Co-Creative Robotics

Turn-Based Human–Robot Assembly for Architectural Design Exploration

Victor Sardenberg[1], Hans Sachs[2], Yusuf Aykin[3], Bo Schneider[4]
[1]Universidade Presbiteriana Mackenzie, [2,3,4]Technische Hochschule Ostwestfalen-Lippe
[1]vsardenberg@gmail.com, [2]hans.sachs@th-owl.de, [3]yusuf.aykin@th-owl.de, [4] bo.schneider@posteo.de

Abstract. *This paper investigates co-creativity in architectural robotics through a design-research experiment that repositions the robot from a fabrication tool to an active collaborator in spatial exploration. A turn-based assembly process enables a human designer and a robotic arm to alternately place modular bricks within a shared three-dimensional environment. Each move is evaluated through computational rules—support, stability, and collision—and interpreted in real time via an AI image-to-image diffusion model. This sequential exchange establishes a reciprocal design dialogue: the human reads the robot's action as a spatial proposition, while the robot responds to the evolving structure. Creative agency becomes distributed across human and machine, encouraging reflection on intent and positioning robotic intelligence as a source of suggestion rather than execution. By prioritizing responsiveness and interpretation over efficiency, the research challenges conventional file-to-factory paradigms and frames robotics as an active participant in design thinking. It contributes to discussions on human–machine collaboration by proposing co-creative robotics as a framework for rethinking authorship in architecture.*
Keywords. *Human–robot Collaboration, Co-Creation, Computational Creativity, Robotic Fabrication, Artificial Intelligence, Digital Fabrication, Generative Models, Discrete Assembly, Human–Machine Interaction.*

INTRODUCTION

Robotics has expanded architecture's capacity to act through material, process, and form, enabling complex geometries and digital-to-physical workflows. Yet, robots largely remain executors: Tools that translate predetermined models into material form. This file-to-factory paradigm confines creativity to the human, limiting shared authorship. Recent advances in artificial intelligence and interactive computation challenge this division. Coupled with adaptive algorithms and perceptual feedback, robots can move beyond precision to participate in design. This shift reframes robotics from a fabrication tool to a design medium, in which design emerges through human–robot interaction rather than through a deterministic chain of commands.

This paper explores this transformation through a co-creative robotic system that embeds design interaction within a reciprocal workflow. The study argues that by fostering mutual interpretation, co-creative robotics opens new pathways for shared imagination beyond automation. Crucially, it reframes design not as a solitary act of control but as a participatory and playful process: one that invites designers to engage with machines as co-authors.

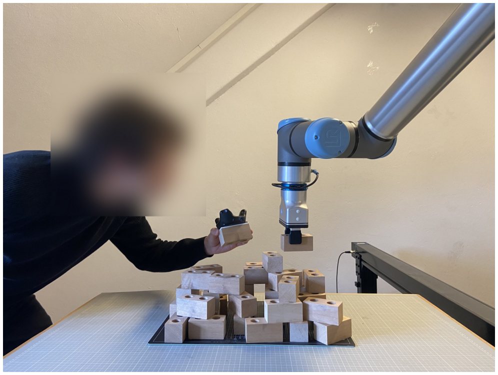

Figure 1
Turn-based human–robot co-creation setup using a UR10e robotic arm and wooden building blocks (80 × 30 × 30 mm). The human participant places a block tracked by a Vive sensor, after which the robot computes and executes its response.

From Screen to Material Interaction

Computational design has transformed how architects conceptualize and produce forms, yet the interface between designer and machine has remained largely confined to the screen, keyboard, and mouse. These tools privilege abstraction, precision, and representation over embodiment and material engagement. These interfaces have enabled unprecedented formal control and parametric flexibility, but they also delimit how designers sense and respond to the spatial and material consequences of their actions. The body is often displaced by a graphical interface that translates intentions into code, commands, and pixels.

