Technical Mentality: Principles for HCI Research and Practice

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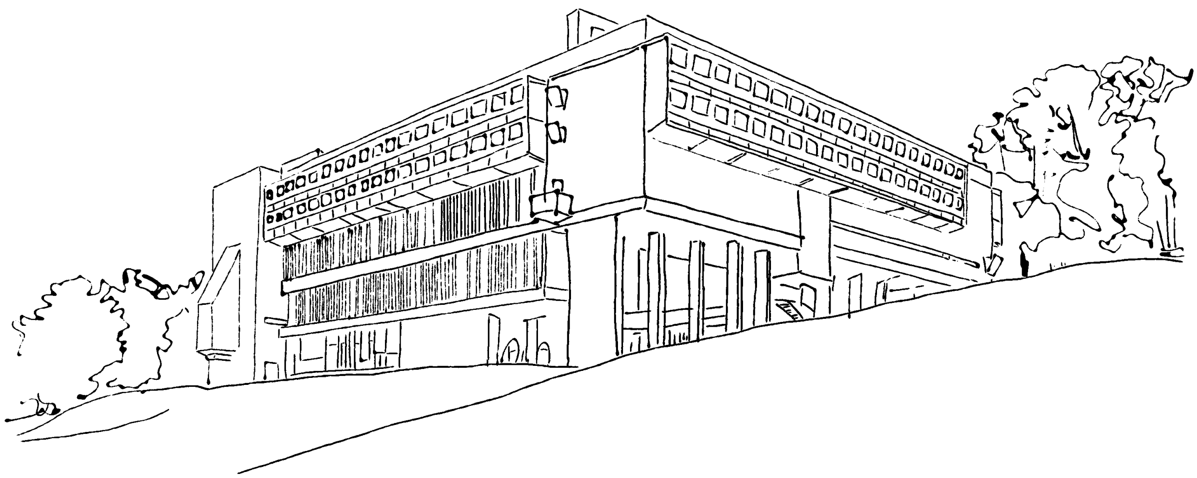

Figure 1: Gilbert Simondon describes Le Corbusier's La Tourette monastery as an example of *technical mentality* because of its clearly exposed materials and of how it includes within its plan the possibilities of its extension and modification.

ABSTRACT

This paper presents a reflection on the role of ontological inquiry in HCI research and practice. Specifically, we introduce philosopher Gilbert Simondon's proposal of technical mentality, an onto-epistemology based on direct knowledge of technical objects and systems. This paper makes the following contributions: an analysis of Simondon's ontological critique and its connection to technical mentality; a reflection on the ethical and practical implications of Simondon's proposal for systems research; an example of technical mentality in practice; and a discussion of how technical mentality might be extended into a design program for HCI through four principles: extension, integration, legibility, and expression.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**.

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1 INTRODUCTION

Technical objects and systems are all around us, yet their mechanisms and inner workings are mostly hidden or unknown. How much should people engage with and understand the mechanisms and inner workings of the technology they interact with? This question has been a concern among design and HCI scholars since at least Weiser's introduction of ubiquitous computing in the 1990s [111]. The debate around seamful and seamless design has raised issues around user appropriation [67], configurability [34], ambiguity [92], and the revelation of complexity [19]. Some researchers and practitioners have called out the harmful implications of 'black boxing' systems [12, 57], while others have emphasized the need to lower technical barriers to facilitate use and increase participation [13, 102].

For philosopher Gilbert Simondon (1924-1989), to know how technical systems work is the condition to developing more sustainable relationships with technology. He wrote: "The most powerful cause of alienation in the contemporary world resides in this misunderstanding of the machine, which is not an alienation caused by the machine, but by the non-knowledge of its nature and its essence" [95, p. 15]. Instead of the Manichean attitude which either fetishizes or instrumentalizes technology [94, 95], Simondon urged his contemporaries to develop more horizontal and companionable relationships with technical objects and systems. This relationship could only grow through an apprehension of machines' dynamic interiority—an understanding of their structure and inner workings.

In this paper, we unpack Simondon's position on the rehabilitation of technical systems within culture, which is best captured by his notion of **technical mentality**. We discuss technical mentality's ontological and epistemological commitments and its affinities with existing strands of research within HCI, notably seamful design and feminist new materialism, in particular Barad's agential realism [5, 6]. We argue that Simondon's technical mentality contains an implicit design program that has not yet been explored, and see this paper as an initial step to formalize this demanding and exciting vision and its possible applications for HCI research. Our objective with this paper is two-fold: 1) to introduce Simondon's ideas to the broader HCI community, and 2) to show that technical mentality is a productive ontological and ethical orientation for HCI, especially if its high level principles can be translated into guidelines for practice.

Simondon's philosophical project has been described as a technological humanism [10, 40]. His two main theses, *Individuation in Light of the Notions of Form and Information* (published in its entirety in 1989; henceforth, ILNFI) [96] and *On the Mode of Existence of Technical Objects* (published in 1958; henceforth, METO) [95], respectively deal with the questions of individuation, i.e., the process by which individuals come to be, and the individuation of technical objects[1]. Simondon's concern with the non-human was less a move to decenter humans in ontological narratives (as posthuman, post-anthropocentric, and more-than-human framings tend to construe it [108, 109]), but to account for the processes that co-constitute humans and their tools. In this sense, Simondon's humanism was a rehabilitation of the 'non-human' dimension of technology into humanist accounts. He spoke of a "complete humanism" that could make space for technicity within its conception of humanity instead of seeing technology as alien to human reality. Simondon was fond of the famous line by 2nd century BC Roman playwright Terence, *humani nihil a me alienum puto*: "nothing human is alien to me." For Simondon, failing to see technical objects and systems as fundamental aspects of human reality would keep culture unbalanced and lead to alienation for both humans and machines.

We argue that Simondon's philosophy is directly relevant to the field of HCI, which seeks to understand relationships between humans and computer systems and foster beneficial ones [26]. Since its inception, HCI has shifted from a dominant concern in building efficient machinery to designing meaningful interactions [14, 71, 112]. While this has enriched the field considerably, we argue that HCI needs to reintegrate engagement with machinery and mechanisms in its priorities. We do not mean the field should go back to its initial concerns, but instead weave the technical dimension of systemsinto its accounts of human-technology interactions. The concern with relational ontologies and the more-than-human that characterizes fourth wave HCI [38] needs to consider the specificity of technical objects' and systems' modes of existence. Otherwise, it risks developing atrophied accounts of sociotechnical processes that cannot engage with the operations that mediate material, human, and technological encounters. Beyond its social and cultural implications, the lack of knowledge of technical systems is a *philosophical* problem. It concerns our ability to think of "technology in the reality of its inventive becoming" [59, p. 109] rather than as purely a set of means, and therefore as static and already-determined realities. Simondon's philosophy provides a much needed path to develop rich accounts of the inner workings of systems. By doing so, more sustainable and balanced relationships with technology can emerge, ones that account for the human content of machines and effectively integrate them in culture.

