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Layers of Control: Live Clay Printing with an AI Agent

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This paper presents a decade-long exploration into the dynamics of control, language, and material emergence through a real-time clay 3D-printing system driven by a conversational AI agent. Rather than producing predefined or functional objects, the system generates live, non-utilitarian clay items shaped by human-AI exchanges and the interwoven agencies of machine, material, and user. Through this process, control becomes distributed, partial, and continuously negotiated. What emerges are intricate artefacts – neither designed nor random, but formed in a dialogue between language, glitch, rhythm, and collapse. We reflect on the aesthetics of ceding control, proposing conversational fabrication as both a method and a poetics for engaging with otherness in tangible interaction.

1 Introduction

Streamline is a decade-long artistic practice that explores and reframes 'control' in digital fabrication processes. It operates through a clay 3D printer connected to a conversational AI agent on the *Telegram* app. Instead of executing preplanned models, Streamline bypasses traditional Computer-Aided Design (CAD) to Computer-Aided Manufacturing (CAM) workflows, creating direct pathways from natural language conversation to material deposition.

The printer generates forms live, in response to the unfolding of a dialogue. Parameters such as shape, toolpath pattern, layer rotation, and growth orientation emerge from real-time interaction, not from a fixed design file. Control becomes distributed, partial, and continuously negotiated. This approach situates Streamline within diverse interactive and performative fabrication practices that circumvent traditional modelling software in favour of flexible, improvisational modalities. This is also the reason why clay was chosen as the printing material, fluid and malleable in nature, embedded in a long history of making culture. The resulting printed artefacts are considered physical traces of a moment in time, neither ornamental nor functional – rather existing as inquiries into a quirky fabrication process (Fig. 1).

The premise of the project is to interact with the printing machine while we live our lives. With the development of a chatbot connected to the printer, we first leverage the smartphone affordances: a 'casual' interface, ready-at-hand, carried on the body, that can take pictures, record sound, track location, a presence manifesting itself at all times (Schrock 2015). In addition, we tune the AI agent mediating the human-machine interaction not as a guide or assistant but as a deviating presence, providing humour, misalignment, and an assertive mindset. A shape grammar was conceived over time to find and map the most

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relevant correlations between data and geometry. For that, a desktop interface was developed prior to implementing the AI agent.

With its concept and method, the project extends a long-standing research into embodied fabrication using body movement, forms of mobility, personal data, and everyday moments as parameters for activating machine functions (Willis et al. 2011; Bitton 2016). These inputs invite opportunistic interaction, playfulness and improvisation. The accent of the exchange is drawn on everyday life aspects, casual moments of the day, a psychogeography experience in which people can drift both in conversation and in their physical locations.

This paper contributes: (1) the Streamline concept & method (2) an interface and shape grammar to experiment with mapping live data to X, Y, Z geometry (3) the integration of Large Language Model (LLM)-driven conversations for real-time 3D-printing (4) a critical reflection on agency and control (5) a non-utilitarian approach to frame the meanings of the produced artefacts.

Fig. 1. Two Streamline glazed items (2025).

2 Related Work

The project Streamline is situated among diverse and broad research fields and artistic and design practices, such as interactive fabrication, embodied fabrication, and counterfunctional design. We highlight inspirations and specificities of the project in contrast.

2.1 Interactive & Embodied Fabrication

Interactive fabrication as a term describes the user's engagement with fabrication machines in playful and intuitive ways (Willis et al. 2011). Other work in this area framed fabrication as an interactive and embodied process rather than a planned sequence of operations, allowing users to intervene during making (Mueller et al. 2012; Gershenfeld 2013; Bitton 2016). Further research has explored ways to increase accessibility of digital fabrication and bypass complex CAD-CAM workflows (Li et al. 2017; Tian et al. 2019). Such systems introduced on-the-fly modelling, direct machine control, and incremental printing to support real-time adjustment of form and process (Peng et al. 2016; Koda and Tanaka 2017; Gleadall 2021). Within this space, several projects have focused on helping beginners, or extending practices with proficient craft artists, or creating drawing-like affordances for CNC machines — all valuable goals (Maleki et al. 2014; Bourgault et al. 2023).

Some of those projects have proposed to materialise datasets within recognizable patterns such as a vase or furniture (Whitelaw 2012; Desjardins and Tihanyi 2019). Other systems embed direct manipulation within CAD environments or creative coding frameworks, balancing immediacy with technical precision (Fossdal et al. 2021; Subbaraman and Peek 2022). Creative coding has indeed long been used to generate data sculptures, the practice often tied to the artist's algorithm explorations (LIA 2014; Lingel and Regan 2014; Twigg et al. 2021). All constitute the diverse creative practices that are expanding the field of 'making with data' (Huron 2023).