In contrast, working physically and collaboratively with robots reintroduces the body and material feedback into the computational loop (Figure 1). When the robot operates in the same physical space as the designer, design becomes an embodied conversation rather than a symbolic instruction set. This mode of interaction does not replace computation but extends it by transforming it into a tactile and situated process (Figure 2). The model is not simply a miniature representation, but a medium of thought and a tool for spatial speculation (Baumgartner et al., 2014). In this co-creative context, the robot joins that process, allowing the model to evolve through material negotiation between human and machine. This recalls the ethos of digital crafting, where computation is not detached from making but embedded within it. The co-presence of human and robot around the model foregrounds a new kind of digital craft: one in which the machine doesn't execute a prewritten design but participates in its unfolding.

Architecture as a Game

For the Dutch philosopher Johan Huizinga (1872–1945), play goes beyond physio-logical or psychological reflexes. As argued in Homo Ludens (Huizinga 1980), play is neither instrumental nor secondary to culture: it precedes it. All animals play, and every culture is rooted in play. Huizinga saw play as a voluntary, rule-bound activity that transcends necessity and resists reduction to external purposes such as relaxation, imitation, or the discharge of energy. Its defining feature is the fun of play: a pleasure that is self-contained, purposeless, and essential to the formation of meaning.

Architecture shares this ludic foundation. Le Corbusier’s famous description of architecture as “the masterly, correct and magnificent play of masses brought together in light” (Corbusier,

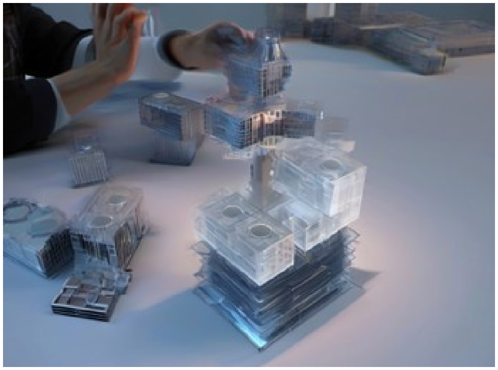

Figure 2
Stable Diffusion rendering extrapolating the co-creative assembly into a speculative architec-tural model. The generated image visualizes the interplay of modular volumes, translating the physical stacking process into a conceptual expression.

1985) situates design within the logic of play. Similarly, Jeffrey Kipnis defined architecture as "a series of effects or games that a few people have an exaggerated relationship to" (Kipnis, 2017), emphasizing that meaning often emerges from repeated engagements with the same disciplinary problems: inside and outside, part and whole, mass and void. Architecture thus consists of a multiplicity of overlapping games, each governed by internal rules that invite invention.

In this sense, the co-creative robotic framework proposed here can be understood as the staging of a new architectural game: One in which the human and the robot share the board. Each player alternates in turns, making moves that follow certain constraints yet remain open to improvisation and surprise. The robotic system's sensor feedback and generative responses establish the rules of engagement; the human designer brings intuition, anticipation, and curiosity. Within this bounded field, form emerges not as a solution to a problem but as the trace of a shared ludic imagination.

Such an interpretation situates co-creative robotics within the lineage of aesthetic play discussed by Huizinga, Schiller (Schiller, 2004), and Kant (Kant, 2000), where pleasure arises from the free play of faculties – between understanding and imagination, rule and sense. When the designer engages materially and temporally with a robotic partner, the act of making becomes both representation and speculation. Architecture, in this view, is not only the construction of buildings but also the production of images and models.

Co-Creativity Between Humans and Machines

If, as Huizinga argued, culture and imagination originate in play, then the emergence of generative artificial intelligences is a new stage in this ludic continuum: one in which machines begin to participate in the cultural act of imagining. Systems such as Stable Diffusion do not invent from nothing; rather, they interpolate and recompose from vast datasets of human creations. Their capacity to generate novelty lies not in autonomous creativity but in the manipulation of learned patterns: a form of probabilistic play across latent spaces (Gün, 2025).

This dynamic reframes creativity itself as a distributed process. The designer no longer stands as the sole author but as a participant within a broader ecology of agents (human and non-human) that collectively produce images. In this sense, co-creativity implies a shared field of action where intuition meets computation (Kretzer, 2024).

Engaging with generative models invites a new kind of aesthetic dialogue. When designers prompt, select, and curate outputs from systems like Stable Diffusion, they engage in a reciprocal game: the model plays with probabilities, and the human plays with interpretation. The pleasure of this exchange (its "fun" in Huizinga's sense) stems from its unpredictability. Each generated image is both familiar and strange.

