TESSERACT

Integrated Reconfigurable Autonomous Architecture System

Wanzhu Jiang, Jiaqi Wang, Tyson Hosmer, Ziming He

TESSERACT is an autonomous architecture developed through a voxel-based robotic material system that continuously reshapes communities through a socio-economic model with shifting fractional ownership. This incentivizes users to trade and share portions of physical space in real-time (Figure 1). Based on the Integrated Reconfigurable Autonomous Architecture System, TESSERACT buildings have a continuously adaptive lifecycle enabling the shifting spatial needs of communities to be negotiated through an Observe, Generate, [re]Assemble feedback loop (Figure 2). TESSERACT is implemented with three integrated components: an interactive platform, a space planning algorithm, and a distributed robotic material system.

The interactive platform is the information collection port observing both the shifting demands of inhabitants and environmental constraints (Figure 3). The environment interface processes dynamic environmental conditions through bitmaps and translates them into 3D data matrices. The user interface collects the community of users' requirements and characteristics such as desired space typologies and willingness to share and structures them as inputs driving the behaviors of the adaptive space generation algorithm.

The space planning algorithm is a multi-agent system that extends the principles of Stigmergic Space Adjacency Software (Meyboom and Reeves 2013), where each programmable agent represents an independent space and communicates through its 3D voxelized environment. Spatial agents are trained with reinforcement learning to learn adaptive policies for adjusting their scales, shapes, and organization in relation to each other in response to changes in the environment and user requirements (Figure 4). Users' requirements are mapped into three collections of agent properties called "schema" that influence changes in their behavior. Relational Schema represented as "User Hue," defines the degree of relationality to neighboring agents of a similar or different color. Space Schema parameters (V, P,

