Designing with Matter: From Programmable Materials to Processual Things

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ABSTRACT

This paper explores the potential of active matter, from a practical exploration of the concept to a theoretical discussion based on the material findings. It begins by addressing the ideas of materiality and material performance through the project "Chrysalis Gemini" and then provides an overview of the notion of programmability.

To this end, we move to the description and analysis of programming, focusing on its relationship with hardware, software and material. In particular, we address the idea of programmable matter, and we introduce the term *processuality*. We consider the importance of adaptability, analysing the experience of humans, their interaction with the environment, with artefacts and with material within a design context.

In this manner this study seeks to highlight how contextualisation and interconnected processes become relevant as a design argument. This is achieved by presenting the relational potential of processual material and things and their ongoing transformation.

KEYWORDS

Materiality; Interactive Matter; Programmable Material; Process; Thing; Non-Anthropocentric Design; Computational Design; Processual.

1 I INTRODUCTION

The digital revolution marked the transition from analogue to digital technology, leading to the transformation of the designer's drafting board into a digital canvas. Within architecture and design, form has grown to the point where the condition of its materialisation has become standardised; material is secondary to form. New digital design spaces have been liberating in terms of formal expression, but they have also led to a higher level of differentiation between matter and form. In addition, they have made the separation of the modelling, analysis and fabrication processes more pronounced.

However, even in its permanent interplay with its surroundings, in the last few decades, material itself has generally been regarded as mutually passive and static. It is only very recent progress in the fields of active matter and programmable material that is challenging this assumption. Suddenly, the previously incompatible worlds of seemingly immaterial processual software and static hardware are beginning 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, determined by relation rather than subject and object separation. This ongoing process calls for close examination, with the aim of revealing the currently implicit potential in this revolution. Therefore, the following paper highlights significant aspects of this shift. We present a practical implementation of the concept of processual materials and processual things, which are later defined in more depth with reference to their theoretical foundations. The proposed design scenario "Chrysalis Gemini" is thereby an example and starting point to investigate the potential of material in relationship with humans and their environment. From this approach a broader theoretical framework of processual material is formulated.

2 I PROPOSED PROJECT: "CHRYSALIS GEMINI"

The project "Chrysalis Gemini" is based on a design scenario that proceeds from the assumption that the development of programmable or smart materials challenges the way we as designers and humans interact with materials. To reflect on this shift, the project is based on speculative technical ground; asking not what is possible with the novel materials presented to us at the moment, but what properties we might wish to develop. From this project central issues of material engagement are traced, forming a theoretical framework for a renewed material understanding.

2.1 DESCRIPTION

"Chrysalis Gemini" is first and foremost an interactive concept for ceramics with self-healing abilities. Technical concepts for ceramic components with self-healing abilities are under development by material scientists and engineers (cf. Ponnambalam, 2012). These concepts focus on nanoscale fractures and are based on embedding microencapsulated healing agents within the structure of the ceramic which, when exposed by a crack or a rupture, starts to react and fill the gap. For the project proposed the laboratory work focused on mechanical endurance, this serves as a starting point to elaborate on a design scenario that engages with the future use of new enhanced materials.

Figure 1 | Photo of "Chrysalis Gemini".

Figure 2 | Photo of "Chrysalis Gemini".

Figure 3 | Photo of "Chrysalis Gemini".

The project's subject is framed as the everyday use of ceramics in the form of archetypical hand-held bowls. These bowls are to be made of self-healing ceramics. Therefore, when one of the "Chrysalis Gemini" bowls is cracked deliberately or by accident, the embedded healing agent is exposed and the composite closes the crack. We imagine this agent as being designed to have the additional ability to absorb flavour and colour. In this way, the food and drink contained after the healing process leave traces in the ceramic. Consequently, breaking a bowl not only changes its appearance but also creates a sensorial memory of dishes consumed (see Figures 1, 2 and 3). On the production of a group of “Chrysalis Gemini” all vessels are initially identical, however through time and experience they become individual, active traces of their interaction with humans and their environment.

2.2 MATERIAL FLOW

“Chrysalis Gemini” renders the interaction with ceramics dynamic. In this case things are dynamic not because they are controlled by external forces, but rather because the material of which they are composed continues to circulate in the surrounding media, which can lead to their dissolution or ensures their regeneration (Ingold, 2011). We can consider Deleuze and Guattari (1987, p. 409), who insist that “matter-flow can only be followed”. According to this theory, bowls 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, concealed by the manufacturing process. However, in the instance of degradation, brokenness, corrosion or wear and tear this scenario changes. 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 complementary 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 closed due to platelets in the blood flow causing it to thicken and clot around the damaged area. Due to this mechanism the tissue is sealed, allowing it to repair itself. However, the majority of artificial materials deteriorate irreversibly with time due to wear, which 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. By contrast the artificial system will not be able to create identical material to replace the damaged area, however the self-repair function could serve to provide new substance in this area. This process 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 indicates 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 an alternative 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 conceptual pathway includes the detection of failure, its diagnosis and subsequent recovery. In this loop, the most general states are “whole”, this refers to the state when the thing displays intentional functioning and all requirements are met as expected. The ‘broken’ state on the other hand could be identified by an unacceptable response, which one can assume is the result of a failure or error in most cases. The possible transitions between states are stored in the code of the material; the system is unstable and inhabits a dynamic processual zone until it reaches the next state in the loop.

