Generative Rules as Design Material: Constitutive Agency in Co-Creative Evolutionary Knit Design

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Abstract

We present an interactive evolutionary system for whole-garment knit design and use it to develop co-creativity frameworks by formalising an under-theorised level of human-computer agency. Current accounts theorise agency at the level of artefact selection and traversal steering, but do not address the case where one agent modifies the generative substrate by which the other operates. We propose three levels: evaluative agency over candidate selection, traversal agency over the operational region $O \subseteq C$, a construct we introduce to capture the practically reachable subset of C under the resource and interaction constraints of co-creative use, and constitutive agency over the transformation rules T_c that define C itself. Through an analytical design session, an experienced textile designer first navigated the existing conceptual space C through human-system co-traversal, then authored a new procedural style that restructured T_c, expanding C rather than redistributing search within it. We illustrate how language model–assisted authoring lowers the threshold for constitutive agency in this context.

Introduction

Many computational creativity systems structure interaction as navigation within a predefined generative space. Designers select, rank, or adjust parameters, but the representational grammar and transformation rules underlying variation remain fixed. While such systems can support rich exploratory traversal, creative agency is confined by the constraints of the design space.

Recent work in co-creative systems has emphasised distributed initiative between human and computational agents. However, even in mixed-initiative settings, the underlying generative rule sets and traversal mechanisms frequently remain architecturally stable, thereby fixing the conceptual space within which interaction unfolds. The question is therefore not only how initiative is shared, but whether traversal strategies and generative rules themselves can be modified during interaction.

Large language model (LLM)-assisted integrated development environments (IDEs) have made generative code editable during creative sessions. This is no longer a technical threshold question but an architectural one: when generative mechanisms become modifiable during use, co-creative interaction is no longer confined to traversal within a fixed conceptual space. The question becomes whether existing co-creativity frameworks adequately theorise such interventions as a distinct level of co-creative agency, or whether a new analytical level is required.

Computational fabrication provides a particularly revealing context for this question. In materially constrained domains such as textile design, generative exploration is shaped not only by algorithmic structure but also by fabrication feasibility, embodied evaluation, and resource limits. Here, expanding or redirecting a design space is inseparable from negotiating material constraints.

In this paper, we investigate how an interactive evolutionary system can support both exploratory traversal and structural transformation of its conceptual space through designer-authored generative rules. We examine a design session in which a professional textile designer first explores a predefined style library and subsequently authors a new procedural pattern style within the same system.

We were interested in the following questions:

(1) What analytical level, if any, is required to account for the case where one agent modifies the generative substrate by which the other operates? (2) If such a level exists, how does intervention at the rule level differ structurally from traversal-level agency within the same system? (3) What does constitutive agency require in a fabrication-constrained domain, where new generative rules must remain materially feasible?

We contribute (1) a co-creative evolutionary system that instantiates all three agency levels within a single fabrication-constrained architecture, and (2) a three-level account of co-creative agency – evaluative, traversal, and constitutive – that extends existing frameworks by formalising the case where one agent modifies the generative substrate by which the other operates. Central to this account is the operational region, the practically reachable subset of the conceptual space under interaction and resource constraints, which enables the traversal/constitutive distinction to be drawn precisely. We demonstrate that authoring assisted by LLM lowers the threshold for constitutive agency during use, and that constitutive agency in materially constrained domains requires analytical frameworks that distinguish between modification of the operational region and restructuring of the conceptual space itself.

By situating this account within Wiggins' formalisation of conceptual spaces, the paper clarifies how existing exploratory/transformational distinctions can be operationalised at the level of co-creative agency, and where current frameworks require extension.

Background and Related Work

To ground the study, we first outline formalisations of conceptual space and co-creativity, then situate the work within evolutionary and computational textile design. The focus is on aspects directly relevant to representational plasticity and rule-level authorship.

Conceptual Space and Co-Creative Transformation

In Creative Systems Framework (CSF), Wiggins formalises such systems as search processes operating within a universe U, structured by transformation rules T and evaluation criteria E (Wiggins 2006); in Wiggins' notation, the space-defining rules are R and the traversal strategy T – throughout this paper we refer to the space-defining rules as T_c. The transformation rules define a conceptual space $C \subseteq U$: the set of artefacts generable under current representational constraints. Exploratory creativity corresponds to traversal within a fixed C, whereas transformational creativity arises when T itself is modified, thereby restructuring C. In the present system, the computational rule set T_c operationalises this distinction concretely.

