Faculty of Design

2023

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Relating Systems Thinking and Design
(RSD12) Symposium | October 6–20, 2023

Materials as Systems: The case of advanced textiles as key actors in a systemic change

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In this paper, we explore how the *materials way of thinking* paradigm, which has defined the development of the materials sciences field since the 1980s, created the premises for a conception of materials as systems. This paradigm impacts the design approaches and processes, but as we try to demonstrate in this text, the communities involved and their ecosystem(s). To better understand what is at stake when it comes to materials-driven inquiries in design, we question the nature of functions. Embracing a philosophical stance in relation to design, we aim to show how the switch from an ontological indexation of materials towards a more functionalist perspective created the premises of a paradigmatical change that understands materials as systems. Using advanced textiles as a case study, we will show how materials could become key actors in the attempts of systemic change where design discipline and industrious enterprises could work together towards more ecological perspectives and economies.

KEYWORDS: systemic design, advanced textiles, nanotechnologies, functionalist ontologies, textiles ecosystem(s)

RSD TOPIC(S): Methods & Methodology, Socioecological Design, Sociotechnical Systems.

Introduction

The birth of design as a discipline is closely related to the imposition of industry as the main form of production. If, before Bauhaus, most designers were still emulating the forms of the past,[1] once with the establishment of the Bauhaus School and the discussions that took place related to the best way to envision a pedagogical model for the arts in an industrious society, the conventions related to the forms and the modalities of production, have been challenged (Droste, 2019). One of these challenges, even if not always acknowledged, was related to the choice and the use of materials. Stepping into the traces left by the Arts and Crafts movement, the well-known Bauhaus pedagogical model placed the materials at its core and invited its students, and implicitly the artists working in industry, to learn the specific properties of different materials to support them in innovating the forms of industrious produced objects. The choice is not without significance, as another option would have been to focus on a good understanding of the industrial tools to stimulate an innovative approach towards the designed objects.

Since the establishment of the Bauhaus School, design as a discipline has made significant changes and started to expand and explore new territories of knowledge and areas of application, from users' experience in the design field to design engineering or design management, to name just a few. Over time, these approaches transformed towards a growing interest in the systems sciences in design (Miles, 1971). The interest in cybernetics is a good example in this sense (Wiener, 1947), but also the attempts to define what research in connection to design means—the well-known expressions such as "research in design", "research through design", "research for design."[2] The Design Research Society and Systemic Design Association are good examples of the institutionalisation of such concerns.

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[1] See Art Nouveau forms of expression, trying to imitate and adjust the crafts' aesthetic forms to the industrious ways of production.

[2] There are many studies and positions related to these aspects of design. A good collection in this sense is *The Design Studies* journal (https://www.sciencedirect.com/journal/design-studies/vol/88/suppl/C).

This, of course, had an impact on thinking of design beyond the production of objects to cover aspects related to the whole chain of production (Huyghe, 1998); if we are about to stay in the framework imposed by industry, including the conditions of work (White-Hancock, 2023) and services, for example. All these perspectives question design's status quo, the role of designers, makers, and users/consumers of everyday objects, as well as the networks of production and consumption.[3] Still, the material, formal, and functional aspects of objects remain central to design investigations.

This paper aims not to analyse the perspective systems sciences (Miles, 1971) are using when looking towards design but to focus on how our understanding of matter and materials pushes us to deal with systemic thinking. This investigation will show how the present materials way of thinking that has manifested in materials sciences since the 1980s (Bensaude-Vincent, 2011) opens to new configurations in which the materials as systems paradigm defines the design stances.

In the following lines, we will take advanced textiles (an umbrella term to define e-textiles and reactive textiles) as a case study to demonstrate this paradigm. Presented as the avantgarde of textiles, being used in a variety of applications, from fashion to architecture, from military and space applications to medicine and agriculture, and from communication to the arts, the electronic and reactive textiles are very often described as revolutionary (Heinzel, 2012), aiming to become actors in our attempts to change the way we live. Still, as we have previously shown (Heinzel et al., 2020), this claim might be of the order of complexity, as there is a need to address aspects where different scales converge (from nano to social and cultural) while the role of designers is often understood as a mediator between different stakeholders (Manzini, 1986). It is precisely such a perspective that justifies the design research related to sustainability and circular economy, for example.

