MATERIAL FLUX: REVEALING THE POTENTIAL OF PROCESSUALITY

AGUSTINA ANDREOLETTI
Independent researcher,
Cologne, Germany
hi@agustinaandreoletti.com

ALICE RZEZONKA
University Wuppertal,
Cologne, Germany
arz@uni-wuppertal.de

Keywords
Materiality
Interactive matter
Programmable material
Process
Thing
Non-anthropocentric design
Computational design
Processual

In this paper, two key features of a framework for active matter (programmable, or rather, "processual" material) that is, programmability and process, are explored via a theoretical and practical discussion. More generally, this paper investigates the concept of materiality and material performance: analysing the experiences of humans in terms of their interaction with the environment, with artefacts and with material within a design context. Finally, the authors propose the conceptual project "Chrysalis Gemini", applying their perspective on the discourse, meaning and contextualisation of interactive materiality. The aim of "Chrysalis Gemini" is to present the relational potential implied in active materials and their ongoing process of transformation - suggesting a world in a state of flux.

2016.
xCoAx
.org
Computation
Communication
Aesthetics
& X
Bergamo, Italy

1 INTRODUCTION

Within architecture and design, form has grown to the point where the condition of its materialisation has become standardised; material is, within the logic of the modernist tradition, secondary to form. The digital revolution, marking the change from analogue to digital technology, transformed the designer's drafting board into a digital canvas. Form, it seemed, was then much more divorced from physical reality. These new design spaces provided liberation regarding formal expression, but they also expanded the difference between matter and form and made the separation of the modeling, analysis and fabrication processes more pronounced.

Today, perhaps because of the recognition of the ecological failures of modern design, design culture is witnessing a new materiality. Society and the way materiality and materials are understood are mutually conditioning one another. Materiality and material performance are no longer a subordinate question of detailing, but instead, one of vital significance. The notion of materiality provides us with a first clue regarding the renewed importance of subjectivity. Materiality, unlike matter, can never be considered as entirely objective. Materiality corresponds to a certain category of experience which is a socially constructed one. The point becomes more evident when considering its opposite, immateriality. Nothing is in itself immaterial. We call something immaterial when we cannot relate to it in certain ways. Materiality corresponds to a range of experiences which give us the impression of being in genuine contact with the physical world. Some of these experiences are based on immediate sensory evidence and others involve instruments and machines. Whatever the case, materiality possesses a relational character. It implies an encounter between a subject and the material world. From this perspective, materiality appears as a mix of permanent, ahistorical features with cultural factors. It articulates physical constraints as well as social constructs, such as the value we attach to certain types of observations.

But even in its permanent interplay with its surroundings, material itself has been regarded, in the last few decades, mostly as mutually passive and static. Only the very recent progress in the fields of active matter and programmable material is challenging this assumption. Suddenly the formerly mutually exclusive worlds of seemingly immaterial processual software and static hardware start to intertwine, evoking what the Self-Assembly Lab at the Massachusetts Institute of Technology considers a "material revolution," succeeding the "hardware" and "software revolutions" (MIT 2015).

Within this discourse, the meaning and contextualisation of materiality and the future relationship with it are being renegotiated. The trace of the inert material left behind suggests a world in a state of flux and determined by relation rather than subject and object separation. This ongoing process is calling for a close examination with the aim of revealing the potential implied in this revolution. Therefore, the following paper highlights significant aspects of this shift. Reaching from the questionable term of "programmability" to Martin Heidegger's understanding of "leaky" things, and looking at the condition of changing states and the potential meaning of ornament, an extensive field of thought is established. The proposed conceptual project "Chrysalis Gemini" derives from and illustrates these principles, stressing the potential of material in a processual relationship with humans and their environment.