The robot or algorithm becomes a partner capable of proposing moves within the game, thereby not replacing imagination but reflecting and amplifying it. This shared authorship transforms the act of design into an iterative loop of anticipation, surprise, and response.

RELATED WORK

A body of research has sought to bridge digital design and physical construction, emphasizing real-time collaboration and the integration of computational intelligence into material practice.

Deep learning techniques have enhanced robotic perception in construction contexts, advancing from object detection to real-time decision-making in complex environments (Aykin et al., 2025). By integrating semantic understanding into the robotic workflow, this research supports more autonomous behavior and lays the groundwork for systems capable of nuanced human–robot collaboration in architecture.

Augmented reality (AR) frameworks have integrated on-site masonry construction, allowing designers and robotic systems to collaborate in real time (Song et al., 2023). Their work demonstrates how visual guidance and data exchange can align human intuition with robotic precision, optimizing design-to-fabrication workflows.

The Prototype-as-Artefact project (Atanasova, 2020) demonstrates an AR-mediated human–robot fabrication process in which design decisions emerge during construction. Alternating actions between human builders and a collaborative robot demonstrates how intuitive human judgement and machine precision can coexist within a shared design grammar, transforming fabrication into a real-time co-creative act.

A framework for collaborative robotic masonry was explored in which a human mason and a robotic arm jointly perform construction tasks (Das, 2019). Using RGB-D (red-green-blue depth) sensing and electromyography to monitor fatigue and posture, the system dynamically redistributes labor between human and robot, proposing a model of embodied co-creation that enhances both ergonomic well-being and craft precision in construction.

Another AR-assisted framework enables real-time dynamic task sharing between humans and industrial robots in construction by combining an immersive AR authoring platform with live robotic control (Fazel & Mcgee, 2024). The system allows users to allocate and adjust tasks intuitively during fabrication. This approach advances interactive co-working environments between human decision-making and robotic execution.

A motion–tracking–assisted robotic fabrication method was demonstrated by coupling HTC Vive trackers with a UR5 robotic arm to machine workpieces beyond the robot's reach (Sardenberg et al., 2021). By manually guiding the material through the workspace, full-scale architectural columns were fabricated, illustrating how low-cost tracking systems can extend robotic capabilities and support craft-based, interactive fabrication workflows.

A large-scale human–robot collaboration for filament-wound structures was demonstrated through an interdisciplinary live exhibit that combined custom robotic fabrication with wearable human interfaces (Vasey et al., 2016). The project showcased a hybrid workflow in which tasks were dynamically exchanged between humans and robots via real-time instructions, highlighting how coordination, communication, and adaptability can integrate robotic precision with human intuition in architectural production.

Collectively, these studies point to a shift toward real-time, embodied collaboration in architectural robotics, where human intuition and robotic precision converge through technologies such as augmented reality, motion tracking, and sensing. Yet, most remain focused on execution and assembly, confining robotics to the fabrication phase. The role of robots as creative partners in early design, capable of shaping conceptual and spatial decisions, remains largely unexplored and constitutes a knowledge gap. This research addresses that gap by repositioning the robot within the ideational and aesthetic dimensions of design.

METHODOLOGY

Co-Creative Robots Framework

The co-creative robotic framework was developed as a hybrid environment integrating Grasshopper, Python, and AI-assisted visualization. Initially, ChatGPT was used interactively to determine each robotic move by generating new code at every step. While this enabled nuanced reasoning, it proved too slow for real-time interaction. The workflow was therefore restructured, with ChatGPT authoring a self-contained Python script embedded in Grasshopper, enabling local execution and real-time response. The script managed a turn-based assembly sequence, alternating between human and robotic actions within a defined 3D bounding box. Assembly states were stored in persistent memory, tracking both human- and robot-placed elements. Geometric routines handled support detection, collision avoidance, and spacing

Figure 3
Experimental setup integrating the UR10e robotic arm, Grasshopper and Python interface, and Stable Diffusion visualization. A 60-inch display projects AI-generated speculative imagery of the evolving assembly, creating a real-time aesthetic feedback loop that informs the human participant's design decisions during co-creative interaction.