PRODUCTION NOTES

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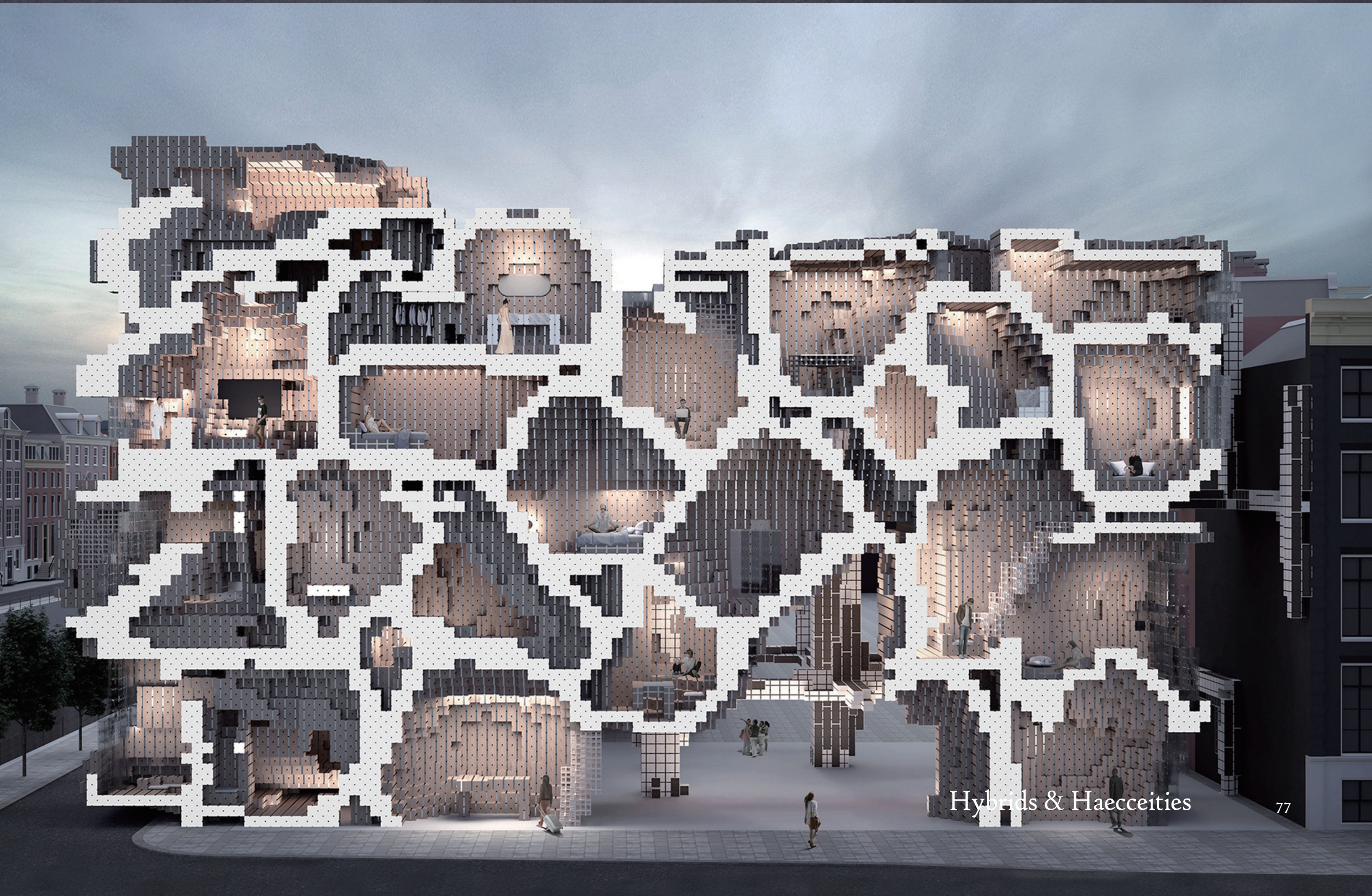
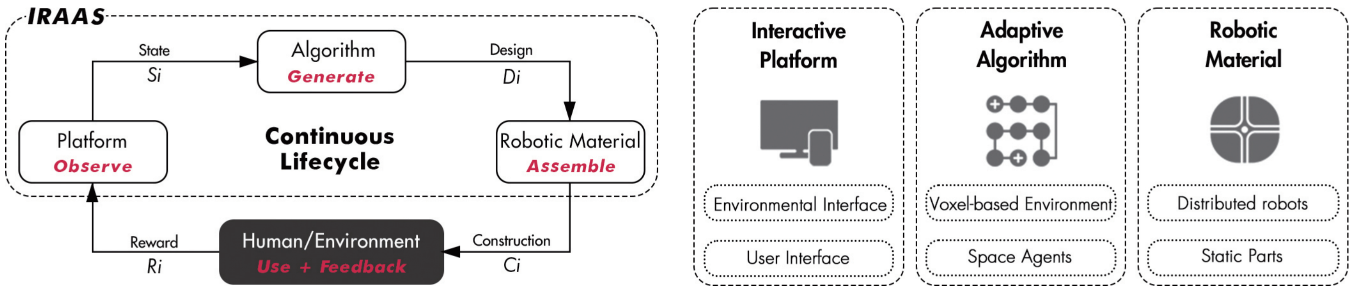
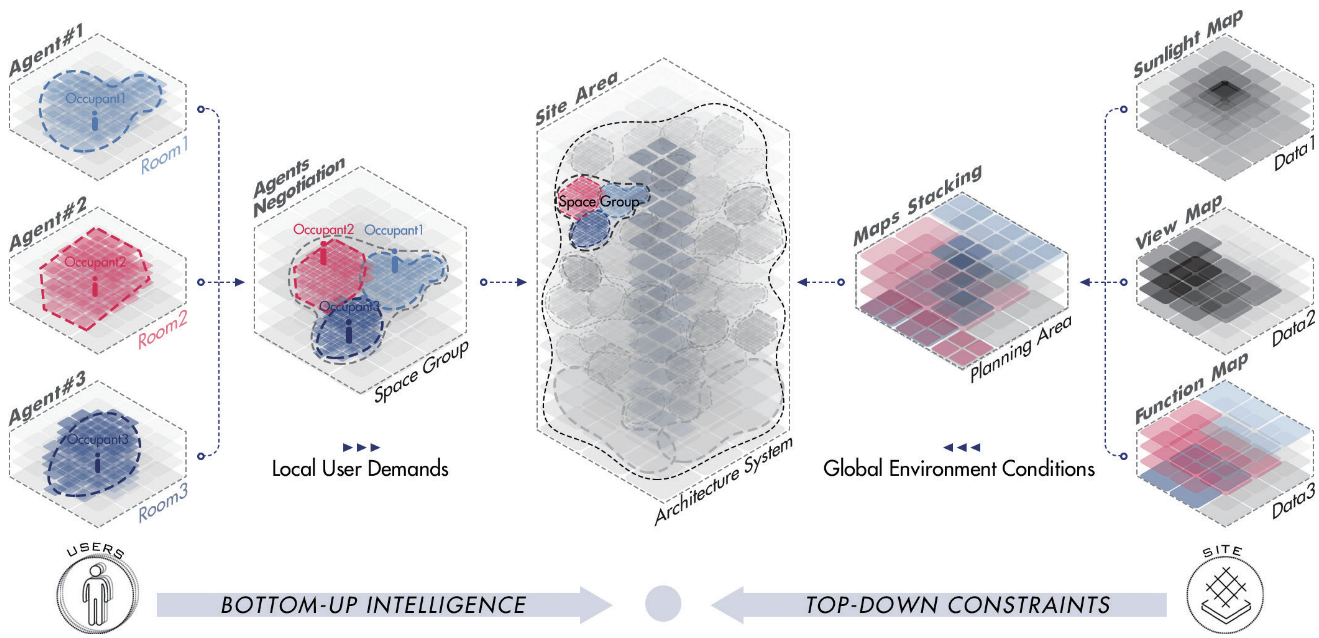
1 The perspective and section of TESSERACT.