2 THE AMBIGUITY OF PROGRAMMING MATERIAL

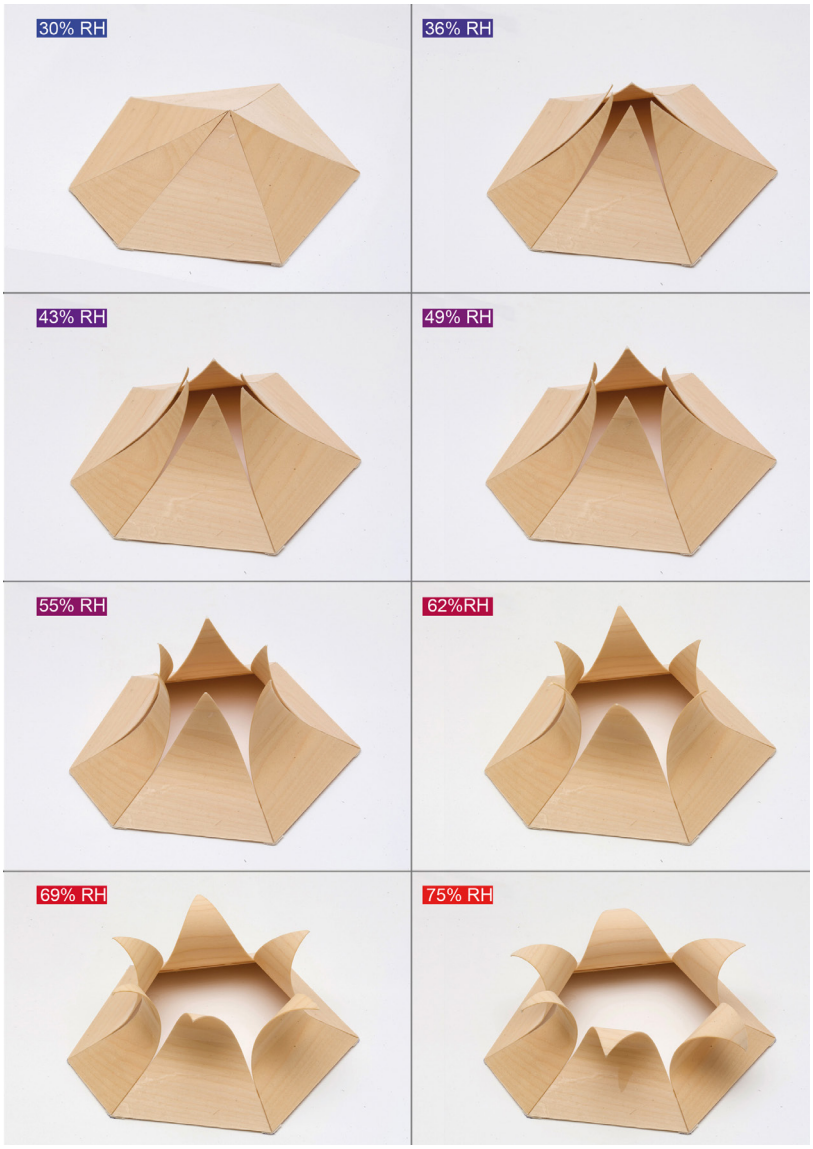

Fig. 1. HygroSkin-Meteorosensitive Pavilion / Achim Menges Architect + Oliver David Krieg + Steffen Reichert. Process-Responsive Component. Courtesy of ICD University of Stuttgart.

The term programmable material might sound paradoxical at first. Programming for the last few decades has been strongly associated with the so-called immaterial; software appears to run the same process on different hardware seemingly regardless of the material the machine is made of. The plastic or aluminium cases that enclose these processes appear as nothing but static decoration protecting the magic occurring inside. Although a closer look at this magic might reveal how desperately dependent it is on specific material resources, from the outside, the material aspects of programming appear to be fully negligible.

