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Rethinking Human-Autonomy Teamwork in the Context of Design and Robotic Fabrication

Iremnur Tokac[1], **Caja Thimm**[2], **and Sigrid Brell-Cokcan**[1]

1 Individualized Production in Architecture, RWTH Aachen University, Germany
2 Media Studies and Intermediality Department, University of Bonn, Germany

Abstract

The integration of autonomous agents in design is challenging due to its unstructured nature. The increasing focus on human-robot interaction (HRI) is driven by its potential to address this issue, enabling human-robot teams to effectively manage creative design tasks. This paper aims to identify interactive processes among the agencies of humans, robots, and materials. We explore how HRI can shift robotic fabrication from a linear deterministic process to an iterative co-creation one. Through reflective analysis of robotic fabrication studies, we illustrated how interaction interfaces can distribute agency among humans, robots, and materials while negotiating the design intent with material and machine constraints. Finally, we discuss the potential of robots to complement human expertise, embracing the material unpredictability as a design quality.

Keywords: human-robot interaction, autonomy, design, agency, co-creation

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CONTACT Iremnur Tokac • tokac.celikyay@ip.rwth-aachen.de • RWTH Aachen University • Production Engineering Cluster • Campus-Boulevard 30 • 52074 Aachen • Germany

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Introduction

In architecture and design, robotic fabrication has introduced new opportunities by allowing designers to investigate materials through versatile mechanical manipulations at various scales. Typically, robotic fabrication follows a linear process, starting with digital modelling of a predefined form and proceeding to programming the robotic motion trajectories for the fabrication of this form. This linear approach often aligns well with automation processes, as it gathers data to control well-defined, pre-programmable tasks (Lee & See, 2004). Although automation facilitates great productivity to repetitive industrial tasks, it is limiting when it comes to creative tasks, such as design. Because the design process is characterized by the continuous refinement of ill-defined design intent (Gero & Milovanovic, 2020) while the tools and materials work alongside with designers to co-create new formal relationships that have not been explicitly predefined.

This co-creation process in design mostly evident in craftsmanship where each artifact is a unique outcome of the combination of human interpretation, material affordances, and the capabilities of tools or machines (Ingold, 2013). This uniqueness is hardly found in pre-programmed forms of digitally produced artifacts since the aforementioned linear approach does not allow design ideas to evolve through the interaction with materials and tools. To instate uniqueness in digitally produced artifacts, this paper explores interaction possibilities among humans, robots, and materials through analyzing a set of robotic fabrication studies. We frame our analyses within the Human-Autonomy Teamwork (HAT) model, which refers to a cooperative interaction of at least one human with one or more autonomous agents (e.g., robots) (McNeese et al., 2018).

Focusing on the shift from linear robotic production to iterative co-creation processes, this paper contributes to extending the HAT model from cooperative work to co-creation in the context of design, where goals are continuously redefined through interaction between humans and nonhumans. We present the concepts of human-autonomy teamwork, along with the main approaches to robotic fabrication in the context of design and architecture in the later work. These approaches are specifically related to material exploration, automation, and adaptivity. Lyons et al. consider agency—the capability to act when and how the agent desires—a key characteristic that distinguishes automation from autonomy and is essential for computational agents to be perceived as teammates by humans (2021). In the fields of design and human-computer interaction (HCI), the concept of agency is also widely discussed as an emergent capacity (Suchman, 2007) that arises from the interaction between humans and nonhumans.

Subsequently, we focus on the concept of agency to explore interaction possibilities within HAT in design. The paper describes the agencies of humans, robots, and materials, along with the main mechanisms involved in enabling respective agencies in the context of robotic fabrication. We analyzes a collection of robotic fabrication studies, focusing on co-creation modes guided by interaction. Finally, we discuss how interaction interfaces could facilitate co-creative teamwork between human and nonhuman agents.

We believe that realizing the potential of Human-Autonomy Teamwork (HAT) in the context of robotic fabrication in design requires exploring how interaction interfaces enables human, robot, and material agencies. Future research should focus on human-robot

interaction by investigating co-creation modes and their dependencies toward implementing more fluent teamwork in creative design tasks.

Related Work

In this section, we first present the research studies on HAT, then provide an extensive overview of robotic fabrication from automated to adaptive approaches. Finally, we present research studies demonstrating the potential of digital fabrication to embrace material complexity, thereby allowing design with and alongside materials.

Human-Autonomy Teamwork (HAT)

HAT proposes a cooperative interaction of at least one human with one or more autonomous agents (e.g., robots) (McNeese et al., 2018). Human-like characteristics are crucial for fostering social attributions in autonomous agents during cooperative interactions (Nass & Moon, 2000; Nass et al., 1994). Following studies explored the notion of *humanness* as separate from robotic autonomy and found that robots exhibiting a high degree of *humanness* can provoke significant social responses, even in the absence of autonomy (De Visser et al., 2018). Attributes like interdependence, humanness or *human-likeness* or autonomy are crucial for a machine's acceptance as a teammate (Pineda & Hecht, 2009). Current research aims to identify the key characteristics that would enable robots to serve as effective team members, despite the challenges in effective human-agent interaction (Sycara & Lewis, 2004).

