

Craft-Inspired Robotic Fabrication and Design: Dialogues Captured in the Art Form

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Abstract—The physical act of “making” is central to craft and design, where artists explore and adapt to the dynamic nature of materials and embrace emergent properties of materials as an integral part of form-finding processes. The interactions with the tools and materials, which comprise the artistic dialogue, are captured in the art form, revealing not just shape but also the memory of action and response. This art project proposes a rule-based human-robot interaction (HRI), where a collaborative robotic arm not only records the finished form but also the evolving, moment-to-moment negotiation between human intent, robotic motion, and material response. A declarative, rule-based program has been implemented as a software add-on, enabling dynamic mapping between real-time sensor input and action selection during robotic fabrication. Using this software add-on, a collection of artworks—including decorative wall tiles and 3D objects—has been created through rule-based HRI. Each piece is characterised by forms and expressions which are inherent to the materials used and the unique artistic “making” process, captured, reproduced and modified by the computational power of the robots. This art project aims to initiate interdisciplinary conversations on bridging the precision and control of robotics with the improvisation and material sensitivity of craft among HRI researchers, artists, designers, and roboticists.

Index Terms—design-through-fabrication, interactive systems, human-robot interaction, digital craft, material-driven design

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I. INTRODUCTION

An extensive body of research has demonstrated how robotic technology could transform creative sectors like design and architecture by enabling the production of digitally modelled, highly complex design elements. In particular, the integration of parametric control for industrial robots within widely used CAD platforms like Grasshopper [1] has further embedded robotic fabrication into creative and individualised production workflows [2], [3]. Through the precise mapping of geometry to robotic operations, new fabrication methods have emerged, including the robotic winding of filament composites [4]–[6], the modulated fabrication of timber shell structures [7]–[9], the incremental forming of sheet materials [10], and the 3D printing of composite plastic elements [11]. A collection

of on-site studies has explored robotic technologies for in-situ construction processes by automating the assembly of traditional architectural materials such as bricks [12], [13] and timber elements [14]. Furthermore, robots have unlocked new possibilities in large-scale digital fabrication, including 3D printing at the building scale through the deposition of natural granular materials [15], [16].

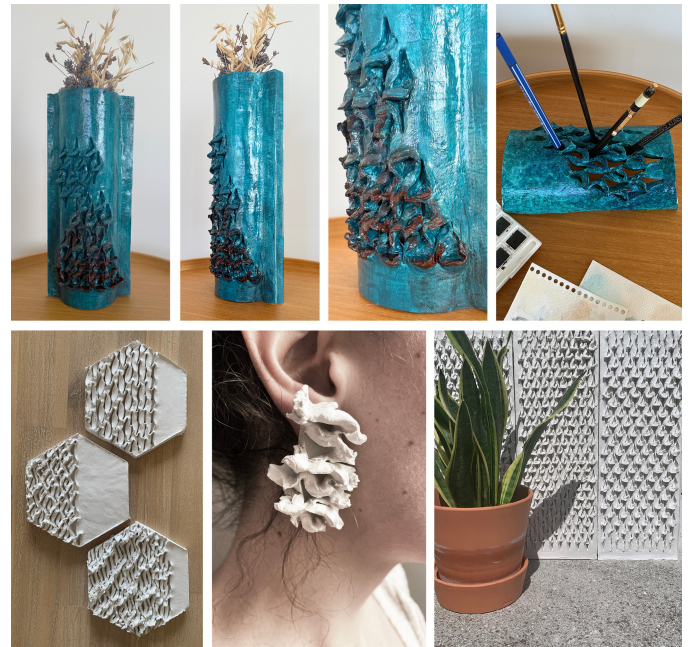


Fig. 1. The decorative ceramic wall tile prototypes and a collection of art objects with intricate material expressions [17], designed and fabricated through the craft-inspired robotic fabrication and design workflow. The top row displays coloured artefacts finished with acrylic paint and varnish, while the bottom row presents uncoloured pieces that emphasise a raw aesthetic.

All of these applications demonstrate the versatility of industrial robotic arms, which can be equipped with a variety of end effectors to manipulate diverse materials and leverage computational control to perform complex and precise movements, following a design-to-fabrication workflow [18]. This workflow describes a process in which digital design models (CAD models) are used to calculate robotic motion trajectories. These trajectories are then compiled into robot programs that directly instruct the industrial robot on how

