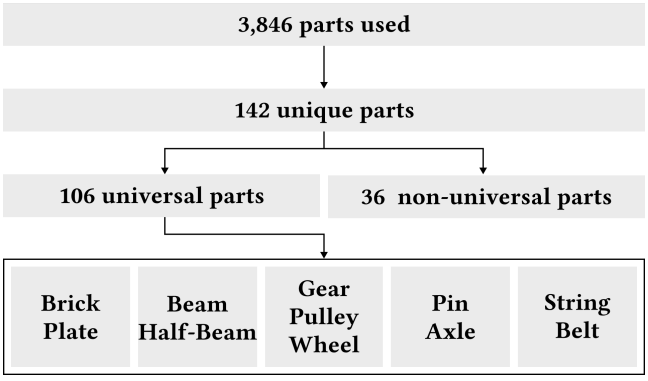


Figure 2: We surveyed all 260 examples from the selected textbook [6]. From these examples, we cataloged 3,846 total LEGO Technic parts and identified 142 unique parts by their part IDs [1]. We then divided these 142 unique parts into 106 universal and 36 non-universal parts based on their form. Finally, we classified the 106 universal parts into 5 functional types: brick/plate type (12 parts), beam/half-beam type (32 parts), gear/pulley/wheel type (26 parts), pin/axle type (23 parts), and string/belt type (13 parts).

3 Interaction Technique

Based on our literature analysis, we designed a bimanual VR interaction technique to create universal LEGO Technic parts across all 5 functional types (Figure 1). Following the kinematic chain model [4], this technique consists of three sequential steps:

Step 1: Grip to summon. Users summon a part by posing one hand to grip the part's primitive. Specifically, they summon a brick or plate as if gripping the top and bottom of a tall or flat cuboid; a beam or half-beam as if gripping the rounded side of a tall or short elliptical cylinder; a gear, pulley, or wheel as if gripping both ends of a short cylinder's central axis; a pin or axle as if gripping a thick rod; and a string or belt as if gripping a thin cord.

Step 2: Pull to size. Next, users size the part by gripping its opposite end with the same gesture and pulling the part to the desired shape. Specifically, they can adjust the width and length of a brick or plate; the length and bend of a beam or half-beam; the diameter of a gear, pulley, or wheel; the length of a pin or axle; and the length of a string or belt. As the hand moves, the part snaps to discrete increments based on a unit length.

Step 3: Pinch to configure. Finally, users configure the part by pinching it. Specifically, pinching a hole on a brick, plate, or beam toggles between circular and cross-shaped holes; pinching the side of a gear, pulley, or wheel cycles among toothed, grooved, and tire profiles; pinching the end of a pin or axle toggles between circular and cross-shaped cross-sections; and pinching any point on a string or belt toggles between cord and track profiles.

4 Showcase

We implemented a system for part creation and assembly using the Unity 3D game engine and a Meta Quest 3 VR headset. Users can create the 106 universal parts with our technique and import the 36 non-universal parts from a library. We built various moving objects using the system (Figure 3) and recorded the processes (Figure 4).

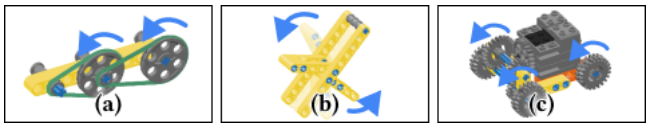


Figure 3: We used the proposed technique to build various moving objects, ranging from (a) a pulley system (4 minutes, 14 parts) to (b) a folding chair (7 minutes, 20 parts) and (c) a car (7 minutes, 21 parts).

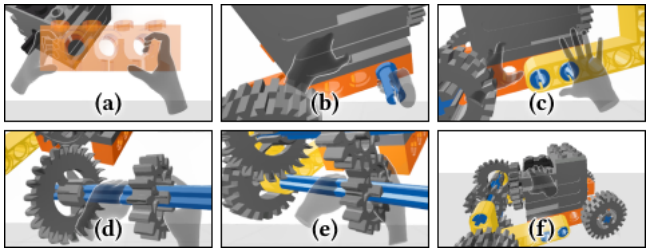


Figure 4: To build a car, an author first created (a) bricks, (b) pins, and (c) beams to construct a chassis that supports the motor. He then created (d) axles and gears to construct (e) a gear system that transmits power from this motor. (f) Finally, he created wheels and attached them to the gear system.

5 Conclusion & Future Work

In this study, we proposed a three-step VR interaction technique to instantly create universal LEGO Technic parts spanning bricks, plates, beams, half-beams, gears, pulleys, wheels, pins, axles, strings, and belts using natural bare-hand gestures. We demonstrated the applicability of the technique by building various moving objects. In future work, we aim to integrate a physics simulator [3] into our prototyping system to realistically actuate assembled models under physical forces such as gravity and friction. We will evaluate the system's usability and usefulness with children, students, designers, and engineers.

Acknowledgments

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