The emerging term programmable material and the work that is being done in that field suddenly bridges this traditional dichotomy between software and hardware. Generally, the term refers to matter with the inherent ability to change its physical properties. This ability may then become part of an information process similar to that which takes place within hardware-software platforms. Prominent examples include shape memory alloys, polymers that can assume different shapes at different temperatures and chromogenic systems that change colour in response to electrical, luminous and thermal stimuli. But even basic materials may reveal similar intrinsic qualities when observed carefully; this has been amply demonstrated by professor and architect Achim Menges at the Institute for Computational Design at the University of Stuttgart. “HygroSkin”, the pavilion built in 2010 in collaboration with his colleagues Steffen Reichert and Oliver David Krieg, possesses several openings covered by paper thin wooden flaps (Menges 2013). In response to the surrounding humidity, these either expand and flatten or curl and open. Skilfully triggering the intrinsic behaviour of timber, the design of these flaps is such that they process the given environmental input and produce an output relative to this. Unlike conventional hardware-software platforms, which aim at producing the same output regardless of the particular materiality, in this case, matter and process coincide seamlessly.

2.1 RECONSIDERING PROGRAMMABILITY

The radical turn of ascribing the adjective programmable to material itself, the traditional silent slave of programming, calls for the re-evaluation of the definition of what is meant by programmability. Professor Georg Trogemann refers to a machine as programmable, in the most essential meaning of this term, if its behaviour can be changed without the reconfiguration of its inner structure (Trogemann and Vierhoff 2005). Therefore, all future responses are, in fact, inherent to the machine, and programming becomes the art of triggering, combining and

manipulating the possibility of these responses. Other authors demonstrate further the very material reality of programming and data-flows (Blanchette 2010, Kirschbaum 2007). Still related to computer-based programming, conventional expectations are the repetition of executed commands and the processing of unambiguous states irrespective of the material platform. Although these expectations cannot be substantiated as accurate even in the specific reality of computer-based processing, they are certainly significant elements of the term's connotation.

Thus applying this term to the material environment and to material-human relations on various scales is a challenging and, in some cases, unfortunate aspiration. It has to be stressed that working with the intrinsic behaviour of matter is a continuously varying process influenced by a large number of factors, unlike the distinct and exact repetition computer-based binary code offers. Furthermore, the different working cycles of hardware and software become intertwined. The behaviour of shape memory alloy metals, for example, is altered through high-temperature forces that change the internal crystalline structure. Programming the behaviour of these metals is therefore achieved by altering the material's inner coherence. This process can be rewound and repeated multiple times, creating continuously shape shifting states. At this point, programming is no longer fixed to commanding unambiguous states to be executed by the materialised hardware, but rather both happen in an inextricably intertwined fashion. To further underline this continuous interdependency and to withdraw from the deterministic connotations of programming, the term *processual material* shall be pursued in this paper.

2.2 PROCESSUAL MATERIAL

Replacing the concept of *programmable* by *processual* shifts the primary interest towards the alterability and the temporal qualities of materials. While *programmable* implies code dictating to passive matter, *processual* defines a relationship between maker, syntax, user, form and material as an open process of influencing agents. Abandoning the static meaning of materiality clears the way for an understanding of material itself which holds the potential of behaving in an active and adaptive way towards environmental processes (Hensel and Menges 2009). Processual materials are, therefore, not a substitute for existing hardware-software platforms but rather represent a new range of interdependent interactivity. It is not about a program allegedly commanding material to act, but about the potential interplay

between matter and agents. In this case external and internal forces engage in the form-finding process much along the lines of Gilles Deleuze and Félix Guattari's theory, enabling interwoven fluid interdependencies between agents within a continuous meshwork (Ingold 2010).

Processual refers, in the first place, to material that can react, either gradually or spontaneously and immediately, to its environmental and to external interactions. A connection can be drawn to the processual art movements and, in particular, to Robert Morris' pamphlet "Anti Form" (1968). Moving this understanding into the everyday exchange with the material world may genuinely alter the human relation towards materiality. Processual material may reveal the traces of the dynamic meshwork it is embedded in; it may turn inside-out its inner state and become part of an open-ended interplay with its surroundings. The idea of static form is contrary to this understanding. It is important to consider that material seldom presents itself in its purest form, detached from the environment. In this sense, it can be regarded as questionable to look at the concept of processual materials as isolated from other materials. New materials in this field are often presented as samples in laboratory settings. Though this might be an efficient way to demonstrate their capabilities such a presentation falls short of considering the complex real-world interplay they must be embedded within. Outside the laboratory, there are many more links and paths than the understanding of a material in isolation can capture.