HAT depends on five key concepts: agency, communication, shared mental models, intent, and (inter)dependence (Lyons et al., 2021). Agency refers to the capability and authority to act when and how the agent desires (Lyons et al., 2019). A more comprehensive view in social sciences and technology, however, considers that agency is not a fixed property or an attribute of either humans and nonhumans, it is rather an effect of an outcome that is generated through interactions (Barad, 2007; Suchman, 2007). HATs need to be able to establish common ground among human and nonhuman agents, so that they communicate through shared mental models (Schaefer et al., 2017). Mental models refer to the knowledge structures that humans use to describe, explain, and predict in engineered environments (Johnson-Laird, 1980, 1983; Rouse & Morris, 1986; Scheutz et al., 2017; Van den Bossche et al., 2011). The theory of mental models was later extended to describe teamwork dynamics through the concept of shared mental models (Cannon-Bowers et al., 1993).

Proficient communication is related to how a teammate describes their intent rather than sharing all possible information, thereby allowing the teams to focus on important issues toward a shared goal (Lyons et al., 2021). When working toward shared goals, interdependence is a core aspect of teamwork (Johnson & Vera, 2019; Kozlowski & Bell, 2003). Working interdependently means that human and nonhuman agents must perform interdependent tasks by dividing the teamwork (Luo et al., 2011). As technologies evolve from assistive tools to teammates, future research should explore the transition from human–automation interaction to human–autonomy teaming (De Visser et al., 2018), by focusing on the key aspects of agency, communication, intent, and interdependence.

From Automation to Adaptability in Digital Fabrication

Parametric control (Braumann & Brell-Cokcan, 2011) and motion simulation (Braumann & Brell-Cokcan, 2012) of industrial robots in computer-aided design enabled designers and architects to define robotic motions based on modelling geometries consisting of lines or curves that readily describe the design form. Consequently, designers explored robotic automation in the context of architecture and design while developing new fabrication techniques with cutting-edge materials (Gramazio et al., 2014), such as winding filament (Prado et al., 2017; Reinhardt et al., 2019; Solly et al., 2018), modulated fabrication of timber shell structures (Bechert et al., 2016; Krieg et al., 2015; Wagner et al., 2020), incremental forming of sheet materials (Kalo & Newsum, 2014), or 3D printing of composite plastic elements (Kwon et al., 2018).

However, these studies were characterized by a linear fabrication process, which is limited in its creative potential by the dependence on predefined digital models and predictable material behavior. Adaptive automation, on the other hand, describes automated behavior which is invoked based on a detected change in the environment of the machine, such as change in a human's state (Chen & Barnes, 2014; Hancock et al., 2013) or material's state (Nicholas et al., 2017). Implementation of sensor data facilitates the machine to detect changes in its environment and state. This approach could enrich the design space of digital fabrication with intricate material expressions as they physically appear during the physical fabrication process, maintaining a fluency. The fabrication outcome is then not predetermined but created through a dialogue in which human, robot, and material agencies interact.

Embracing Material Agency via Digital Fabrication

In traditional craft practice, the physical form of an artifact emerges through a manual making process, during which an artisan experiences material agency. Material agency describes how material affordances and constraints can inherently suggest subsequent formal transformations (Malafouris, 2008). However, the typical linear process of digital fabrication relies on geometric representations, thereby largely disregarding the inherent ability of materials to assume forms beyond geometric representations. When a material cannot fully conform to the intended digital design model, the fabricated outcome demonstrates emergent outcomes which inspire a growing group of researchers to study such *imprecisions* (Anzalone et al., 2018; Austin & Matthews, 2018; Zboinska & Dumitrescu, 2020) or *imperfections* (Murphy, 2009; Pedgley et al., 2018; Zoran, 2016) in digital fabrication.

The imprecisions or imperfections resemble craft-like expressions that can only be encountered through physical interaction with materials (Baljko & Tenhaaf, 2008). In art and design, this interaction is considered as a dialogue between the maker and the material employed (Leroi-Gourhan, 1993). Ingold terms this dialogue as a *correspondence* in which each action of the artisan received a response from the material, helping to reveal an as yet undefined final form, rather than imposing a definite form on material (2013). The tools and materials work alongside with artisans to co-create new formal relationships that have not been explicitly predefined. Such formal relationships build up a design language, which is hardly found in pre-programmed forms of digitally produced artifacts (Zoran et

al., 2014). Consequently, automation, typically characterized by linear processes, struggles to establish such a co-creation process revealing new formal relationships, which is central to design.

Exploration of the Concept of Agency for Human-Autonomy Teamwork in Design

Human-autonomy teamwork (HAT) explores cooperative interaction between humans and autonomy, such as robots (Chiou & Lee, 2016) in terms of communication (Wright & Kaber, 2005) and (inter)dependence (Walliser et al., 2017, 2019). In this cooperative interaction, humans and autonomies exhibit self-directed behaviors toward a goal, referred to as agency. However, agency describes a more comprehensive notion in creative fields. Agency is not a fixed property or attribute, but rather an emergent capacity that can be experienced when human and nonhuman entities constantly interact with each other (Suchman, 2007; Tholander et al., 2012). This section focuses on defining the concept of agency within the creative fields of robotic fabrication and human-robot interaction in design and architecture.