2 Continuous lifecycle and system composition



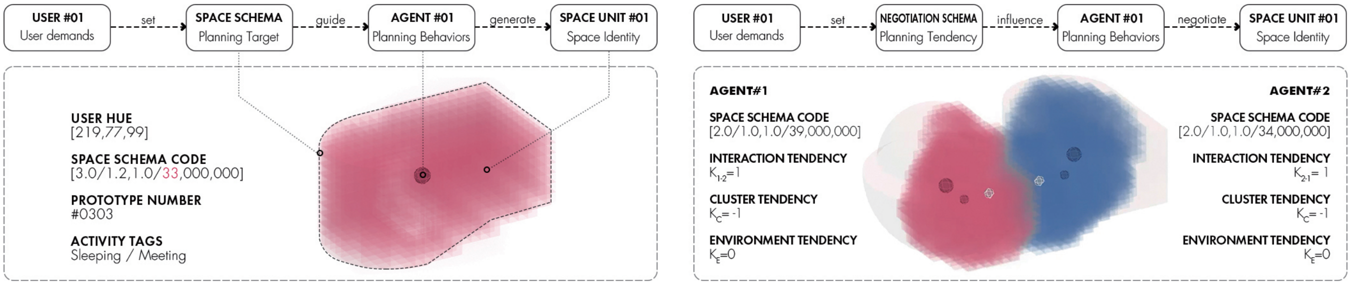
3 Integration of local agents and global constraints from the platform to the space planning algorithm

F) define the target space's volume, proportion, and form. Negotiation Schema parameters (I, C, E) define the agent's relationship with its neighbors, neighbor clusters, and the planning environment (Figure 4). Deep Reinforcement Learning with Self-Play was used to train the agents to maintain a mapping between their Space Schema goals and their adjusted volumes while negotiating their space in relation to each other through their Relational Schemas and Negotiation Schema parameters (Figure 4). Different types of agents were trained and tested through a series of experiments with 2 users and 5 agents (Figure 5). The trained agents were applied to the design of a station to get real-time results with different occupancies (Figure 6).