Increasingly, such creative modalities include the input of AI agents. Some systems analysing generative AI interrogate the "hidden layers" of AI models (Grabe and Jenkins 2025) and the "fault-lines" of their decision-making (Benjamin et al. 2021). In the field of digital fabrication, shapes can be generated with a LLM that are then printed (Elran and Zoran 2024).

Streamline shares similar intentions of interactive fabrication and the premise of direct engagement but shifts the focus away from pragmatic aims. The generated shapes follow a geometry grammar that purposefully avoids any usable 'container' or familiar vessel. It looks more closely into ways to capture casual, unintentional expressions such as fleeting thoughts, personal data, city walks and improvised exchanges as live parameters for 'embodied fabrication'. This is the context in which we are primarily integrating the familiar uses of a chatbot – albeit as a sparring partner rather than as a helpful guide. The goal is to form an intimacy with it and the machine – literally: a mutual attunement over time, shifting the intention away from the efficient completion of a predetermined task.

2.2 Counterfunctional Design

Several concepts in the field of human-computer interaction, and in design and craft research have emerged in the last decade that shift the consideration of our environments solely from the perspective of commodity and usability. They have encouraged among others to rethink the roles of design and of technology as problem-solvers (Lindtner et al. 2016), have in some cases argued for "undesigning" and for "counterfunctional design" (Pierce 2012; Pierce and Paulos 2014), for "unmaking" (Song and Paulos 2021; Song et al. 2025), for appreciating imperfection and cracks (Tsaknaki and Fernaeus 2016) or foregoing the pursuit of innovation altogether (Bonnet et al. 2021). Together, they offer an outlook at the diversity of non-utilitarian practices and non-human centric approaches. Streamline thus aligns with the notion of counterfunctionality, subverting the efficiency demanded of fabrication machines. It constitutes a critique of the productivity-oriented culture where anything latent, slow, or ineffective is deemed a weed or a parasite – an anthropocentric shortsighted perspective that realises the value of a discarded item once it's been destroyed.

In the context of planned obsolescence and extractivism, Streamline similarly affirms the value of process over product. We frame this as a "non-utilitarian approach", a proposal to reframe control as a mediated kinship with nonhuman agents (Lewis et al. 2018; Andersen et al. 2019).

2.3 The Fabrication of Meaning

The project Streamline treats making as a mode of sense-making rather than execution. Similarly, for Tin (2013), fabrication is a cognitive and cultural process where meaning emerges through material engagement. Craft studies have highlighted the role of indeterminacy and error, particularly with unstable materials like clay that resist full control and remain "in a state of becoming" (de Freitas 2008). Rather than matter passively being shaped, information emerges as an ensemble distributed across data, machine behavior, material response, time, and chance (Malafouris 2008). Its inscription, whether algorithmic or physical, leaves traces that bind thought to matter (Derrida 1998).

Streamline answers Derrida's question of timing between event and machine (Derrida 2001) by collapsing conversation, computation, and material deposition into a single temporal process and by tinkering with the interval between intention and outcome. This perspective challenges functional and ornamental classifications, instead situating artefacts within broader notions of transformation and variation, where form is defined by process rather than fixed intent (Carpo 2004; Philpott 2013).

3 System Overview

Streamline is a clay 3D-printing concept and method, operating with live and real-time G-code commands, via a desktop interface or via a conversation with an AI agent on a smartphone.

The desktop application was first developed to test out a series of design parameters.

Through many iterations, we produced a shape grammar that maps the data to geometry. A dozen design factors have been implemented and the possibilities are amplified with practically endless combinations. As such, Streamline becomes a platform for creative users to experiment with different mappings and establish correlations through iterative practice.

Each conversation produces a unique artefact. The whole system frames a reflection on control and agency, and on a non-utilitarian approach of digital fabrication.

3.1 Hardware, Firmware & Material

We use the DeltaWASP 2040 Clay for printing all of our pieces. We chose clay for experimentation with real-time printing: the material, its agency, its fluidity, its uncertainty reflect the overall intention of playfulness and embodied interaction.

To enable sending G-code instructions to the machine while printing, we retrofitted an Arduino Mega 2560 board running the open-source firmware Marlin and a RAMPS 1.4 shield controlling the printer's XYZ and extruder motors (Fig. 2). This allowed us to connect directly and send data via USB to the machine using the printcore.py library. Through experimentation and based on Jonathan Keep's guide to clay printing, we found suitable extrusion rate and flow rate settings. Both parameters influence the speed at which the motor inside the extruder spins. For example, if the clay is too wet or the air pressure is increased, it is best to increase both parameters to prevent clay from overspilling.

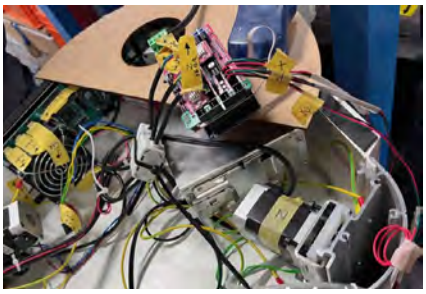

Fig. 2. Wiring of the RAMPS 1.4 shield with printer motors.