Human Agency

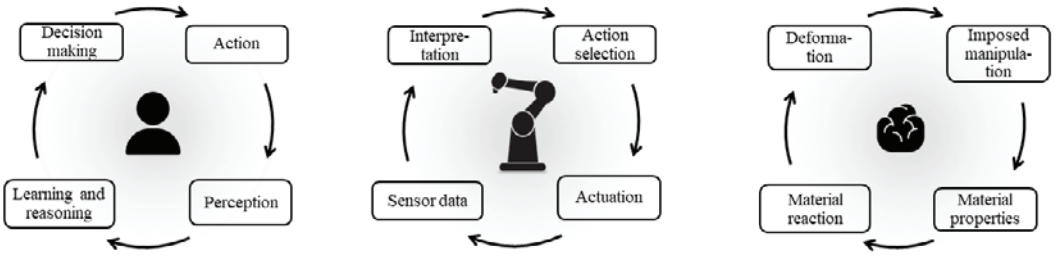
Human agency describes one's ability to reflect, adapt, and act (Gibbs et al., 2021). This involves human's cognitive mechanisms that take place from perception to action (O'Connor, 2006; Sharif, 2013), while involving environment, brain, and body (Clark, 2008, 2017). In the context of design, the continuous perception of the act of making and the material outcome dynamically shifts the design intent, as the intent is incomplete and not encompassing all possible situations and outcomes that might arise during the making process (O'Connor, 2006). This incompleteness of intent allows for learning through the process of making, while recognizing the design potential that emerges in the process.

In the context of design, artisans learn how materials take shape and reason about the potential next form before making a decision and acting on it during the process of making (McCullough, 1998). Based on this learning, the artisans iterate their design intent. Accordingly, we listed key cognitive mechanisms that take part in the iteration of design intent: perception, learning and reasoning, decision-making, action. We regard these mechanisms as the core components of human agency, which describe the capacity for human action and are almost always performed simultaneously, as illustrated on the following page in Figure 1 (left).

Robot Agency

Robot agency typically involves the mechanisms of automation, information acquisition, information analysis, decision selection, and action implementation (Parasuraman et al., 2000). Inspired by the perception mechanisms of humans, machine sensors continue to become implemented to robot systems (Tholander et al., 2012). Such robot systems then become able to collect (Kröger, 2011) and interpret (Wang et al., 2017) real-time data regarding the changes in the environment and in itself of the robot. Followingly, these

FIGURE 1 The main mechanisms that are involved in the agencies of human (left), robot (middle), and material (right).



systems can select *what to do next* (Mueller et al., 2019). For example, given an agent with a repertoire of available actions, some knowledge of its internal state, and some sensory information concerning environmental context, the task is to decide which sequence of actions to perform in order for that agent to best achieve its goals (Shah et al., 2011). Upon action selection, the physical parts of the robot system start working to actuate the selected action. The circular process starting from collection of sensor data to actuation is illustrated in Figure 1 (middle).

Material Agency

In addition to the human and robot agents, each material possesses complex mechanisms of responding to the physical manipulations that are imposed on it during digital fabrication workflow in design. Such mechanisms are framed as *material agency* within the fields of digital fabrication and design, described in detail in the Introduction and Related Work. Accordingly, each material reacts to physical manipulations due to its intrinsic properties (e.g., plasticity, ductility, or brittleness). The manipulations imposed on the material intertwine contrapuntally with its physical reaction, inherent in its properties, within an encompassing, morphogenetic field of forces. The combination of the physical manipulation and the material's reaction deforms material, which is not necessarily a conformation of the imposed manipulation (Malafouris, 2019). The loop as seen in Figure 1 (right) demonstrates the material formation with the involving mechanisms.

Defining Co-Creation in Human-Autonomy Teamwork (HAT) Guided by Interaction: Insights From a Series of Robotic Fabrication Studies

The HAT framework acknowledges that enabling one's agency increases interdependence and proactivity in the activities of that agent, leading to more fluent teamwork (Lyons et al., 2021). Agencies are figured and reconfigured at the interaction interface, with all agents continually enacting autonomy and responding through this interface (Suchman, 2007). To be able to understand and then establish human-autonomy teamwork in the context of robotic fabrication in design, it is necessary to describe how interaction enables the agencies human, robot, and material.