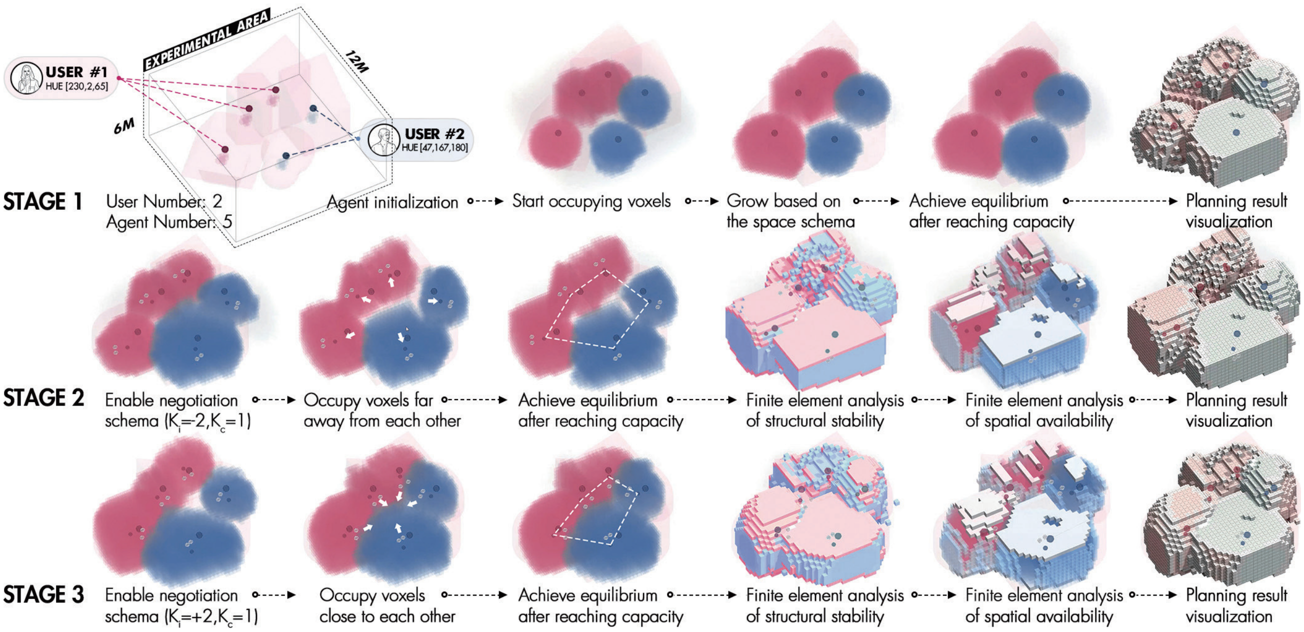
The distributed robotic material system was developed with a structured environment, where distributed robots slide their bodies on tracks built into passive blocks that enable their locomotion while utilizing a locking system of knobs to reconfigure the assemblages they move across (Figure 7).

The distributed robots have L-shaped bodies of three voxels with behaviors for sliding, changing direction, pushing and pulling, locking and unlocking static parts (Figure 7). Our custom robotic control system employs a wireless bi-directional communication protocol that connects the Unity 3D simulation environment to the physical environment, triggering the Dynamixel motors while returning motor sensor data. Our physical prototype testing demonstrated a series of locomotion and reconfiguration tasks (Figure 8). Self-play reinforcement learning was used to train multiple robots in the simulator to cooperatively reconfigure a wall from a default state through efficient sequences closely matching the series of goals (Figure 9).