constraints based on the dimensions of the wooden blocks (80 × 30 × 30 mm). At the same time, the PhysX plugin simulated gravity to ensure structural stability before each move. A Vive tracker (Fig. 3 and 4) system enabled spatial registration: each placed block was briefly tracked to synchronize the digital and physical models. The robotic workspace was defined as an 80 × 60 cm area on a 2 × 1 m table, operated by a UR10e robotic arm mounted on a linear track. Visual feedback was provided via a live camera stream sent to a RunPod server running Stable Diffusion, which generated architectural interpretations of the evolving structure. These images, generated by a consistent prompt, were displayed in real time on a 60-inch screen, allowing participants to reinterpret the assembly as architectural scenarios and to link computational logic with aesthetic imagination.

Workshop Testing

The co-creative experiment took place at the TH-OWL in Detmold in 2025 as part of a design-research workshop on human–robot collaboration. Five participant groups, each composed of architecture students and researchers, were invited to explore different design intents:

Rotating towers, emphasizing vertical repetition and torsional alignment; Self-supporting assemblies, testing overhangs and equilibrium; Pile-like compositions, exploring randomness and aggregation; Branched structures, emphasizing connectivity between clusters; and Hybrid geometries, combining rule-based and intuitive placement strategies.

Each group interacted with the system through turn-based co-creation, alternating physical placements with robotic responses. Human actions

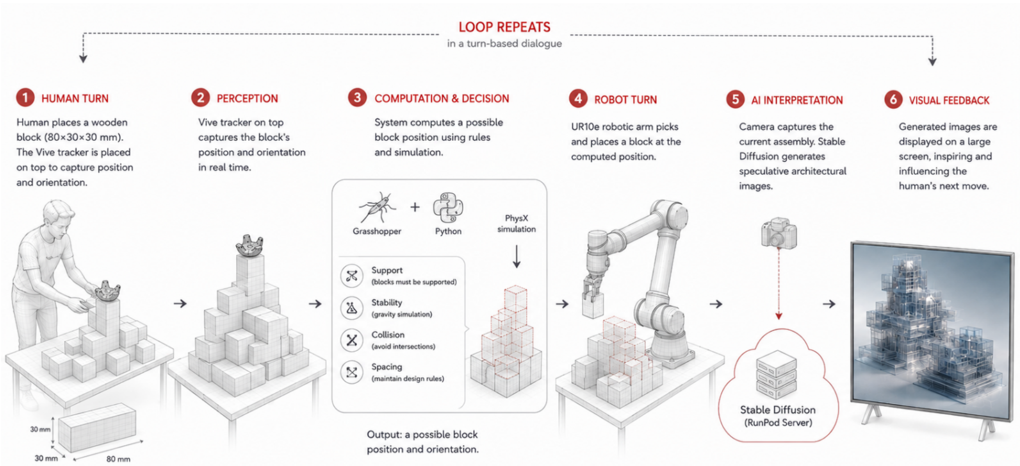

Figure 4
Diagram representing the co-creative robotic loop.

Figure 5
AI-generated speculative visualization produced through Stable Diffusion during the co-creative process. The image extrapolates the tabletop assembly into an imagined urban-scale scenario, illustrating how generative feedback can transform a small physical interaction into an architectural vision that blurs the boundary between model and city.

were captured and synchronized digitally via the Vive tracker, while robotic decisions were computed and executed through the Grasshopper–Python logic. Between turns, the Stable Diffusion projections (Fig. 5) served as speculative "mirrors" of the emerging structures, helping participants reassess their strategies through visual association rather than quantitative feedback.

RESULTS AND OBSERVATIONS

Across the five design scenarios (rotating towers, self-supporting assemblies, pile compositions, branched structures, and hybrid forms, Fig. 6), a diverse range of spatial organizations emerged. Despite operating under the same geometric constraints and robotic logic, each group developed distinct organizational patterns reflecting different balances between order and spontaneity. These contrasting outcomes underscored how small variations in human input could propagate through the system, producing complex emergent behavior from simple rule sets.