Extending this framework to co-creative settings, Kantosalo and Toivonen distinguish alternating and task-divided co-creativity, noting that human and computational agents may operate with partially overlapping universes $U_h \cap U_c$ (Kantosalo and Toivonen 2016). In interactive co-creative systems, practical exploration is further shaped by resource constraints, interaction history, and mutual adaptation, factors that bound which regions of C are actually reachable during a session. We refer to this practically accessible region as the operational region $O \subseteq C$: adjusting traversal mechanisms shifts O without altering C, while modifying T_c restructures C itself. In materially grounded design, U_h additionally encompasses fabrication constraints and embodied knowledge that cannot be fully encoded within U_c, making co-creative interaction a negotiation across representational boundaries rather than traversal within a single shared space.

Most directly related, Hauhio (2024) recently extends the CSF to a user-centered framing in which the search is performed by the user, defining a traversable set $T \subseteq A$ of artefacts a user can practically reach given their mental model and traversal strategy, together with control, value, and meaningful-control coefficients that quantify session-level outcomes for non-interactive prompt-based generative tools. Our $O \subseteq C$ structurally parallels Hauhio's $T \subseteq A$ and shares the user-centered extension of CSF, but differs in three respects: it applies to programmable systems in which the designer can modify T_c during the session; it formalises the move from rule-following to rule-modification as a distinct constitutive level of co-creative agency, orthogonal to Hauhio's control and value coefficients; and it treats material constraints, fabrication feasibility in the present case, as bounding O alongside algorithmic reachability.

Ritchie (2012) refined CSF by abstracting away its symbolic language machinery and formally defining transformation as a metalevel operation that produces a distinct norm-set for the space ($N' \neq N$), distinguishing it from object-level traversal that modifies only the search heuristic Q. In the present system, the computational rule set T_c operationalises this norm-set: adding a new procedural style restructures what artefacts are generatable and thereby constitutes a transformation in Ritchie's formal sense.

Broader work in mixed-initiative and co-creative systems has emphasised distributed initiative in artefact generation and evaluation (Karimi et al. 2018; Deterding et al. 2017; Muller, Weisz, and Geyer 2020), establishing interaction frameworks that inform the present study's analytical approach. In most implementations, however, co-creativity is enacted through traversal and selection within representational substrates that remain fixed during interaction – the condition that the present work examines as a site of potential extension.

Outside the computational creativity literature, design research has long discussed how design spaces are shaped by activity. Halskov and Lundqvist (2021), extending Lim, Stolterman and Tenenberg (2008), distinguish *filtering* the design space (extracting selected parts for investigation, without modifying the space) from *informing* it (adding new aspects and options that establish or transform the space). We adopt this distinction as background terminology: in our framework, traversal agency operates within the established space, a filtering-style activity, whereas constitutive agency expands the space by modifying its generative substrate, and is thus a specific computational form of informing.

Evolutionary Design Systems

Evolutionary design systems generate artefacts through iterative variation and selection applied to encoded representations (Bentley 1999). A genotype–phenotype mapping specifies how parameter vectors are expressed as artefacts, while mutation and recombination define available transformations. Representational choices therefore determine both the structure of C and the modes of designer intervention and have typically remained fixed once a system is deployed. Interactive evolutionary systems have been studied extensively as exemplified by the recent review by Wang and Pei (2024).

Indirect encodings such as Compositional Pattern-Producing Networks (CPPNs) (Stanley 2007) shift control from explicit geometry to developmental processes, enabling complex structure from compact rule sets. While these representations have been extensively studied algorithmically, their role in co-creative authorship at the level of modifying transformation rules during interaction remains comparatively underexplored.

Computational Textile Context

In computational knit design, significant advances have focused on fabrication-aware translation from geometric intent to machine-executable instructions (Narayanan et al. 2018;

2019; Hofmann et al. 2023). Compilation pipelines and scripting environments abstract low-level machine control while ensuring manufacturability. These systems expand operational flexibility but typically treat the generative architecture as structurally given.

In textile design, generative exploration is inseparable from fabrication feasibility and material constraint. The structure of C is therefore entangled with manufacturing logic, resource limits, and embodied evaluation.

Representation as a Site of Co-Creation

Meta-design research argues for systems intentionally structured to support modification during use rather than remaining fixed at deployment (Fischer and Scharff 2000; Fischer and Giaccardi 2006). In such frameworks, the boundary between system designer and user becomes permeable, enabling participatory evolution of the artefact-generating substrate. In computational generative design, an analogous distinction has been drawn: the designer specifies the rules and processes that produce artefacts rather than manipulating artefacts directly, a mode characterised as meta-design of the generative substrate (McCormack, Dorin, and Innocent 2004).

Work in procedural content generation (PCG) has established an explicit definition and analysis of generative spaces (Smith and Mateas 2011; Shaker, Smith, and Yannakakis 2016), and some mixed-initiative PCG systems allow the designer to steer within these spaces (Liapis, Yannakakis, and Togelius 2013). Yet interaction generally operates through parameter control or search guidance rather than modification of the underlying transformation rules during use.

