NOVA SCHOOL OF SCIENCE & TECHNOLOGY
DEPARTAMENT OF COMPUTER SCIENCE

EXTENDED SKIN

DESIGNING INTERACTIVE CONTENT FOR UBIQUITOUS COMPUTING MATERIALS

Isabel Maria da Silva Paiva
BSc in Communication Design

DOCTORATE IN DIGITAL MEDIA
NOVA University Lisbon
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Abstract

Current research is inspired by the impact of digital media on disciplinary division. Simultaneously, recognizes the difficulty of engineering (applied science) to consider the humanities as fundamental contributors in the process of making. Steaming from a design perspective, the intersection between art (design) and science, questions if these relations can open perspectives on the matter of designing within a U.C. context, and fundamentally, introduces the question on how this can be done

Furthermore, the motivation for this research arises from considering that innovation in technology is happening in the fields typically identified as engineering. And, despite this, the in-corporation of these inventions in life, considering some discussed exceptions, has not typically been present in the concerns of design action and methods. Therefore, the challenge of current research is to contribute to the realm of ubiquitous computing, routed by design, to some degree aiming to contribute to the field. A deeper analysis into the subject of U.C., there is the realization that there is minority presence of the humanities in the discussion of U.C. (Dourish and Bell, 2011).

Technological disruption offers continuous inspiration for design innovation within U.C. Furthermore, the inquiry labeled as "material turn" contextualizes a dialogue between nanotechnology and traditional materials. Nanotechnology is applied to project development, while considering a human centred design approach. This focus is present throughout this dissertation.

The research proposal describes SuberSkin, as a responsive surface that works as a screen. The exploration of aesthetical effects is focused on visual properties – using high contrast between natural cork colors, dark and light brown. The proposal is highly experimental, and ultimately, aims to explore potential routes on cork research, linked to that of U.C. Thus, recreating and transforming this material into an intelligent surface.

In sum, this thesis discusses displacement of disciplines suggested as having a positive impact in interdisciplinary thought and for future design. Therefore a methodology, "research through *techne*" is presented that illustrates this intention.

Keywords: ubiquitous computing, materials, digital media, sustainability, interdisciplinarity, speculative design

RESUMO

A presente pesquisa é inspirada pelo impacto exercido pelos media digitais na divisão disciplinar. Simultaneamente, reconhece a dificuldade da engenharia (ciência aplicada) em considerar as humanidades como contribuintes fundamentais no processo de fazer. Partindo de uma perspectiva de design e da interseção entre arte (design) e ciência, questiona-se se essas relações poderão abrir perspectivas na criação no âmbito da Computação Ubíqua. Fundamentalmente, introduz a questão de como poderá ser feito.

A motivação para esta pesquisa decorre de considerar que a inovação tecnológica acontece nas áreas normalmente identificadas como engenharia. E, apesar disso, a incorporação dessas invenções na vida, considerando as exceções discutidas, normalmente não está presente nas preocupações, ação e métodos de design. Portanto, o desafio da pesquisa é contribuir para o domínio da Computação Ubíqua, orientada pelo design. Uma análise mais profunda sobre o tema da Computação Ubiqua, constata que há na sua discussão uma presença minoritária das humanidades (Dourish e Bell, 2011).

A disrupção tecnológica oferece inspiração contínua para inovação de design, e o mesmo se aplica no âmbito da Computação Ubíqua. Além disso, a pesquisa intitulada como "material turn" contextualiza um diálogo entre a nanotecnologia e os materiais tradicionais. A nanotecnologia é aplicada ao desenvolvimento de projetos, considerando uma abordagem de design centrada no ser humano. Este foco está presente ao longo desta dissertação.

O projecto de pesquisa descreve SuberSkin, uma superfície responsiva. A exploração centra-se nos efeitos estéticos da cortiça, recorrendo a um contraste entre as suas cores naturais: castanho escuro e claro. A proposta é experimental e, em última análise, visa explorar potenciais linhas de investigação ligando a cortiça à Computação Ubíqua. E assim, recriar e transformar este material numa superfície inteligente.

Em suma, esta tese discute o deslocamento disciplinar como tendo um impacto positivo no pensamento interdisciplinar e no futuro da prática do design. Consequentemente, apresenta uma metodologia, "investigação através da *techne*" que a exemplifica.

Palavras-chave: computação ubíqua, materiais, digital media, sustentabilidade, interdisciplinaridade, design especulativo

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INTRODUCTION

1.1 Motivation

Current research interest rose from acknowledging that technological innovation is consistently happening in the fields of applied science (a.k.a. engineering). Despite this, the incorporation of state of the art inventions in quotidian life, excluding some discussed cases, has not typically been the priority concern of Architecture, Design and Art (A.D.A.) action.

A deeper analysis into the case of Ubiquitous Computing (U.C.) research shows that there is a minority contribution from the humanities to the field. Dourish and Bell, simultaneously recognize difficulties of applied science (engineering) to recognize the humanities as fundamental contributors to the process of making (Dourish and Bell, 2011). Current research pursuits to foster relations between disciplines, and questions if these can open perspectives on the matter of designing within a U.C. context.

In particular, research is aiming to make a contribution to the field of U.C., intending to address this faulty expression from the humanities. As such, the intersection of A.D.A. (Art, Design, and Architecture) and science underlines the interdisciplinary perspective taken throughout this work.

1.2 Problem

The problem to tackle is to clearly identify an interdisciplinary methodology that resolves U.C. and A.D.A. intersection. Thus, as proposed by Weiser U.C. directives, research is expected to assume disciplinary cross- pollination (Weiser, 1991). This is pursued both theoretically and practically. Disciplinary re-linking is resolved throughout step-by-step practical research work.

1.3 The claim

The claim tested on this thesis is that disciplinary divisions tend to condition human action regarding making, and to some degree, limits the imagination of what might be possible.

This observation is inspired by the impact that digital media had on disciplines. The pressure of digital media highlights, to some degree, that specialization, often, emphasizes institutional defensiveness, and disciplinary reinforcement. These reactions to new technologies might reveal that the separation of knowledge originates entropy, instead of offering opportunity to tackle human problems. Thus, the theoretical approach adopts a critical point of view on specific disciplinary design boundaries (A.D.A.) and science paradigms that might produce that effect specifically concerning design/making.

Some persistent arguments that reinforce this division are identified, in both fields of A.D.A. or science, aiming to possibly draw lines of action. The critique can objectively, offer conditions for dialogue and innovation.

A demonstration of a successful outcome that merges the fields gives an irrefutable answer to the problem. Thus, having an "object" as a research result translates the full force take on having knowledge production through practice.