3 POTENTIAL OF PROCESSUAL THINGS

The problem of considering materials as samples is the lack of context, social semantic and culture. Tim Ingold intervenes into discussions of material theory with his critique of the conceptual reduction of things to objects. His ideas might be applied to our concept of processual materials and how they become *processual things*. In this context, processual things are much more than the material that unfolds the form of the object. Things are understood, not as lifeless matter, but, to pick only a couple of Ingold's descriptions, as "a particular gathering together or interweaving of materials in movement," (Ingold 2010, 214) or a "knot whose constituent threads, far from being contained within it, trail beyond, only to become caught in other threads in other knots" (Ingold 2010, p.4). Following this idea, threads of forces and interaction are what distinguishes things from objects. Objects can exist in a vacuum, but things are in a permanent relationship with the environment, in a continual process of becoming, as a result of internal and external forces.

The thing, in opposition to the object, is a becoming, a process of interaction whereby several becomings undertake a reciprocal process with each other. Its identity is not limited by external forces, but enhanced by the osmotic character of the thing - what creates its appropriation of the environment and make its drives internal. Ingold's writing finds its basis in the later works of the German philosopher Martin Heidegger (Heidegger 1968; Heidegger 1971). The fourfold - the gathering of earth, sky, mortals and divinities - is what constitutes the thing, according to Heidegger. The thing is desubstantialised: no longer a self-enclosed entity but instead the intersection of these four constitutive elements. It extends beyond itself along the relation presented, and becomes the particular node for such relations that contextualise it. The processual character of the thing does not consist in an isolated fixed state, but can be defined in regard to the thing's fluidity within a social process.

Processual things carry the potential of individualisation within utilisation. The success of this development not only creates an adaptive artefact but enhances the emotional bonds between people and things. The generative potential of processual materials, where growth and flexible mechanisms have an essential role in the delineation of form, may have the capability to promote emotive connections. These connections may emerge from a deeper understanding of the artefact's morphogenesis and the proximity and time required for their development. There we can find Christopher Alexander's (Alexander 1977) work regarding parametric design, by which a particular artefact can be generated in response to people's needs. In his perspective, an adaptive process will be successful only if it is unfolded and takes into consideration all kinds of possible interactions. The local uniqueness of an artefact cannot arise unless each part has an absolute autonomy so that it can adapt to specific conditions. However, this autonomy should be organised and systematised under some sort of deeper regulation. The adaptation will not only make the local part correctly adapted to its own processes, but it will also be shaped to form a larger whole.

This process seeks to develop artefacts which exist in a permanent evolving position. The things which are becoming during this transformation are the result of a close relationship between the various constituent forces which provide individual singularity. The uniqueness of the artefact is related to the experience of its use, but that experience cannot be designed directly but only through affordances. Affordances are simply the possible interactions with, and uses of, an object based on the properties of the object and capabilities of the user (Norman 2013). In the

case of processual materials, affordances can provide the framework for a new class of interactive systems which can adapt to interaction and context, so sustaining more open-ended design practices. The qualities of the materials should be considered in designers' decisions to create products based on the behaviour of the users, their environment, and the possibilities of engagement and interaction.

The fluidity needed in the interplay around processual things triggers a fully deep and boundlessly open set of experiences. A responsive environment cannot be adequately modeled by any small finite number of experiential trajectories through that environment. A growing literature in the fields of material computing points to non-digital processes that do not follow the organisation or logic of a finite state machine (Glanville 2007; Kretzer and Hovestadt 2014; Krippendorf 2007; Pask 1969). The proposition inherent in the concept of processual things is that artefacts are created simultaneously both from the point of view of humans and from the perspective of the behaviour of materials. This conceptualization demands a shift in attitude about computation, and an extension of views on material qualities to a much broader base. Characteristics such as weight, elasticity, endurance or stiffness, belong to the world of seriality and sequential-processing thinking. In this argument, it is proposed to think spatially, introducing elementary topological concepts with which material and cultural change can be articulated using relational notions of proximity, limit, and adjustment (Sha 2013).