Assessing Co-Creativity

A prior study in evolutionary design case indicates that designer agency may be constrained by representational complexity and technical friction, while exploratory sessions can motivate expansion of the design space itself (Uusitalo et al. 2024). This aligns with accounts of the cognitive gap between computational and design thinking (Kelly and Gero 2021).

Within materially grounded domains, evaluation extends beyond internal fitness functions to external contexts of fabrication and presentation. This motivates the analytical approach adopted in the present study, which focuses on how representational and traversal mechanisms are configured during use.

A recent systematic review of agency in human-AI co-creation across 134 HCI papers confirms that agency is predominantly analysed through locus, dynamics, and granularity of control without addressing interventions that modify the generative substrate itself (Zhang, Wang, and Yi 2025). This pattern is consistent with mixed-initiative game design tools, where a recent analysis finds no cases in which conceptual spaces are modified during interaction (Margarido et al. 2025). This gap motivates the present study's focus on constitutive agency as a distinct analytical level.

System Overview

The system is a web-based co-creative textile design environment built around an Interactive Genetic Algorithm (IGA) core and a modular procedural representation. Designs are encoded as unified genotypes combining shape and pattern parameters and rendered into fabrication-aware bitmap output. Evolutionary variation is guided by human selection and bounded mutation, complemented by a local language model operating at the traversal level. Crucially, the system is not limited to exploration within a fixed generative space: its modular style architecture allows the designer to extend or modify the underlying generative logic itself, thereby altering the structure of the design space over time.

To clarify how representational rules, traversal mechanisms, and evaluation processes interact, Figure 1 presents a layered conceptual architecture of the system.

Representational Substrate

Each candidate design is encoded as a hierarchical genotype that combines shape and pattern variables within a single representational schema. Shape parameters define boundary conditions and masked regions, while pattern parameters control the procedural generation of internal structures. Together, they specify a complete design instance without separating structural and pattern layers at the representation level.

Genotype–Phenotype Mapping The genotype is translated into a phenotype through a rendering pipeline that produces a bitmap image (PNG). The same file functions both as a visual evaluation artefact for the designer and as a machine-interpretable specification for downstream fabrication processing. Colour encodings correspond to knitting-relevant instructions rather than purely aesthetic values.

Fabrication-aware constraints are embedded directly into the representation and rendering logic. Invalid region assignments, incompatible parameter combinations, and structurally infeasible configurations are prevented at the genotype level. As a result, evolutionary variation operates within physically realisable bounds, ensuring that exploration remains aligned with production constraints.

Pattern structures are rendered with region-aware logic derived from a template image, ensuring motif coherence when knitted: the generative pipeline applies distinct rendering rules to torso and hem regions so that patterns repeat consistently in the physical artefact rather than distorting at seams. This encoding instantiates a whole-garment knitting requirement directly within the representational substrate, ensuring that evolutionary variation cannot produce patterns that would be visually coherent in the bitmap but structurally incoherent when fabricated.

A bitmap can be added as a starting point for a design process. This template image functions as a pre-session agency mechanism: by encoding admissible regions through colour-coded pixels, the designer operationalises external constraints from the human/material universe U_h directly within the representational substrate, bounding the conceptual space prior to traversal.

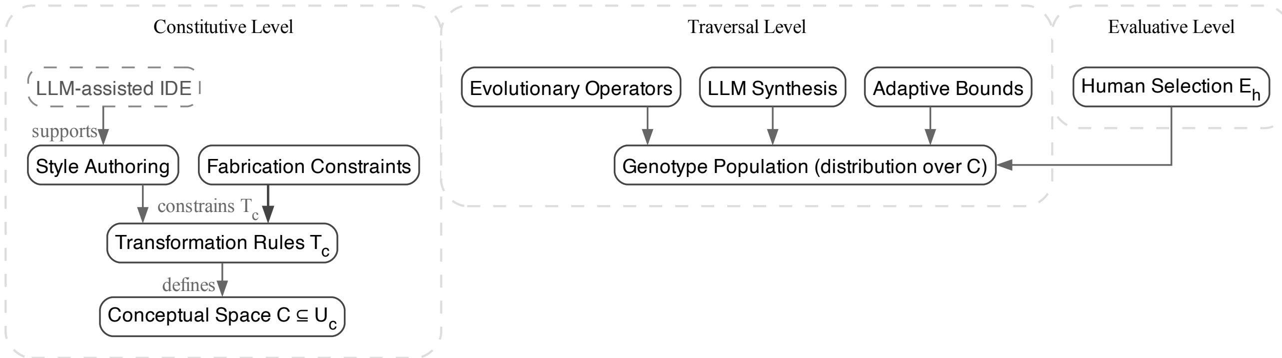


Figure 1: Conceptual architecture separating constitutive, traversal, and evaluative levels of co-creative agency. At the constitutive level, LLM-assisted IDE supports Style Authoring, which modifies transformation rules T_c — subject to fabrication constraints that bound admissible rule modifications. Traversal mechanisms induce an operational region $O \subseteq C$, and human selection E_h evaluates candidate artefacts at the evaluative level.