2.3 TRACES OF AN INTERCONNECTED PROCESS

In the context of self-healing materials, the ornamental can be understood as the element that takes care of sharing information rather than a decorative element. In the case of “Chrysalis Gemini” the cracks that can be regarded as ornament are traces of former use in relation to the material properties. 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.

Figure 4 | 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.

When regarding the act of breakage and repair the Japanese craft of "kintsugi" introduces a related handling. "Kintsugi" is the traditional technique of mending broken pottery using powered gold with plant resin lacquer acting as an adhesive (see Figure 4). The unintentionally broken vessels reveal 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, subsequently creating a new component for appreciation. The individual reaction of the material to its breaking, the usage of gold for repair and the craftsmanship involved increases the value of the piece.

In the process of repair its individual brokenness is valued, putting the craftsman in close relation to the material. Ultimately, instead of becoming hidden, the trajectories of repair are brought into focus and the final piece is a constant emotional reminder of this process. When autonomous self-healing materials are viewed as similar, the act of breaking and repairing is taken even further. One can refer to the traditional procedure that a potential "kintsugi" piece undergoes as separate states and decisions (see Figure 5). In the proposed project, which is viewed as autonomous self-healing, these states can no longer be separated distinctly but rather blend into a continuous process (see Figure 6). Changing from the active-passive term of repairing to healing implies a permanent alteration. This repositioning transforms the relation between human, thing and environment into an interconnected process.

2.4 INTERACTION IN THE ENTANGLEMENT

In the field of self-healing materials, the proposed scenario alters more than the relationship between the lifespan of things and the things themselves. The connotations and meaning of the act of breaking objects change with "Chrysalis Gemini." The project considers breaking or cracking as a form of interaction, a changing of the state of a thing and 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.,

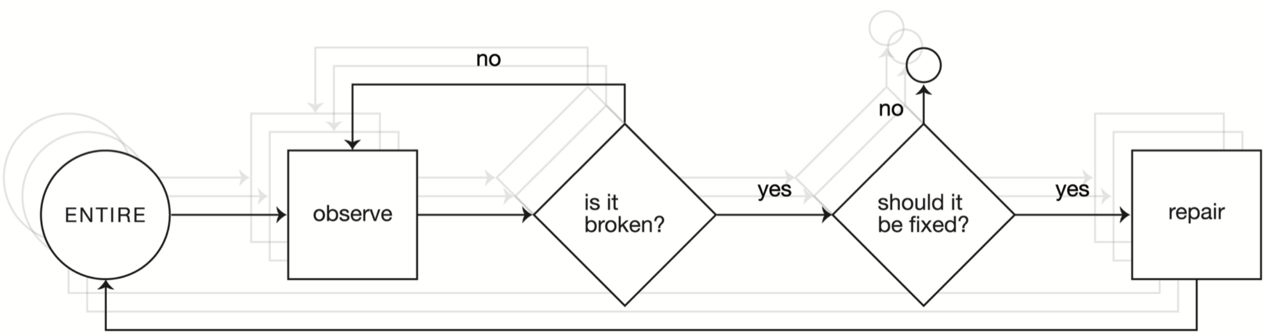

Figure 5 | Non-Self-Healing Thing – External decision loop.

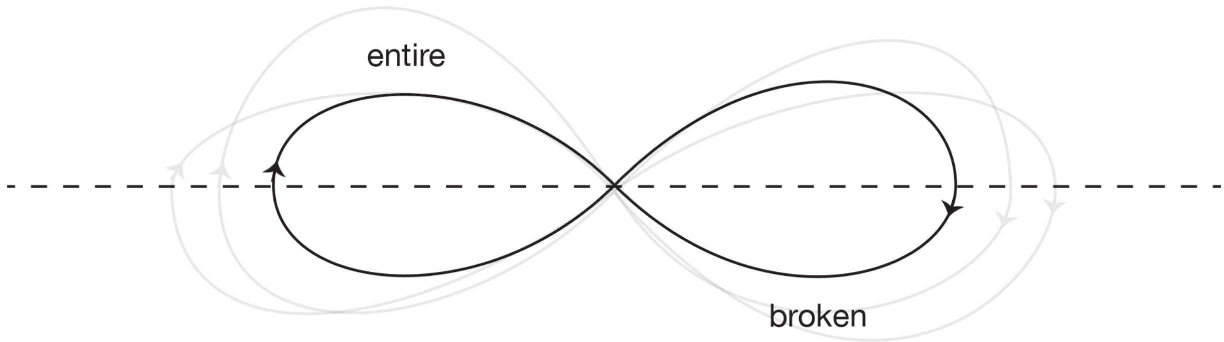

Figure 6 | Self-Healing Thing – Internal decision loop.