3.1 SHIFTING PHASES

The development and reconfiguration of processual things imply a physical category characterised by the combination of events-effects. Events refer to the deformations and transformations that occur when flows reach the beginnings of transitional phases and state-changes. Effects apply to the absolute qualities that consist in each state, defining the capacities and differential relations of an assemblage at a particular moment in space-time (Deleuze and Guattari 1987).

Things are dynamic, not because they are controlled by spirit, but because the material of which they are composed continues to circulate in the surrounding media, and this forecasts their dissolution or ensures their regeneration (Ingold 2011). We can consider Deleuze and Guattari, who insist that "matter-flow can only be followed" (Deleuze and Guattari 1987, 409). According to this theory, vases are no more stable than human bodies but are constituted and held in place within flows of material. By the

time materials have turned into objects, they become hidden to us: they disappear in the manufacturing process. Degradation, corrosion or wear and tear, however, changes this scenario. Despite the best efforts of designers and manufacturers, no object has a fixed state, neither can it last indefinitely.

A functional application for material flow is the capability of self-healing materials to repair damage to themselves, at early stages. This process is inspired by the sophisticated organisational structures of biological organisms. A living body has many simultaneous and complementing mechanisms with which to perform partial or complete self-restoration at many different stages. For instance, when the skin is cut, the body instantaneously responds, and the wound is clotted via "platelets" in the blood flow. By this mechanism, the tissue is sealed, allowing it to repair itself. However, the majority of artificial materials deteriorate with time irreversibly, due to wear, and this limits the life of many components. The implementation of self-healing techniques in inorganic materials is a new field of research. When self-healing materials are broken or injured, a healing process can be triggered; for instance, an agent flows into the cracked section to seal and repair it. Whereas the artificial system will not be able to create identical material to replace the damaged area, nevertheless the self-repair function could serve to provide new material in this area, and this is similar to the way in which skin damage results in the formation of scar-tissue.

There are two basic types of self-healing systems: autonomous and non-autonomous. Autonomy indicates that there is no external intervention; on the other hand, non-autonomous repairing designates that a particular external mediation is necessary to initiate the process: for example, heat and/or humidity. The self-healing methods currently proposed use a repair agent implanted into the matrix of the material. When activated by damage, the agent is released and seals the void or crack by solidifying or through other chemical reaction. In this process, a collection of regeneration strategies in the format of a trigger, a rule and an action must be specified; thus creating a self-healing loop. This notion includes the detection of failure, its diagnosis and the subsequent recovery. In this loop, the most general states are the *entire*, when the thing displays intentional functioning and all requirements are met as expected, and the *broken* which could be identified by an unacceptable response that most probably is the result of a failure or error. The possible transitions between states are stored in the code of the material; the system is unstable and inhabits a fuzzy processual zone until it reaches the next state in the loop.

3.2 PERFORMATIVE ORNAMENTATION

Visual organisation of form communicates information to people through the surfaces and geometry it presents. Experience is based on an intimate interaction of human beings with surfaces and spaces which influences emotions and physiological states and consequently, actions. Ornamentation may be understood to be concerned with a particular way of arranging information and presenting it to the user: connecting space and time, and thus structuring human experience. The ornament can create a dialogue, and be further developed by that conversation between man and artefact.

In the context of self-healing materials and processual materials in general, the ornamental can be understood, not as decorative applied to the logical and organisational structure, but instead as the element which takes care of sharing information: information about material, ways of interaction, cultural values and the society the thing is immersed within. *Kintsugi* is the traditional Japanese technique of mending broken pottery, using plant resin lacquer as an adhesive and powdered gold. The unintentionally broken vessels reveal the, hitherto potential, vulnerabilities, flaws and imperfections that these things possess. The gold seams of *kintsugi* enhance the unique pattern generated by this relationship-centred human-thing-environment, thus creating a new component for appreciation. The intermediate character of ornament, between ideal and material, places reciprocity in the relation between matter and concept. Both representation and meaning occur at the ornament. The aesthetic form of knowledge is not optional: every artefact is available only by way of appearance, the inner structure of an artefact and its materiality are evident by aesthetic mediation.