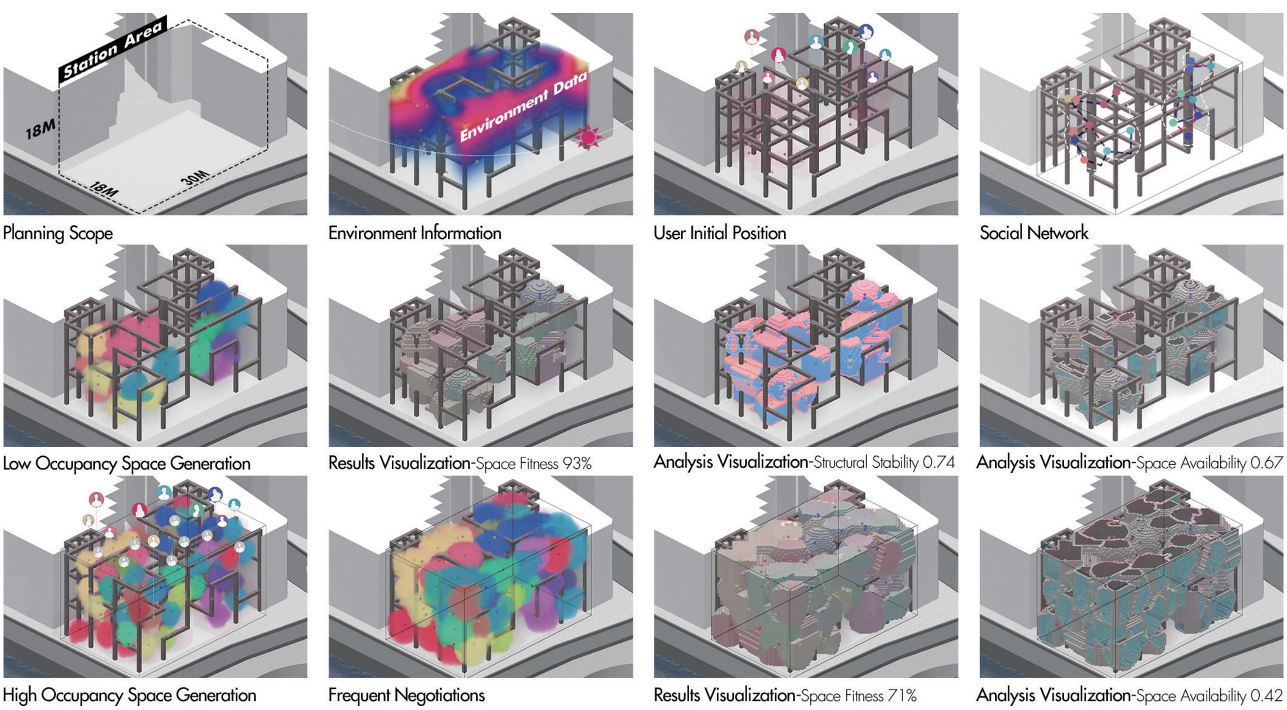
TESSERACT is situated within a larger body of research undertaken at the Living Architecture Lab at the Bartlett related to developing autonomous architecture systems (Hosmer and Panagiotis 2019). By designing the three subsystems in relation to each other— with a cyber-physical



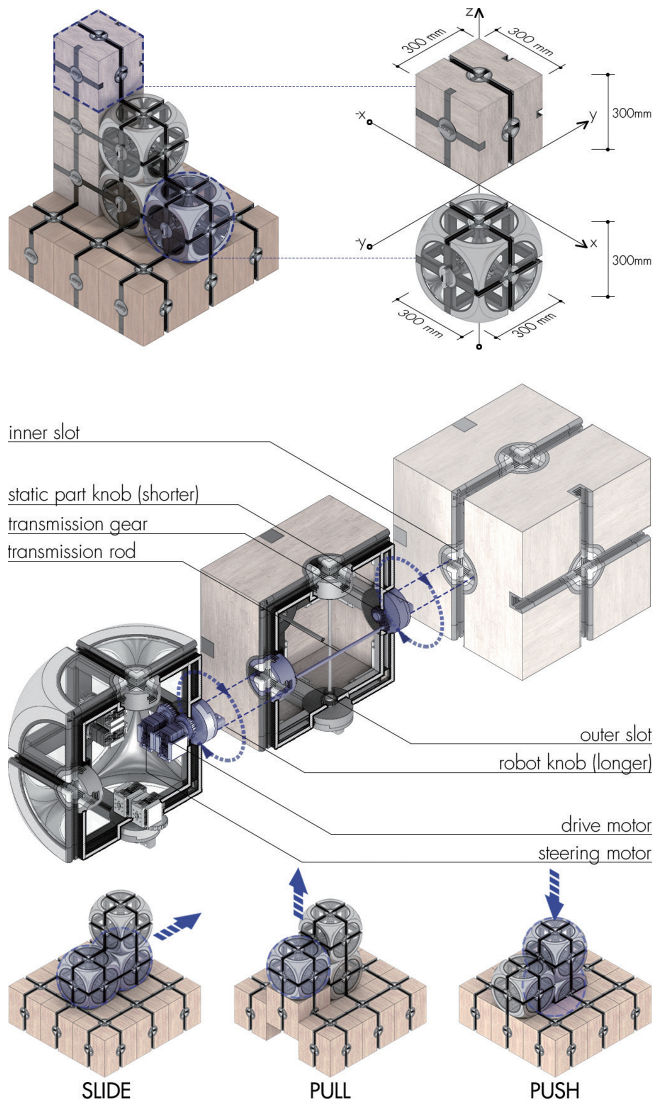
4 Space schema and negotiation schema control the agent's occupation and negotiation behaviors