p. 237). The (successful) result of this process is often the complete re-concealing of these trajectories.

For “Chrysalis Gemini”, this idea 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.

2.5 GENERATING RELATIONS

Processual materials can offer strategies for making multipurpose things that perform more adaptively. Designers examine how things interact with their environments, as well as with people and with other things. This exploration could lead users to think about the processes for which those things are created. Processual design exists as an evolving system: the active substance remains “alive” in the sense that 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 outcome but rather creates an experiential setting.

The concept presented is meant to visualise how processual things reveal potential beyond their functional use when placed into a context. The process of healing was considered not only because of its functionality, but also for its emotional characteristics. It exposes how processual things carry the inherent 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-thinking and hardware-thinking, offering a system procedure that determines materiality as a continuous characteristic by allowing relative degrees between 0 and 1, between “broken” and “whole”.

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 proposes 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.

3 | MATERIAL BETWEEN THE DICHOTOMY OF SOFTWARE AND HARDWARE

The material understanding derived from the engagement with the design scenario proposed renders a new view on material development in the field of programmable material. Self-healing materials that are framed under the expression “programmable material” may present a special case but also lead us to question the term “programmable” and consider deliberately replacing it with ‘processual’. In the following theoretical discussion, the meaning of programmability is explored and a framework for a processual understanding is presented as an alternative. This shift in language is considered important since a new understanding of materials also implies new approaches to designing with them.

3.1 THE MEANING OF PROGRAMMABILITY

For the last few decades programming has been heavily associated with the so-called immaterial. The software appears to run the same code on different hardware seemingly regardless of the substance the machine is made of. The plastic or metal boxes that enclose these processes appear as nothing but static protection concealing the operations occurring inside. Although a closer look at these operations might reveal how strongly dependent it is on specific material resources, from the outside, the material aspects of programming appear to be entirely insignificant.

The radical turn of assigning the adjective programmable to material itself, the traditional insignificant partner of code, calls for the re-evaluation of the definition of what is meant by programmability. Trogemann and Vierhoff (2005) refer to a machine as programmable, in the essential meaning of this term, if its behaviour can be changed without the reconfiguration of its inner structure. Therefore, all future responses are in actuality 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, general expectations are the repetition of executed commands and the processing of unambiguous states regardless of the material platform. Although these expectations cannot be substantiated as accurate, even in the particular reality of computer-based processing, they are certainly essential elements of the term's connotation.

3.2 THE LIMIT OF PROGRAMMABILITY

The emerging term "programmable material" and the work that is being done in that field suddenly bridges this traditional dichotomy between software and hardware. In general, 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. However, even basic materials may reveal similar intrinsic qualities when observed carefully. This idea 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 (see Figure 7). Skillfully triggering the natural behaviour of timber, the design of these flaps is such that they process the given environmental input and produce an output relative to it. In contrast to conventional hardware-software platforms, which aim at producing the same output regardless of the particular materiality, matter and process coincide seamlessly in this case.

Applying the title "programmable" to the material environment and material-human relations, as has been done through the expression "programmable