In addition to independent parameter effects, certain metagenes introduce developmental couplings between shape and pattern. For example, boundary-sensitive modulation parameters or CPPN-based spatial biases may cause pattern density, scale, or orientation to vary as a function of the shape-defined geometry (e.g., gradual intensification toward edges or central attractors). In such cases, the phenotype emerges from interactions between shape-related and pattern-related parameters rather than from two fully separable layers. This introduces a developmental dependency within the genotype-phenotype mapping, where geometric boundary conditions influence procedural pattern expression.

Universe, Conceptual Space, and Operational Region To clarify the ontological and operational layers of the system, we distinguish three levels. The *computational universe* U_c is the set of all artefacts expressible within the bitmap-based knitting representation, bounded by encoding limits and structural constraints. Within it, transformation rules T_c define a *conceptual space* $C \subseteq U_c$, instantiated as genotype structure, procedural styles, and compositional operators. Traversal dynamics then induce a non-uniform probability distribution over C; we refer to the high-probability, practically reachable subset as the *operational region* $O \subseteq C$.

Under this distinction, changes to traversal parameters shift O (exploratory creativity), whereas modifications to T_c alter C itself (transformational creativity). This separation ensures that representational ontology (U_c and C) and exploratory dynamics (O) remain analytically distinguishable throughout the system architecture.

Modular Styles as Generative Units Pattern generation is organised around modular *styles*, each implemented as an encapsulated procedural generator adhering to a shared rendering interface. A style defines its own parameter schema and may optionally include style-specific mutation or recombination operators. At runtime, one or more styles are instantiated and combined within the unified genotype.

Styles can be composed through logical and spatial compositing operations (e.g., conjunction, masking, blending), enabling hybrid pattern structures without redefining the underlying representation. In this sense, the available style library defines the structural extent of the conceptual space C at a given moment.

Certain styles operate at a developmental level rather than specifying local pattern structure directly. For example, a CPPN-based component functions as a spatial metagene, introducing global regularities such as symmetry, smooth gradients, or coordinated variation across the surface. Additional metagenes (e.g., global scale factors, symmetry biases, or attractor-like modulation parameters) shape how lower-level pattern parameters are expressed across space. These metagenes bias phenotypic realisation without prescribing a fixed aesthetic outcome, preserving evolutionary variability while maintaining coherent global structure.

Structural and Adaptive Bounds To distinguish representational limits from adaptive search bias, the system employs a two-layer bound model defined in external JSON configuration.

Structural_bounds specify the ontological limits of each parameter (e.g., type, valid range, discrete sets). These bounds define the admissible region of the conceptual space C and remain invariant unless the representational schema itself is modified.

Adaptive_bounds are updated incrementally from interaction history and accepted selections. They do not alter the structural limits of C, but bias sampling and mutation toward historically preferred parameter regions.

During evolution, all parameter updates are constrained by structural bounds, while adaptive bounds modulate probability distributions within those limits. This explicit separation preserves a stable representational ontology while allowing historically conditioned reorientation of the operational region $O \subseteq C$. In this way, representational structure and exploratory dynamics remain analytically separable.

Evolutionary and Meta-Evolutionary Dynamics

This section describes how the implemented conceptual space C is traversed during interaction.

Interactive Genetic Algorithm Core The system maintains a population of candidate genotypes that evolve across discrete generations. At each iteration, the designer selects one or more preferred candidates, which serve as parents for the next generation.

Variation is introduced through crossover and bounded mutation within structural limits. Mutation strength is globally controllable; additionally, a *focus mode* implements an exploitation bias by contracting the operational region O toward parent-adjacent solutions. Concretely, focus mode (i) increases the mutation amplitude of developmental metagenes for a subset of the brood while strengthening adaptive memory-range biasing, and (ii) selects the displayed next-generation candidates by proximity to the selected parents in a standardised genotype-derived embedding space, rather than prioritising cluster-representative diversity. Adaptive bounds remain active in focus mode, further conditioning variation toward historically preferred regions.

The designer may also lock either shape-related or pattern-related components, constraining evolution to the unlocked part. Human selection – denoted E_h to distinguish it from computational evaluation processes – remains the primary evolutionary pressure guiding population drift over time.

Traversal-Level Synthesis and Diversity Mechanisms In parallel with the genetic operators, a local language model periodically proposes candidate parameter configurations, operating exclusively on structured parameter summaries, selection history, and simple population statistics, without access to rendered images. This component is confined to the traversal level, shaping the operational region O within a fixed C, and is architecturally and functionally distinct from the LLM-assisted development environment through which generative rules themselves are authored.