[3] If we are about to adopt an actor-network perspective. For more details see the writings of Bruno Latour and Michel Callon.

This paper advances arguments of why textiles are a relevant case study for the materials as systems paradigm and investigates the conceptual arguments used in the definition of *nano-convergence* understood as the next scientific and technological revolution in which nanotechnology, biotechnology, information technology, and cognitive science converge (Bainbridge, 2007). In this scope, the paper will investigate:

1. the displacements from a hylomorphic schema[4] involved in the development of materials sciences
2. the nature of functions from a philosophical perspective
3. the complex structures involved in the formation of textiles-based materials
4. the perspective defining the materials as systems
5. the implications for the design of materials as systems paradigm

Materials as machines paradigm

The constant growth in the use of synthetic materials since the 1940s supported the establishment of materials sciences as a discipline in the 1980s with a clear agenda and advancing new epistemologies (Bensaude-Vincent, 2011). It was also the moment when nanotechnologies were taking the stage, and we assisted in the installation of "materials way of thinking" as a new paradigm in sciences. The development of nanotechnologies and nanomaterials added another layer to the attempts the philosophy was putting into the investigations related to the concept of "matter" and its ontologies. Some prominent philosophers of sciences and historians of chemistry[5] were trying to address these concerns. These investigations took place in the context in which philosophy itself, as a

[4] See the meaning of techniques in a hylemorphic schema as inspired by Aristotle's writing (...).

[5] Some examples of philosophers of sciences that were taking on this task are Isabelle Stengers and Bernadette Bensaude-Vincent.

discipline,[6] was questioning its premises and when the debate on techno-sciences[7] was gathering momentum.

In her article, “The Concept of Materials in Historical Perspective,” Bernadette Bensaude-Vincent (2011) addresses precisely these aspects. From her point of view, what defines this new materials paradigm is a construction that replaces the ontological status of materials” as prerequisites to technical manipulations and imposes limits and constraints to knowledge (and therefore science) to transform them into engineering projects into “objects of design” (Bensaude-Vincent, 2011). Furthermore, as engineering projects (Drexler, 1986), objects of design, that is, the atoms and molecules, to be more precise, were submitted to the crossed scrutiny of sciences, technologies, and society. We are no longer dealing with matter that needs to be transformed at its macro level but with materials that could be designed, functionalised, and made to gain specific properties at their molecular level. It is, in fact, about the definition of materials in functionalist terms, based on materials’ properties and what they were able to perform in certain contexts of use. As several researchers have noticed, the establishment of materials sciences as disciplines is concerned with the transformation of molecules into machines, into “molecule-machines”[8] (Bensaude-Vincent, 2011; Loeve, 2009).

Certainly, such a change wouldn’t have been possible without a performative turn. If the performative turn is mostly discussed in the humanities and social sciences, its manifestations in the natural sciences displaced the elements that were composing the hylomorphic schema advanced in Antiquity by Aristotle (Gossens, 2022). In a *hylomorphic schema,* the matter does not have a form—it is a passive or resistant element—it is substance that needs to be modelled. It is the man, in the sense of the

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[6] See the writings of Jacques Derrida focusing on the nature of writing medias and texts’ grammar as supports for philosophical analysis, or the writing of Paul Ricouer’s on the limits of interpretation and even some of the writings of Bernard Stiegler related to writing as a mnemotechnology - a technology of memory.

[7] For more details related to techno-sciences, see the special issue of *Perspectives on Science – Historical, Philosophical, Social* journal, Vol. 13, No. 2, Summer 2005 coordinated by Ursula Klein and Barry Barnes.