Simondon's position is anchored in a deep understanding of technical systems as well as in a critique of traditional Western metaphysics. In Section 4, we unpack his ontological critique and explain how it connects to his concept of technical mentality. Technical mentality stems from Simondon's anti-substantialist ontology and extends its focus on operations and processes into the realms of epistemology and ethics. We then discuss the implications of these onto-epistemic commitments for the design of technical systems through the description of one specific example, a system for CNC milling [106]. We conclude with an initial proposal to extend technical mentality into a design program for HCI through the discussion of four design principles: *extension*, *integration*, *legibility*, and *expression*.

In this paper, we make the following contributions: 1) An analysis of Simondon's ontological critique and its connection to technical mentality, 2) A reflection on the ethical and practical implications of Simondon's proposal for systems research, 3) An example of technical mentality in practice, and 4) A discussion of how technical mentality might be extended into a design program for HCI.

In Sections 2 and 3, we historically situate Simondon's work and discuss his influence in philosophy of technology and science, science and technology studies (STS), media studies, art, architecture and design. Furthermore, we discuss the connection of technical mentality to existing strands of HCI research, namely agential realism and seamful design.

2 SIMONDON IN PHILOSOPHY AND SCIENCE AND TECHNOLOGY STUDIES

Simondon's work has been very influential in the fields of philosophy of science and technology, as well as science and technology studies (STS), media studies, architecture, and the arts. In this section, we provide a brief overview of how Simondon's ideas have been taken up in these fields. We show that while Simondon's ideas have been influential in design theory, they have not yet been formalized into principles or guidelines for design practice.

[1]We further discuss Simondon's individuation in Section 4.

2.1 Simondon in Philosophy of Technology and STS

Gilbert Simondon wrote his main two theses Individuation in Light of the Notion of Form and Information (ILNFI, [96]) and *On the Mode of Existence of Technical Objects* (METO [95]) in the 1950s as part of his dissertation work. He kept refining the ideas contained in these two manuscripts over the course of the following three decades, until his death in 1989. While METO received some attention after its publication in French in 1958, it is not until 1966 that the work of Simondon was introduced to a larger audience through a review by Gilles Deleuze of ILNFI, then partially published. The full version of ILNFI was made available in 1989, the year of Simondon's death, triggering a wave of interest among scholars and philosophers in France who would revive Simondon's legacy, including Muriel Combes [21], Jean-Hugues Barthélémy [9, 10], Vincent Bontems [15, 16], Xavier Guchet [40], Ludovic Duhem [28, 29], Sacha Loeve [64, 66], Bernard Stiegler [98] and Isabelle Stengers [97], among others. Bernard Stiegler, who wrote the preface of the 2007 reedition of ILNFI, emphasized the relevance of Simondon's philosophy to understand the role of technology in shaping processes of individuation in Western culture [98, 99].

While Simondon's work is mainly discussed in philosophy [1, 7, 9, 21, 40, 50, 64, 91, 97, 98], his work has also been influential in STS [30, 31, 61] and media studies [69, 70, 73, 110]. For instance, Feenberg [30] shows how Simondon's theory of concretization extends constructivist perspectives in technology studies, not only by including non-human actors (as Actor-Network Theory did) but by attending to the role of "technical rationality" in these accounts of technological non-humans—by offering a way to engage with their specific mode of existence, that is their technicity.

Simondon's theory of concretization is a genetic (as opposed to historical) approach to technological evolution. Instead of describing technical objects through their social history or usage practices, Simondon is interested in their mechanisms, their design, their mode of operation, and the process of progressive innovations that develops parts and adapts tools and systems to a variety of functions. Machines become more concrete as the different parts of their system becomes more tightly coupled, each more coherent with its internal structure as well as its milieu. Feenberg argues that Simondon's notion of concretization provides a way out from the false dilemma of "rationality versus ideology," where rationality is identified with technological understanding, efficiency and control, and ideology with the social agendas in systems design [30]. To engage with the mechanisms, which are the proper mode of existence of technical objects, enables one to that machines are more than simply "means to an end" but cultural artifacts in and of themselves—reifications of human invention and labor, which transform human milieus and the possibilities of existence, i.e., culture.

2.2 Simondon in Art, Architecture and Design

Simondon's ideas have also been influential in the fields of art [1, 28, 37, 42, 59], architecture [63, 72, 103] and computational design [81, 84, 87]. For instance, Poulsgaard [81] uses Simondon's theory of individuation to explore"enactive individuation" in robotics. Enactive individuation refers to the "complex interplay of forces in a given ecology reaching across material and informational domains" that produces individuals in computational design processes." Rather than arising from manipulation of mental plans and representations, Poulsgaard argues that computational design objects (designs, artifacts) emerge from the situated, material, informational and energetic operations enacted by various bodies. Similarly, Lloyd-Thomas [62] uses Simondon's account of individuation to build an argument on how architectural specification impact approaches and attitudes to materials.

These ideas are not new to HCI, as we discuss further in sections 3.1 and 4.1. The "plans and representations" that seem to guide most computational design processes are expressions of a hylomorphic, or matter-forming [105], ontology. By contrast, Simondon's notion of individuation, not unlike Karen Barad's agential realism (which we discuss in 3.1), are process-based ontologies that recognize the agency of materials, energy, bodies and environment in the emergence of individuals [5, 96]. Simondon's critique of hylomorphism has indirectly influenced HCI research [25, 105] through the writings on making of anthropologist Tim Ingold [51, 52].

The impact of Simondon's ontological critique in the domains of art, architecture and computational design have lead researcher to investigate and formalize materially-oriented approaches to production processes. His notion of technical mentality, however, has gained less traction in these fields. We argue that is it because technical mentality's high-level reframing of epistemology and ethics as process-based events is more directly applicable to think sociotechnical issues than for the design of technical systems. While scholars have commented on the political and cultural implications of technical mentality [1, 21, 40, 91], the design orientation of Simondon's work has thus far remained implicit. In this paper, we propose a first step towards explicitating and formalizing technical mentality's implicit design program.

3 SIMONDON AND HCI

While few HCI scholars have explicitly engaged with Simondon's work [36, 56], his philosophy echoes existing strands of research and conceptual framings in the field, namely feminist new materialism, and Karen Barad's agential realism in particular, as well as seamful design. In this section, we discuss how Simondon's ontological proposal overlaps with Barad's, and how the implicit design values in technical mentality connect with conversations on seamful and seamless design in HCI. We conclude by showing that while Simondon's work overlap with new materialist framings and discussions on seamful design, his philosophy positions technical systems as rich sites of ontological and epistemological inquiry through the notion of operations.