Fig. 2. Bottle covered in overlapping dark brown glazes; large break extending around the body repaired with gold lacquer. Takatori, Japan. 1700-1800. Courtesy of © Victoria and Albert Museum, London.

Processual materials generate ornamental effects that are not simply added at the end of the design process; instead, they are inherent to rhythmic forces that activate dynamic changes in space, reflecting mutations and transitions. Ornaments reveal an internal organisation, a consistency against which experience and knowledge can be tested and questioned. To this extent, an ornament emerges if material, form and structure are able to interact with each other, and most importantly, if they can be interrelated by, and so establish a conversation with, the user. Conversations affect and impulse the transitory states of social beings. Ornament is the figure that emerges from the material substrate, the expression of embedded forces through processes of construction, assembly and growth. In this way material, and finally the thing, transmits effects.

4 PROPOSED PROJECT: “CHRYSALIS GEMINI”

Reconsidering the shift of material from its static perception to a state of flux requires a strong focus on contextualisation. From a design perspective, this renewed view on processual material and its bundling as a processual thing propose a new level of interactive and autonomous form finding. Therefore, it is important to leave the laboratory setup, wherein new materials are usually presented, and look at their embedded purposes.

“Chrysalis Gemini” is an interactive materiality concept for ceramics with self-healing abilities. Technical concepts for ceramic components with self-healing abilities are currently being developed by scientists and engineers (Ponnambalam 2012). This kind of material carries microcapsuled healing agents; when exposed by crack or rupture, these fill the gap. The laboratory concept proposed for mechanical endurance serves as a starting point for our design scenario as it is immersed in the everyday use of ceramics. When the surface of “Chrysalis Gemini” is cracked, voluntarily or by accident, the embedded healing agent is exposed, and this then closes the crack. Furthermore the agent is imbued with the capacity to absorb the flavour and colour of the dish or liquid contained after healing. Therefore, breaking the bowl does not only change its appearance but also creates a sensual memory which is added to its experiential realm. Initially, the vessels are identical, but through time and experience, they become individual active traces of their interaction with humans and their environment.

Continuing the line of thought of current technological achievements in the field of self-healing materials, this scenario alters, not only the relationship between the lifespan of things and the things themselves, but also the connotations, the meaning, of the act of breaking something. “Chrysalis Gemini” considers breaking or cracking as a form of interaction, a changing of the state of a thing and of its material. As the French philosopher Bruno Latour points out, in our everyday experience the act of breaking might reveal the complex network within which things are entangled (Latour 1999). A broken car may unveil the unforeseen trajectories of insurance companies, car repair shops and spare part supplies which have initiated an in-line process of repair (ibid., p. 237). The (successful) result of this process is often the complete re-concealing of these trajectories.

The Japanese craft of *kintsugi* introduces a different handling of brokenness and repair. Here the unique reaction of the material to its breaking, the usage of gold for repair and the craftsmanship involved, actually increases the value of the piece. In

the process of repair, its unique brokenness is valued, putting the craftsman into close relation to the material. In the end, instead of becoming hidden, the trajectories of repair come into focus and the final piece is a constant emotive reminder of this process. Considering autonomous self-healing materials, understandings of the act of breaking and repairing are altered further. One can describe the traditional procedure that a car or a potential *kintsugi* piece undergo in terms of separate states and decisions (see fig. 3). With autonomous self-healing, these states can no longer be separated distinctly but rather melt into a continuously looped process (see fig. 4). Changing from the active-passive term of *repairing* to *healing* implies a constant alteration. This reposition transforms the relation between human, thing and environment into an interconnected process.

For “Chrysalis Gemini”, this is key to the relational individualisation of everyday objects and how one might interact with them. Healing is not considered as reestablishing the exact initial condition, but a process leaving traces of its occurrence - scar tissue of a sort. The process of breaking and healing is actively or by accident initialised by the user and then takes place in correspondence with the environmental settings. The haptic experience of continuous breaking and healing discloses the processual change within the material, rendering a complex and unforeseeable interplay between multiple factors.