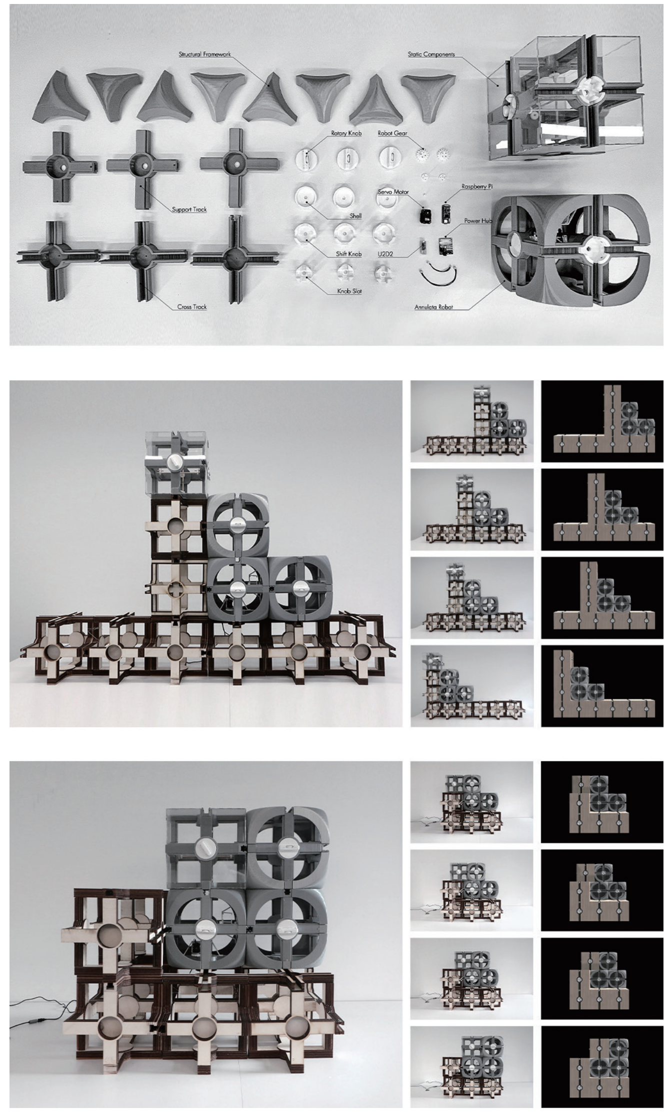
5 Multi-user space negotiation experiments



6 The generation process of TESSERACT's example station in different occupancy rate



7 Static parts and distributed robots, joint details, and action examples



8 The physical prototype tests: locomotion and reconfiguration

control protocol that considers both the constraints of the AI-driven space planning algorithm and the robotic material system—this research has potential for autonomous physical adaptation with a continuous feedback loop. The project further speculates on the potential for this to fundamentally change our relationship to our built environment through its socio-economic proposition.