1.4 Design and science

Adopting a critical point of view aims to open the mind-step beyond what seem to be a given fact to discussion in science and design. Currently, Joi Ito (2018) inquires if design can advance science, or science advance design, forging new connections between fields (Ito, 2018). Also looking at this relation U. Texas School of Design and Creative Technologies at The University of Austin aims to graduate diverse and creative students looking to foster these relations (Lorenzo, 2018).

The benefit of this approach is to offer a better stand to boost innovative outcomes, thus contributing to the future of the discipline.

The gain to the scientific point of view is to possibly give contributions that source from less explored fields. However, considering design, and the dialogue with science, it could be fair to note, that within engineering persists resistance to the influence from A.D.A.

Popper identified in Big Science problematic delimitations that might impact interdisciplinary relations. The most problematic issue put forward by scientific action, can be said, is the total avoidance of contact with the humanities, and a tendency to hubris, deriving from close access to power (Popper, 2009).

1.4.1 The case of design

Lipovetsky & Serroy (2013) evaluation on current state of economical aesthetics (such as under digital media influence), describe one precise moment in history where low and high culture, advertisement, art, design and architecture, are hybridized. Lipovetsky & Serroy's perspective correlates with the popular stance on digital media production being on a continuous remix. Under this light, several paradoxes arise from disciplinary divisions and their particular premises of mutual distinction.

This is the case within the theoretical discourses committed to find an exceptional authorship complying to professional boundaries. For instance, the emergence of a collaborative paradigm (the model explored in the context of new shared economies) creates a tension with the professional paradigm. In the case of design professions, these are confronted with the "prosumer", that is, the possibility of everyone becoming both a consumer and a producer. This is a fact that not only reveals a dissonance with the authorship model, but in fact, display dissolving limits within the digital economy.

Occasionally, design is defined as an orthodox discipline belonging to a high-culture of production of objects. For instance, design's theoretical discourse and practices tended to be fundamentally displaced from any concern with "innovation" addressing a bottom-up social transformation. However, with digital media pressures, it can be said that these resulted in new scope of action within design. Social, and sustainable problematic, bring, in fact, innovative approaches into the disciplinary definition. This is the case with adding new themes aiming to solve social problems (Schaltegger and Wagner, 2008) such as poverty and access to safe drinking water, or those targeting behavioral change and social well-being (Manzini, 2007). Manzini has put forward concerns and techniques of social innovation considering collaboration with grassroots technicians and entrepreneurs, local institutions and civic society organizations (Meroni, 2007, Jégou and Manzini, 2008, Tonkinwise & Irwin, 2015) present the radically new socio-economic and political paradigms as part in concern of "transitional design".

One of the issues within design research that this thesis tackles is brought by acknowledging certain avoidance on adopting new technologies. These innovations typically result from discoveries made in several other disciplinary fields, in particular, applied science.

For instance, observing design education and digital media, demonstrates how this resistance can manifest: education institutions took more or less a decade to consolidate programs that addressed the highly impacting new media internet (commercial internet was founded in 1990, CERN, Tim Berners Lee). Buchanan argues that creation of interaction design programs, concerning conceiving products, experiences, activities, services finally acknowledges this technical achievement, and thus the effect on communication, and as an imperative to relate with design concerns (Buchanan, 2001b).

However, thirty-one years later, within interaction design, it is still common to discuss the purpose of HTML/CSS - which is the visual markup language used in ubiquitous *medium* the Internet: the tool for creating aesthetical experiences. This avoidance might be explained, in part, due to referring to skills typically excluded in how the discipline was and is still defined. Within a traditional design scope, software is insistently observed as a tool to design, used under the perspective of a "graphic user interface", and thus avoiding contact with the markup language, logic, mathematics or coding.

By this token, anticipating the future, the same reaction might be expected to occur, regarding current state of the art of scientific invention. The perspective that this thesis defends is that this happens without critique on the consequences that this absence might have on the discipline development. But in particular, in acknowledging, in fact the impact this absence has in the real place of design contributions into shaping the world.

Corroborating Addington & Schodek the issue with this resistance is that design practical knowledge instead of contributing to transform society, reinforces a secondary role. According to Peter Hall this resistance, in part, relegates design practice to merely work with superficial aesthetical processes. Indeed, this is the common sense perception on the discipline role within the economics world, under other disciplinary paradigms (e.g. economics, marketing) (Hall, 2011). This is a role which within new digital economies becomes highly problematic.

In this context, Rodgers, Hall and Winton (2013) discusses the authorship model, that (re)creates genius of design. Considering that under the light of digital media, is becoming an anachronism. However, this model still legitimates the disciplinary "innovation". The sequence of authors supports an idea of evolution and change, and the apparent succession of "new" trends. This discourse also consolidates the history of the autonomy of the discipline relatively to others. In fact, Rodgers et al. refers to talent (authorship) as an attempt of perpetuation of the historicist view, where the authors of history are demarcated from the networks, or, in interest for current research, relations between things and people.

Under nowadays technological shifts and opportunities, becomes relevant to consider a contribution from the history of things. Actor-Network Theory (A.N.T.) elaborates a focus on a materialistic perspective. As a model ANT intends to discuss, and evaluate, the impact of things in transforming society. This can be relevant when considering designing sustainable futures. Under this model, the authorship model becomes secondary. Indeed, this model, makes things, instead of people, in practical sense, to be targeted and get the critic attention. In fact, ANT previews a dense network of relations, that can be between objects.

Current shared economy model presents a vivid picture of objects performance. Typically, the last evaluation room, the market, used to follow an active producer, passive consumer logic. However, the model has moved to the shared and globalized economy – whereas collaboration and choice was reinforced. For instance, new producers with knowledgeable skills are not necessarily validated or protected by institutions. Apparently, we all can become designers, independently of training, and there are in fact new means of distribution, as for instance in projects like Kickstarted. Digital media increased the gap between design theory, design practice and institutions, as well as the discussion around the role of the professional/amateur creative. This is a major displacement on the traditional A.D.A. scenery.

One last motivating factor was the reaction by design community to pressure of the emerging technologies: this is, the increment of disciplinary fields within design. Thus, current research approach was inspired by this observed and relevant impact given by digital media: design's disciplinary dispersed identity and reinforcement related with a specific medium.

It can be said that digital media gave light to interaction design as an autonomous discipline. The practice emerged from computer science and is latter adopted within design community (Moggridge, 2007)." Graphic design" became linked to paper and printing, "industrial design" and "architecture" to a myriad of materials (Buchanan, 2001), as "interaction design" contemplated the (new) digital media. This multiplicity and separation of the disciplines, inside a unique discipline, might be a symptom of instability. However, it is recognizable that the purposes of design in modernity have been highly dependent on the *media* (plural of *medium* (Manovich, 2002). Design practice creates content for a hegemonic media of a given time, and these media are typically created by outsiders to disciplinary design concern, often, applied science. For instance, this is the case of virtual or augmented reality. Simultaneously, interaction design as a differentiated discipline allowed to maintain traditions and institutionalized practices.