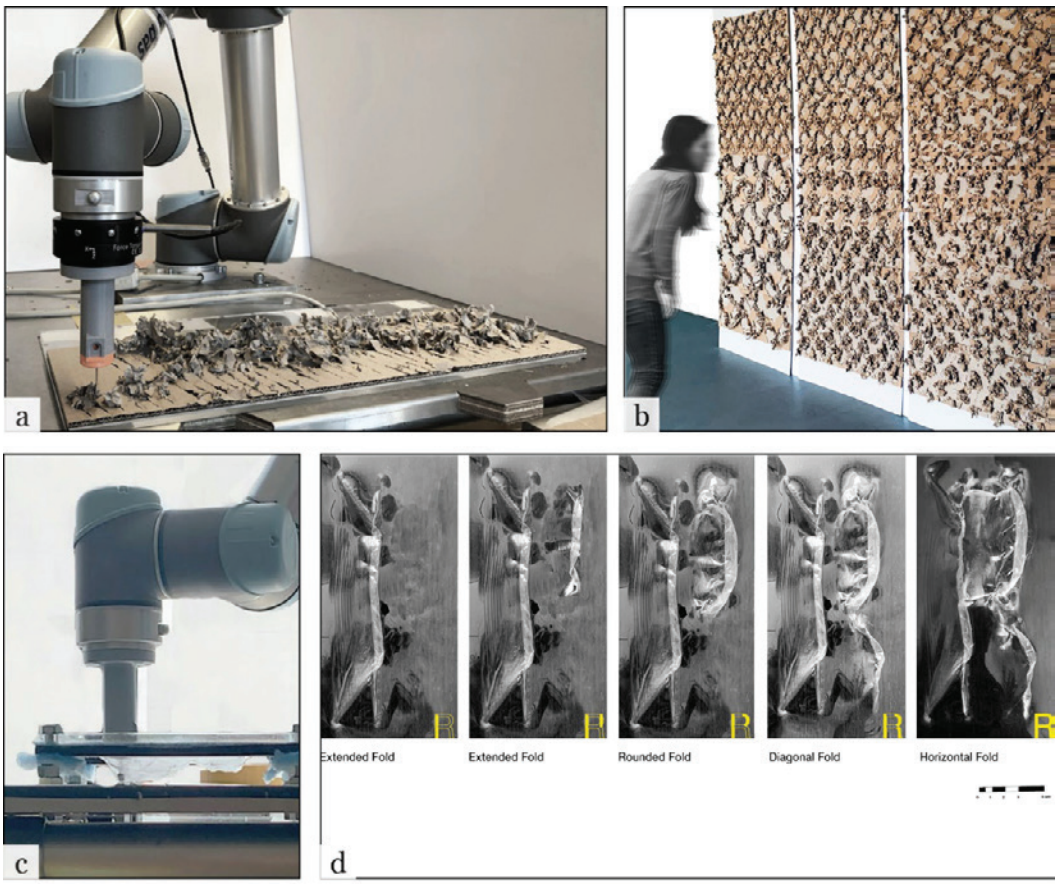
In this section, we present our insights from a series of robotic fabrication studies. It is important to note that the fabrication processes and methodologies of the presented studies have already been published in journal articles and conference proceedings, thus not constituting the contributions of this paper. Instead, this paper offers insights into how different modes of co-creation, guided by interaction among human, robot, and material agents, emerge from these studies.

Co-Creation Guided by Human-Material Interaction

Robotic Fabrication Study

First robotic fabrication study consisted of a collaborative robot that executes linear cutting operations on corrugated cardboards (Figure 2a). In this fabrication process, the designer took turns between configuring the operational parameters (e.g., speed or length of cutting

FIGURE 2 (a) Robotic cutting of corrugated cardboard wall panels. (b) The emergent frizzle cardboard effects were controlled to compose panels with intricate patterns. (c) Robotic single point incremental forming of plastic sheets. (d) Controlling ductility of plastic material into purposeful compositions, such as the letter "R."



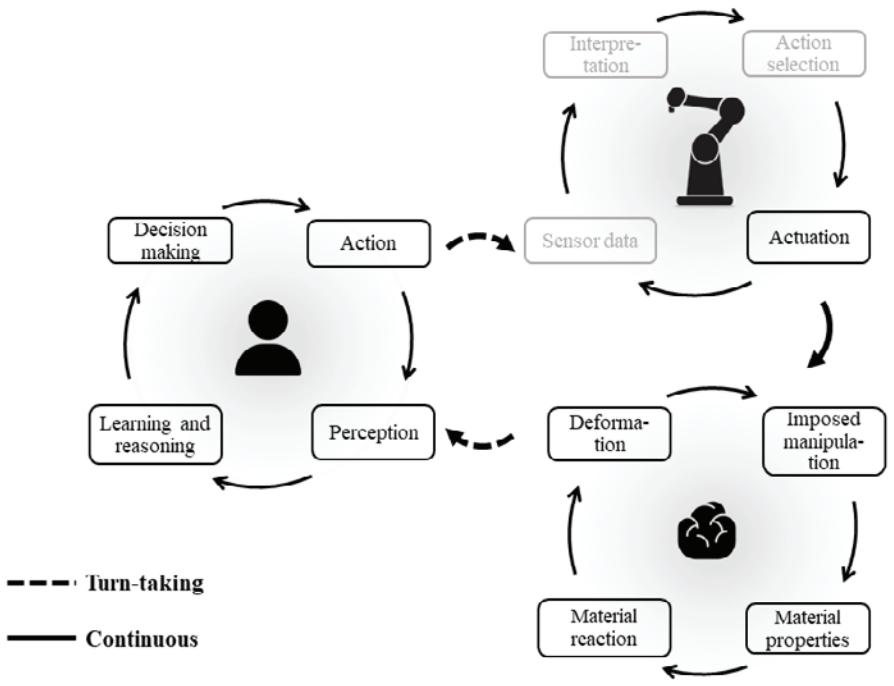
trajectory) and observing the material outcomes. From these observations, the designer perceived emergent frizzle effects and learnt how the malleable corrugated cardboard reacted to the cutting operations. Subsequently, they reasoned about controlling material deformations to achieve unique design forms by combining the accuracy of robot agency with the emergence of material agency as seen in Figure 2b (Tokac et al., 2019).

The second study demonstrated a single point incremental forming process of plastic sheets with a robotic arm (Figure 2c). In this study, the designer explored a computational model that translates the domain-specific knowledge regarding the design intent and material outcome into machine-specific information (Tokac et al., 2021). Accordingly, the domain knowledge about how the ductility of plastic could accommodate folds was transferred into the robotic forming operations to produce *R* letters composed by folds (Figure 2d).