The AI-generated visual feedback had a pronounced influence on design strategies. When projected images suggested recognizable architectural typologies, such as towers, walls, or clusters, participants often shifted their approach, aligning the physical assembly with these visions. In other cases, the imagery inspired deliberate divergence, as teams explored how to contradict or reinterpret the system's predictions. This feedback loop between physical and imagined construction fostered an expanded sense of agency, in which aesthetic intuition was guided not by optimization but by dialogue with the machine's imagination.

DISCUSSION

Co-Creative Dynamics: Alternating Agency and Emergent Authorship

The experiment's human–robot design process revealed a rhythm of alternating agency, in which control passes back and forth between the designer and the robotic system. In this co-creative dynamic, the human would make a choice or intervention, then the robot would respond with its own adaptive move and call for a dialogue of making. The result is an emergent authorship of the artifact that transcends a single author; the design is neither solely human nor machine, but a product of their interactive exchange. In our case, the robot's moves (e.g., incremental adjustments, placement of material) often prompted the human to see new possibilities and vice versa – a process in which each interaction informs the next. This iterative feedback loop yielded creative outcomes that neither party could have fully envisioned alone.

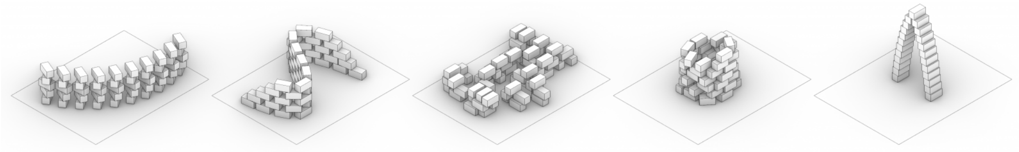

Figure 6
Five design variations developed by the workshop participants.

In other words, the design grows from a conversation rather than a top-down plan. By shifting between human and robotic initiative, the workshop demonstrated how authorship becomes shared, and the final design encapsulates decisions made by both agents. It echoes early visions in cybernetics and design research – for example, Nicholas Negroponte's idea of an "architecture machine" that would collaborate with designers in creative exploration (Negroponte 1970). Our findings put such concepts into practice, highlighting that when agency alternates dynamically, the creative process becomes a two-way street. The co-creative dynamics observed here thus point to a future in which design is a "co-evolutionary dialogue" between human and machine, with unpredictable, richer results emerging from this synergy.

Pedagogical Implications: Making Robotics Legible as a Design Medium

One of the most important outcomes of the experiment is how it reframes robotics as a legible and approachable design medium, particularly in educational contexts (Kondziela et al., 2025). In the workshop, participants quickly moved beyond intimidation, engaging with the robot as they would with any creative tool – experimenting, adjusting, and learning through making. This hands-on interaction fostered embodied knowledge of both material behavior and robotic capabilities.

Such integration reflects broader shifts in architectural education, where the divide between design and fabrication is dissolving in favor of iterative, tool-assisted learning. As students began to anticipate and interpret the robot's behavior, robotics became demystified: it is less a black box and more a collaborative partner in design. This aligns with studies showing that combining craft sensibilities with robotic tools can offer enriched ways of engaging materials and processes.

By positioning the robot within the design process – not just at its end – our co-creative setup encouraged students to develop fluency in both physical and digital making. The result is a pedagogical model that supports experimentation, adaptability, and a more open mindset toward intelligent tools. In this way, "dialogue-to-design" becomes not only a technical framework, but a valuable teaching strategy for future architects.

Cultural Dimension: Robotic Craft as Performative Collaboration

Beyond the technical and educational aspects, this experiment frames robotic making as a performative collaboration. Instead of a sterile, hidden automation process, the workshop revealed a lively studio performance between human and machine — a kind of duet in which gestures and movements continuously responded to one another. The artifacts produced carry the memory of this improvisation: subtle asymmetries and variations that document decisions made in the moment.

Reframing robotic craft as performance challenges the conventional narrative of automation as precision and repetition. Here, the human touch and robotic accuracy converge in real time, turning fabrication into a shared creative act. By making robotic fabrication "a creative design performance" (Tokac, 2025), the process becomes legible, participatory, and culturally meaningful — engaging audiences not only with the final object but with the act of building itself.