The above describes strategies show adaptation instead of disruptive change. Simultaneously reveals a degree of dependence, instead of the pronounced independence of the creative practice. These are relevant questions to ask if defining what design research might be under new technologies. Again, both Papanek, Addington and Shodeck converge that since the industrial revolution, invention is coming from scientific laboratories. And meanwhile design practice reveled a certain avoidance in extending its scope beyond the modernist programs heir of the Bauhaus.

Nowadays it is still possible to re/invent instantiations of the chair, however, looking forward, might be to invent news ways of sitting, for instance multi-sensorial ones. This is, being open to listen, learn, and ask, and resolve new questions.

In sum, there are two problematic issues within the realm of A.D.A. Firstly, the slow progress in adopting emergent technologies and even accepting (some) speculative critique within the field of A.D.A. (e.g. Dunne and Raby). This is, creating room for the development of the discipline. Secondly, the insistence on an authorship program, that gives to the designer the responsibility of becoming an individual creator (Rodgers, Hall, and Winton, 2013). This is, there is a particular historicist view avoiding on an open mind-set prone to cross-pollination and innovation.

1.4.2 The case of science

Laurel and Sanders referred to the division between science an art in disciplinary fields occasionally causing inter-disciplinary dispute (Laurel, 1993, Sanders, 2013). This tension persists as a challenge concerning the adopted method, in between design and science. As described, on one side of this quarrel, lays conservative A.D.A. On the other hand, within applied science, U.C. research is mainly sourced within computer science. Indeed, not considering about the Humanities is an expectation, and documented difficulty (Dourich, 2014). This state of things, the presentation of two distinct cultures is referenced already by Snow (Snow, 1959).

Some authors have regularly pointed out at Humanities, as basically lacking skills-set to transform the world, and therefore regarded as powerless. The practical standing that engineering put forward often considers the "ocean of words" of the social sciences as creators of opacity (Popper, 2009). Popper considers that these derive from institutional academic validation practices. However, Popper reveals a reverse angle. This is, ignoring the Humanities, makes applied science, often lie trust in power of making *per se*, instead of relying in the force of analyzing the world (from the Humanities) before action to define and resolve problems.

Popper stated that scientific operability tends to find closer relations to power structures which can condition results (e.g. Big Science). Indeed, Popper makes a distinction between creating Big Science instead of Great Science. Popper also refers that being closer to power is not a context prone to use humanistic critique, as understandably, tends to follow a for profit pursuit. But this, can limit uninterested pursuit of knowledge, as one would expect from scientific outcome (Popper, 2009). In fact, these settings can reproduce environments (as for instance to perpetuate inequality as the norm, male privilege, disregarder of otherness), as well as privileging top-down approaches, instead even consider to look further into the relevance of using some bottom-up innovative contributions taken from soft sciences methods.

Technological market context reinforces the view of makers (in the case, designers) as givers of surfaces, workers of the superficial beauty of things, as final skins, and not typically as innovators (Hall, 2011). Understandable, when critical design is not a common perspective adopted inside the disciplinary education the makers of the superficial, becomes an expected role. Even A.D.A. potential in relinking disciplines, as in closer relations to the overall discussion of the humanities (e.g. aesthetics) is not easily explored. Indeed, without critique, even A.D.A. as a disciplinary guardians of a diverse skilled practical knowledge might be regarded as irrelevant, outdated, in opposition to the state of the art technical power.

This reluctance of acknowledging critical thought, in their potential to transform the world of things, might also indicate a lack of perception on the limits of applied science. Popper (2009) refer that this attitude can perhaps reflect a lack of will for knowledge, and also indicate a tendency to hubris. Indeed, human kind shall never dominate nature.

The lack of interdisciplinary discussion within science might obscure the realization, for instance, that mathematics is a medium that translates Nature – as physics - but not the truth. Nowadays mathematics, uncovers current digitally mediated economics (e.g. Blockchain). It is a thought process that persists in the world, contributing to the tendency to evaluate life according to measurement. Indeed, facts are easily confused with measurement. However, the demonstrations of science and economics can easily obfuscate awareness that mathematics, in fact, generates culture, not being "the" culture.

A simplistic analysis on these manifestations is that they are representations.

The advantage of critical standing, taken from the humanities, is to allow to ground, and expand, to freely ask overwhelming wicked questions. The questions no one asks that are too big. As for instance, would it be nowadays beneficial to mankind to have interdisciplinary humanistic science? What would this knowledge be?

In sum, Popper alerted about the dangerous of *Hubris* concerning achieving knowledgeable action. In the context of making (design and science), as is the case of concern in present research, the implication is, for instance, originate products that reflect ideology. This is unconsidered of the variety of human factors (as object of study of the Humanities) but fundamentally the creation of common good (*agape*). The never neutral implications of technologies have social, cultural and economical impact that cannot be neglected, and are now indisputable global.

The creation of common good (*agape*) has in Philosophy of Science analysis sources of reflection, ranging from considering ethics, meaning of life, the nature of good or evil, or what future we want to design. These are important contributions to be made, equally relevant for the scientist, economist, designer as for the historian as actors in shaping the human condition of the future.

The art of inquiring that is a philosophical standing allows to freely ask fundamental questions. Also known as wicked, these are for instance: what could happen to the process of making if listening (learning about) one another disciplinary fields. What could happen to applied science if listening to inoperative analyses closer to the interest of the humanities? What happens to makers themselves as subjects when they include knowledge of art?

The same intuition can be perceived on the transition from the S.T.E.M. (Science, Technology, Engineering, and Mathematics) to a S.T.E.(A.)M. paradigm, this is, including the Arts, in education and making. Design/engineering of the future generation is apparently becoming (un)disciplinar.

1.5 Approach

This interdisciplinary theoretic and practical approach refers to the initial premise, presented as the PhD proposal (2010). The initial belief that sustained this inquiry was that the quest for new ideas and projects would happen, preferably, under an open and cross-disciplinary knowledge pursuit, as an open society (Popper, 2013).

"Skin" works as a guiding metaphor. As a concept "skin" translates the ambiguity of what separates, and it is simultaneously a porous boundary. Thus, the metaphor "skin" serves to connect what is not always obvious. Furthermore, the metaphor intends to direct a meaningful experimental exploration, grounding assumptions, while projecting into the future.