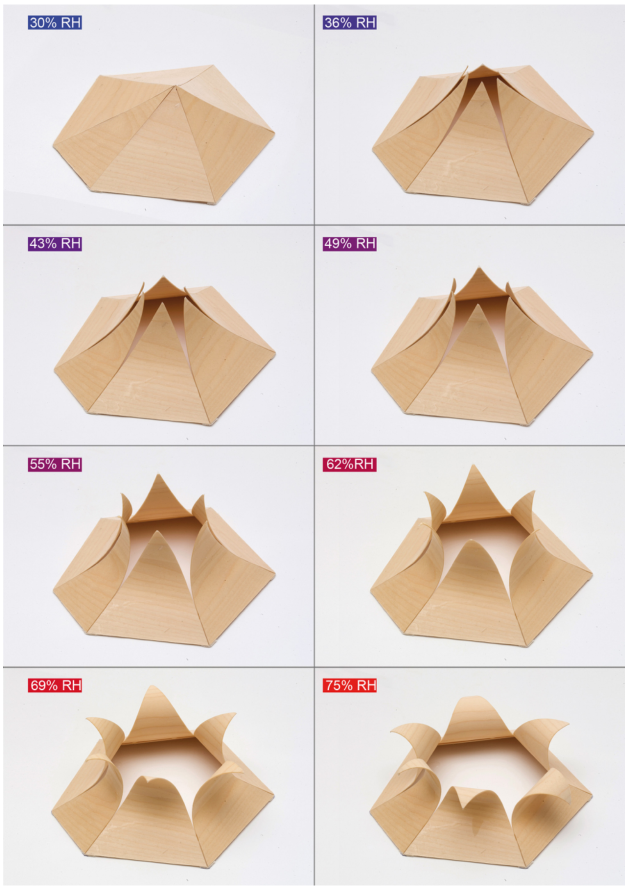

Figure 7 | HygroSkin-Meteorosensitive Pavilion / Achim Menges Architect + Oliver David Krieg + Steffen Reichert. Process-Responsive Component. Courtesy of ICD University of Stuttgart.

material", is challenging and in some cases an undesirable ambition. It has to be stressed that working with the 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 performance of these metals is therefore achieved by modifying 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 command 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 "processuality" shall be examined further.

3.3 FRAMING PROCESSUALITY

Replacing the concept of "programmable" with "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 interpretation of materiality clears the way for an understanding of material itself that holds the potential of behaving in an active and adaptive way towards environmental processes (Hensel and Menges, 2009). Consequently, processual materials are 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" first and foremost refers to material that can react, either gradually or spontaneously and immediately, to its environmental and external interactions. A connection can be drawn to the processual art movements and in particular to Robert Morris's 1968 pamphlet "Anti Form" (Morris, 1993). Moving this understanding into the everyday exchange with the material world may genuinely alter the human relation towards materiality. A processual material may reveal the traces of the dynamic meshwork it is embedded within; it may turn its inner state inside-out 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 rarely 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 material in isolation can capture. All things are defined in part by the materials and methods used to create them. They not only tell a story about the process of making, but also narrate the adaptation, use, and integration within the environment.

4 I FROM PROCESSUAL MATERIALS TO 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 way, processual things are much more than the material that unfolds the form of the object. Things are understood not as lifeless matter. By contrast, with reference to two of Ingold's (2010, p. 214) descriptions, things are understood as "a particular gathering together or interweaving of materials in movement," or a "knot whose constituent threads, far from being contained within it, trail beyond, only to become caught in other threads in other knots" (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 writings 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 regarding 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 emotional 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 (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 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 deeper regulation. The adaptation will not only make the local part correctly adjusted to its processes, but it will also be shaped to form a larger whole.

This process seeks to develop artefacts that exist in a permanent evolving situation. The things that 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 that can adapt to interaction and context, to sustain 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 opinion 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 fundamental topological concepts with which material and cultural change can be articulated using relational notions of proximity, limit, and adjustment (Sha 2013).

5 I CONCLUSION

Through the design scenario "Chrysalis Gemini" a new understanding of material in relation to designing and engaging with it is proposed. In investigating the potential of processual understanding of material further, it becomes evident that its continuous temporal and interconnected qualities are vital. Considering processuality, the potential of new material development merges the knowledge of computer-based programming and real-world material interaction. This combined awareness 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 practical terms but represents a constant repositioning of actors. In their materialised form, the otherwise hidden processes become a tangibly integrated part of thingness.

Processual materials may hold the potential of being process-starters rather than just being considered as design outputs. In this case the proposed design concepts opens a reflection on how to design with and for these kind of materials. As a result of this, the intrinsic qualities of the materials are of core value in determining the potential of interaction and the individual 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 in a constant state of negotiation.

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BIOGRAPHICAL INFORMATION

Agustina Andreoletti is an Argentinian designer, researcher and maker based in Cologne. Her work includes the use of a variety of techniques, media, hardware and custom software systems. She studied Graphic Design at the University of Buenos Aires (2011) and Integrated Design at Köln International School of Design (2015). Andreoletti has worked for many years in the field of design; alternating among print, digital and immersive experiences. Her projects are meant to create and inspire experiences that place processes at the centre of development. She is currently attending the exMedia Postgraduate Programme at the Academy of Media Arts Cologne.

Alice Rzezonka is a Cologne based designer and research fellow at the University of Wuppertal. The focus of her work is the continuous relationship between the analog and digital with the key interest of communicating to the user in poetic, haptic, emotional and functional terms. With a diploma in Landscape Architecture (2011) she ventured further into the field of design with a bachelor in Integrated Design at Köln International School of Design (2015). She is currently engaged in a doctoral research project exploring a processual understanding of material in interface and interaction design.