Co-Creation in HAT

In these robotic fabrication studies, although the material and robot agencies inspired and played a part in final outcomes, the human designer proactively orchestrated the entire creative process and determined how the robot and the material agencies should be enabled. Figure 3 illustrates the interaction among human, robot, and material agencies. In this type of

FIGURE 3 Co-creation loops guided by human-material interaction. Human agent orchestrates the robotic fabrication process while taking turns between observing robot and material states. As the robot does not contain sensorial feedback, its actions rely on pre-programmed path planning by a human.



interaction, there is a turn-taking between the action and the perception of the action's outcome. Such turn-taking is characterized by separate mental models for humans and robots.

In first fabrication study of robotic cutting, the human and the robot have different mental models. Consequently, the human agent communicated their design intent to the robot by way of programming the fabrication operations. For programming, the human agent first decided a material outcome, then encoded algorithms and configured parameters to instruct the robot on how to deform material according to their initial intent. Next, the actuated robot imposed mechanical manipulations on the material, while the human agent perceived the emergent material outcomes that were not predetermined in the programming.

The human agent took turns between learning and perceiving these emergent outcomes, reasoning about their relationships with fabrication operations, and adapting the robot program to purposefully control the fabrication operations. This process signifies an interaction between human and material agencies, through which the final design is co-created based on the dependencies between material outcomes and fabrication operations. The robotic SPIF study explored formalizing such dependencies for encoding robot programs, thereby hinting at a kind of shared mental models between humans and robots in the context of design.

Co-Creation Guided by Robot-Material Interaction

Robotic Fabrication Study

We analyzed a clay carving study with a collaborative robot that was equipped with a force-torque sensor. Different from previous studies, material outcomes (i.e., the physical changes in material states) were recognized through specific sensor measurements. These measurements digitally logged what the designer perceived. Instead of predetermining the robot program, the designer formally described a repertoire of actions from which the robot could dynamically select, based on the recognized material state (Tokac et al., 2023). Figure 4 illustrates the consecutive steps showing how the robot's actions were updated in response to the protrusions formed on the clay surface and how these protrusions were composed into unique textures.

Co-Creation in HAT

In this robotic fabrication study, the human agent took turns between observing how sensor data changed during material deformation and associating the changes with fabrication operations. Through this turn-taking, the human agent defined declarative rules to combine fabrication operations based on their design intent. These rules then automized the orchestration of fabrication process by continuously adapting algorithms and reconfigured parameters without an active intervention from human agent. Consequently, a continuous interaction loop was established between the material and the robot as shown in Figure 5.

The declarative rules communicate the human's design intent to the robot based on the dependencies between material outcomes and fabrication operations, bridging between human and robot mental models. However, the final outcome is co-created through continuous interaction between the robot and the material, negotiating the design intent with both robotic and material agencies. As a result, the patterns on cardboard (Figure 2-b)

FIGURE 4 The robot carved a slit in the clay until sensing a specific heap amount, which immediately triggered the next action. It then began carving in the opposite direction, accumulating and pushing up against the initial heap to form a protrusion (top). Clay artifacts that are created through material-robot interaction (bottom).