"Skin" conveys an overall desire of touch, promoting cross-fertilizations of disciplines, including an imaginary of lively contaminations, disappointments, mutations, and excitements. The plasticity of a sensitive organ, "skin", further widens the metaphoric potency. Skin is a surface (thing) in process (method), alive. Clearly, "skin" is a thing and a process. As such, "skin" illustrates the approach to research, and outcome, which is divided in theoretical, critique, and a practical answer: a methodology and a "new" thing. Practice as research is a goal therefore shaping exploratory projects. Hence the title "Extended skin". Finally, the metaphor connects this last project based on cork, which is, itself a tree skin.

1.5.1 Why cork?

This choice aimed to highlight a particular know-how concerning cork as a material. But also, to use design knowledge to create a cork speculative object that projects a design transition for a possible future within the digital economy. From this point of view the experience within New Media Industries, grounds opportunity for reflection, addresses Portuguese Industrial culture and legacy..

1.5.2 How?

Insight was taken from observing disciplinary reorganization strategies as described above. Reading from the past, it is expected that design of the future, assumed as "learnt skill sets", will use emergent communication technologies (arising from applied science) as media. This is the case of virtual reality, or augmented reality. However, instead of designing content for the hegemonic digital media, my research proposal was to design with the available state of the art materials. Specifically designing a speculative *medium,* and conveying specific content. This *medium* would use smart materials, and computation (as the emergent technologies), and be linked to Portuguese cultural industry (traditional materials). This approach follows the defined "material turn" in U.C. research that integrates knowledge from the A.D.A. with digital.

1.6 The hypothesis

Blending art and science puts forward the idea of knowledge production through making. In the case of current investigation, the disciplines in interplay are engineering (nanotechnology focused in new materials and computer science) and art/ design/ architecture. The latter is resolved under the acronym A.D.A., as one field. The hypothesis to be proved is that disciplinary divisions condition imagination of the possible. Thus, the hypothesis to be proved is a research project and a demonstration of possibility. The approach is practical and research adopts a critical point of view of on certain disciplinary design and science.

1.7 The research question

The questions were divided in three vectors:

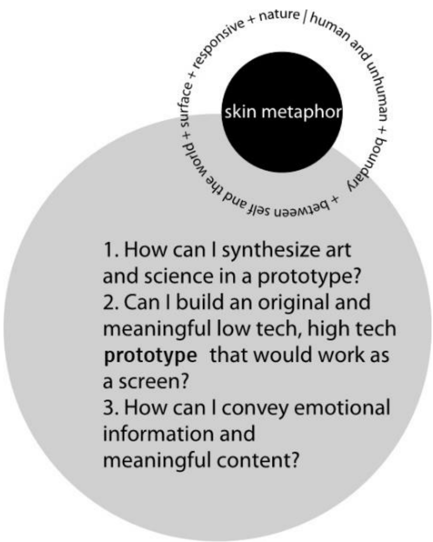

Figure 1. The three research questions diagram

The project is as a speculative design proposal. The overall outcome aims to reflect the future. Specifically, it will tackle a collaboration between engineering and art; and design in the context of technology under sustainable concerns.

1.8 Invention

The research project is a responsive wall. This is the hypotheses to be proved. The project diagram was initially mapped as following:

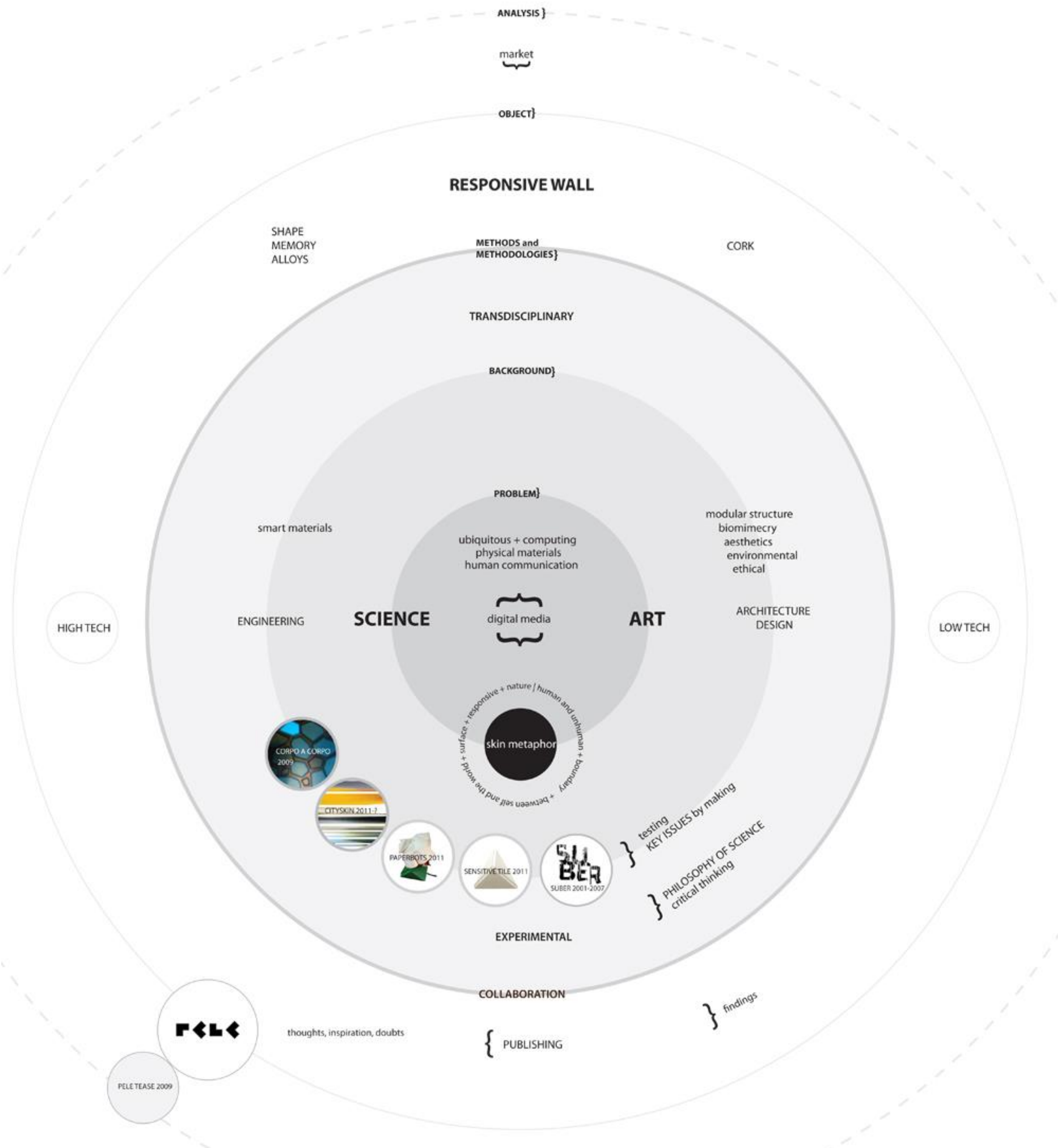

Figure 2. Research Map

The research contribution is a prototype. The first realization is made using visualization is a method (Hall, 2006). The map tackles the wicked problem as defined by Rittel, as having an interconnected, complex and often overwhelming nature as is the case of current thesis (Rittel, 1970). Therefore, the diagram (**Erro! A origem da referência não foi encontrada.**) demonstrates relations between and inside disciplines, also situating a dialogue between industry and academy. The theoretical dissertation is focused in discussing these relations, and describes the adopted methodological solution.