3.2 Software & AI Agent

Desktop Interface

We first established a desktop interface to test out parameters for live-printing and developing our shape grammar. The desktop interface enables control of the different printing and design parameters – each of them can be changed and continuously adjusted live during the print.

– 'Set-up': printer basic parameters.
– 'Layer': affecting layer height, rotation & transition rate.
– 'Shape': control of the overall geometrical structure and volume (Fig. 3).
– 'Line': adjustment of the toolpath pattern and behaviour, including non-planar elevations.

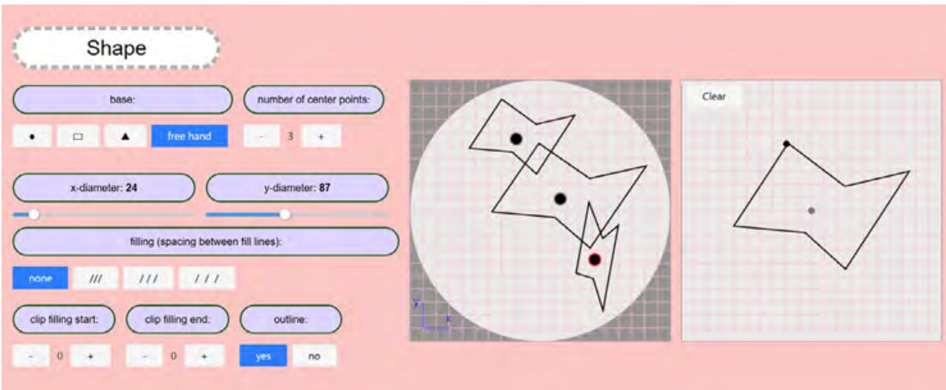

Fig. 3. Screenshot of the desktop interface - segment 'Shape' and the structural parameters that can be modified in real-time during the print.

Phone Interface and AI Model

In a second step, we extended the system to connect the printer to a *Telegram* chat on the user's phone and to an OpenAI language model. As the conversation unfolds, it is continuously translated into printing parameters. Instead of adjusting settings on a control panel, the user influences the process indirectly through dialogue.

Using a personal mobile phone and a messaging environment is deliberate. Messaging is already embedded in everyday life, habitual activity. The mobile personal phone invites embodiment, proximity, and spontaneity. The project's original intention is precisely to explore those qualities as factors in digital fabrication processes. Thus, bringing fabrication control into a familiar space shifts the interaction from machine operation towards relational modes of engagement.

With the arrival of largely accessible commercial LLMs, the technological hurdles have generally lowered (McTear and Ashurkina 2024) and we were able to further realise our vision. To shape how the AI agent behaves, we fine-tuned the base model on a small set of custom example conversations. Rather than positioning the system as a helpful assistant, the training encourages a more autonomous, conversational presence, a sparring partner with its own tone, humor, and perspective. This supports the idea that the interaction is a dialogue between agents, not a one-way instruction channel.

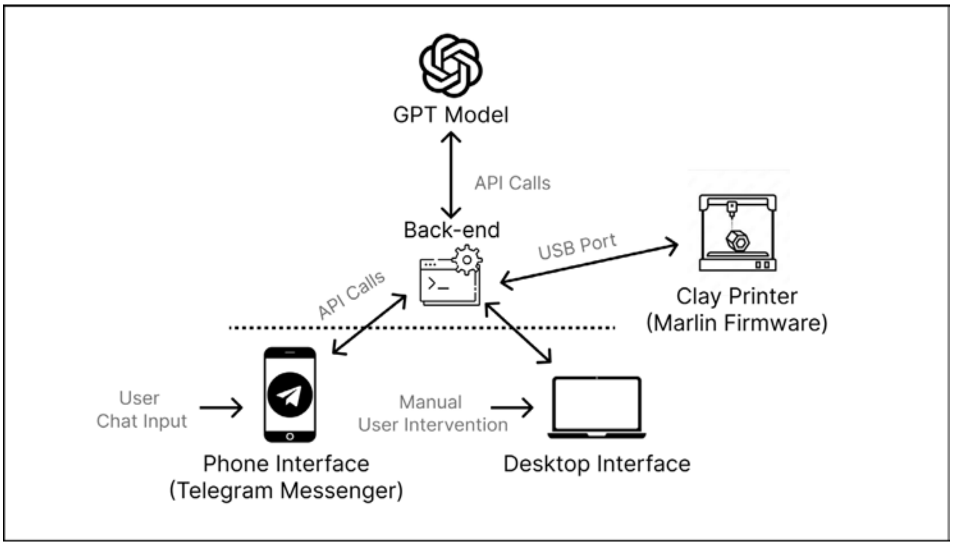

Fig. 4. Interaction of the system's components.