[8] See the work of Jean-Pierre Sauvage, Sir J. Fraser Stoddart, and Bernard L. Feringa for the design and synthesis of molecular machines, all recipients of Nobel Prize in Chemistry The two types of molecular machines are molecular switches (or shuttles) and molecular motors (related to the trajectory).

person holding a tool, who is able to manipulate it to bring it into the form of an object or device.[9] It is the technique that (in)forms the materials. Technique, in this sense, is both about knowledge and information (what it is about?), as it is about the manipulation of materials (the how? and for what?). In the context of performative turn, the displacement that is taking place is one that conceives the materials as active and alive.[10] It is a perspective that was embraced by philosophers such as Gilbert Simondon (Simondon, 2005) or Bruno Latour (Latour, 2002), if we are to refer to the French-speaking context, or Tim Ingold (Ingold, 2015), in the English-speaking context. Certainly, the interest in cybernetics[11] nurtured by a series of scientists has long influenced such perspectives. It is noticed that this performative perspective takes place both a nano-molecular level, in which case we are speaking of micro-performativity (Hauser, 2009), as it takes place at the macro level when we deal with objects and devices (object-oriented ontology), or performative bodies (Davies, 2008). Such considerations have pushed some designers to look into the in-between scales perspective (Heinzel, 2020).

If the theoretical inquiries related to performativity have long addressed the nature of artworks, the performative turn in design manifested through the attempts to create a materials library which collected and organised the materials according to their characteristics (mechanical, thermochemical, and electrical properties, to name just a few). These materials libraries were at the core of the work of Mike Ashby from Cambridge University and his inquiries into the selection of materials (Ashby et al., 2013). Mirroring those physical and chemical properties of materials, the

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[9] See here also the phenomenological perspective advanced by Martin Heidegger. Martin Heidegger (1996). *Being and Time*. A Translation of "Sein und Zeit". Translated by Joan Stambaugh (7th ed.). Albany, New York: SUNY Press.

[10] A good example for such a perspective is the Cluster of Excellence “Matters of Activity. Image, Space, Material” of the Humboldt University in Berlin. To notice “Design, Gestaltung, Formativita. Philosophies of Making” edited by Patricia Ribault, and published Birkhauser Verlag in 2022. Another example in this sense is the recent publication of The Royal Society, Animate Materials, published on line in February 2021 and available at: https://royalsociety.org/animate-materials.

[11] We have here in mind the Macy conference which reunite scientist from different fields interested in cybernetics. The first Macy conference took place in 1949 and continued for several editions.

material-driven design focuses on the user experience and perceptive (aesthetics) aspects of materials (Karana et al., 2014).

What is at stake in these cases is finding the most compatible materials for different uses and contexts of use. It is the selection of the right combination, the right materials characteristics and their manifestation, that resurge once again; only that compared to the mental map developed by the Bauhaus School, we are far from a similar understanding of materials. It is precisely the molecular manipulations and the performativity of molecules and that of molecular assemblies that support the vision of "molecules-machines" (Loeve, 2009). It is not the specificity of materials that is researched but the right calibration for a specific context, situation, and moment of use.

On function

But what exactly involves a functionalist perspective on materials? Or if we are allowed to push the question forward, what an ontology of functions in connection to the materials would be?

The notion of function implies a division of tasks inside of a system. Therefore, the concept of functionality cannot be detached from systemic thinking. At the same time, we cannot dissociate the notion of function from the notion of performance. Having a function means to perform, to act inside of a system, to be part of a system. The function cannot exist out of a functioning schema. From this point of view, function is synonymous with laws and norms, while each new functionality is a form of normalisation, of calibration of the values involved in a system.

The philosophical inquiry related to function might be traced back to the mathematical questioning launched by Leibniz. It is also what mobilised the inquiry into the nature of virtuality and probability (Chatelet, 1988). The contemporary interest in the notion of function is to be understood in relation to the operational turn that is taking place in many disciplines. Performing and being operational are not quite the same thing, though. To better understand the difference, one could refer to the difference between using a tool and operating a machine to address the difference between crafting and industrial fabrication in the philosophy of technology (Gossens, 2022). The difference has an impact at both individual and collective levels. Using a tool to recall the logic of craft, that of the embodied knowledge, often defined in the writings related to practice-based research in design as “tacit knowledge” (Polanyi, 1958). Operating a machine has to do with an operational chain, like that of industry, where what is exercised is a certain operation without an overview of the whole chain of operations and which allows a certain “interoperability”, defined as the capacity to be replaceable. It is to notice that in the context of synthetic materials, of “molecules-machines”, it is precisely with this “interoperability” that we are dealing with.