Fig. 3. The agent filling the gap carries the additional ability to absorb colour and flavour.

One can think of this in terms of a (re-)generative design which exists as an evolving system: the dynamic substance remains alive, the surface is reconfigured as it matures. The code of the material is implemented in the design process but then left to unveil itself through the interplay of forces. The designer does not determine the final outcome, but rather creates an experiential setting.

The concept is meant to visualise how processual things, when placed into a context, reveal potential beyond their mere functional use. It exposes how processual things carry the inner potential to rearrange the interactions with, and connections towards them. This approach proposes a radically new way of thinking about the meaning of material in design, bridging the gap between software- and hardware-thinking, offering a fuzzy system approach that determines materiality as a continuous characteristic by allowing relative degrees between 0 and 1, between *broken* and *entire*.

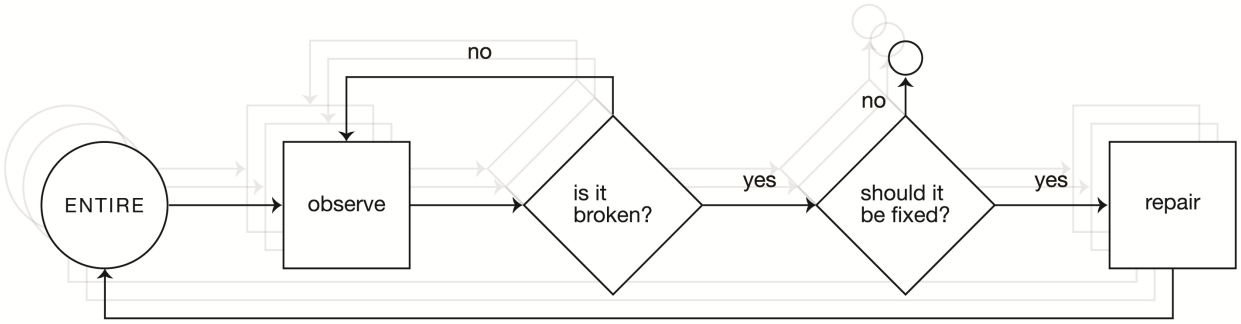

Fig. 4. non-self-healing thing – external decision loop.

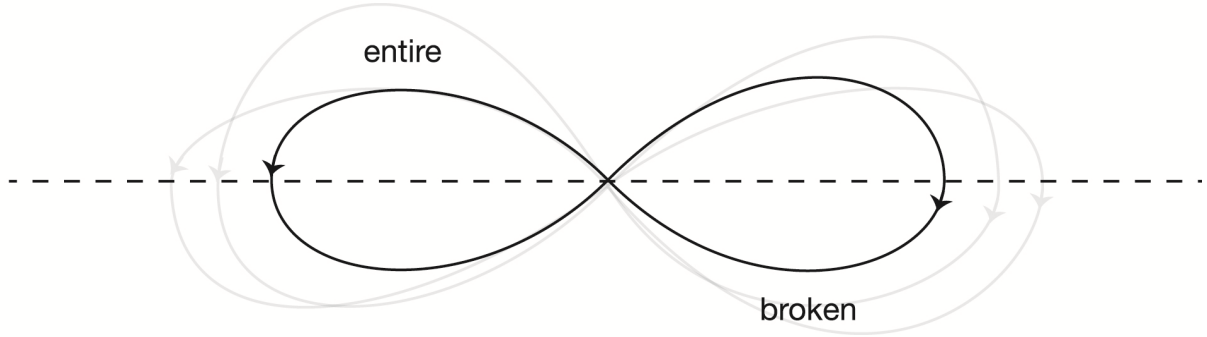

Fig. 5. self-healing thing – internal decision loop.

5 CONCLUSION

In investigating the potential of processuality, it becomes evident that its continuous temporal and interconnected qualities are vital. Manifold aspects of performative and generative design already correlate to this understanding. Considering processuality, the significant potential of interactive material merges the knowledge spaces of computer-based programming and real-world material interaction. This combined knowledge opens up an understanding of co-acting, in which thing, human and environment continually influence each other. In addition, the proposed concept “Chrysalis Gemini” highlights the contextual appeal of this idea. Interaction is not only allowed in functional terms but represents a constant repositioning of actors. In their materialised form, the otherwise hidden processes become a tangibly integrated part of thingness.