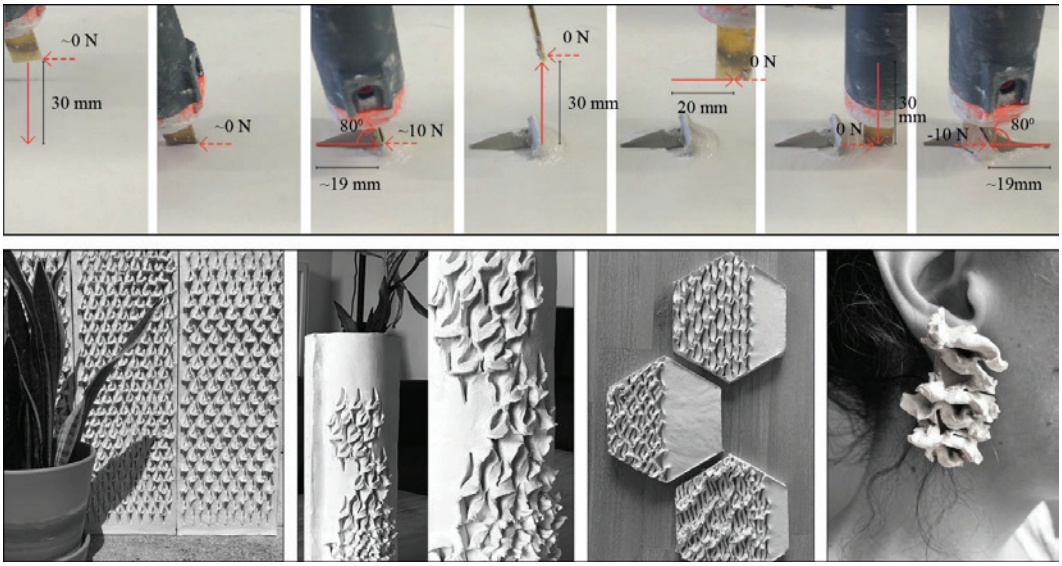
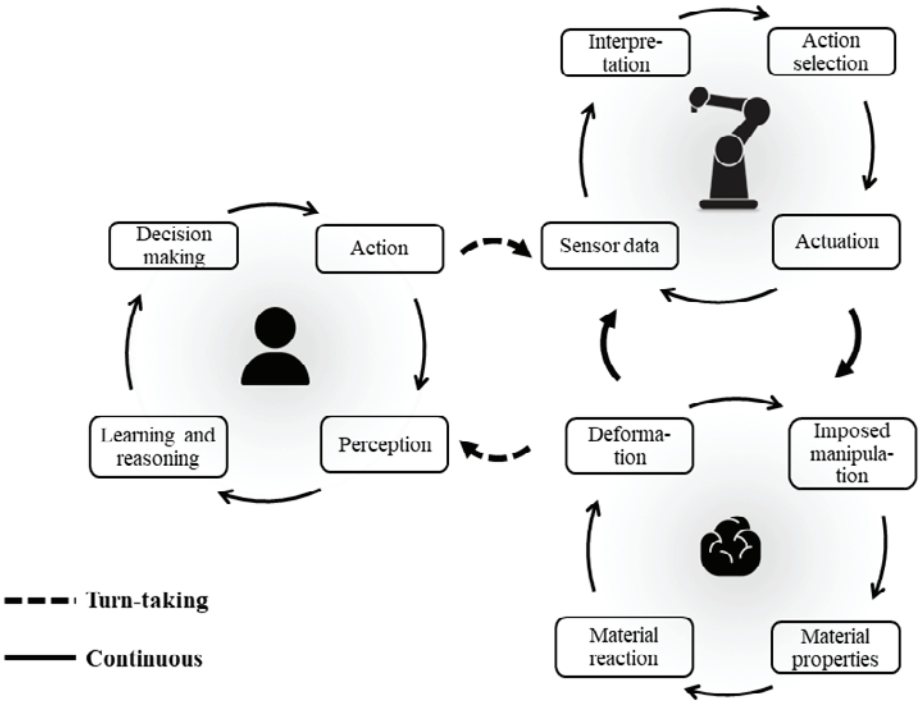


FIGURE 5 Co-creation loops guided by the robot-material interaction. Despite this initiation, the human agent does not have direct control over the fabrication process.



display a visible order, hinting at the design determination inherent in human agency. In contrast, the clay textures (Figure 4) exhibit a natural serendipity achieved through the material agency.

Co-Creation Guided by Human-Robot Interaction

Robotic Fabrication Study

Finally, we evaluated a clay carving study wherein the human designer's physical interventions to a robotic arm equipped with a force sensor control the fabrication operations on the fly. During this study, the physical interventions were recognized in force measurements and specific force values adapted the robot program automatically. The human designer constantly perceived the material deformation and updated their interventions, dynamically shifting their design intent with each update. Consequently, the designer created unique textures that were incorporated into the clay artifacts (Figure 6). The robot's

FIGURE 6 Controlling the fabrication operations through physical interventions to the robot on the fly, revealing serendipitous clay textures (top). Tile compositions by reproducing and modifying such textures found through human-robot interaction.