Still, these differences do not help us address the implications of a functionalist definition of materials, and to answer such a question, one needs to define the nature of function. Ingvar Johansson’s (2004) article “On Function” reunites texts addressing the theoretical aspects related to the notion of function and its role in thinking and designing technology. Johansson addresses the functional entities and their four-dimensional shapes (the three spatial dimensions, but also the temporal dimension); the main argument is that functions cannot exist other than in a processual way and that we must consider both the functions’ property-bearer and processes-bearer dimensions. Moreover, we have to be aware that all systems have different degrees of functioning and that there are structures (or infrastructures—as some media theorists would call them) of functions. He also makes the distinction between logical and prototypical categories, the first one being related to the natural sciences order, while the second one being related to the technological order. The categories are not negligible if we are about to think of design as a way of form-giving, aka *Gestaltung*. From this perspective, the prototype is a form of experimentation which allows an object to perform in an existing context to study an object's degree of impressiveness and disruption (Huyghe, 2022). It is the objective of design studies and proves design as an evolutive aspect of materials systems (Miles, 1973).

Moreover, it also questions, as Ingvar Johansson (2004) has shown, if it is about a cumulative function, bringing under the same umbrella several functions (multi-functionality)—or about a latent, virtual function that gets activated only on certain conditions—or about necessary functions (necessary and sufficient functions) without which a system wouldn’t exist. Or one might ask, following Simondon’s (2015) path, where a system starts and ends. How do we define the different concretisations and individualisations of a system? This applies specifically to biological systems. These issues are not secondary if we think that in the context of nano-technologies, in the world of molecules-machines, the multifaceted aspects of functions can apply to one molecule, as they can apply to broader materials configurations and social contexts.

Wybo Houkes et al. (2004) discuss the need to make the difference between function and action. This difference allows, in their eyes, the articulation of the class of accidental functions important in the understanding of a system. This class recalls the role of feedback in cybernetics and allows us to understand the evolutive systems as well, as well as the difference between the actual and factual use of artefacts.

On advanced textiles and textiles' complexity

At the beginning of this text, we asserted that advanced textiles are an exemplary case study for the study of materials as systems. As a matter of fact, textiles have always been defined as materials. Still, in many cases, it has been difficult to decide which aspect of textiles one should take into account. Should it be the fibre, the fabric or a textile object that needs to be considered? There are at least two ways of dealing with this ambiguity: (a) focusing on the nature of materials used in the fabrication of fibres or (b) focusing on the form taken by the used materials—in this case, a fibre.

Most technical books related to textiles[12] use the natural and man-made fibre differences to point to the composition of the fibres. One understands natural fibres to be vegetal and the animal origin of the materials used in the production of fibres. Man-made fibres, the synthetic fibres developed since the beginning of the 20th century, have a molecular structure that has been manipulated by man.

The latter approach, which deals mainly with the form of materials, might investigate the chain of operations that needs to be executed in order to obtain a fibre. It is the perspective opened by the French anthropologist Andre Leroi-Gourhan (Leroi-Gourhan, 1971), who, in his attempt to classify the techniques, started to look into the forms of materials and the forms of technical gestures involved in their manufacturing. From this point of view, textiles might be what he called "soft solids" (Leroi-Gourhan, 1971). It is not just that both the natural and man-made materials can be then taken in this way into account, but it also introduces a new classification when it comes to the textile

[12] See, for example, Kadolph, S. (2010). *Textiles*, 11th ed., London: Pearson.

materials: between directly manipulated materials, the craft-based approaches to materials manipulations, and the mediated manipulations that define most of the advanced textiles materials resulting from the use of nanotechnologies to modify, to visualise and to control the structure of molecular assemblies (Loeve, 2009; Heinzel, 2020).

Prevalent nowadays, this second perspective involves some challenges related to the multitude of forms the synthetic materials might take. This is the consideration that pushes Ezio Manzini (1986) to place textiles into the category of composites and complex materials. As composites, complex materials, the man-made fibres are muddying the water of skills and knowledge involved in their manufacturing as well as uses, and with that, the cultures, the markets, and the ecologies they are sharing. In many cases, old and new fibres co-exist in the same contexts, while the new materials still need to discover their own forms of expression, their uses, their aesthetics, and their forms of recycling. Superpolymers, metal alloys, fibreglass fabrics, carbon fibres, and aramid fibres are examples of new complex materials that take the shape of wires, threads, and fibres. Apart from the matrix fibrous reinforcement forms the complex materials might take, we will encounter resistant sheets, the quasi-organic aspects such as bone, flesh, and skin, or the films, plates and structural shapes made by layering different materials.