3.3 Data Processing

We use a pretrained OpenAI GPT model, adapted through prompt engineering and custom fine-tuning, for two roles in the Streamline system. First, the model generates conversational responses to the user's messages. Second, it performs real-time analysis of the conversation to extract higher-level conversational properties.

This property extraction relies on predefined prompts stored in a JSON configuration file, allowing the creative user to easily modify or expand the set of extracted features without altering the core codebase. In parallel, the application records basic metadata from incoming messages, such as location, message length, and input modality (text, image, audio), alongside AI-extracted scores. These metadata and AI-derived items become a set of variables that are mapped to fabrication parameters (see section 4).

3.4 Printed Artefacts

The prints produced with the Streamline experiment all vary in shape and style (Fig. 5). What emerges is neither functional nor ornamental, the artifacts exist as probes into material traces of human-machine dialogue and witnesses of a moment in time (Csikszentmihalyi and Rochberg-Halton 1981). We call them "objects of a third kind" (see section 5).

Fig. 5. Series of Streamline close-ups (2016-2025).

4 Mapping Data to Geometry

As mentioned previously, our desktop interface enables users to control and adjust the different design factors of the print in real-time. In order to create volumes without a preplanned design and generated from parameters that can be continuously modified, we need a set of rules that establishes how the incoming data is mapped to geometry. Those rules are decided based on various factors, together they form a shape grammar (Knight 1999).

Across four iterative phases between 2015–2025, the project developed an evolving shape grammar through hands-on testing with different machines, materials, and mapping strategies. Early experiments explored correlations between "moods" and toolpaths. Next phases expanded the geometric vocabulary toward distributed and irregular growth patterns. Later phases focused on fully integrating conversational mapping into the shape grammar and improving on the AI scoring of the data.

4.1 Taxonomy

A taxonomy of design factors was developed as a framework for experimenting with the mapping from data to volume. The inspiration is based on typical language syntax. As such 4 rules were established: 1. Nouns (Structural Rules), 2. Verbs (Growth Rules), 3. Adjectives (Modulation Rules), 4. Punctuations (Disruptive Rules).

A fifth rule, *Relational Rules*, is being developed to leverage the AI's learnings from the growing dataset of conversations and printed geometries.

a. 'Nouns' or Structural Rules (Form & Volume of the Printed Artefact)

It is possible to print four types of shapes: circular, rectangular, triangular, and a fourth one, fully freehand (Fig. 6). One or multiple outlines of the same shape can be printed over the print area, which we refer to as 'centre points'. Allowing multiple centre points enables us to introduce relationships between the shapes and gives the whole structure a more abstract character, intentionally separating it from a vase-like object. We restrict the mixing of different shape types within a single print, as this helps maintain visual harmony and stylistic coherence.

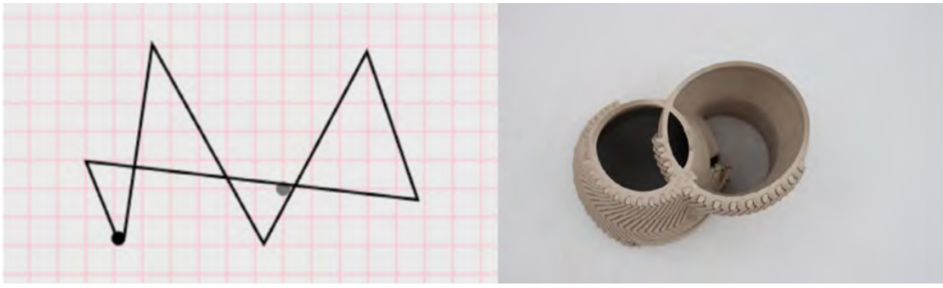

Fig. 6. *Left:* Freehand shape, one center point. *Right:* Circular shape, two center points.

b. 'Verbs' or Growth Rules (Progression & Development as the Print Continues)

They decide the direction and angle of the growth as the conversation progresses and can shift over time. The outline for each printed layer can be modified through translation, scaling, and rotation operations. Each modification to the outline occurs gradually, layer by layer. Furthermore, the number of printed centre points can be reduced during printing.