Furthermore, processual materials may hold the potential of being process-starters rather than just being considered as design output. Hereby the intrinsic qualities of the material are of

core value in determining the potential of interaction and the unique relation it may hold. This idea asks for more flexibility and precision in materiality evaluation and greater insight regarding testing and investigation in contextualised scenarios. It can only be stressed how important this research is since the human-world relation is continually being re-negotiated at this particular point.

REFERENCES

Alexander, Christopher, Sara Ishikawa, and Murray Silverstein. *A Pattern Language*. New York: Oxford University Press, 1977.

Blanchette, Jean-François. *"A Material History of Bits."* Journal of the American Society for Information Science and Technology, 62 no. 6 (2011): 1042-1057.

Burnham, Benjamin J. "Notes on Art and Information Processing." *Software, Information Technology: It's New Meaning for Art*. Ed. Jack Burnham. NY: Jewish Museum,1970, 10–11.

Deleuze, Gilles and Félix Guattari. *A Thousand Plateaus*. Minneapolis: University of Minnesota Press, 1987.

Heidegger, Martin. *Poetry, Language, Thought.* New York: Harper and Row, 1971

Heidegger, Martin. *What Is a Thing?* Chicago: H. Regnery, 19 68.

Hensel, Michael and Menges, Achim. "Patterns in Performance-Oriented Design". Architectural design 79.6 (2009): 89–93.

Glanville, Ranulph. "Try Again. Fail Again. Fail Better: The Cybernetics In Design And The Design In Cybernetics." *Kybernetes 36.9/10, 2007*, 1173-1206.

Ingold, Tim. "Bringing Things to Life: Creative Entanglements in a World of Materials." *NCRM Working Papers, 15.* Manchester, UK: ESRC National Centre for Research Methods, 2010. Online: http://eprints.ncrm.ac.uk/1306/1/0510_creative_entanglements.pdf

Kirschenbaum, Matthew. *Mechanisms: New Media and the Forensic Imagination*. Cambridge, Mass.: MIT Press, 2007.

Kretzer, Manuel, and Ludger Hovestadt. Alive: Advancements in Adaptive Architecture. Basel: Birkhäuser, 2014.

Krippendorf, Klaus. "The Cybernetics Of Design And The Design Of Cybernetics". *Kybernetes 36.9/10.* 2007.

Latour, Bruno. *Pandora's Hope*. Cambridge, Mass.: Harvard University Press, 1999.

Menges, Achim. "HygroSkin: Meteorosensitive Pavilion". 2013. Online: http://www.achimmenges.net/?p=5612.

MIT. "Active Matter Summit: A Conference Organised by the Self-Assembly Lab." Online: http://activemattersummit.com. Cambridge, MA: The MIT Press, 2015.

Morris, Robert. "Anti Form." *Continuous Project Altered Daily: The Writings Of Robert Morris*. Cambridge, Mass.: MIT Press, 1993.

Norman, Donald A. *The Psychology Of Everyday Things*. New York: Basic Books, 1988.

Nosonovskiĭ, Mikhail and P. K. Rohatgi. *Biomimetics In Materials Science*. New York, NY: Springer, 2012.

Pask, Gordon. "The Architectural Relevance of Cybernetics." *Architectural Design* 7. no. 6. New York: John Wiley and Sons, September 1969.

Ponnambalam, Sivalinga Govinda; Parkkinen, Jussi; Ramanathan, Kuppan Chetty. *Trends in intelligent robotics, automation, and manufacturing*. Berlin: Springer 2012.

Sha, Xin Wei. *Poiesis And Enchantment In Topological Matter*. Cambridge, MA: The MIT Press, 2013.

Trogemann, Georg, and Jochen Viehoff. *Codeart. Eine elementare Einführung in die Programmierung als künstlerische Praktik.* Wien: Springer, 2005.