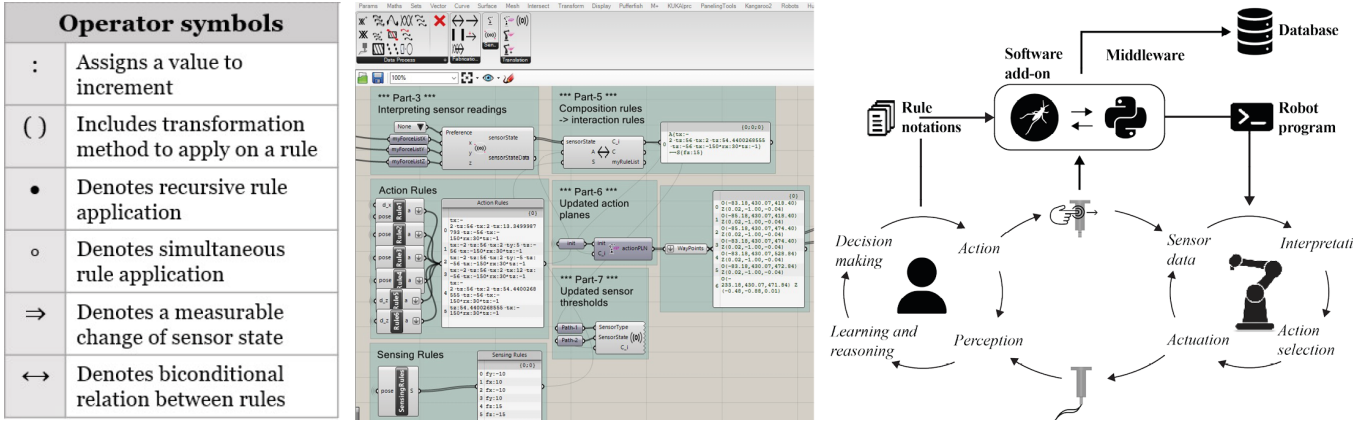


Fig. 2. The image on the left shows algebraic symbols used as operators to combine robotic action and sensing parameters into rule notations. The middle image is a screenshot of the Grasshopper interface, displaying the software add-on and its custom-developed components that convert rule notations into a sensor-feedback-integrated robot program. The image on the right illustrates a rule-based, declarative human-robot interaction (HRI) system.

to fabricate the predetermined geometry of the CAD model. The design-to-fabrication workflow typically follows an imperative programming approach, where robotic movements are explicitly defined through sequential commands. This method ensures precise control over fabrication processes, as robots require detailed instructions to execute the designed geometry accurately. However, this approach has notable limitations: it is rigid, difficult to scale with design complexity, and unable to adapt to real-time changes without manual reprogramming. As a result, unexpected material behaviour or changes in material conditions that cannot be predetermined and digitally modelled are excluded, often leading to fabrication failures.

On the other hand, artists typically follow an iterative workflow based on a “dialogue” with materials and changing conditions in craft processes [19]. Through this dialogue, they heuristically adapt their manual actions, continuously responding to the dynamic material behaviours during the creation process. By engaging directly with material affordances, artists and crafters spontaneously discover novel expressions and forms, allowing new design possibilities to emerge that are intrinsic to the materials themselves [20], [21]. Inspired by the craft processes, we introduced a novel interaction modality for robotic fabrication where users dynamically control and improvise fabrication operations by applying force to the end effector with their hands [22]. Extending this force feedback mechanism, we have developed a rule-based programming grammar that encodes the relationships between material changes and the adaptation of actions [17]. This grammar formalism adopts a declarative programming approach, enabling the robot to detect changes in its surroundings and adapt its actions accordingly [23].

During the research studies mentioned above, I produced several artefacts, as seen in Figure 1, by adopting HRI-based robotic fabrication as an active component of the creative design process. In doing so, I frame these processes under the concept of design-through-fabrication. Accordingly, this work explores a declarative *design-through-fabrication* approach, which positions fabrication as an active part of the creative

process. Similar to craft practices, *design-through-fabrication* allows form to emerge through a direct, artistic dialogue with material and motion. In this approach, the evolving design form is captured by recording the memory of the moment-to-moment negotiation between human intent, robotic motion, and material response. As a result, emergent expressions are integrated into computational fabrication processes, allowing material nuances and authenticity to be preserved in each robotically produced artefact.

This art proposal aims to exhibit a collection of artefacts while questioning how human-robot interaction (HRI) can sustain a craft-like, iterative design and fabrication workflow. Through this process, human users are invited to explore materiality in real time, heuristically incorporating emergent material properties into the evolving artefacts via HRI. Central to this investigation is the concept of **Strata Sapiens**: the idea that each interaction between human, material, and machine leaves layered traces of decision, adaptation, and response. The objective of the proposed exhibition is thus to combine traditional craft sensibilities with the computational precision and memory of robotic technologies, proposing a new vision for creative making as a co-evolutionary dialogue.

II. CRAFT-INSPIRED ROBOTIC FABRICATION AND DESIGN

The craft-inspired robotic fabrication and design depend on a novel rule-based programming approach [17]. This approach allows users to describe action sequences, sensor thresholds, and their relationships as rules. The rules thus define how robotic actions should be updated using real-time sensor feedback. Consequently, these rules enable users to engage in an embodied and enactive interaction with both materials [17] and robotic fabrication tools [22]. This transforms the fabrication process into a creative design performance that can be simultaneously recorded and later replayed by the robot on demand.