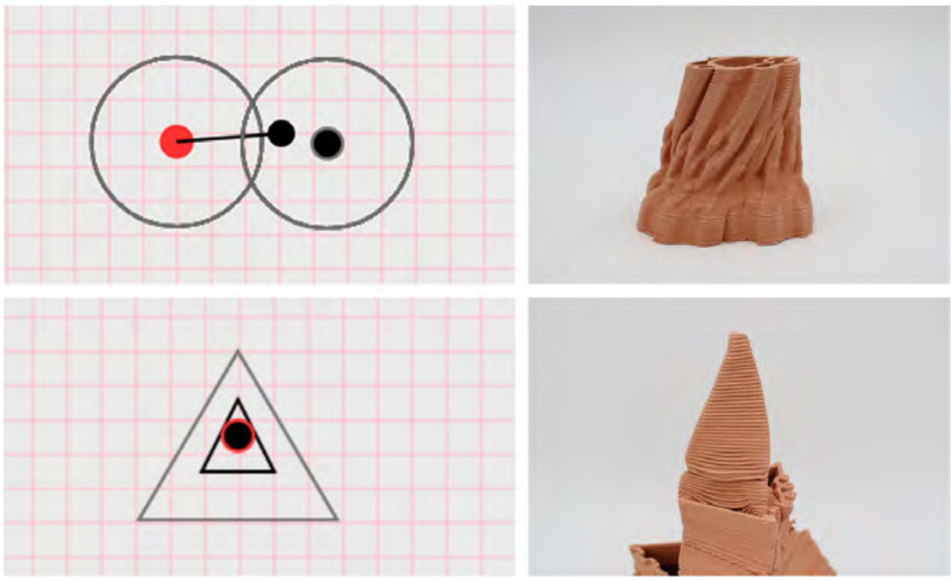

Fig. 7. Side by side views of desktop interface and the resulting prints. *Top*: One center point gets translated towards another. *Bottom*: The triangular shape is scaled down.

c. 'Adjectives' or Modulation Rules (Surface & Texture Aspects of the Artefact)

Toolpaths variations (thickness, structure, pattern, stepover) mainly influence the textured surface of the object. We defined six different line patterns – including straight line – and for each pattern, the amplitude and frequency can be modified as well. In addition, it is possible to introduce noise to the line pattern.

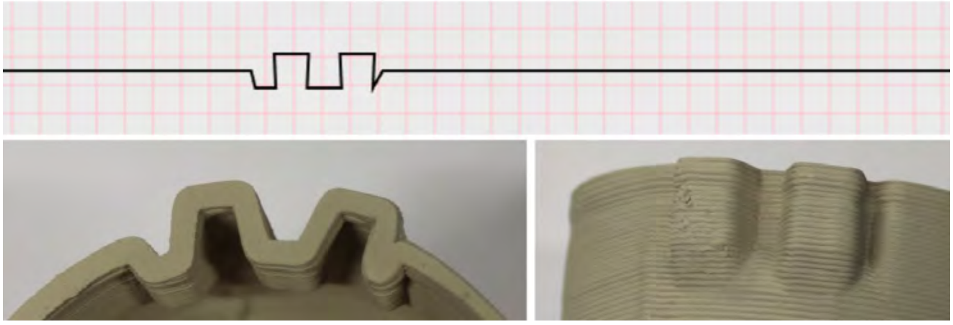

Fig. 8. Views of desktop interface and the resulting prints. Rectangular pattern, with medium frequency and small amplitude.

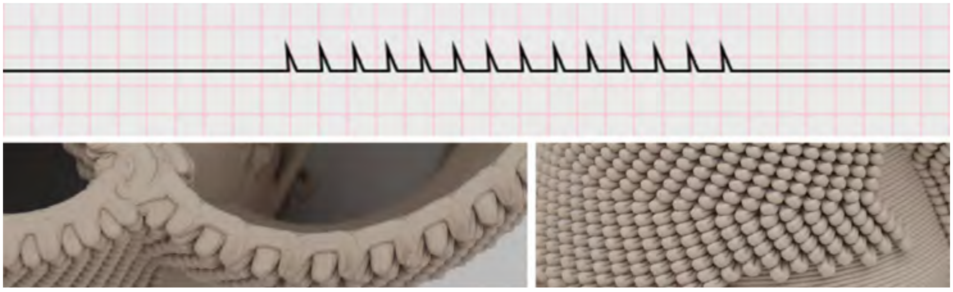

Fig. 9. Views of desktop interface and the resulting prints. "Nobs" pattern with high frequency and small amplitude.

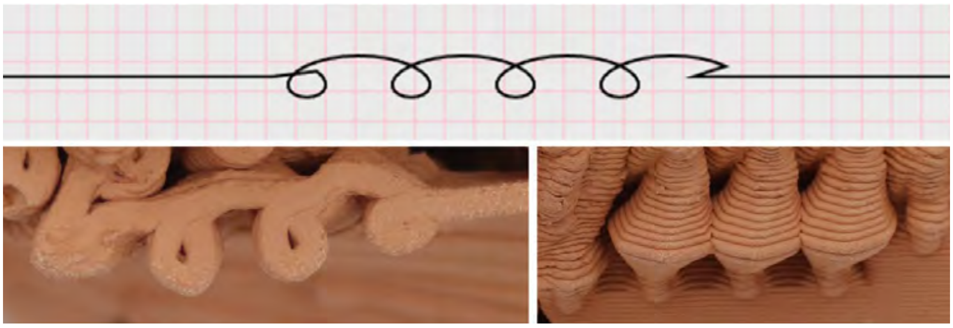

Fig. 10. Views of desktop interface and the resulting prints. Loop pattern with low frequency and changing amplitude.

d. 'Punctuations' or Disruptive Rules (Adding Interruption & Anomaly)

Embracing the unpredictable and playful aspects of everyday experience, this rule incorporates intentional noise and interruptions into the line pattern, allowing irregularities and disruptions to emerge as aesthetic events.