3.1 Technical Mentality and Agential Realism

Simondon's ontology highlights the primacy of operation in individuation as opposed to the already-realized principles of form and matter. We can find many parallels with Karen Barad's agential realism in Simondon's attention to the processes that bring together (and co-constitute) materials, information, energy and milieus [6]. Like Simondon's ontogenesis[2], agential realism argues that the main ontological principle is not "independent objects

[2] Which account for of the production (*genesis*) of beings (*onto*).

with inherent boundaries and properties but rather phenomena" [5]. Both Barad's agential realism and Simondon's ontogenesis seek to produce robust accounts of phenomena, of "the materialization of all bodies—"human" and "non-human"—and the material-discursive practices by which their differential constitutions are marked" [5]. Simondon's ILNFI is precisely such an account, starting with physical individuation, followed by the individuation of living beings, psychical individuation, and ending with the individuation of groups, or what Simondon calls the transindividual [96]. And whereas Simondon's accounts center on the various *operations* that make up individuation, Barad's invokes agential *intra-actions*, which are "specific causal material enactments" that reconfigure "locally determinate causal structures with determinate boundaries, properties, meanings, and patterns of marks on bodies" [5, p.17]. Both Barad and Simondon view these processes as simultaneously ontological and epistemological, as the move away from atomist physics (in the case of Barad) and hylomorphism (in the case of Simondon) implies a reunification of the traditionally distinct subject and object. In agential realism as in ontogenesis, there are no longer "knowers" on one side and "things known" on the other (Descartes' *res cogitans* and *res extensa* [23]) but individuals caught in an ongoing process of individuation that involves negotiations with the material, informational, and energetic potential of a given milieu. Knowledge is not the direct or mediated apprehension of things in the world, but is itself an individuation, a process of becoming. In the words of Simondon: "[We] cannot know individuation in the ordinary sense of the term; we can only individuate, be individuated, and individuate within ourselves" [96, p. 17].

Agential realism has been influential in HCI through the use of diffraction as an analysis and reflection method [24, 90], the eschewal of representational paradigms in interaction design [39], and more generally as a framework to think human-non-human entanglements [38, 46, 76]. Both Barad's and Simondon's work account for the interdependence of materials, information, energy, and milieu in material and epistemological production processes.

Simondon's notion of operation, however, has particular relevance for HCI in that it provides the basis for a way of thinking technology from the inside. Simdonon defines an operation as the "conversion of a structure into another structure" [96, p. 664]. Operations are also reified in machines and systems, which makes technology the potential ground for "a general science of operations," which Simondon called allagmatics[3] [96, p.662]. Simondon develops allagmatics as a way of thinking technical systems' operations through their analogical relations to other realities and processes, whether social, cognitive, biological, ecological, or ontological. Simondon's notion of operation offers a path to engage with the dynamic interiority of systems while simultaneously extending the epistemological reach of their mechanisms. Simondon's attention to the operations reified in technical systems extends his onto-epistemic position into the realm of ethics (as we discuss in Section 4), and design (as we discuss in Section 6).

3.2 Technical Mentality and Seamful Design

Simondon's insistence on developing deeper relations with machines is expressed through his idea of the open machine. The open machine refers to systems that are repairable, reconfigurable, and extendable; they are designed and built to allow the easy replacement of "weak parts," i.e. parts that are more exposed to use or stress, without affecting the core mechanism. For instance, the bearings in the hubs of bicycles can be taken out and replaced without affecting the frame and other parts of the bicycle. The notion of the open machine is an important tenet of technical mentality and has many parallels with seamful design. Seamful design refers to the strategic revelation of seams to better support technical integration and appropriation [53]. The debates around seamlessness and seamfulness in HCI have been concerned with the revelation and concealment of human and technological operations. Seamlessness has often been held as an implicit design virtue that emphasizes the disappearance of technology (since Weiser's presentation of ubiquitous computing [111]). However, as Weiser himself emphasized later, invisibility is a property of human cognition, not design. Bell and Dourish [11] point out that encounters with technical systems happen in fragmented and heterogeneous contexts, and seamful design is therefore better suited to support these experiences of discontinuity and change that are inherent to interactions with technology. Furthermore, Chalmers and Galani [20] emphasize that appropriation is part of the process of weaving *any* technology into the fabric of everyday life. To this point, they discuss Heidegger's hermeneutics of technology, from which Weiser's ubiquitous computing partially derives. Heidegger conceptualizes two modalities of technical interaction: ready-to-hand, whereas engagement with technology is embodied and recedes from cognition, and present-at-hand, where the relation with the tool is analytical and at the forefront of cognition. While the goal of seamlessness might seem to be more aligned with ready-to-hand, Chalmers and Galani point out that a user often encounter both modalities (ready-to-hand and present-at-hand) when interacting with a particular technology, alternating between moments of troubleshooting, maintenance, extension, and reconfigurability and moments when tool usage becomes more embodied and intuitive. In this light, seamlessness and seamfulness are not so much fixed states as they are properties of relations.

But troubleshooting, maintenance, extension, and reconfigurability often require a deeper understanding of the technology at hand than the user might have. Simondon is aware that this openness in technical systems requires "a certain level of technical competency" [94, p. 28] and therefore a certain conflation between the machine builder and its user. This is a recurring theme in Simondon's work, and he addresses this issue by emphasizing the need for technical knowledge to be distributed via infrastructure. He writes:

> " The openness of technical object ... supposes a second type of relation between builder and user: the builder must be represented on the entire territory of use by a network possessing the necessary parts [for repair and extension]. In other words, in addition to technical information, a *material communication* must connect the user to the builder. There can be no ... genuine openness of technical objects without the creation of a network of technicity. This condition is fundamental." [94, p. 28]

[3] From the Greek *allagma*, meaning change.

The comment highlights an important difference between technical mentality and seamful design. While they both emphasize configurability, user appropriation, and revelation of complexity, technical mentality views these concerns as the expression of an ethical and social project that extends into educational policies and infrastructural recommendations [1, 94]. Seamful design, by contrast, stems from the practicalities of the discipline of HCI, concerned with the implementation of, and interactions with, technical systems. As such, both projects can benefit from each another: seamful design by embracing technical mentality's deep ontological and epistemological commitments, revealing "beautiful seams" as an ethical and social orientation that fosters open systems, horizontal relations with machines, and the collaborative practices and infrastructures that would support them. Technical mentality, on the other hand, would benefit from the clear design orientation of seamful design, and therefore ground Simondon's onto-epistemic and ethical project within a praxis of systems design, building, and implementation.

3.3 Technical Mentality as an Onto-epistemic Design Program

While Simondon's ontology is close to Barad's and technical mentality is close to seamful design, Simondon's philosophy engages with both simultaneously. What is the relationship between process-oriented ontology and seamful systems? The answer lies partially in the notion of operation. On a metaphysical level, attention to operations reveals the proper locus of ontological and epistemological processes; on a practical one, it communicates the human reality crystallized in technical systems and points to an approach for apprehending systems (technical, but also social, cognitive, biological, etc.) transversally and not in silos.