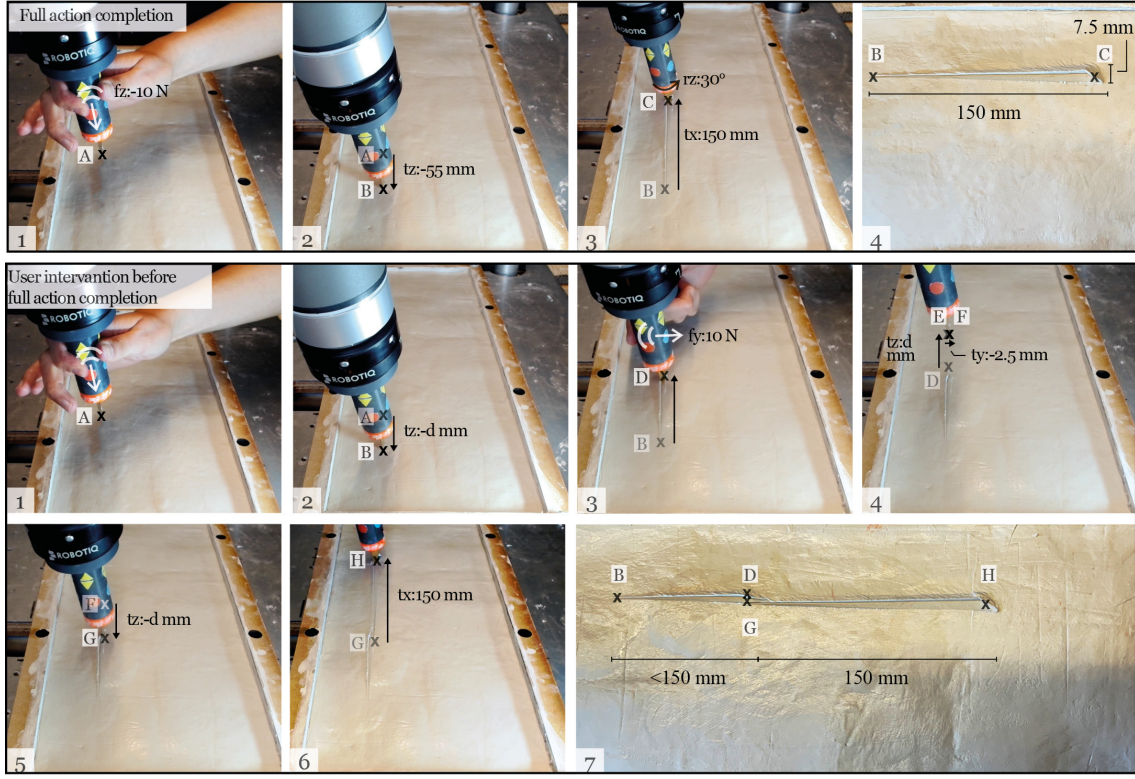


Fig. 3. The top row illustrates a simple human-robot interaction guided by the rule $tz : d \cdot tx : 150 \circ rz : 30 \circ tz : -1 \leftrightarrow fz : -10$ in its full sequence. The two rows at the bottom depict a user intervention before the action is completed. Frame 3 shows the user gently pushing the robotic end effector backward. This action is detected by force values exceeding $10N$, triggering the rule $tz : d \cdot ty : 2.5 \cdot tz : -d \cdot tx : 150 \circ rz : 30 \circ tz : -1 \leftrightarrow fy : -10$, which updates the robotic actions to carve a stroke 2.5 mm below the previous one.

A. Rule-Based Grammar Formalism and Technical Implementation

A set of algebraic symbols, shown in Figure 2 (left), serves as operators for describing spatial, temporal, and conditional relationships between action and sensing parameters. These parameters are identified based on the specific robotic fabrication setups. The studies presented in this work were conducted using a 6-DoF collaborative robotic arm equipped with an external force sensor. The robotic arm's action capabilities are defined by the parameters tx , ty , and tz , representing translations along the X, Y, and Z axes, and rx , ry , and rz , representing rotations around these axes. The sensing parameters fx , fy , and fz correspond to the forces measured along the X, Y, and Z directions, respectively.

The technical implementation of the rule-based human-robot interaction consists of a custom-developed software add-on and a middleware program that manages a real-time sensor feedback loop. The software add-on operates within Grasshopper, a widely used parametric modelling platform in the creative industries (Figure 2, middle). Its components enable users to define how sensor feedback influences robotic movements through declarative rules [23]. A custom-developed middleware program monitors sensor thresholds and relays data to the add-on components, which update the robot action planes in real-time as illustrated in Figure 2 on the right.

At each interaction, the updated action planes, detected sensor thresholds, and triggered rules are recorded in a database, segmented by discrete interaction moments.