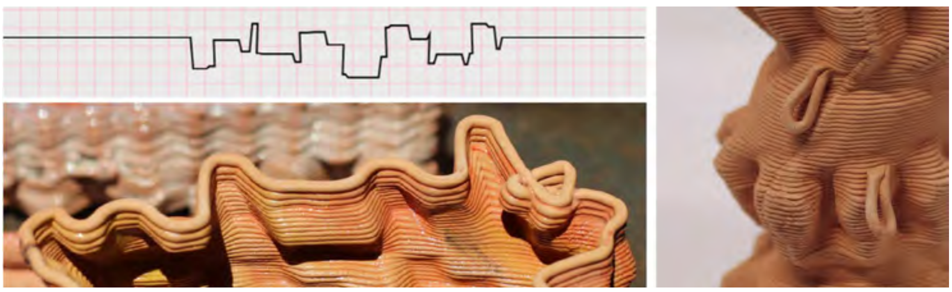

Fig. 9. Views of desktop interface and the resulting prints. "Nobs" pattern with high frequency and small amplitude.

4.2 Mapping of the Conversation Live Data

As we integrated the chatbot interface for live printing, we tested our shape grammar to further establish correlations between linking linguistic patterns with spatial geometries. This required extensive and iterative experimentation. The most difficult aspect involves in such endeavour avoiding prescriptive correlations that would reduce complex human expression to predetermined and literal geometric outputs. The system addresses this through probabilistic rather than deterministic mapping, where conversational qualities influence rather than dictate material outcomes.

The focus is therefore not on the semantic meaning of words. Attention is rather placed on the conversational dynamics as a temporal architecture: rhythms, pauses, shifts in tone, emphasis, and diversity (text, image, audio) are treated as signals for geometric and toolpath variations.

The following experiment conducted in July 2025 presents four selected moments illustrating how the system translates conversational dynamics into material form with side-by-side views of the chat interface and the resulting print. The conversation unfolds casually around topics of hiking, frogs, and puzzles, with no predetermined agenda:

(1) The first chat item type determines the base shape (structural rules). Here it's an image, the print starts with a rectangular base shape. The AI categorizes this image as 'calm,' triggering a wave line pattern for sections of the toolpath.

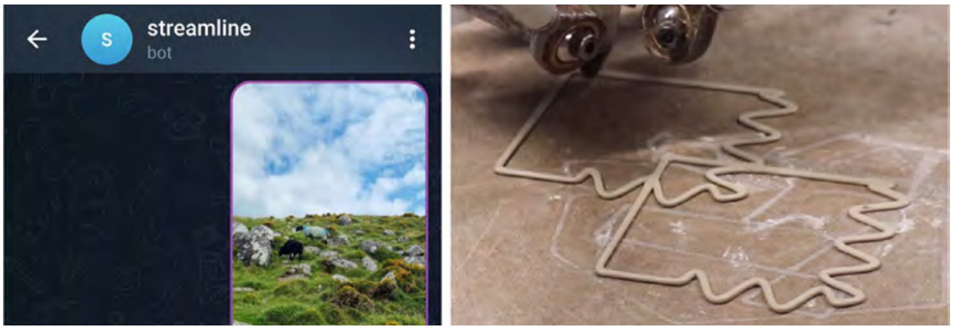

Fig. 12. First chat item.

(2) An AI sentiment analysis of images and text influences the line pattern, while the message complexity affects the pattern's range (modulation rules). Here, the response from the user is scored by the AI as simple and straightforward, the line pattern shrinks.

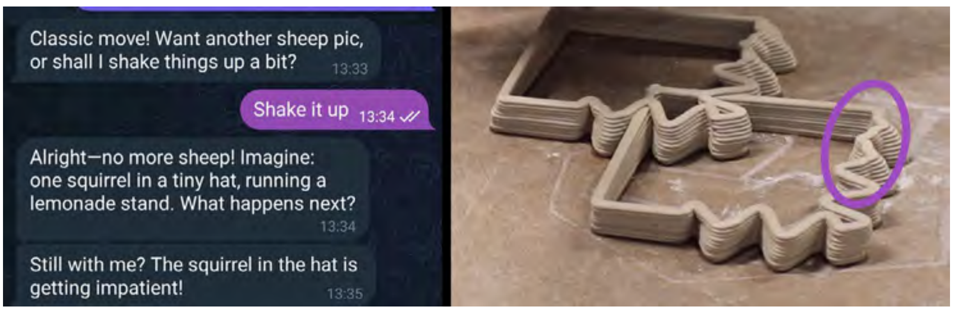

Fig. 13. The line pattern shrinks.