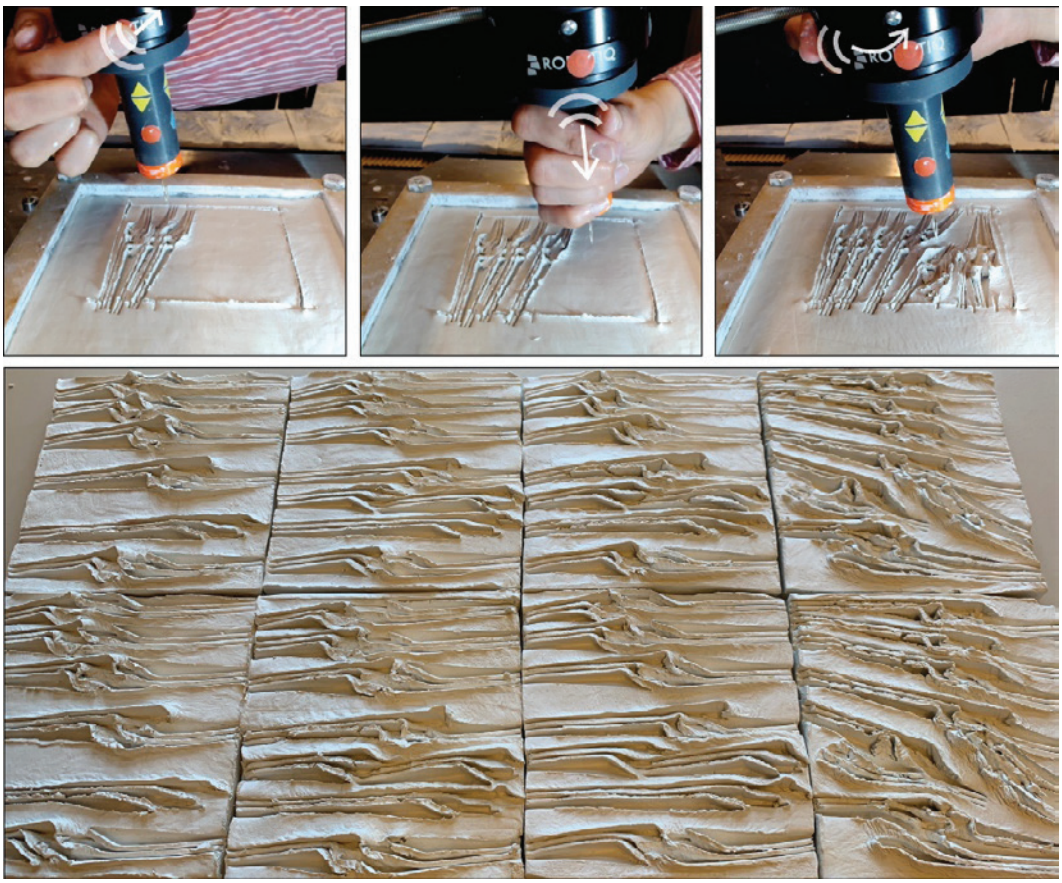
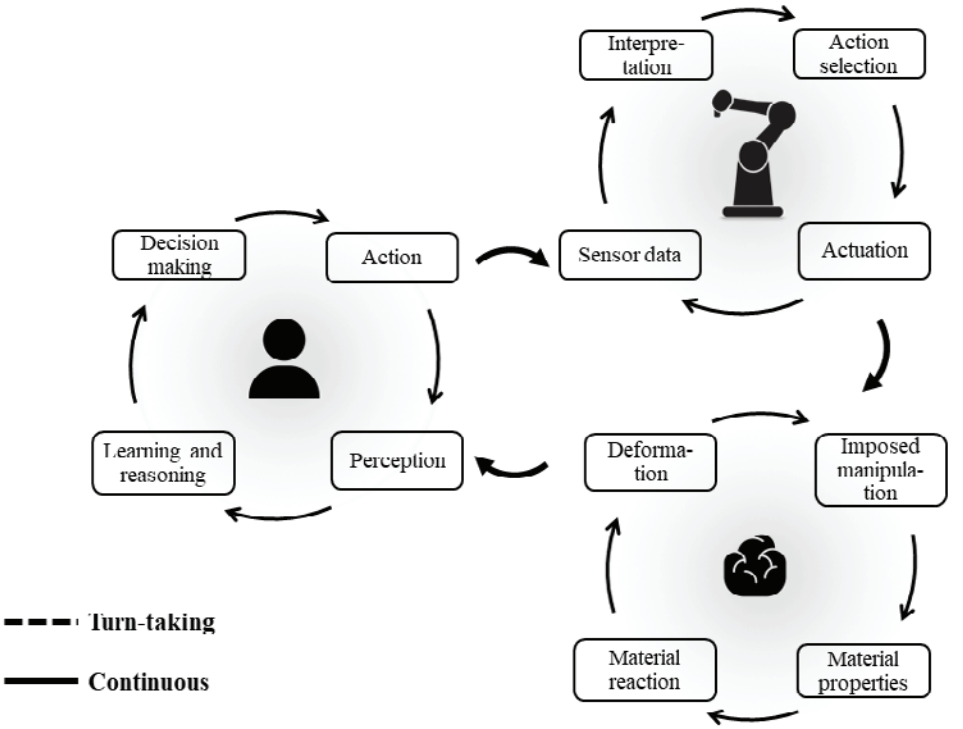


FIGURE 7 Co-creation loops guided by human-robot interaction. During this interaction, the human agent continuously perceives the material changes and immediately adjusts their interventions to the robot.



computational capabilities, such as collecting and categorizing real-time positions at each user intervention, allowed the creative process to be recorded and thus reproduced or modified (Tokac et al., 2022).

Co-Creation in HAT

In this study, the human agent continuously interacts with the robotic arm and changes the fabrication operations, establishing a human-robot interaction loop as illustrated in Figure 7. Through this loop, the human agent perceived material deformations and immediately communicated their intent by way of their actions to guide the deformation. Accordingly, the human intuitively engaged with robotic fabrication in an embodied and enactive way, eliminating the need for the designer to update algorithms or reconfigure parameters. As a result, human-robot teams begin collaboratively creating artifacts, hinting at co-creation guided by human-robot interaction.

Discussion

Based on our analysis of the presented robotic fabrication studies, we discuss how human-robot interaction interfaces should be designed to foster creative teamwork among humans, robots, and materials.

Co-Creation and the Key Mechanisms of Human-Autonomy Teamwork

We argue that understanding the mechanisms underlying human, robot, and material agencies significantly help future development of shared mental models. Such shared models potentially enable common interpretations of dynamic contexts within the teams (Cooke et al., 2013). The cardboard cutting study exemplifies a fabrication process in which human and robot agents have separate mental models. Consequently, such fabrication processes are characterized by turn-taking, wherein the design intent must be translated from the human's mental model into the robot's mental model. The robotic SPIF study suggests the rule formalisms as knowledge structures bridging between humans and robots. The following studies of clay carving show how such rule formalisms replace turn-taking with continuous interaction. These rule formalisms could potentially be used for the development of "shared mental models" (Scheutz et al., 2017, p. 203), which is the key aspect leading an intuitive communication in human-autonomy teamwork (Schaefer et al., 2017).