By using the algebraic notations, a simple incising rule (i.e., action rule) was defined as $tx : 150 \circ rz : 30 \circ tz : -1$. This rule moves the end effector 150 mm along the X-axis while simultaneously rotating 30 degrees about the Z-axis and penetrating 1 mm more into the clay, thus creating a widening groove on the clay surface. For example, combining a gentle pull, represented as $fz : -10$, with the incising rule, $tz : d \cdot tx : 150 \circ rz : 30 \circ tz : -1 \leftrightarrow fz : -10$ applies incising on the spot after moving down the end effector. The user's pulling the end effector caused the force measurements to exceed $-10N$. This sensor state first triggered a linear translation from point A to B ($tz : d$), where d is calculated based on the distance between the real-time TCP position and the clay surface. Subsequently ($\cdot$), a combined action of linear translation and axial rotation ($tx : 150 \circ rz : 30$) began from point B, aiming to reach point C (Figure 3, top row). If there is no further user intervention, the triggered robotic action is completed. Otherwise, it is interrupted, and a new action sequence is initiated. For example, before the end effector reaches point C, the user pushes it backward, causing the force state to exceed $10N$ at point D ($fy : 10$). In response to this intervention, the robot momentarily pauses and updates

its actions to reproduce the incision slightly lower ($ty : -2.5$ mm) than the previous one. The resulting outcome consists of two carved strokes differing in both length and position (Figure 3, bottom two rows). [23]

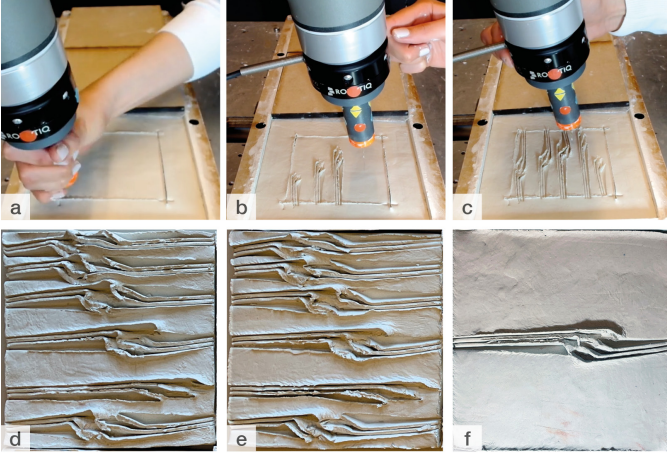


Fig. 4. (a, b, c) By physically interacting with the robot’s end-effector, such as pushing or pulling it, users can improvise (d) intricate material expressions on the fly. The robotic actions are recorded and can be replayed to (e) quasi-reproduce the improvised textures or (f) isolate a small part.

B. Exploration of Material Forms and Expressions

During the craft-inspired robotic fabrication workflow, users continuously observe how materials afford intricate and organic-looking expressions and forms due to their inherent properties, such as the malleable qualities of clay. Figure 4 (top) shows how the human user manually guided the fabrication operations while exploring emergent layered and undulated textures. These textures were not foreseen or pre-designed; rather, they appeared serendipitously and were composed throughout the dynamic fabrication process. The completed outcome (Figure 4-d) is a tile design with a textured surface, characterised by dynamic, layered patterns and grooves that reflect the plasticity of clay.

C. Reproduction of Material Forms and Expressions

The rule-based formalism facilitates recording and structuring data regarding the dynamically created toolpath through human-robot interaction. Accordingly, improved textures can be (quasi)reproduced or segmented into small parts. For example, Figure 4-e shows the quasi-reproduction of the improvised tile design with a layered and undulated texture. Although the overall design was preserved, each undulation, layer and groove in the texture looked slightly different. This makes each robotically produced tile unique, as though it were hand-crafted. Furthermore, the recorded and structured data from HRI allows for the segmentation of dynamically generated toolpaths. Subsequently, specific parts of a design can be isolated. For instance, Figure 4-f showcases how a fine-layered expression was isolated from the overall design.

D. Modification of Material Forms and Expressions

Since the data from HRI process, e.g. dynamically generated toolpaths and sensor states, are recorded and structured based on activated rules by user interaction, the fabrication operation parameters of each expression and how they are updated throughout HRI can be traced. Accordingly, improvised material expressions can be purposefully modified by changing specific parameters in their underlying fabrication operation. For example, Figure 5 shows how the increased axial rotation of the robotic end effector resulted in more convoluted textures.

III. STRATA SAPIENS: DIALOGUES IN STONE

Strata Sapiens explores the intersection of deep geological time and artificial intelligence. Drawing inspiration from the fossilisation process, the project imagines how human-robot collaboration can “carve time” into clay—preserving not only physical form, but also traces of memory, erosion, compression, and transformation. The created artefacts reflect an aesthetic reminiscent of geological formations, evoking sediment layers, fossil imprints, and mineral crystallisations, similar to the ones that are seen in Figure 6. Using robotic carving techniques, the process embraces the dynamic nature of clay, allowing emergent material behaviours to shape the final outcome. Each piece becomes a layered record of interaction, where robotic precision meets the improvisational spirit of craft. The title, *Strata Sapiens*, combines the Latin words for “layers” (strata) and “wisdom” (sapiens), suggesting that knowledge, time, and memory are embedded within material processes. In this work, rather than uncovering ancient fossils, robots inscribe the present—capturing the evolving dialogue between human intent, material response, and computational interpretation.