(3) Detected detachment triggers the centre point reduction, the user location affects the centerpoint translation and the message frequency affects the layer rotation (growth rules). Here, the location of the user triggers a translation for one of the centre points.

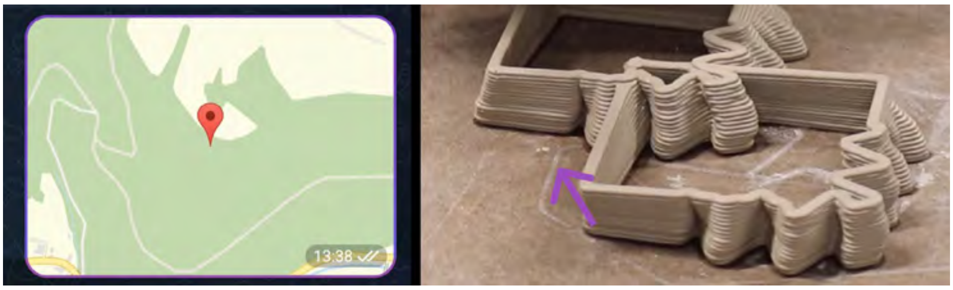

Fig. 14. Translation of one of the centre points.

(4) At arbitrary points in time, small protrusion could appear in the print (disruptive rules). The responses from the user are categorised as 'detached', one of the centre points shrinks.

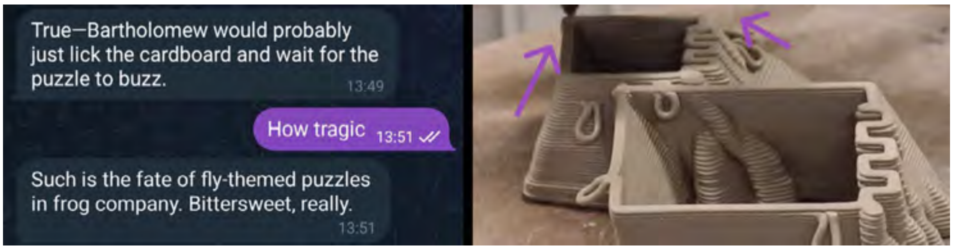

Fig. 15. The center points shrinks.

5 Discussion

The development over time of the project Streamline enables us to reflect on several aspects touching upon human-machine-material interaction, upon the notion of control itself and the question of efficiency in fabrication.

5.1 Control & Agencies

In the context of a study on interactive fabrication, the multiple agencies at play question the very notion of control — and thus the definition of interaction (Campbell 2000). Control in Streamline is always between: between suggestion and interpretation, between gesture and material response. The work lives in this in-between space, where intention is reflected through the sensibilities, limitations, and impulses of other agents. The notion of control is at the heart of this project: it's the tacit link in the expectations of the execution of a computer command, it's there in the 'CNC' acronym for 'computer numerical control' (fabrication). And it is the core disposition of interactivity. Interactive systems are often considered as giving an illusion of control to its users (Campbell 2000). Aims of actual participatory design, inclusion of the user in the decision process, shared authority and power (or the surrender of it) by the author can be elusive (Wacnik et al. 2025). Instead of following those aims, the distribution of agencies in the Streamline experience

Fig. 16. Screenshots of exchanges with the AI agent at various times (2025).

is precisely made to highlight the contrarian goals at play: mechanical, material, conversational. The printed artefacts are thus the material residues of that distributed agency, co-designed by human, AI agent, machine, and clay, all volatile actors.

In Streamline, control is a relationship continually tested by the presence of other agents. Among these is the AI agent. Its design was never to be a compliant assistant. Instead, its conversational tuning was oriented toward obliqueness akin to a sparring partner, not a subordinate. We iterated its tone away from task-oriented helpfulness and toward something quirkier, banter-like, with a fast, occasionally tangential wit. Screwball comedy became a model: exchanges that ricochet, derail, self-mock (Byrge and Miller 1991). We consider those screwball traits as markers of autonomy, of a 'mind of its own'. A bot that can tease, change the subject, behave 'out of order', with its own inclinations (Fig. 16).

The bot's oddities are only one part of the equation. The printer itself is an agent in the relinquishing of control. Recalibrated with open-source firmware after wrestling with a proprietary system for many years, its stability and operation remain a negotiation, with the constant fear of the next technical malfunction. Stepper motor alignments, latency in extrusion control, mis-timed pauses, crashes can too easily affect a print, producing happy accidents but more often unlucky setbacks. The printer is not a silent intermediary: it intervenes, slows, mistranslates (Andersen et al. 2019; Song and Paulos 2021; Twigg-Smith et al. 2021).