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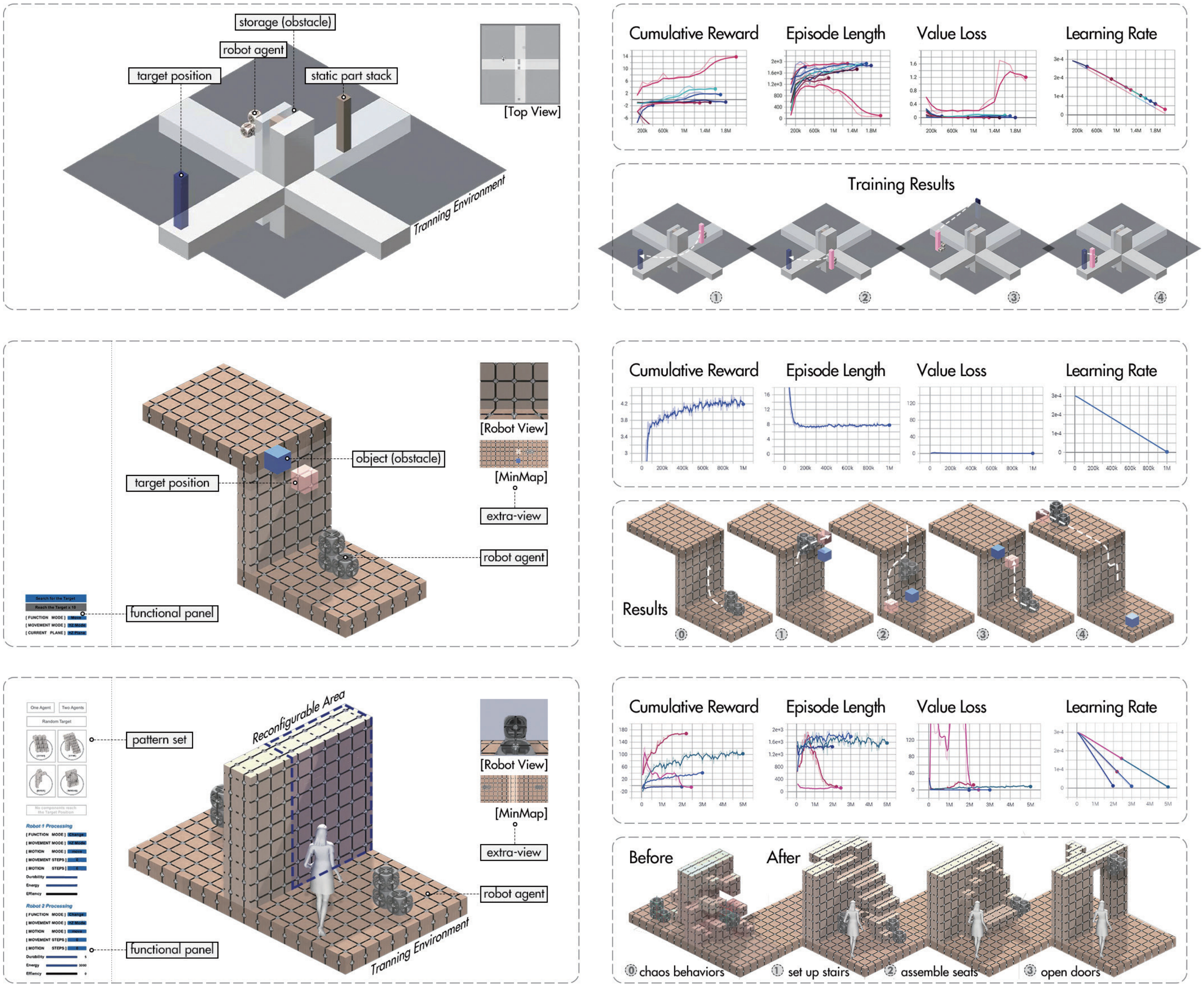

9 Three stages of the deep reinforcement learning: (1) 2D transporting, (2) 3D path finding, and (3) cooperatively design goal assembling

IMAGE CREDITS

All drawings and images by the authors

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