A composition of wall tiles (33 cm x 63 cm) will be submitted to the conference as seen in Figure 7. This tile composition embodies the *Strata Sapiens* concept by materialising a layered dialogue between human, machine, and material. Created through a rule-based, declarative human-robot interaction workflow, each tile records a moment-by-moment negotiation where human intent, robotic precision, and the dynamic behaviour of clay. Rather than executing a fixed design, the robotic system responded to evolving conditions, adapting toolpaths in real time based on declarative rules. These rules governed relationships between sensing inputs and action parameters, allowing form to emerge naturally through interaction, rather than strict predefinition. The resulting tile designs evoke the textures of geological formations—radiating folds, fractured ridges, and sediment-like accumulations. Every surface captures the memory of pressure, resistance, and adaptation, mirroring the way fossils preserve traces of ancient motion. Assembled together, the tiles form a stratified landscape where robotic technology and materiality intertwine, inscribing a contemporary memory record of creative human-robot interaction.

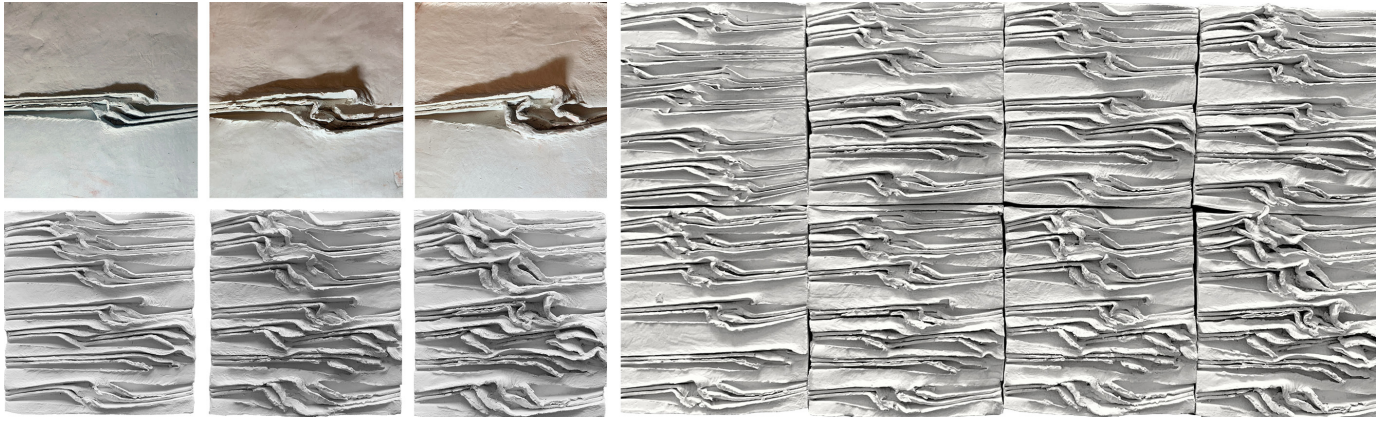


Fig. 5. The layered and undulated expression becomes more intricate with increased axial rotation (top right, from left to right). Clay tiles fabricated by the robot show progressively articulated textures as the axial rotation increases (bottom right, from left to right). The decorative wall composition (21 cm $\times$ 42 cm) on the left combines the variation of these textures.



Fig. 6. Fossilized rock formations: trilobite fossils (*Acadoparadoxides briareus*, left) and a bivalve shell impression (right). These natural records of layered formation processes inspire the Strata Sapiens concept of capturing memory through material and robotic interaction. Photographs taken by the author at the Natural Sciences Museum in Brussels.

IV. DISCUSSION AND CONCLUSION

This art proposal aims to provoke conversations among researchers, roboticists, and artists about how robots, digital fabrication, and human-robot interaction (HRI) can enable innovative design processes. Moving beyond the purely geometrical parametric form-finding of established robotic fabrication procedures [6], [9], [13], [14], the craft-inspired robotic fabrication opens new opportunities for *material-driven design* [24]. The fabrication process of the artefacts, to be exhibited, closely resembles crafting in terms of developing a unique design language specific to each material [25], [26]. Accordingly, the proposal extends the recent advancements of HCI research in craft and material exploration with 3D-printers [27]–[29] or looms [30] to robotic fabrication.