Simondon develops this method for thinking systems in the essay *Technical Mentality* [1] through an analogy between the Cartesian mechanism and the process of argumentation. The "schemas of intelligibility" of the Cartesian mechanism is the "fundamental operation of the simple machine" which operates a transfer of forces analogous to the enchainement of links in rational thinking: "The transfer of forces goes from link to link, so that if each link is welded well and there are no gaps in the enchainement, the last link is fixed to the anchoring point in a more mediated but also more rigorous way than the first" [1, p. 18]. The chain that pulls a piece of concrete from the ground, for instance, distributes a force along each link of the chain to lift the material, so that there is solidarity between the first and the last link in the action of lifting. Similarly, an argument connects the first and last elements alongside a chain of axioms in a way that is "more mediated but also more rigorous" [1]. The relation between the Cartesian mechanism and rational thinking is not instantiated by identity but by operations. Instead of thinking things through their categories and knowing them "by defining operations based on the structures," technical mentality is an invitation to apprehend "structures based on the operations that dynamize them" [96, p. 666] . This attention to operations is at the crux of technical mentality, which stems from Simondon's ontological critique.

4 TECHNICAL MENTALITY AS ONTOLOGICAL CRITIQUE

As we have seen, operation is a key concept in Simondon's work and unifies his ontology and his epistemology. He further defines an operation as "what makes a structure appear and what modifies a structure" [96, p. 661], in which a structure refers to an individuated being (such as a brick, a machine, a flower, a human). In classical ontology as in technical systems, the operations that make beings remain hidden. Technical mentality is the attitude that seeks to manifest and understand these operations and recognizes them as the proper site of being. In order to understand technical mentality, therefore, we must start with Simondon's ontological critique which, as we will see, has implications for how HCI researchers and designers might apprehend the ethics of the systems they design and study.

4.1 'Blackboxing' the Operations of Being

Simondon's work starts with a critique of the hylomorphic schema, the ontological model proposed by Aristotle, which states that beings come from the combination of form and matter [3]. The critique of hylomorphism is not new to HCI: drawing from Ingold [52], several scholars have reported on the influence of hylomorphism in digital fabrication. Devendorf et al. [25] show that the design of 3D printers embraces a hylomorphic model through the imposition of a form (in this case, a mathematical description of geometry) onto matter (thermoplastic filaments). As a response to this model, Torres proposes *Crafting Proxies* as intermediaries to support the manipulation and intervention of materials in digital fabrication workflows [105], emphasizing the agency of matter in design and fabrication processes. Twigg-Smith et al. [107] highlight the hylomorphic nature of the canonical digital fabrication workflow and demonstrate that despite this authoritative account of fabrication processes, makers and artists using plotters embrace how technical and material constraints shape the art and artifacts they produce. As Devendorf et al. [25] put it: "While a designer's imagined workflow of 3D printing may be hylomorphic, the reality of 3D printing is anything but: 3D printing, like all craft, forces the maker to contend with stubborn recalcitrance and unpredictability of the material world."

Simondon's critique is aligned with this observation that hylomorphism is in fact an *external assessment* of a technical operation. Aristotle's example is brick making but the process he describes is—like the 'designer's imagined workflow—severed from the reality of making bricks. Hylomorphism remains external to the actual principle of individuation, which is neither form nor matter but the *operation* that puts them in relation.

For Simondon, Aristotle's description of brick making focuses only on the structures: the visible, already realized elements that form the brick—the clay, the mold—whereas the process that brings them together is never explained. The hylomorphic schema obscures the 'true mediation' that links matter and form, which is the operation [96, p. 32]. To illustrate this, Simondon describes the process of brick making by carefully unpacking the 'chains of operations' that prepare the clay and the mold themselves (see Figure 2).

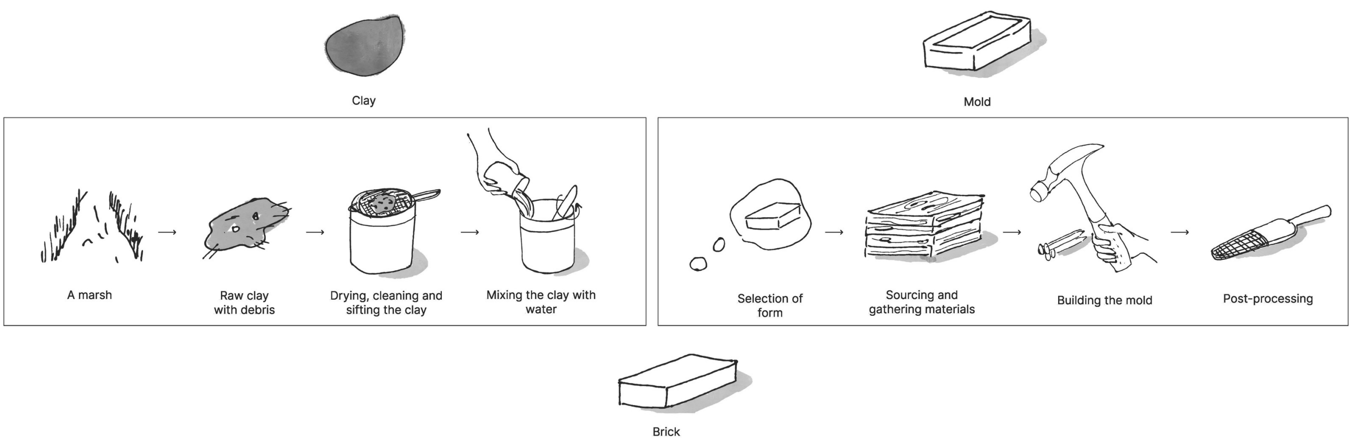

Figure 2: The matter and form of the hylomorphic schema are underspecified, according to Simondon. The actions and labor that prepare the clay and fabricate the mold reveal the crux of ontological processes: not substances, but operations.

The brick does not result from the combination of an "unspecified matter and an unspecified form" but from the *preparation* of clay and the *fabrication* of the mold [96, p. 22]. The labor required to prepare clay and mold not only enables the combination of form and matter, it is what makes the dirt in the marsh into malleable clay and transforms the pile of wood and nails into a mold. The form of the mold is also not arbitrary, but selected according to the properties of materials, already bearers of forms. The mold is built in such a way that it can be opened or closed without breaking its content; its interior might be prepared so as to avoid (or facilitate) the absorption of the water in the clay. Similarly, the clay homogeneous enough for brick making does not happen spontaneously in nature, but is lifted from the earth as raw matter: "it's what the shovel raises to the surface at the edge of the marsh with roots of rush and gravel grains" [96, p. 23]. This matter is then dried, crushed, sifted, wetted, shaped, and kneaded to arrive at the homogenous dough that is plastic enough to be able to embrace the contour of the mold and "firm enough to conserve this contour long enough for this plasticity to disappear."