In a sense, Manzini's *Materials of Invention* (1986) marks the acknowledgement by the world of design that there should be a shift in the way the discipline understands and makes use of materials and the way in which the design discipline positions itself when it comes to the new trajectories of materials, including their production, consumption, recycling. It is also the reason why the book incorporates reflections on the sustainability of materials as a strategy to address the economic and ecological aspects related to materials.

Moreover, as Ezio Manzini noticed, not only in the case of plastics, which are nowadays everywhere (from our coffee cups to the wings of planes and into the packaging), but their cultural indexation has changed. This new indexation stopped taking into account the traditional use of materials, their forms and functions, to focus on the multiplication of materials, their functions and contexts of use, blurring the traditional cultural identities of materials. To this cultural indexation, we can add the legal definitions of materials and materials processes as they translate practices and uses.

Materials as systems

The development of active, adaptive and autonomous materials (The Royal Society 2019) is coupled with the awareness that materials should be seen as a complex system of interacting subsystems. In most cases, it is about models and experiments at multiple scales of material structure hierarchies. A goal-oriented discipline, the materials design faces challenges when it comes to the framing of process-structure-property relationships. What is at stake is the feasibility of these materials. It is also the reason authors such as Raymundo Arróyave and David McDowell (Arróyave et al., 2019) are militating for interdisciplinary approaches by establishing collaborations with systems engineering, systems engineering, uncertainty quantification and management, optimisation, and materials data science and informatics. All these disciplines are nowadays part of the “industrial complex”. Still, it is noticeable that none of these disciplines address the social aspects of fabrication in the proper sense of the word.

Focusing on the participatory aspects of practice-based research, designers such as Luis Vega (2023) are looking into sociomateriality as a way to look into the negotiation of meaning through the handling of multiple materials (multimateriality). It is about a performative approach to materiality which adopts a phenomenological stance to size the broader system of the involved materials.

Still, the design position is critical when it comes to materials design. As Sacha Loeve (2019) has shown, the aesthetic aspects of nano-materials are complex. Manipulated at the nanoscale through devices that recall the mediated nature of their intervention (image-objects), the aesthetics of nanotechnology play an important role in the definition of molecules.

We have already shown that the new materials configurations are contextual and situations-based. They translate both into physical-chemical and mechanical properties, but they translate as social or psychosociological gears, called “engrenages” by Simondon (1960). Still, where the raw materials have created a well-established system that takes into consideration the professions and the social hierarchies, the new materials design field multiplies tensions and constraints.

Materials (eco)systems—implications for the design of materials as a systems paradigm

In conclusion, we offer an analysis of the implications for design with the imposition of materials as a systems paradigm. We have already shown that the materials-driven inquiries in design were acerbating the question related to the nature of functions in design. We have adopted a philosophical stance when looking into materials design, and we showed how the switch from an ontological indexation of materials towards a more functionalist perspective created the premises of a paradigmatical change that understands molecules as machines and materials as systems. This paradigm allows us to deal with the complex facetted aspects of advanced materials, which are seeing their properties altered and transformed at the molecular level to answer different situations of use. We also analysed the nature of functions, and we have shown that functions cannot be detached from the concepts of “performance” and “operability”. We also investigated the case of advanced textiles and noticed the complex and multi-layered perspective of functions when it comes to their performances. This complexity is certainly troubling the waters of our understanding of materials and our capacity to interact with them. Moreover, the goal-oriented and purpose-defining ontologies of new materials are to be taken with caution.

Given the implications at different scales of possible interventions on materials, we suggest looking not only at the materials system(s) but also their ecosystem(s) as a form of creating meaningful relations at different scales. Often neglected from the goal- and purpose-oriented interventions, a more reflective and artistic perspective might help deal with the complexity of materials systems.

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