Three constrained mechanisms are implemented at the traversal layer: (1) selection-weighted recombination of parameters from previously preferred candidates, (2) bounded perturbation triggered when population variance falls below a threshold, and (3) diversity-driven replacement when intra-population similarity exceeds predefined thresholds. All proposals are validated against structural constraints before admission into the population, and each is accompanied by a short textual rationale referencing measurable signals such as repeated selection or detected convergence, keeping proposals inspectable and reversible at the parameter level. In each synthesis cycle, one slot is reserved for a deliberately contrarian candidate that inverts the metagene centroid of recent selections and prioritises underexplored styles, functioning as a persistent diversification probe within the traversal layer. Operating on explicit genotype representations rather than latent visual embeddings, the model remains lightweight and locally executable, enabling near real-time interaction without external API latency and supporting sustained use without interrupting the designer's cognitive flow.

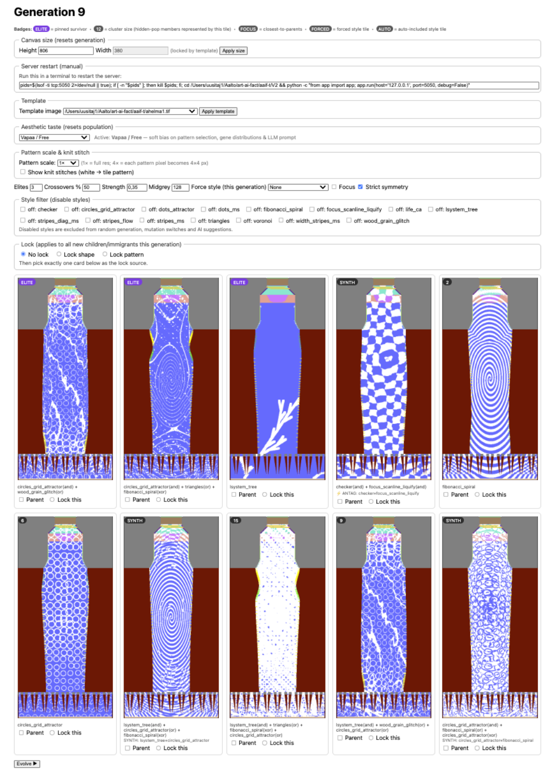


Figure 2: The browser-based interface presenting a generation of ten candidate designs for iterative selection by designer. Controls at the top expose traversal parameters including mutation strength, focus mode, style filtering, and shape/pattern locking. Each candidate displays its active style composition; ELITE and SYNTH labels indicate selection history and LLM-synthesised proposals respectively.

A backend controller manages the evolutionary loop, maintaining population state, applying variation operators, triggering rendering, and logging interaction history across generations.

Space Transformation and Co-Creative Agency

Having described representation and traversal operationally, we now situate the system within a formal account of computational creativity.

From Exploratory to Transformational Creativity Within the present system, exploratory creativity corresponds to traversal within a fixed conceptual space C, where mutation rates, adaptive bounds, or operator weighting reshape the operational region O without altering C itself.

Transformational creativity occurs when the transformation rules T_c are modified – for example, through the introduction of a new procedural style or changes to the generative pipeline – thereby expanding or restructuring C.

Styles as Objects of Authorship Within the present system, styles function not only as sources of variation but as modifiable generative units. Authoring a new style introduces new parameters, spatial logics, or developmental couplings, thereby redefining the structural extent of C.

Because styles encapsulate generative rules, they provide a clear locus at which the designer can intervene in the construction of the space itself. The design process thus extends beyond selection among candidates to modification of the mechanisms that produce them.

Design Session: Authoring a New Procedural Pattern Style

A single professional designer engaged with the system in order to enact and expose its co-creative dynamics under realistic conditions of use. The design session is treated as a critical case (Yin 2003, p. 41): a single instance sufficient to establish that the proposed three-level agency structure is instantiable in practice. The purpose of the session was not to evaluate user satisfaction or generalisable usability outcomes, but to examine how agency, initiative, and generative control are distributed between human and system within the given architecture.

Study Design

The study involved two human participants with clearly delineated roles. The first author designed and implemented the interactive evolutionary system and a set of styles, and was responsible for the study setup and data analysis.

The system user was a professional textile designer with a postgraduate degree and extensive experience in industry and university-level design education. They contributed domain expertise, material knowledge, and an independent design brief – the U_h resources not available to the system designer – and provided the real-world design context (the Hylky garment project). Although they are a co-author, their contribution to system development was explicitly bounded: they provided Shima Seiki fabrication requirements and sample designs but did not participate in data analysis or interpretation of findings. Their familiarity with the system's design intent means the session is not representative of independent or novice use, but is appropriate for a proof-of-concept demonstration of constitutive agency enacted by a domain expert operating within their area of competence.