However, our studies present interactions wherein the robot is dependent on the human agent at different levels. As a result, the role of the robot, despite its contributions, is still at the level of a tool rather than a teammate. In highly interdependent interactions under proper conditions it can assume the role of a teammate benefiting from the increased fluidity and coherence of joint actions (Lyons et al., 2021). Going back to the notion of agency as an emergent outcome rather than a static attribute (Suchman, 2007), co-creation should be achieved through the embodied interaction between humans and nonhumans, characterized by incompleteness (Miyake, 2005).

The notion of interdependent interaction thus becomes central for human-autonomy teamwork. We believe that further consideration and development on rule formalisms toward shared mental models potentially deepen the ongoing investigations on co-creation with nonhuman agents (Han & Parascho, 2022; Saffiotti et al., 2020; Taylor et al., 2011; Thörn et al., 2020).

Computing as a Craft

The computation of fabrication operations, achieved either by turn-taking or continuous interaction, emerges as a crucial skill. This skill enables humans to uncover new design opportunities afforded by both material and robot agencies. Accordingly, the design space of digital fabrication, which is characterized by a complex computational aesthetics (Dörfler et al., 2016; Krieg et al., 2015; Reinhardt et al., 2019; Wagner et al., 2020), can be broadened to include serendipitous and emergent outcomes inherent in craft practice.

The presented studies incorporate craft sensibilities into robotic fabrication, as the human designer engages in a kind of correspondence between their actions and the artifact being created (Ingold, 2013). Different from traditional craft, the computational capabilities of robots, such as collecting and categorizing real-time positions, enable capturing the data of this creative process. Computing with such data thus allows the reproduction or modification of an authentic creative process (Rosner & Taylor, 2011; Zoran et al., 2014). This can serve to the advancement of artificial intelligence algorithms. This will enhance the computational capabilities of robotic agents to the extent that they might develop their own design language, ultimately positioning them as competent teammates in design.

Materials Becoming Proactive Participants in Digital Fabrication

The facilitated material-robot interaction presented empowers materials to proactively influence fabrication operations. The fabrication outcomes were not directly guided by the human agent; rather, they emerge due to material agency. Our study then extends the view of material agency which describes the dynamic and influential capacity of material, rather than a passive and inert entity (Barad, 2007; Knappett & Malafouris, 2008; Suchman, 2007) to robotic fabrication in the context of design. Accordingly, we reinterpret interactive fabrication through the lens of materials and broadening the studies of interactive fabrication from the perspective of human (Mueller et al., 2012, 2019; Peng et al., 2018; Willis et al., 2010).

Ultimately, we anticipate that further research into material-robot interactions will lead to data structures that enable more efficient execution and monitoring of material outcomes. The development of interfaces for material-robot interaction is a foundational step in creating a sensorial environment for autonomous agents. This environment would facilitate reasoning, rather than just learning, a capability currently attributed solely to humans in mixed human and nonhuman teams. Should autonomous agents begin to exhibit reasoning abilities, even at a basic level, their role could gradually transform from mere tools to partners or teammates.

Conclusion

In conclusion, this paper highlights the potential of Human-Autonomy Teamwork (HAT) to transform robotic fabrication from merely a production process into an iterative co-creative design process. We explored the role of interactions among human, robot, and material agents in such co-creative processes. This study argues that agency is the key concept to understand the interaction possibilities among humans, robots, and materials. Accordingly, we describe human, robot, and material agency within HAT in the context of design and robotic fabrication. The interactions among these agents and the relationships between their agencies define the various types of co-creation. Subsequently, through the analysis of a collection of robotic fabrication studies, we identified three types of co-creation, guided by human-material, material-robot, and human-robot interactions. We presented our insights for future research and the implementation of HAT in robotic fabrication by means of interaction. We believe our insights extend the concept of HAT to the field of robotic fabrication and human-robot interaction in design and architecture.

Author Biographies

Iremnur Tokac (PhD) is a postdoctoral researcher at the Chair of Individualized Production at RWTH-Aachen University, specializing in the fields of architectural robotics, computational fabrication, and human-robot interaction. She serves as an associate editor in *Construction Robotics Journal*. She earned her PhD degree from KU Leuven, Belgium. Prior to her PhD, she held an MSc degree in Media Architecture from Bauhaus University-Weimar, Germany, an MSc degree in Design Computing from Istanbul Technical University, Turkey, and a Bachelor's degree in Architecture from the same institution.

https://orcid.org/0000-0001-5217-1774

Caja Thimm (PhD) holds a chair in Media Studies and Intermediality at the University of Bonn, Germany. She has done extensive research on social communication on the web, e-learning, and e-democracy and taught as a visiting scholar at UC Santa Barbara (USA), University of Cardiff (UK), and as a professeur invité at the Université de Bourgogne Dijon (France). She also served as a member of various political committees. She was head of the research program "Deliberation Online" (2010–2016) and is now coordinator and principal investigator of the collaborative research program on "Digital Society" (2017–2022).

https://orcid.org/0009-0004-3167-7038

Sigrid Brell-Cokcan (PhD) is the founder and director of the Individualized Production chair at RWTH Aachen University and is currently the president of the Association for Robots in Architecture (RiA) and on the board of directors of euRobotics, and the editor-in-chief of *Construction Robotics Journal*. In 2018, she co-founded the cross-faculty Center for Construction Robotics to focus on the automation in construction with key industry leaders along the construction industry value chain. In the past years she has been pioneering the easy use of industrial robots for the creative industry while participating in international research and industry projects.

https://orcid.org/0000-0003-1463-7515

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