Then there is the clay: a material whose physical properties famously make precision conditional (Malafouris 2008). Its viscosity changes with moisture and time; it collapses under its own weight if layers are too ambitious; it warps subtly as it dries; it is unsecured before it dries; it is brittle after it dries, it is susceptible to further changes in the kiln and the glazing process adds to more chaotic outcomes. These shifts are not bugs to be ironed out, but the clay's own way of interacting. It forces turnarounds to expand the aesthetics beyond the 'tower-like' accumulative form, an issue which constituted its own research thread and one of the reasons for which we developed the distribution of clay deposition into 'center points'. The constraints of clay deposition motivate the continued aesthetic exploration. The clay material's agency is stubborn, shaped by physics rather than code, yet it makes the project all that it is: aesthetically, meaningfully, tangibly.

5.2 Non-Utilitarian Approach

Streamline operates in real time. The user's conversation with the chatbot is translated directly into machine movement and clay deposition, bypassing the need for a predetermined 3D model. This collapse between intention and outcome transforms fabrication into a live performance shared between human, AI agent, machine, and material. The machine reacts instantly: a change in tone or phrasing can alter layer rotation or extrusion rhythm within seconds. The machine's reactions, sometimes hesitant, sometimes abrupt, are perceived as direct responses. In that sense, the print is not the endpoint but the trace of a shared temporal proximity, material witness to an encounter, an object 'born witness' – we refer here to an expression used by Csikszentmihalyi and Rochberg-Halton for photography (1981). Unlike traditional additive manufacturing workflows that expect a predictable and purposeful outcome, this process accepts surprise and deviation as conditions of making. We argue that the forms that emerge are "non-utilitarian": they do not aim to fulfil a function, optimise performance, or conform to ornamental expectations.

5.3 Printed Artefacts: A Third Kind

We further frame the considerations discussed above with naming the generated artefacts of Streamline as "objects of a third kind". The objects are not particularly recognisable beyond the odd clay volume – possibly enough to seem intentional, yet not specifically finished, still in a state of 'becoming'. They are not purely designed, nor are they random. They purposefully fall outside the traditional design dichotomy of ornament vs function. They could be labelled artistic, speculative, prototype, probe… yet any of those could be limiting in its meaning. The true alien nature of those artefacts inspired the naming of "third kind", emphasising their quality of "other", beyond the design polarity. It is also, of course, a nod to Spielberg's 1977 film "Close Encounters of the Third Kind", the close encounter with an unfamiliar entity – not least because the film is permeated by a very geological, accumulative, clay-like symbolism.

The term 'third kind' puts forth a statement: an invitation to ponder the qualities of erosion, frailty, and mutation. These forms are semi-legible: one might detect spirals, lattice fragments, or shell-like layers, but also interruptions, collapses, and textures. Inconclusive states, or states-in-progress are all telling of a conversation that is being kept open.

Fig. 17. Streamline pieces being 3D-printed.

6 Conclusion

With the latest phase of the Streamline project, control continues to shift, opening new directions rather than closing the inquiry. As the Streamline technical set-up has gotten more reliable and optimised, we can pursue several creative opportunities, hidden promises that have motivated the overall journey since the very beginning.

The accumulated dataset of printed structures and corresponding chat histories enable the model to learn to generate its own structures. This would bypass the need for explicitly mapping conversation characteristics to design parameters. Over time, and with exposure to previous examples, the AI model could develop a deeper understanding of the experiment, make consequential autonomous design decisions and possibly make its own sense.

As well, Streamline had always intended to include a form of intimacy at a distance: connect multiple users, friends – fabricating collaboratively across different locations, or triggering one's remote printer to print live an artefact akin to sending a 'postcard', or manifesting a background presence (Patel and Agamanolis 2003; Gayler et al. 2020) Another one of the original intentions was to imagine prints taking place over much longer timeframes (days, weeks, or even months), using delays and latency as creative elements. The current hardware set-up may not allow for this specific intention but the concept could be adapted in a different capacity.

Overall, further user testing could reveal unforeseen creative possibilities. The mapping between conversation patterns and clay forms is still being explored – potentially uncovering new geometries and correlations. Additional materials beyond clay might offer different affordances – temporal rhythms and structural possibilities (Gayler et al. 2020; Song and Paulos 2021; Bell et al. 2024; Bell et al. 2025).

With the Streamline project, we argue for looking at all the components of the system as agents and including them in a 'strange' relationship. In particular, as AI systems become increasingly ubiquitous, the project argues for a collaborative drive welcoming them as entirely 'other' as opposed to metaphors for assistants, pets, servants, or executors of commands. Streamline highlights instead the opportunity humans have to decenter themselves: how we live, work, talk with AI systems, how we expect obedience, how we hope they solve all issues or how we fear they take over, reveal much about our tendencies to want control and dominate our environments, especially the non-human ones we can't fully understand or predict. The project's emphasis on material mediation and patient dialogue moves away from instrumental approaches to human-AI collaboration.

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