The computational system, which includes the IGA and the LLM-assisted IDE, functions as a co-creative agent within the session, contributing proposals and modifications under human selection control.

Session Procedure The in-person session lasted 180 minutes and was conducted with the browser-based system interface. In the first phase, the designer employed the existing style library with the aim of producing a garment design suitable for full whole-garment knitting. This phase served both as creative exploration and as a means of identifying structural limitations of the current design space.

The second phase focused on authoring a new procedural style intended to better support the identified design ambitions, employing the Cursor IDE and instant evaluations of developments in the browser-based interface. Following this intervention, a short post-session reflection was conducted to capture immediate impressions of the interaction and perceived distribution of agency.

Design Intent and Intervention The design task involved developing a whole-garment knitted piece using a yarn derived from historically sourced wood pulp, from a recently discovered, late 17th-century shipwreck (Ahverdov, Koivikko, and Vuori 2026). The material was available only in limited quantity, introducing strict resource constraints. The garment was intended for public exhibition, introducing external evaluative criteria beyond internal system optimisation. In 4P terms (Rhodes 1961), the exhibition context constitutes a *Press* factor shaping E_h, requiring technical robustness and aesthetic coherence suitable for public display.

In addition, the garment was intended for physical display on a human and a mannequin, imposing embodied geometric and proportional constraints external to the computational representation. These constraints originate in the human/material universe U_h and were operationalised within U_c through a template file that restricted the admissible generative regions. This image file was prepared prior to the session by the participating textile designer.

The intervention was not framed solely as a functional refinement of outcomes, but as an exploratory act aimed at examining how a professional designer appropriates the ability to modify the design space itself. Rather than limiting interaction to traversal within a predefined conceptual space, the session introduced style authoring as a structural intervention at the level of T_c. The implications of this shift, from navigating a space to reshaping it, are discussed in the analysis section.

Data Captured The system logs all evolutionary runs, including selected candidates, parameter configurations, generation counts, and exported pattern files. Screen capture documented the interaction process and discussion in line with contextual inquiry, appended by written notes. The resulting designs were fabricated as knitted garment samples, providing material validation of the generated outputs.

Contrasting Before and After Style Authoring

The session unfolded in two phases. In the first phase, exploration proceeded using the existing style library and traversal mechanisms. The designer interacted with the system through the browser-based interface (Figure 2), selecting candidates to guide subsequent evolution. By generation 81, the designer selected a configuration considered sufficiently aligned with the project constraints to justify physical prototyping. This phase demonstrates the system's exploratory capacity within a fixed conceptual space C.

The second phase introduced style authoring as a structural intervention. The designer entered with a pre-articulated generative intent described as a "wood grain pattern disrupted with digital glitch artefacts." Through approximately ten iterative refinements in the LLM-assisted development environment, a new procedural style was implemented in Python.

Fabrication constraints shaped constitutive intervention directly: during the design session, the designer verbally reflected on whether a potentially interesting pattern organisation would become illegible when knitted, effectively performing mental simulation of material feasibility as a real-time filter on generative rule construction. This illustrates that constitutive agency in a fabrication-constrained domain is not equivalent to unconstrained code authoring – new generative rules must be evaluated not only for their parametric behaviour but for their viability as physical artefacts.

The resulting style introduced additional parameters (e.g., scanline and liquify intensities, focus bias, softness controls) and extended the generative pipeline with a post-effect stage operating on a preceding pattern layer. This modification did not merely reweight existing parameters or redirect traversal. Instead, it altered the transformation rules T_c by adding a new generative step to the mapping from genotype to phenotype.

As a consequence, the conceptual space C defined by T_c was structurally expanded: the post-effect stage introduced a generative step absent from the prior mapping, expanding C rather than redistributing search within it.

In Wiggins' formal terms (Wiggins 2006), this intervention corresponds to a modification of T_c rather than a change confined to traversal dynamics. Notably, the locus of control shifted from phenotype selection to rule-level manipulation, marking a transition from exploratory traversal to transformational engagement.

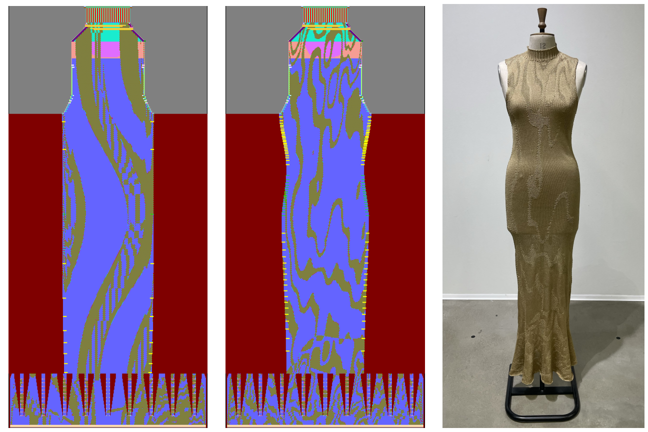
Reflection on Co-Creative Agency

The session highlights an asymmetry in agency distribution. The computational agent operated primarily at the level of candidate generation and traversal structuring, while rule-level transformation remained a human-initiated intervention. This became evident in the second phase, where the designer shifted from selecting outcomes to modifying generative logic.