This perspective positions the robot not as a replacement for craftsmanship but as a partner in a new, hybrid form of craft — one that is dynamic, transparent, and collaborative. It transforms automation from a paradigm of replacement into one of dialogue and co-creation.

Limitations of the Current Approach

While the workshop was conducted at model scale, the goal was not to automate scale model making, but to explore co-creative design processes that could later inform full-scale construction – whether through traditional means, larger robotic systems, or swarms of small cooperating robots. The models served as spatial prototypes, testing how alternating agency between human and machine could generate design logic adaptable to 1:1 realization.

The setup relied on a single robotic arm and a simplified material system (uniform wooden blocks), which enabled clear observation of interaction dynamics but did not account for the complexity of real construction materials or multi-agent coordination. Similarly, structural logic was only approximated through simulation and simplified stacking rules. While adequate for the scope of the experiment, scaling up will require new approaches to material variability, distributed authorship, and construction-level constraints.

Finally, the process was intentionally slow and reflective, suited to a design research context rather than industrial workflows. These limitations frame the experiment as a proof of concept, demonstrating that robots can meaningfully participate in early-stage design. The real contribution isn't the output itself; it's showing how co-creative interactions at model scale can seed scalable design-to-construction workflows grounded in shared authorship.

Future Integration and Research Directions

Building on the insights and acknowledging the limitations, we envision several directions to advance co-creative robotics in design and architecture. A key avenue is enhancing the robot's learning and adaptability. In our workshop, the robot followed preprogrammed rules and responded deterministically to human input. Future systems could incorporate machine learning, allowing the robot to improve its responses over time or even predict the designer's intentions.

In a co-creative setting, a robot with reinforcement learning could learn from a designer's feedback – for example, adjusting its technique if the human frequently intervenes or signals dissatisfaction. This could lead to a more fluid partnership, where the robot anticipates and adapts in real-time rather than just reacting. Similarly, integrating multi-modal sensing and feedback loops will be crucial. Our current setup could be expanded with computer vision, depth sensors, tactile sensors, or even auditory cues, giving the robot a richer awareness of both the material and the human collaborator's actions. We foresee co-creative robots that can "see" what they are building via Computer Vision and perhaps recognize the designer's gestures or the state of the design, leading to more nuanced interactions.

Another exciting direction is scaling up through multi-agent cooperation. This could mean a team of robots working with one or more human designers simultaneously – a scenario that could tackle larger, more complex constructions. In a co-creative context, this might mean different robots taking on complementary roles (one places components while another secures them, etc.), all the while coordinating with human input. Developing a shared language or interface for multi-robot, multi-human dialogue will be an important research challenge. Finally, expanding the material palette and fabrication processes is on the horizon. Each of these research directions brings its own challenges – technical, practical, and even ethical – but together they sketch a roadmap toward truly symbiotic design automation.

CONCLUSION

This study introduced a shift from conventional file-to-factory workflows to a dialogue-to-design approach, in which humans and robots engage in co-creative, turn-based design processes. Rather than automating outcomes, the system fosters iterative interaction, enabling shared authorship and real-time spatial negotiation. The robot is positioned not as a tool for executing plans, but as a participant in their formation.

Though tested at model scale, the principles demonstrated – alternating agency, procedural feedback, and speculative visualization – can inform scalable design-to-construction workflows. The models act as spatial prototypes, proposing ideas that could be realized 1:1 through traditional construction, larger robotic systems, or distributed robotic agents. In this framework, creativity becomes a shared and evolving process, grounded in responsiveness rather than predefinition.

Pedagogically, the system makes robotics legible as a design medium, and culturally, it repositions robotic craft as a collaborative and performative act. Rather than scripting every move, designers engage in a dialogue with computational systems – balancing intuition, structure, and suggestion. This invites new perspectives on process, authorship, and agency within architectural practice.

What emerges is a vision of architectural design where machines are not endpoints but interlocutors – entities that propose, respond, and learn. The studio of the future may be less about mastery and more about mediation: a space where humans and machines co-compose spatial futures. This isn't automation as an escape from design – it's an invitation to design with.

We conclude with a call to action: it's time to move beyond the human vs. machine dichotomy. The next design revolution may well be human with machine, united in creative dialogue – an alliance that transforms how we design, build, and imagine our world.

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