Simondon pays close attention to all the processes that allow the convergence of form and matter: the first chain goes from the abstract geometry to the physical mold and the second from the raw dirt in the marsh to the prepared clay. These operations are absent from the hylomorphic account of brick making which, according to Simondon, reveals classical ontology's substantialist premises, i.e. the assumption that substances are a fundamental ontological category. Instead, Simondon argues that *relations* are what constitute substances, which can never be fully apprehended as discrete, complete and finished. The principle of individuation, the process by which individuals come to be, is to be found neither in form nor matter but in their relation—or rather, in the process that puts them in relation: "The veritable principle of individuation is genesis itself in the course of being carried out, i.e. the system in the course of becoming while energy is actualized [...] The principle of individuation is an *operation*" [96, p. 32, our emphasis].

As Simondon's detailed description of the process of brick making illustrates, matter's plasticity and form's structuring action are only actualized in the process of individuation. Beings are not the reunion of fully actualized principles; rather, it is the very process of beingess—of becoming, of individuation—that actualizes and realizes the principles of form and matter—that makes form informing and matter plastic, able to express its 'implicit forms' [96, p. 38]. The ontological 'method' proposed by Simondon consists in "considering every [...] relation as having the status of being" [96, p. 12]. To use an analogy, an individual is not simply the sum of its 'ingredients' but rather "the totality of its production" [50], including all the steps, labor, potential energy and tribulations required to make it.

This reformulation of classical ontology bears on HCI in important ways. First, it highlights the various forms of labor—human, material, energetic—that are central to the existence of technical (including digital, [41, 50]) objects. For instance, AI-generated text and images are the results of not only algorithms and data but especially of the (hidden) labor of data collection, formatting, annotation, and labeling [22, 47, 57, 65]. In the context of digital fabrication, it suggests that the essential aspect of fabrication that needs to be supported is not the realization of form but the material and human operations that make things, of which form-taking is only one dimension. Systems research should support, in other words, the *conditions* of production and not just the realization of computational designs. In their empirical study of nine different digital fabrication workflows in professional contexts, Hirsch et al. [45] show that the design decisions made by professionals included not just the selection of form and pattern, but the negotiation between material constraints, resource management, access to tools and skill acquisition, among others. Yet, these 'details' of production tend to be abstracted or overlooked as too specific, contextual or mundane to enter the official accounts of fabrication that prevail in HCI. According to Simondon, these 'details'—the labor that is simultaneously technical, material, scientific, domestic and logistical—are the crux of beingness, both for living beings and technical objects.

But this labor is blackboxed in the hylomorphic schema as in technical systems, because material and situated labor is historically dismissed as irrelevant to discourse.

4.2 The Ethics of Blackboxing

Hylomorphism is an ontological account that stems from a specific time and place: Athens, in Ancient Greece, where slave labor was instrumental to running the democratic city-state [32, 54]. While Aristotle based his ontological model on a technical operation (brick making), he was not the brick maker; slaves were. Simondon writes that the 'dark zone' of the hylomorphic schema, i.e. the indifference or ignorance of the operations and labor that make bricks, is the expression of those specific exploitative labor relations, namely, slavery [96, p. 35-36].

The passivity of matter supposed by the hylomorphic schema is therefore a reflection of the exploitative human relations that coordinate the labor of brick making. Form is expressible and expressed as an order coming from the free man, the citizen (and philosopher), whereas matter is mute, handled by slaves—individuals who have no say in the matters of the *polis*, the discussions on collective becoming.

Coiled deep within the dark zone of classical Western ontology are therefore not just operations and mechanisms but what Rancière calls a 'distribution of the sensible': a particular configuration of matter and discourse that reveals "who can have a share in what is common to the community" [85]. This configuration of matter and discourse is concealed in the black box of technology as well. The mechanisms of machines, as well as socio-political technologies such as race and capitalism, are concealed and therefore naturalized [12, 79]: technology becomes deterministic, and exploitation systemic.

Technical mentality starts with paying attention to the labor, decisions, and operations that articulate material and socio-political technologies. The development of technical mentality is intimately linked with a shift in the relationships humans have with technology. The same way classical ontology is an expression of alienating and exploitative labor relations, for Simondon the current relationship with technology in the contemporary world is the expression of an alienation of the human labor present in technical systems: "What resides in the machines is human reality, human gesture fixed and crystallized into working structures [...]." [95, p. 16]. The essence of technicity is human labor, effort, and invention, but it remains unacknowledged and unknown, 'trapped' in the black boxed machine. Technical mentality orients culture towards a direct knowledge of technicity, and this knowledge can be supported by developing 'open' systems, in the sense of systems that reveal their mechanisms, are flexibly composed, and integrate in their design the possibility of their extension and reconfiguration.

This direct knowledge, however, is not easily acquired. Simondon often comments on the need for the machine "user to become the builder" of machines. In an article written in 1954 for an education journal, Simondon writes that educators can instill in children a respectful attitude towards machines by teaching them to build, repair and maintain technical systems [94, p. 233-253]. This avenue has, of course, been explored: initiatives to teach physical computing and programming skills to children are too numerous to list here (an entire paper could be written about the relationships between Simondon's philosophy, constructionism and the maker movement. See [2]). Another approach, discussed by Guchet [40], is to recover the "affective content" of technical systems. Simondon describes in various essays [94] the evolution from the magical to the technical regime in Western societies, and the progressive loss of the symbolic and imaginal power of technical objects as they move from one to the other. He writes that affectivity and emotion "bring their dimension of collective participation to tools and technical objects" [94, p. 104] and have therefore the power to be the vectors of more respectful and companionable relationships with technology.

How can technologists and designers restore this affective content in technical systems? Simondon mentions aesthetics and art as domains in which technical mentality can be further developed. We discuss this point in section 6.4.

In the next section, we give an example of technical mentality through the discussion of a fabrication system called Imprimer, a machine infrastructure for direct control of a CNC mill from a computational notebook [106]. This example is not an exemplar but rather a case study to illustrate how the ontological and ethical commitments of technical mentality might be expressed in systems.

5 TECHNICAL MENTALITY IN PRACTICE

In this section, we use a specific case study to discuss how technical mentality can translate into a design orientation for systems research. The commitments discussed below and which our example illustrates are the results of our interpretation of Simondon's work. The process of applying Simondon's theoretical proposal to the concrete project of systems building asks that we read his vision through the more materially-oriented lens of design. We welcome other HCI scholars and practitioners to question, challenge and engage with this interpretation in the hope to derive a more fully articulated design program from Simondon's philosophy.