The oscillation between exploration and exploitation was explicitly articulated by the designer: "sometimes one wants it to stay same, next, one wants to see something different." This reflects conscious engagement with traversal control rather than passive selection. Likewise, the remark that "the antagonist is good to have there" suggests that computationally introduced provocation was experienced as a productive counterpoint rather than as noise.

At the same time, the desire for "more local control" indicates that agency at the representational level remained bounded by the current architecture. While rule-level transformation was accessible, fine-grained spatial editing was not, revealing limits in the current distribution of initiative.

Together, these observations suggest that co-creativity in this system does not rely on symmetrical transformation capabilities. Instead, it emerges from complementary roles: computational structuring of traversal and human-driven modification of generative rules. The introduction of style authoring shifted the designer's activity from selecting among generated artefacts toward manipulating the generative logic itself. An LLM-assisted IDE functioned as a coding assistant within this process, supporting iterative refinement of procedural logic, but the structural intervention i.e., adding new parameters and a post-effect stage remained conceptually directed by the designer.



(a) Design co-created through traversal within the pre-existing style library.

(b) Design generated through constitutive intervention: a new procedural style was authored, modifying T_c and expanding the conceptual space C.

(c) Fabricated garment produced from the design in Figure 3b, made from substitute yarn. The sample produced from shipwreck yarn is in Fig. 4.

Figure 3: Contrastive design outcomes from the session and a knitted prototype garment.

Discussion

The following discussion interprets the design session through the analytical framework introduced earlier, distinguishing between traversal within a fixed conceptual space C and structural modification of its defining transformation rules T_c, in order to clarify how co-creative agency was distributed across system layers.

Traversal Control and Operational Plasticity

The session first illustrates agency at the level of traversal within a fixed conceptual space C, where the designer explored the conceptual space widely. In late generations, focus mode enabled controlled exploitation by contracting the operational region toward parent-adjacent solutions. Rather than restricting parameters explicitly, it reshaped the search distribution by amplifying developmental metagene variation and replacing diversity-based population turnover with proximity-based selection in a standardised genotype-derived embedding space. Final selections in both phases emerged under such focused refinement, indicating that traversal dynamics functioned as meaningful control mechanisms rather than opaque stochastic variation.

In parallel, the LLM-based synthesis mechanism and adaptive bounds further shaped which artefacts became likely or reachable within C, conditioning the operational region O without modifying the transformation rules T_c. In

Wiggins' terms, they correspond to exploratory creativity: the induced distribution shifts, but the generative rule set remains stable. In Ritchie's (2012) terms, these operations modify the search heuristic Q while the norm-set N – operationalised by T_c – remains fixed.

Transformational Intervention

The transformational intervention was intentionally introduced as part of the session design. The contribution therefore does not lie in demonstrating that rule-level modification can occur, but in analysing how enabling such modification restructures the conceptual space and redistributes co-creative agency within a materially constrained evolutionary system.

In contrast, the assignment to introduce a new procedural style modified T_c by adding new parameters and a post-effect stage to the generative pipeline. This extended the set of artefacts generable under the system by modifying the generative mapping from genotype to phenotype, thereby restructuring the conceptual space C defined by T_c. The shift from phenotype selection to rule-level modification therefore marks a transition from exploratory traversal to transformational engagement.

The architecture made such structural interventions possible during interaction. The language model supported iterative refinement of procedural logic, but the structural modification itself remained a designer-directed intervention at the level of T_c.

By Ritchie's (2012) criterion (Definition 7), this constitutes transformation rather than traversal: the new style rewrites T_c, introducing parameter types and a rendering stage absent from the prior pipeline, so the norm-set changes structurally ($N' \neq N$) rather than merely redistributing probability across a fixed one. Adjusting traversal parameters (focus mode, adaptive bounds, LLM-mediated proposals) modifies Q while T_c remains fixed; only the rule-authoring step crosses the $N' \neq N$ threshold.

Ventura and Brown (2024) argue on information-theoretic grounds that creativity-as-search at the base-artefact level is generally infeasible due to density constraints, and propose reframing creativity as a search for short programs that generate the artefacts. Our notion of constitutive agency arrives at a structurally similar conclusion from a different direction: the locus of creative intervention shifts from candidate artefacts to the generative procedures (T_c) themselves. Where Ventura and Brown frame LLM-based generation as a creative dead-end at the artefact level, our system situates the LLM as a programming assistant at precisely the rule-authoring level they identify as the productive locus.