The dissertation is divided in six chapters:

Introduction situates current research in terms of motivation, problem, approach, as well, as the research question and invention.

The second chapter discusses theoretical interdisciplinary research. Firstly, the concept "research through *techne"* is presented as reestablishing the link between art and science.

Secondly, presents methodological and historical background in computer science and A.D.A.. Specific research territories, ubiquitous computing, materials, computer science and A.D.A. are discussed. This enunciation intends to open research to collaboration between disciplines.

Third, divining the future sustainability, discusses speculative design as one of the solutions conveying emerging technologies.

Finally, the specific experimental "practice as research" methods are discussed.

The third chapter makes a full description on the adopted method. First, hands-on material exploration, and secondly, four research projects: supermirror, cityskin, responsive tile, paperbots. Responding to specific research questions the projects demonstrate a step-by-step research agenda.

The fourth chapter enunciates the state of the art, specifically concerning suberskin. The research project proposal contextualization is firstly, made considering the combination of ubiquitous computing and A.D.A. And secondly, discussion about selected materials, i.e., cork, and smart memory alloys.

The fifth chapter describes suberskin project development. The invention of the interactive cork system is an original contribution.

Lastly, the **conclusion** discusses results, and future work.

.

2

UBIQUITOUS COMPUTING DESIGN: AN INTERDISCIPLINARY RESEARCH

2.1 Research through *Techne*

2.1.1 Territories of action for contemporaneity

Moore's law has supplanted Gordon Moore's own prediction on its time frame validity. The initial prediction to have the transistor size reduced each year by double, expected to last 10 to 15 years, is after 50 years still valid (Intel Corporation Webcast Events, 2015). Despite existing a presumed limit to Moore's law, it offers a view on electronics and digital technology development rate in a continuous acceleration. McLuhan in the 60's claimed that technological transformations had strong effects on human organizations and communication (McLuhan, 1964), and the same expectation is replicated and discussed in contemporaneity (Kurzweil, 2009). However, considering Moore's Law, contemporaneous life is under technological pressure happening at exponential rate. Nowadays, the most excel expression of this impact on communication occurred with the commercial Internet initiated in 1990 (CERN, 2018), and with it, the so-called digital revolution.

One of the consequences of digital media is the pressure on disciplinary paradigms, as found with Journalism or Medicine (Gilmor, 2006). The same impact can be equality found on disciplines with Design background. When considering the subject of making within interdisciplinary research this is a question of particular relevance that confronts the persistence-existence of two cultures (Snow, 1959): science and humanities. As Snow described, these fields of knowledge have presented difficulties in understanding one another. We can identify, on one side a culture of making based in an engineering tradition, and, on the other, design, routed in arts. Indeed, digital media created an increasing shifting on the criteria employed to validate these body of knowledge and disciplinary relations, and process of making. In fact, some authors go further to consider that the "prescriptive manner of the digital's total disrespect for the disciplines; (...) has resulted in the dissolution of the disciplines" (Bremner & Rodgers, 2013, p.9).

2.1.2 Perspectives on Making

The crumbling of disciplinary walls of design, contrasts with the stability of contemporary institutions presenting art and sciences as belonging to different disciplinary traditions. Museums, industrial or academic set-ups tend to reify this idea. Physical barriers in departments, distinct buildings and networks are just one of many examples of that division. This realization supports what was stated by Brenda Laurel in 90's and later by Fallman in 00's when considering that the practices of design still appear to be operating culturally in opposing fields (Fallman, 2008; Laurel, 1993).

Indeed, a first interesting issue is to recognize that there are divergent points of view on making and evaluation belonging to art, design, architecture (A.D.A.) (Rust, Mottram, & Till, 2007) and engineering. To which degree these fields have similar/ different definitions and reinforcement strategies are the focus of the design research methodologies (Schön, 1984, Petroski, 1996, Buchanan, 2001a, 2001b; Swann, 2002, Cross, 2008,). However, currently and with the contributions made by digital fabrication, there is an apparent openness, and new avenues to knowledge production in making. For instance, Hackerspaces are intended to be both physical and conceptual places where designers and engineers share ideas and make use of the same tools. However, and despite the claim of the end of traditional disciplinary boundaries in an informal place, these makers/actors/entrepreneurs are still formally educated within the traditional disciplinary divisions. As consequence theoretically and methodologically separated, their interaction translates in different approaches and contributions to the world of things. And might reproduce *in loco* the same relations.

The "design/art/humanities" versus "science perspective" described by Snow, refers to a quarrel, and will be given a focus of interest regarding the discussion of current work. Indeed, this apparent division is relevant to inquiry, as well as to acknowledge that this separation is a "modern" tension. In fact, the requirement of visible "new" relationships between "opposite" fields may hide an evident link that has been always present.

2.1.3 Modern tension within design

This discomfort can be explained as resulting from the progressive trend towards specialization that began in the 19th century (Buchanan, 1995). According to Buchanan, at the time of the industrial revolution, the creation of the discipline "design" aimed to achieve a balance between art, science, and industry. The paradox is that the autonomization of design as a discipline appointed a definitive departure from the initial humanistic drive of relinking. Indeed, despite art, science and industry sharing objectives and common values, the identification of disciplines created dynamics such as described by Snow in 1959: mutual ignorance of practices, if not clear disregard between applied science and the humanities. However, the reappearance of a holistic motivation consolidates that interdisciplinary thought is present since the earlier history of the making but as well as during Industrial Revolution (Buchanan, 1995). According to Buchanan, the intended humanistic synthesis was a failure in terms of what was accomplishment by the performance, creating the modern divide, a heritage that persists.