5.1 The Example of Imprimer

We choose Imprimer [106] as a case study because it effectively opens up the black box of low-level control for automated machines tools, which has historically been designed to enhance management's authority over production [74, 75]. CNC machines are controlled via code but the code (g-code, a series of coordinates that tell the machine where to move) is difficult to read and does not have great programmatic capabilities. Machine code specifies all the operations of the machine and is therefore an important design dimension of digital fabrication and yet, it tends to remain hidden behind software abstractions. A typical workflow for CNC milling machines resembles this: a geometry is generated with a Computer-Aided Design (CAD) program, which is then translated into a series of machine movements (toolpaths) through Computer-Aided Manufacturing (CAM) software. The toolpaths are sent to the machine and the machine executes them (see Figure 3).

Researchers in fabrication HCI have sought to change this rigid mode of interaction by developing more flexible and interactive fabrication systems [33, 35, 100, 104]. These important contributions enable more direct machine control through CAD environments, [33, 60], programming frameworks [17, 35], or tailored interfaces

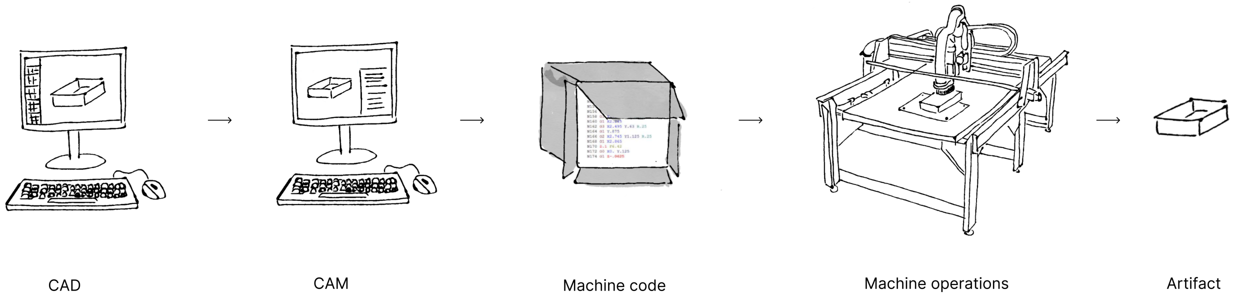

Figure 3: A 'typical' CNC milling workflow: the design is specified in a computer-aided design software (CAD), then translated into toolpaths in a computer-aided manufacturing software (CAM). The toolpaths are sent to the machine but often remain black boxed, as the low-level nature of machine code makes it hard to read and modify without expertise.

for specific applications [104]. In these contributions, however, the machine code still remains hidden.

Imprimer supports users' experimentation and exploration of direct machine control by enabling them to write their own programs in computational notebooks. Imprimer interfaces Observable notebooks [77], computational notebooks that run a modified version of Javascript, with a ShopBot CNC mill [93]. Computational notebooks are a literate programming environment that support code, natural language and, in the case of Observable, graphics, so that the code can be executed as well as documented in prose and images [58]. Imprimer allows direct control of the CNC mill from the notebooks, enabling users to quickly send commands to the machine and make on-the-fly adjustments or modifications to the machine code. Because the programs are written in computational notebooks, the code can easily be extended, modified, documented, as well as duplicated and shared.

Through Imprimer's example, we share three commitments of technical mentality as an orientation for systems design.

5.2 Technical Mentality is Systems Design

In this section, we bring the example described section 5.1 in conversation with the postulates of technical mentality. This section provides a mid-level analysis between the metaphysical critique in section 4 and the design principles discussed in section 6. As such, it introduces the high-level ideas of technical mentality as a way to frame the design space we further explicitate in the next section.

5.2.1 Technical mentality reveals and supports engagement with the operations of technical systems. As described in Section 5.1, machine control in fabrication is usually mediated by a toolpath-generating program, or CAM software. CAM software gives the ability to create complex toolpaths and does so partially by handling many manufacturing decisions to optimize other aspects of the milling process, such as as travel movements. This tends to relegate much of the domain expertise to the software rather than the user—which according to Noble, was an intentional design choice to seize production control from machinists [74]. From a design perspective, this prevents users from engaging with low-level machine control and therefore develop their own understanding of machine operations. With Imprimer, users can easily access the programs that control machines and start modifying or extending them to suit their needs. Imprimer does not hide the complexities of low-level machine control but makes them easier to access, annotate, and document.

5.2.2 Technical mentality supports extensibility and shareability. By virtue of making visible the underlying code that is usually hidden in traditional CAM software, Imprimer invites not only direct control of machines, but also the ability to keep the notebooks actual by easily forking them and customizing them to a new project. This is made possible by the use of computational notebooks. The code generated for each toolpathing job no longer lives only on a user's computer but is accessible to a community of makers who can fork, modify, and extend existing notebooks and projects. Simondon writes that one of the key aspects of technical objects and systems is that, unlike living beings, there are not "metaphysically one and indissoluble" [1, p. 3]. They can be taken apart; they are reparable; they can be completed; they are (or can be) designed to be maintained, modified, and extended.

This principle of modularity, repairability, and extension also provides the model for a certain ethical orientation beyond systems building: "To accept or reject a being wholesale, because it is a whole, is perhaps to avoid adopting towards it the more generous attitude: namely, that of careful examination" [1, p. 4]. Technical objects that are built as closed and complete 'packages' hide the mechanisms of the system and therefore allow little opportunity to access their parts and components, making it difficult for users to maintain interpretative engagement [27] with the technical reality of the object. End-to-end fabrication systems tend to black box their operations, but Imprimer makes them visible and accessible by using computational notebooks that reveal the programs used to control the machine.

5.2.3 Technical mentality is an expression of technical openness. Together, these commitments form what Simondon perceives as the chief principle of technical mentality, that of *openness*. He writes: "Technical reality lends itself remarkably well to being continued, completed, perfected, extended" [1, p. 13]. Openness is understood here as the conception and fabrication of artifacts that are flexible, open to modification, repair and extension, and allow access to their 'technical' layer. Simondon gives the example of Le Corbusier's monastery, a Dominican Order priory located near Lyon, France, and built in the 1950s (see Figure 1). The building features in its very design the possibility of its extension: "it will be possible, without any break between the old and the new [structure], still to use concrete, shuttering, iron, cables and the tubulature of long corridors" [1, p. 14]. For Simondon, the "non-dissimulation of means" that characterizes the design of the building is an expression of technical mentality: the 'inner workings,' the structure of the building are laid bare rather than hidden behind the socialized layer of the interface or the facade.

This fundamental conception of technicity as open, extensible and interoperable is strong and alive in open-source communities. Similarly, technical mentality's implicit design orientation is doubled by an implicit political framing of technological development as dependent on practices of collaboration and exchange enabled by the network [1, 94], as discussed in Section 3.2.