In Human-Robot Interaction (HRI) research, most studies have focused on developing Augmented Reality (AR) interfaces to provide communication within human-robot teams

by overlaying computer graphics on the real-world view [31], [32]. The AR interfaces mostly superimpose user input and CAD models, for example, to guide fabrication operations [33] or to visualise trajectories [34]. Although these AR-enabled interfaces successfully provide a common reference frame and spatial referencing between the real and the virtual worlds via CAD, they are limited to CAD capabilities that do not cover all the events that may occur in unstructured environments [35].

In this art proposal, a traditional craft method, clay carving, has been implemented into robotic fabrication based on HRI. Clay provides a flexible medium that can be shaped and moulded to easily create unique and bespoke forms, which are difficult to find and represent via CAD models. The presented rule-based approach enabled capturing unstructured conditions as an integral part of the design form, instead of relying on CAD models. This proposal thus extends HRI to digital fabrication and craft, integrating material affordances into design ideation without the need for synchronization with a CAD model. As a result, fabrication and design merge into a single creative making process where human users refine their ideas by adapting their physical actions to changing material and machine conditions.

Recent studies in HRI have shown that embodied interaction modalities, without graphical feedback or overlays, encourage users to engage with autonomous agents in intuitive and heuristic ways [36]. Such modalities, when implemented in interactive systems, support human-autonomy collaboration in unstructured environments by collecting and interpreting real-time data [37] about environmental changes [38], and subsequently selecting appropriate next steps [39]. By digitally recording the making process, human artists can gather data on contextual and material nuances, as well as machine constraints. This open data collection offers insights into otherwise tacit craft knowledge, typically conveyed through hands-on demonstration [21]. Ultimately, such insights could inform the development of intelligent systems capable of co-creating alongside humans.



Fig. 7. (Exhibition representative image) A decorative wall composition (33 cm x 63 cm) depicts intricate textures that reflect the plasticity of clay. The ceramic tile prototypes (10,5 cm x 10,5 cm) were designed and fabricated via human-robot interaction.

Within the scope of interactive robotic fabrication [40], custom interfaces have been developed to facilitate human input in robotic fabrication technologies [41], [42]. Building on these advancements, this proposal emphasizes the dynamic and open-ended fabrication process. However, broadening this line of HRI studies, craft-inspired robotic fabrication focuses on the design space that is generated by material emergence. Its three phases, 1) improvising fabrication outcomes, 2) identifying and isolating promising expressions within those outcomes, and 3) composing those expressions into more complex designs, support the continuous convergence and divergence of design ideas during robotic fabrication.

In conclusion, the art proposal will showcase how HRI can enrich creative opportunities and empower human users to leverage material affordances. Ultimately, this proposal aims to spark innovative ways to combine robotic technology with craft sensibilities, involving dexterity, improvisation and skill. By speculating about alternative futures with different kinds of creative processes, the proposed exhibition will underline a conceptual shift in perspectives of the authenticity of craftsmanship, opening new reproduction possibilities.

ACKNOWLEDGMENTS

This research is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation), project number 456072683. I would also like to acknowledge that the robotic studies analyzed in this paper were part of the author's doctoral research supported by the KU Leuven Internal Funds C2/2017 (BOF) grant entitled Towards Interactive Robotic Architecture Design and Fabrication.

AUTHOR'S BIO

Iremnur Tokac (PhD) is a postdoctoral researcher at the Chair of Individualized Production in Architecture at RWTH Aachen University, Germany. Her research focuses on computational making, digital fabrication, and human-robot interaction (HRI) within the context of design and architecture. She develops intuitive interfaces that support human-robot interaction, aiming to complement human expertise through digital transformation in the AEC (Architecture, Engineering, and Construction) industries.

Tokac earned her PhD in Architectural Engineering from KU Leuven, Belgium, with a dissertation titled Grammatical Robotic Fabrication: Introducing a Grammar for Programming Real-Time Interaction among Human, Robot, and Material. She holds two Master's degrees: one in MediaArchitecture from Bauhaus University Weimar, Germany, and another in Design Computing from Istanbul Technical University (ITU), Turkey, where she also completed her Bachelor's in Architecture.

Alongside her research, she actively teaches at RWTH Aachen, developing and leading courses in human-robot interaction, computational fabrication, and interdisciplinary digital design. She currently serves as the Managing Editor for Construction Robotics Journal (Springer) and participates in various scientific committees.

REFERENCES

- [1] Grasshopper 3D. Grasshopper 3D. <https://www.rhino3d.com/6/new/grasshopper>, 2022. Accessed: 2022-07-08.