2.1.4 Art and Science synthesis

The contemporary perception of the link between engineering and art offers room for a lasting discussion but is of oblige usefulness to address if considering creating new technological devices. The desired re-connection gains deeper insight when considering the word "technical", which is derived from the ancient Greek *technê* (τεχνή), that also means "art" (in Latin is *ars*) (Flusser, 1999). In ancient Greece, the practices were not divided, in fact, they were represented by the same word.

The root meaning of *technê* serves current research as clearly covering a wider spectrum of practices than modern technologies (Cuomo, 2007). *Technê* offers a look into practices that reveal values directly linked to technical knowledge, but also on what was designated as art. Realizing that technology was as ubiquitous in the ancient world as in present time, also projects a relation between culture and technology – an introduces a desired reflection that is ultimately the aim of U.C. design. Fundamentally, *technê* grounds interdisciplinary tendency for dispersion, by clearly defining a scope of action.

To explain *technê* in its diverse nuances and interpretations in ancient world is beyond the scope of our analysis. But, it would be relevant to note that, as today, exists within classic authors, like Aristotle, Plato or the Stoics, different readings on *technê* implications on the society, which reflect anxieties that resonate with contemporaneity. For instance, Cuomo's contemporaneous reassessment of the concept of *technê* in ancient Greece provide stimulating insights for today's discussions on disciplinary boundaries. The objective in the case of current research is to retain a sense of what "future" means through the action of time, and simultaneously gain perception of the unaltered. The use of the concept of *technê* is an attempt, if not a surprising tool, to find out possible contributions for our future, beyond acquiring a broader sense on how *technê* shaped past civilizations. Simultaneously realize the transient state of todays *technê*, as part of human condition. Therefore, *technê* becomes a useful filter to discuss technology, and the contemporary human being, juxtaposed to his own artifices.

The conceptual potential of *technê* is shown by the practices it relates to. It encompasses practices as diverse as poetry, shoemaking, medicine, sculpture, horse breaking, and rhetoric.

In fact, it refers to the human ability to make and to perform. In addition, *technê* implies learning by doing, and acquiring skill. Indeed, skill is an insightful way of rendering its translation. Further relevance on *technê* is added by the Stoics interpretation. They considered virtue as a kind of *technê* or art of living, "one that is based on an understanding of the universe" (Parry, 2014). This introduces another dimension of most particular interest, the interplay between *technê*, knowledge and ethics.

Cuomo explains that "experience is not different from *technê*, and *technê* is acquired through experience" (Cuomo, 2007, p.13). Therefore, practice is directly validated as a kind of knowledge. There is a slight differentiation "unlike experience, *technê* has knowledge of the universal and can be taught" (Cuomo, 2007, p.13). Hence *technê*, reveals the teachability of the practical knowledge and one vital aspect, the power of its reproducibility. The acquired knowledge, that stays in oneself, reveal *technê* as being nomad, which make technicians "associated with unregulated mobility and change." (Cuomo, 2007, p.37)

2.1.5 Technê for contemporaneity

Technê present and widens the point on view on making. And resonates with what some contemporaneous authors claim to be the ecology of the future (Papanek, 1985), or when speculating about the next industrial revolution (Anderson, 2014). The underlying premise in this position is that all mankind are designers, or at least having the potential to become one.

Papanek's (1971) holistic perception on making echoes *technê* in the following:

> "All that we do, almost all the time, is design, for design is basic to all human activity. The planning and patterning of any act towards a desired, foreseeable end constitutes the design process. Any attempt to separate design, to make it a thing-by-itself, works counter to the inherent value, of design as the primary underlying matrix of life. Design is composing an epic poem, executing a mural, painting a masterpiece, writing a concerto. But design is also cleaning and reorganizing a desk drawer, pulling an impacted tooth, baking an apple pie, choosing sides for a back-lot baseball game, and educating a child. Design is the conscious effort to impose meaningful order." (p.3)

Anderson (2014) comments on the myriad of possibilities brought about by new digital fabrication suggesting the democratization of *technê*, which corroborates with the premise that we all (again) are designers. After a period of digitalization, Anderson mentions the return of the physical computing, or the maker's skills, allowed by the liberalization of the digital makers tools. Now accessible to everybody, these tools invite people, from children to adults, to design their own things. As such, and paraphrasing Anderson, if we all are designers, might as well become good ones.

The place resulting from *technê* is the world of the objects. And the terms of evaluation objects are controversial. One of such terms is the naturally disputed category of beauty – which broad discussion and conclusion is again an unattainable objective, and not in the scope of current research. However, it can be considered that the concept of beauty varies along social-historical discussion. As such, dichotomies are, for instance, part of the history of ideas as presented by Umberto Eco opposing beauty (Eco, 2010) and ugliness (Eco, 2011). Understandably, "beauty" is a central category on aesthetical experience. As opposing concepts they entail, for instance, the early modern evaluations on beauty of raw materials, in relation to decoration (Loos, 1997). Or, on other words, these evaluations are presented in dual terms, which are mutually exclusive points of view. They are found in new "ugly" aesthetics of machines and industry, versus the soft, "feminine" aesthetics debate, which coexists with direct opposite position considering the "beauty" of machine, masculine, fast, and war like, versus the ugliness of softness, sentimentality and passivity. This simplification, expresses both what one finds in discussions of early modernism, for instance, put forward by the Futurists, Dadaist as the avant-garde, as well in a perception of a common sense. Despite all aesthetical criticism that transcends dualities, for instance with concept of formless (Bois & Krauss, 1997), these seam to survive today in the dichotomies of the objects created by science and art. Science operates typically removed from aesthetics, and critical theory.

Returning to current analysis aligned with the classics, in ancient Greece beauty had a different take. Indeed, beauty combines what our aesthetical theories have typically separated. "Beauty" *kalon* was a general term commendation that applied to mind and character, customs and political systems as much as to form or physical appearance (Shiner, 2003).

Dichotomy is also a source of tension, already present on Plato's division between ideas and things. However, when considering the results of *technê*, the evaluation does not depend on essentialist, intangible - that you cannot touch - qualities, as is the case of the Platonic Idea. On the contrary, *technê* produce things. The problems raised with *technê* are associated with the idea of value, as raised by Plato. In antiquity, according to Plato, objects of *technê* spelt ambiguity about the values they preconized (Cuomo, 2007).

2.1.6 Technai reviews of making

The Platonic duality is brought back during the Re-naissance with the [re]interpretation of the Greco-Roman authors, and becomes the source of the division between theory and practice that one finds in modern Academy. In addition, to affirm that, in fact, Universities based in the Renaissance's institutional organization of knowledge (although this trend started already in Medieval times) are a recognized source of a prevailing divide. Meanwhile the polymath (e.g. Leonardo Da Vinci) - that defined the early sages - was lost as a paradigm of universal knowledge.