In Section 4 we described how classical Western ontology, represented by the hylomorphic model, is tied to a particular ethics that favors the expressibility of form over the tacit and embodied knowledge associated with the manipulation of matter. This worldview carries over into digital fabrication machines. Ontology reveals the fundamental assumptions that normalize particular power dynamics and labor relations, and how they are reified in technical systems. Simondon proposes an alternative ontological model grounded in an attention to process and operations, of which technical systems are one of the most articulate expressions. In the next section, we develop these initial commitments of technical mentality into four principles for systems research, orienting the design of technical systems towards greater *legibility* of the human labor and invention in technology. By doing so, we take a first step in the direction of formalizing technical mentality into a design program for HCI that carries deep ontological and ethical commitments to process, materiality, and relationality.

6 DISCUSSION: TECHNICAL MENTALITY AS A DESIGN PROGRAM

In this section, we offer a synthetic analysis of technical mentality through the lens of four design principles we derive from Simondon's work: *extension*, *integration*, *legibility*, and *expression*. In doing so, we follow one of the postulates of technical mentality which states that "the subsets are relatively detachable from the whole of which they are a part" [1]: rather than reading the proposal of technical mentality as an indivisible proposition, we see it as a vision with parts that are directly actionable through practice, and with parts that remain an orientation without directly translating into action (at least for now). Rather than accepting or rejecting technical mentality's vision wholesale, we choose the "more generous attitude towards it, namely, that of careful examination" and interpretation [1, p. 4]. We want to emphasize the preliminary and propositional nature of the principles we are about to articulate. These foundational concepts are provisional, serving as the first strokes on the canvas of our exploration. This is a first step towards formalizing the implications of Simondon's philosophy for design. We illustrate each principle with examples, such as Imprimer, and refer to existing literature to provide a robust context for these initial principles.

6.1 Extension

Extension refers to the design strategies that make systems able to be modified, extended, repaired, and maintained.

The first tenet of technical mentality is that "the subsets are relatively detachable from the whole of which they are a part" [1, p. 3]. Technical objects and systems achieve their highest degree of technicity not when they are automated, which requires to sacrifice a number of possibilities of operations (which is useful for specific applications) but when they are *open*, that is able to be understood, reconfigured, extended, and maintained in a perpetual state of actuality. For Simondon the "postindustrial technical object," i.e. the object made through the means of industrial production but according to a logic of openness, would be the unity of two layers of technical reality: one as stable and permanent as possible and the other "that can be perpetually replaced, changed, renewed, because it is made up of elements that are all similar, impersonal, mass-produced by industry and distributed by all the networks of exchange" [1, p. 13].

Currently, the option to engage with the technicity of objects and systems—to open them up to understand their operations, or to repair or extend them—is difficult, resource-intensive and sometimes inaccessible [49, 55, 89]. Discarding broken or obsolete objects is merely the path of least resistance, less a choice than a convention. Technical mentality envisions a culture in which technical systems are not black boxed or simply consumed but constantly reactualized through practices of repair, care, extension, and invention.

In the case of Imprimer, the possibilities of extension are built into the system itself. Because machine toolpaths are usually hidden under layers of abstraction in CAD-CAM software such as Fusion360 [4], or expressed through G-code and therefore hard to read, the opportunities to build on, extend, modify, and share machine operations for CNC milling are rare and often limited to one user or one context. Because Imprimer leverages the environment and features of computational notebooks, it not only makes toolpaths and the programs that create them accessible, but easily allows users to fork and share them.

6.2 Integration

Integration refers to the design strategies that take into account the existing natural and artificial ecosystem in which a particular technology exists and will exist.

Integration is connected to the second postulate of technical mentality, which states that "if one wants to understand a being completely, one must study it by considering it in its entelechy, and not in its inactivity or its static state" [1, p. 4]. Simondon argues that technical objects are better understood 'in action,' in the process of completing or realizing their function. Implicit in this postulate is the core principle of Simondon's techno-aesthetics, which is that technical objects and systems are best understood when integrated in a milieu, and according to their own normativity. For instance, Internet of Things (IoT) devices are smart objects only insofar as they are connected to a network—their entelechy, the realization of their potential, the dispensation of the services they are designed to offer, is achieved through their integration to an existing infrastructure. Simondon warns against the technocratic attitude that consists in "reinventing the world like a neutral field for the penetration of machines" [1, p. 8]. The world is saturated with "living possibilities'" and already existing natural structures that afford particular natural-artificial configurations. Integration acknowledges and engages with these configurations during systems design and use.

Integration is part of understanding the object as part of a "global technicity" [16]. This technicity is both historical (what is the immediate and broader history of this particular object or system; how was it made; according to what existing technology) and actual (what existing machines/infrastructures does it work or interface with). Simondon, who was very interested in agricultural machinery, gives the following example of techno-aesthetics:

> "The tractor in a garage is merely a technical object; however, when it is at work plowing, leaning into the furrow while the soil is turned over, it can be perceived as beautiful. Any technical object, mobile or fixed, can have its aesthetic epiphany, insofar as it extends the world and becomes integrated into it." [95, p. 197]

The beauty of the tractor is best grasped when it is at work, in the action that let it *extends the world and become integrated into it.* Integration, in this view, is not just the acknowledgement of a particular milieu but how the action and workings of a particular object or system shape it (for instance, how the tractor plows the fields and enable the turning of the soil for things to grow).

For Simondon, techno-aesthetics is not the aesthecization or 'beautification' of technical objects and systems but the appreciation of technicity. In a letter to Jacques Derrida, Simondon describes a viaduct as a work of techno-aesthetics: "perfectly functional, perfectly realized and beautiful, simultaneously technical and aesthetic, aesthetic because it is technical, technical because it is aesthetic. There is a fusion of categories" [94, p. 382]. Techno-aesthetics is a sensibility (in the sense of a sensory attunement and disposition) for the thing well made, which expresses an intelligence of components, materials and how they work together. On a smaller scale, a box lid that perfectly snaps in place and secures the content of the box is an expression of techno-aesthetics; well-toleranced wood joinery is as robust as connections with metal fasteners; it is harmoniously realized, both technically and aesthetically.

Integration, as rooted in his second postulate of technical mentality, underscores the importance of considering how technical systems shape a particular milieu, which is best grasped through an understanding of their dynamic state, the actualization of their operations, rather than their static form.

Techno-aesthetics therefore contain an implicit ethics which demands that users and technologists consider systems not in and of themselves (an attitude that can lead to the fetishization of technical systems, see [101]), but through their action on and mode of intervention in the world. This orientation can prevent the reification of technical systems and instead acknowledge their dynamism as beings that complete, shape, and extend existing social, material, and informational configurations.

6.3 Legibility

Legibility refers to the design strategies that make the mechanisms or technical operations of systems visible and intelligible.

The core injunction of technical mentality is to develop an attunement to and understanding of the operations of machines and systems. In order to extend, modify, or care for a machine or system, one first needs to understand it. While this ability depends largely on training and background, we argue that systems can also be designed to support understanding of their mechanisms and operations, something we refer to as legibility.