- [2] Sigrid Brell-Cokcan and Johannes Braumann. Kuka—prc (parametric robot control). 2011.
- [3] Sigrid Brell-Cokcan and Johannes Braumann. Industrial robots for design education: robots as open interfaces beyond fabrication. In *International Conference on Computer-Aided Architectural Design Futures*, pages 109–117. Springer, 2013.
- [4] Marshall Prado, Moritz Dörstelmann, James Solly, Achim Menges, and Jan Knippers. Elytra filament pavilion: Robotic filament winding for structural composite building systems. In *Fabricate 2017: rethinking design and construction*, pages 224–231. JSTOR, 2017.
- [5] James Solly, Nikolas Frueh, Saman Saffarian, Marshall Prado, Lauren Vasey, Benjamin Felbrich, Daniel Reist, Jan Knippers, and Achim Menges. Icd/tike research pavilion 2016/2017: integrative design of a composite lattice cantilever. In *Proceedings of IASS Annual Symposia*, volume 2018, pages 1–8. International Association for Shell and Spatial Structures (IASS), 2018.
- [6] Dagmar Reinhardt, Ninotschka Titchkosky, Chris Bickerton, Rodney Watt, Dylan Wozniak-O'Connor, Christhina Candido, Densil Cabrera, Mitchell Page, and Sascha Bohnenberger. Towards onsite, modular robotic carbon-fibre winding for an integrated ceiling structure. *Construction Robotics*, pages 1–18, 2019.
- [7] Oliver David Krieg, Tobias Schwinn, Achim Menges, Jian-Min Li, Jan Knippers, Annette Schmitt, and Volker Schwieger. Biomimetic lightweight timber plate shells: computational integration of robotic fabrication, architectural geometry and structural design. In *Advances in architectural geometry 2014*, pages 109–125. Springer, 2015.
- [8] Simon Bechert, Jan Knippers, Oliver David Krieg, Achim Menges, Tobias Schwinn, and Daniel Sonntag. Textile fabrication techniques for timber shells. *Advances in architectural geometry*, 2016, 2016.
- [9] Hans Jakob Wagner, Martin Alvarez, Abel Groenewolt, and Achim Menges. Towards digital automation flexibility in large-scale timber construction: integrative robotic prefabrication and co-design of the buga wood pavilion. *Construction Robotics*, 4(3):187–204, 2020.
- [10] Ammar Kalo and Michael Jake Newsum. An investigation of robotic incremental sheet metal forming as a method for prototyping parametric architectural skins. In *Robotic fabrication in architecture, art and design 2014*, pages 33–49. Springer, 2014.
- [11] Hyunchul Kwon, Martin Eichenhofer, Thodoris Kyttas, and Benjamin Dillenburger. Digital composites: robotic 3d printing of continuous carbon fiber-reinforced plastics for functionally-graded building components. In *Robotic fabrication in architecture, art and design*, pages 363–376. Springer, 2018.
- [12] Tobias Bonwetsch, Fabio Gramazio, and Matthias Kohler. Digitally fabricating non-standardised brick walls. In *ManuBuild, 1st International Conference, Rotterdam*, 2007.
- [13] Kathrin Dörfler, Timothy Sandy, Markus Gifftthaler, Fabio Gramazio, Matthias Kohler, and Jonas Buchli. Mobile robotic brickwork. In *Robotic Fabrication in Architecture, Art and Design 2016*, pages 204–217. Springer, 2016.
- [14] Jan Willmann, Michael Knauss, Tobias Bonwetsch, Anna Aleksandra Apolinarska, Fabio Gramazio, and Matthias Kohler. Robotic timber construction—expanding additive fabrication to new dimensions. *Automation in construction*, 61:16–23, 2016.
- [15] Petrus Aejmelaus-Lindström, Jan Willmann, Skylar Tibbits, Fabio Gramazio, and Matthias Kohler. Jammed architectural structures: towards large-scale reversible construction. *Granular Matter*, 18(2):1–12, 2016.
- [16] Petrus Aejmelaus-Lindström, Gergana Rusenova, Ammar Mirjan, Fabio Gramazio, and Matthias Kohler. Direct deposition of jammed architectural structures. In *Robotic Fabrication in Architecture, Art and Design*, pages 270–281. Springer, 2018.
- [17] Iremnur Tokac, Herman Bruyninckx, and Andrew Vande Moere. A programming grammar for robotic fabrication: Incorporating material agency into clay textures. *Design Studies*, 88:101220, 2023. Publisher: Elsevier.
- [18] Jan Willmann Fabio Gramazio, Matthias Kohler. *The robotic touch: how robots change architecture*. Park books, 3 edition, 5 2014.
- [19] André Leroi-Gourhan. *Gesture and speech*. MIT Press, 1993.
- [20] Lambros Malafouris. At the potter's wheel: An argument for material agency. In *Material agency*, pages 19–36. Springer, 2008.
- [21] Lambros Malafouris. Mind and material engagement. *Phenomenology and the Cognitive Sciences*, 18(1):1–17, 2019.
- [22] Iremnur Tokac, Benay Gursoy, Herman Bruyninckx, and Andrew Vande Moere. Craft-Inspired Digital Fabrication: A Study of Interactive Robotic Clay Carving. In *Proceedings of the 7th Annual ACM Symposium on Computational Fabrication*, pages 1–14, 2022.