However, as Buchanan attests, this relation between ideas and things is one of the most complex themes in Western culture. Both Plato that inspired interest on imitation of ideal models, as well as Aristotle's *Poetics* had a major impact on the definition of the rhetorical humanism of the Renaissance. The *belles lettres* was thought to reproduce the ancient union of the art of making in the realm of poetry and rhetoric. These were considered closest to the spirit of the ideal. But the *beaux arts* which were created additionally were also based in rhetoric, and explored the "delightful and the noble of the visual arts" (Buchanan, 1995). According to Buchannan these creations and the rebirth of rhetoric was the great achievement of the Renaissance. Eventually, these realizations of the Renaissance influenced sciences as well. However, during the seventeenth and eighteenth centuries the links were lost, with critical impact to the practical arts (Buchanan, 1995).

Therefore, in the Renaissance there was a distinction between rational art of rhetoric, poetry and practical arts. But the relation between them was appreciated and considered to offer insight for innovation. Buchanan considers that progressive loss of the understanding of this connection is due to the institutionalization of the distinction, between the fine arts and practical arts. In conclusion, the author claims: "following the Renaissance, the consequence of separating the theoretical from the practical, the ideal from the real, and the cognitive from the non-cognitive was a loss of the essentially humanistic dimension of production" (Buchanan, 1995, p.34).

The outcome of this divide was the appearance of a dogmatic view on practical knowledge organized according to schools of reasoning or making. As such this explains that despite sharing common source, industry, crafts, academy and other places of innovation that fall under the definition of *technê*, are now perceived as divided, and essentially different.

Current research is far from an essentialist point a view, but rather following an empiricist route, which considers science and art as *technai*. And, in a time of highly fragmentary concepts, looking into the ancient Greece is also a way of realizing that the Romans were already 'remixing' the Greeks, as the Renascence was of the Greco-Roman civilization. Ultimately, this realization aims at understanding that the hybrid is the norm of creation. The rupture of a technological push (*technê*) introduces what we can expect to be a new time of fast remixing. Finally, there will be the gaze, this is, the way the outcome is perceived by the senses, and through the ability of *intelligere*. But discussing the turmoil of the aesthetical experience, in detail, is not in the scope of present research.

2.2 Undiscipline of knowledge

Undertaking *techne* as a heuristic category highlights the paradox of current disciplinary autonomy. But also, claims of originality, sourcing from art and science interaction. Indeed, mutual requests for collaboration are evident in the proliferation of festivals and exhibitions that highlight the link. This is the case of Ars Electronica, which since the 70's presents annually discussions and exhibitions. And N.Y. MoMA design curator Paula Antonelli that defines design in the intersection of engineering and art (Antonelli & Museum of Modern Art, 2008, 2011). The emergence of new categories, such as bioart, software art, internet art, sharing scientific, technical and artistic achievements further confirms the reappearance of the relation (Paul, 2015). In this latter case, instead of considering the synthesis, the contemporary solution within the disciplinary pressures, concerning resolving this interplay, is creating a proliferation of art categories and difference.

Bremner & Rodgers considers this fragmentation to be a definitive sign of instability. This dispersion within design, as part of a broader crisis of disciplines, become an indicator of the end of disciplinary definition. Bremner & Rodgers support their claim by observing the impact of digital media in three design sectors of design action: technological, economical and professional.

The technological realm is populated with new fabrication methods bringing forward, once again, the concept of democratization of making. This idea is reinforced by new fabrication methods. The open source movement linked to the beginnings of the Internet has influenced the emergence of Hackerspaces, FabLabs and Makerspaces, which become, in a sense, a material expression of the open source movement. The open making movement turn "bits" into "atoms" (Gershenfeld, 2006) and define these spaces as communities of human-to-human relations, turning D.I.Y. (Do It Yourself) models, into an emerging D.I.T. (Do It Together) culture. This project builds upon the idea that all people are creative and have the potential to become makers. As such, positions people's levels of literacy in science or art as a factor that can be addressed informally.

The displacing offers a coincidence of methods and tools of making, and thus, opens rooms for inquiry on the *locus* of the professional design. In fact, these spaces are new set-ups, part of international communities that propose to explore a point view on democratization of technology and art. Moreover, these spaces are made possible, due to technological and economical evolution. For instance, this downsizing of processes results specifically from the drop of patents rights. Tools like laser cutting, or 3d printing are free to be taken from the factory setting and assembled in open contexts. And, once removed from a typical specialist setting (the factory or academia), design processes are accessible to experimentation becoming of common use.

The "bits into the atoms" movement demonstrates how computation is both analogue, i.e., having a material expression (electronics, mechanics for instance), as digital. As such these spaces propose to revisit crafts, or handmade skills, into a dialogue of hybridization with new technologies. Crafts are fruitful realm of discussion in design in the context of the digital world (Kolarevic & Klinger, 2008; Risatti, 2013). In sum, these spaces and philosophy are a radical displacing from where the institutional design validation happens.

Understandably, these innovations have economic impact, reflecting on designers practice. For instance, Bremer & Rodgers highlights that nowadays, in Milan, royalties from furniture sales are not able to pay for designers' work. Thus, a typical economical model that sustains design practice is also being transformed.

However, this crisis, both on the role of the designer in question, as well as the role of disciplines and institutions is not entirely new. For instance, Foucault's philosophical early work presented arguments that centered the power of discipline and institutions, as a way of disciplining bodies (Foucault, 1977) Foucault's early critique, on the role of madness and institutions, ultimately contribute to revisit mental institutions. On the effect of this critique, mental institutions are for instance referenced by Manzini (2014) as a case study of social design success.

Furthermore, Foucault's critique on the author's function exposed a relation between the writer and the text, introducing the idea that an *oeuvre*, does not circulate autonomously (Foucault, 1977). Instead, the function-author puts forward an idea of network of relations instead of the idea of the individual creative.

According to Bremner & Rodgers current pressure created by digital media, originated a crisis with particularities in design. Indeed, revisiting design history is possible to acknowledge that current crisis is far from being new. The similar disruption happened with Italian Anti-Design movement in the 1960s, or with Donald Norman, when considered everyone to be a designer (2004), or with British movement Archigram.

Bremner & Rodgers argue that the debate is continuous. For instance, concerning the development of design as a research discipline, Nigel Cross claimed that there is a design crisis every 40 years. Cross points at transitional moments. For instance, the transformation of a scientific design (in the 20), into the concern of finding a "scientific" design process in the 60's. The same concern motivated economist Herbert Simon to develop the concept of "sciences of the artificial". Simon postulates a general definition, assuming that any action aimed at changing existing situations into preferred ones, is in fact design (Simon, 1996). Lipovetsky in his last essay on aesthetics of the globalized world, debates design as having achieved what the Noveau Art couldn't but postulate: total design. This is expressed in a presence of art in daily life. Lipovetsky's argument is supported by dividing design in three development phases, according with the relation between art and economy. The contemporary period is one of hybridization. Lipovetsky considers that currently we have passed beyond questioning the modernist program as design paradigms. Instead, economics created a new moment in culture, leveling the high and low cultures, creating a moment of democratization of art (2013), among other effects.