Rather than focusing on the interface as the only humanly legible part of the system, this design principle states that the mechanisms of technical objects and systems should also be identified and arranged in ways that support their understanding. HCI has a long tradition of documentation and technical communication [86, 88]. Yet, technical systems' very design can inform the user as to the function of the various elements and their arrangement. In the case of Imprimer, the fact that computational notebooks also support prose alongside code and graphics integrates documentation in the system itself. Documentation is not extraneous to the system but part of it—it makes the tool more legible and therefore more likely to be understood, used, modified, and shared.

Historically, legibility refers to the ability of readers to recognize a written character. It is associated with the design of typefaces, a technology that was refined over centuries to make texts more readable. Before the invention of the printing press, punctuation was initially developed as a textual technology to increase the legibility of liturgical texts [48]. Similarly, the page as a unit of information in manuscript and later print culture was developed over centuries to organize information and make it more easily readable and "sharable" [68]. Adjacent to Chalmers and Galani's 'seamful revealing' [19], legibility might entail various strategies of technical 'punctuation' such as labeling, color-coding, formal experimentation, composition, or built-in documentation. While literacy refers to the ability of the user or reader to decipher a text or system, we use the term legibility to emphasize the responsibility of designers, researchers, and technologists to make systems and their inner workings legible.

For Simondon, technical mentality invites the user to 'take the place of the maker' and in doing so become able to discern the technical being, "to understand it, to love it as if they had made it" [94]. His suggestion is not so much to turn everyone into a maker but to cultivate an inventor and maker-*like* sensibility—to develop the attitude of an amateur [99] towards technical objects rather than that of a consumer whose main modality of intervention is economic. Simondon notices that industrial production has warped the relationship with technical objects, as mass manufactured goods are conceived as things to *own* rather than things to engage with and *care for.* The object of industrial production allows for neither the exercise nor the development of the technical mentality because it is designed to be used and consumed as one entity, not as a system that can be opened, repurposed, extended, and maintained in actuality. By contrast, the amateur refers to the individual who seeks to *understand* because they like or love something and therefore invests not just money but also time, attention, care, and effort. To encourage this attitude, we suggest *legibility* as an orientation for systems design, which would support the visibility and legibility of the mechanisms and operations of systems—as well as of the human labor that went into making them.

6.4 Expression

Expression refers to the design strategies that encourage exploration, and experimentation with the operations and mechanisms of systems.

This principle is more specific to practices around technical systems than to the design of systems themselves, although designs tend to encourage particular practices. We argue that an inquisitive and exploratory attitude towards technical objects and systems is necessary to the development of technical mentality, and how technical objects are designed can support this attitude.

Expressivity emphasizes the affective dimension of technical systems and seeks to investigate it through aesthetic exploration. It is therefore different from legibility in that it focuses not so much on the visibility of mechanisms and operations but on the perceptive, sensory and aesthetics transformations that occur in people and systems when visibility and access are enabled. Lapworth [59] mentions that the "technoaesthetic attitude" proposed by Simondon is opposed to the technocratic one in its valuation of inventivity and emergence rather than productivity. Expressivity emphasizes invention in the Simondonian sense, which is not innovation but "the transformation of thought and action along trajectories that could not have been anticipated in advance" [59].

There is an invitation in Simondon's proposal to extend and practice technical mentality through expressive, aesthetic and formal exploration. This attitude is close to DIY and craft approaches to electronics [18, 78, 80, 82, 83] which are "embodied in and attentive to process ... and [embrace] a fuller and more complex notion of the amateur" [43]. Perner-Wilson et al. [78] note that their handcrafted electronics "naturally afford visibility" and that their designs "showcase functional elements instead of hiding them beneath others." The designs reveal information that indicate how the artifacts were made, so that users can more easily 'read' and eventually reconfigure them. Another example of expression is circuit bending, a practice that involves opening up, modifying, and creatively short-circuiting consumer electronics (often discarded childrens' toys) to create novel applications, sounds and visual outputs [44]. The practice and attitude of circuit bending appropriate these discarded electronics to reactualize them into novel, experimental, and idiosyncratic functions. In the case of digital fabrication, Imprimer again exemplifies a system that allows more expressive and interactive use of the CNC mill by allowing to modify toolpaths and parameters on the fly and quickly dispatch them to the machine. Iteration and real-time adjustments become more accessible, which encourages expression and experimentation. This engagement is in turn rewarded by a fine-tuned understanding of the machine's operations and limits, which leads to more fine-grained control and greater expressivity.

Expression therefore attends to the *affective* dimension of engaging with technical systems; it highlights how practices of repair, maintenance, and extension are also practices of meaning-making.

All four principles of technical mentality discussed above are connected. *Legibility*, by making the mechanisms and operations of technical objects and systems easier to decipher for users, encourages intervention and *extension. Integration* acknowledges the social and natural milieu in which a system will exist, and cultivates an appreciation for how things are made and how they extend and shape the world through their action. This attunement to the specific normativity and mode of existence of technical systems feeds *expression*, which support creative practices of experimentation, exploration, care, and *extension* with technical systems.

Technical mentality brings these design orientations together and aligns them towards a social and ethical vision in which technical understanding is cultivated alongside artistic and scientific ones. Technical mentality views technology as the expression of *a material and human engagement with reality*, and as such contains an aesthetic and cultural value in the same way art does.

We want to reiterate that these principles are provisional: lines drawn to start sketching what Simondon's conceptual project of technical mentality could look like when operationalized through design principles. These principles are a first attempt at developing a holistic framework for changing users' and researchers' relationships with technical systems; for understanding, engaging with, and extending them so that they can be better integrated into culture. By formalizing Simondon's proposal into a design program for HCI, the field can participate in the development of technical mentality and grow its commitments to an *open* technological landscape: legible, extensible, integrated into its milieu, and sustained by constant human engagement and care. Embracing technical mentality is crucial to avoid polarized attitudes towards technology. Instead, the vision proposed by Simondon enables the understanding and integration of technicity as the seed for social, ethical—and political—invention [8].

7 CONCLUSION

This paper has explored Gilbert Simondon's philosophical proposal of technical mentality as a possible framework for HCI research. Simondon's ideas challenge the conventional approaches to understanding technical systems, urging us to delve deeper into their inner workings and to recognize the co-constitutive relationship between humans and technology. Through an analysis of Simondon's ontological critique we have distilled four essential design principles: legibility, extension, integration, and expression. These principles provide an orientation for systems research, encouraging us to view technical systems as dynamic and evolving expressions of human labor and invention. Furthermore, this paper sheds light on the inherent biases and ethical concerns embedded in classical Western ontological perspectives, prompting a critical reflection on the role and responsibility of HCI in acknowledging its own ontological assumptions and the skewed labor relations they normalize in technology design and utilization. We hope HCI researchers and practitioners will engage with the proposal of technical mentality as it might offer an approach to the design of systems that is grounded in a relational, materially-attuned, and labor-oriented ontology.

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