Within the CSF tradition, this separation is anticipated by Hauhio (2024), who treats user-driven modification of goal rules R, and the consequent change in the mental model M and traversal strategy T_M, as forms of transformative creativity rather than continued traversal. The same categorical distinction is independently established in design research: by Halskov and Lundqvist's (2021) definitions, modifying the generative procedures is informing-work, not filtering-work, regardless of whether the modification capability was anticipated by the system designer.

Material Constraints and External Evaluation

Textile design is materially constrained. Display context, fabrication feasibility, and resource limitations introduced requirements originating in the human/material universe U_h, which were operationalised within U_c through template-based shape encoding and fabrication-aware representation. Rule-level modification was therefore not a purely formal expansion, but one constrained by fabrication feasibility and exhibition context.

The exhibition outcome functions as an external evaluative context, situating creative value beyond the interaction loop. The fabrication and public presentation of both pre- and post-intervention artefacts indicate that the system supported viable creative production under real-world constraints.

Implications for Co-Creative Agency

The session illustrates how the three levels of agency are enacted in practice: evaluative agency, in the form of candidate selection guided by material and aesthetic judgement, operated continuously across both phases as the baseline mode of co-creative interaction. The analytically significant finding concerns the remaining two levels: traversal agency, enacted through focus mode, adaptive bounds, and LLM-mediated proposals that shaped O without modifying C; and constitutive agency, exercised when the designer restructured T_c by authoring a new procedural style, expanding C rather than redistributing search within it. The first two correspond to exploratory reorientation within a fixed representational substrate; the third constitutes transformational intervention at the level of the generative rules themselves.

Agency is asymmetrically distributed across these levels. The computational agent operates primarily at the traversal layer, proposing candidates and reshaping the operational region through synthesis and diversity mechanisms. The human designer retains evaluative authority and uniquely performs rule-level modifications that alter T_c. Co-creativity here emerges not from symmetric transformation capabilities, but from complementary roles across traversal, constitutive agency, and evaluation.

Crucially, the modular implementation exposes transformation rules T_c as inspectable and editable during interaction, enabling intervention at multiple levels of the generative pipeline. This makes structural modification part of the co-creative process rather than a prior design decision fixed at deployment. While the language model facilitates iterative development, the key shift lies in the relocation of generative authority: the designer restructures C rather than merely re-orienting the induced probability distribution over it. However, evaluation remains grounded in the human agent situated within the broader material universe U_h, where fabrication constraints, exhibition context, and aesthetic judgement determine what is worth producing. The system expands generative plasticity; the human anchors value.

These findings resonate with prior analyses of interaction design in co-creative systems (Kantosalo et al. 2020; Rezwana and Maher 2023), which emphasise how initiative

Figure 4: Detail of the fabricated garment showing structure at the knitted surface. The physical artefact evidences viability under fabrication constraints and situates evaluation beyond the computational interaction loop. (Photograph: Esa Kapila)

distribution and feedback structure shape creative experience. In the present case, however, neither initiative distribution nor control granularity – the dimensions foregrounded in recent empirical work on agency in HCI systems (Zhang, Wang, and Yi 2025) – adequately captures the intervention that occurred: constitutive agency operates at a qualitatively different level, one that existing co-creativity frameworks and control mechanism taxonomies were not designed to accommodate. When LLM assistance lowers the threshold for modifying T_c during use, the boundary between system design and system use becomes structurally permeable – and the frameworks used to analyse co-creative agency may need to expand accordingly.

Limitations and Future Work

The presented system is domain-specific, restricted to bitmap-based pattern representations for whole-garment knitting, and evaluated through a single analytical design session with a co-author participant. The findings therefore illuminate architectural implications of constitutive agency rather than generalizable behavioural outcomes. Although LLM-assisted authoring lowers the threshold for rule-level intervention, such interventions still require capacity to articulate structural generative intent.

Future work may extend the representational substrate toward integrated topological garment modelling, and investigate how traversal-level and rule-level interventions interact over longer-term use with multiple designers. Studying how shared or evolving style libraries reshape the conceptual space over time would clarify the social and collaborative dimensions of constitutive agency in co-creative systems.

Conclusions

By formalising three levels of co-creative agency – evaluative, traversal, and constitutive – the study identifies an under-theorised mode of human-computer co-creativity in which one agent modifies the generative substrate by which the other operates. In a fabrication-constrained domain, LLM-assisted authoring facilitates this constitutive intervention during use, embedding co-creative agency within the constraints of physical production.

As generative systems become increasingly programmable, computational creativity research may need to extend existing exploratory/transformational distinctions toward frameworks that operationalise co-creative agency across structural levels, from traversal within a conceptual space to authorship of the space itself.

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