- [23] Iremnur Tokac. A declarative human-robot interaction workflow: Integrating improvisation and materiality in robotic fabrication and design. In *Creativity and Cognition (C&C '25)*, Virtual, United Kingdom, June 23–25 2025. ACM.
- [24] Bahareh Barati and Elvin Karana. Affordances as materials potential: What design can do for materials development. *International Journal of Design*, 13(3):105–123, 2019.
- [25] Daniela K Rosner and Alex S Taylor. Antiquarian answers: book restoration as a resource for design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 2665–2668, 2011.
- [26] Amit Zoran, Seppo O Valjakka, Brian Chan, Atar Brosh, Rab Gordon, Yael Friedman, Justin Marshall, Katie Bunnell, Tavs Jorgensen, Factum Arte, et al. Hybrid craft: showcase of physical and digital integration of design and craft skills. *Leonardo*, 48(4):384–399, 2015.
- [27] Samuelle Bourgault, Pilar Wiley, Avi Farber, and Jennifer Jacobs. Coilcam: Enabling parametric design for clay 3d printing through an action-oriented toolpath programming system. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, pages 1–16, 2023.
- [28] Blair Subbaraman and Nadya Peek. p5. fab: Direct control of digital fabrication machines from a creative coding environment. In *Designing Interactive Systems Conference*, pages 1148–1161, 2022.
- [29] Ilan E Moyer, Samuelle Bourgault, Devon Frost, and Jennifer Jacobs. Throwing out conventions: Reimagining craft-centered cnc tool design through the digital pottery wheel. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, pages 1–22, 2024.
- [30] Lea Albaugh, Scott E Hudson, Lining Yao, and Laura Deven-dorf. Investigating underdetermination through interactive computational handweaving. In *Conference on Designing Interactive Systems*, pages 1033–1046, 2020.
- [31] Scott A Green, Mark Billingham, XiaoQi Chen, and J Geoffrey Chase. Human-robot collaboration: A literature review and augmented reality approach in design. *International journal of advanced robotic systems*, 5(1):1, 2008.
- [32] Ryo Suzuki, Adnan Karim, Tian Xia, Hooman Hedayati, and Nicolai Marquardt. Augmented reality and robotics: A survey and taxonomy for ar-enhanced human-robot interaction and robotic interfaces. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, pages 1–33, 2022.
- [33] Huaishu Peng, Jimmy Briggs, Cheng-Yao Wang, Kevin Guo, Joseph Kider, Stefanie Mueller, Patrick Baudisch, and François Guimbretière. Roma: Interactive fabrication with augmented reality and a robotic 3d printer. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, page 579. ACM, 2018.
- [34] Daniela Mitterberger, Selen Ercan Jenny, Lauren Vasey, Ena Lloret-Fritsch, Petrus Aejmelaus-Lindström, Fabio Gramazio, and Matthias Kohler. Interactive robotic plastering: Augmented interactive design and fabrication for on-site robotic plastering. In *CHI Conference on Human Factors in Computing Systems*, pages 1–18, 2022.
- [35] Xinyan Yu, Marius Hoggemüller, and Martin Tomitsch. From agent autonomy to casual collaboration: A design investigation on help-seeking urban robots. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, pages 1–14, 2024.
- [36] Sarah Schömb, Saumya Pareek, Jorge Goncalves, and Wafa Johal. Robot-assisted decision-making: Unveiling the role of uncertainty visualisation and embodiment. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, pages 1–16, 2024.
- [37] Torsten Kröger. Opening the door to new sensor-based robot applications—The Reflexes Motion Libraries. In *2011 IEEE International Conference on Robotics and Automation*, pages 1–4. IEEE, 2011.
- [38] Yi Wang, Hai-Shu Ma, Jing-Hui Yang, and Ke-Sheng Wang. Industry 4.0: a way from mass customization to mass personalization production. *Advances in manufacturing*, 5:311–320, 2017. Publisher: Springer.
- [39] Julie Shah, James Wiken, Brian Williams, and Cynthia Breazeal. Improved human-robot team performance using chaski, a human-inspired plan execution system. In *Proceedings of the 6th international conference on Human-robot interaction*, pages 29–36, 2011.
- [40] Karl DD Willis, Cheng Xu, Kuan-Ju Wu, Golan Levin, and Mark D Gross. Interactive fabrication: new interfaces for digital fabrication. In *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction*, pages 69–72, 2010.

- [41] Stefanie Mueller, Anna Seufert, Huaishu Peng, Robert Kovacs, Kevin Reuss, François Guimbretière, and Patrick Baudisch. Formfab: Continuous interactive fabrication. In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction*, pages 315–323, 2019.
- [42] Rundong Tian and Eric Paulos. Adroid: Augmenting Hands-on Making with a Collaborative Robot. In *The 34th Annual ACM Symposium on User Interface Software and Technology*, pages 270–281, 2021.