However, the discipline identity crisis has been prevalent. Bremner & Rodgers listened to designers reaction on present pressures. In the case, Dieter Rams, the reference designer at Braun that deeply influenced Apple design, and Sottsass, the herald of Italian post-modernism. Both are concerned with the seriousness of the profession (Bremner & Rodgers, 2013).

For Rams the practice was always related to economy but with relation to ecology. Rams' views design as a network of influences ranging from, traffic and communication, products and services, technology and innovation, culture and civilization, sociological, psychological, medical, physical, environmental, and political issues, and with all forms of social organization. However, Rams still laments the moment of the overuse of the word "design". Sottsass makes similar considerations on questioning the durable ethical and political dimensions of the discipline. Despite professional open point of view, Bremer & Rodgers positioning is clear on that the "project of design has been changed by digital technology" and with these present conditions makes, ultimately design as a discipline to be dissolving (Bremner and Rodgers, 2013).

In fact, the emergent design is hybrid. Bremner and Rodgers (2013) observes that the paradigm is shifting and that designers are "a mixture of artists, engineers, designers, thinkers." Even that the continuity of a modern model is present in art education, supported by "talent resided in the few and required skill", the authors emphasizes that now "creativity" is taken as universal and just requiring a medium for its expression. As such the new model presents "talent" replaced with "creativity" (p.5).

In sum, these are circumstances created by digital media, and contributing for the indiscipline of design and the crisis of the professional.

Hybridization as paradigm is simultaneously expressing the contact between disciplines. Bremner and Rodgers presents the mode and variation on disciplinary relation synthesized in the table 1. Utilizing formal prefixes (inter, multi, cross) the authors identify relational topologies. The table portrays an analytical description of the indiscipline of today's world of design offering a systematic review on the long discussion on disciplinary interplay.

Inquiry	Character of the Designer	Character of the Discipline
Disciplinarity	Individuals demonstrate understanding of one set of conceptions and one methodological approach. They are able to generate unique questions and contribute new research in this field.	An understanding is demonstrated of one set of conceptions and one methodological approach from field of practice. Able to tolerate questions and contribute new designs in this field only.

Multidisciplinarity	Individuals demonstrate disciplinary competence and understand that their endeavors must be related to the endeavors of others in surrounding disciplines. They therefore come to know and use some concepts used in these disciplines.	An understanding is demonstrated of disciplinary difference and shows ability to learn from other disciplines.
Crossdisciplinarity	Individuals demonstrate disciplinary competence and know how concepts from other disciplines relate to their own, having mastered some of those concepts. They are able to constructively communicate with those from other disciplines.	An understanding is demonstrated of disciplinary difference and can follow problem-focus of other disciplines.
Interdisciplinarity	Individuals demonstrate at least two disciplinary competences. One is primary, yet they are able to use the concepts and methodologies of another discipline well enough to contribute to its questions and findings. New understandings of the primary discipline result.	An understanding is demonstrated of at least two disciplinary competencies. One is primary, yet it is able to employ the concepts and methodologies of another discipline. Strengthens understanding of the primary discipline.
Transdisciplinarity	Individuals demonstrate at least two disciplinary competences, neither of which is primary. They work in and contribute to both and generate unique conceptions and artifacts as a result of an emergent transdisciplinary perspective. They are able to communicate with individuals from a variety of disciplines in	An understanding is demonstrated of at least two disciplinary competencies, neither of which is primary. Results in a trans methodological perspective. Abstracts disciplines to bridge new problems.

	a synoptic manner.	
Pluridisciplinarity	This problem-solving mode combines disciplines that are already related, such as design and engineering. Some of the various domains in design itself involve pluridisciplinarity.	An understanding is demonstrated of a combination of disciplines that are already related in the various domains within design itself.
Metadisciplinarity	This mode connects history/theory and practice so as to overcome specialization; it seeks to develop an overarching framework that differs from disciplinarity in that it does not address single problems.	An understanding is demonstrated that shows an effort to overcome disciplinarity by using methods to construct overarching frameworks to connect practices and their histories to new problems.
Alterdisciplinarity	Globalization and the proliferation of the digital results in connections that are no longer “amid” systems, cannot be measured “across systems, and do not encompass a “whole” system. Instead, the digital has generated an “other” dimension so that we might now need to consider “alter-disciplinarity.”	An understanding is demonstrated that shows an ability to make connections that generate new methods to identify “other” dimensions of design activity and thought.
Undisciplinarity	Practice shifts from being “discipline-based” to “issue- or project-based.” “Undisciplined” research straddles the ground and relationships between different idioms of distinct disciplinary practices. Here a multitude of disciplines ”engage in a pile-up of jumbled ideas and perspectives. Undisciplinarity is as much a way of doing work as it is a	An understanding is demonstrated that purposely blurs distinctions and has shifted from being “discipline-based” to “issue- or project-based;” an ability to mash together jumbled ideas and methods from a number of different, distinct disciplinary practices that can be brought together to create new unexpected ways of working and new projects.

	departure from ways of doing work." It is an approach to creating and circulating culture that can go its own way without worrying about what histories-of-disciplines say is "proper" work. In other words, it is "undisciplined."	Displays an "anything goes" mindset that is not inhibited by well-confirmed theories or established working practices.

Table 1. Similarities and Differences of the Disciplinary Dissolve, reproduced from Bremner, C. & Rodgers, P. (2013). Design Without Discipline. *Design Issues*. 29. 4-13. 10.1162/DESI_a_00217.

Bremner and Rodgers consider that economics and technological adoption rates are actively causing these changes. Indeed, the professional standing that depends on a clear economic model definition cannot be immune to this convulsion. The authors make the point that "the traditional design disciplines need to transform themselves, moving from a convention domesticated by practice to a responsive reformulation of practices revolving around networked communication infrastructure." It is a fact that, "design now starts from a globalized state of culture" (p.13).

For Bremner and Rodgers design in the *Zeitgeist*, if to "retain some characteristics of a discipline, then it should re-evaluate its history" (p.13). Therefore (Un)disciplinarity beyond legitimating a way of doing work offers possibilities of "departure from ways of doing work. (…) It is an approach to creating and circulating culture that can go its own way without worrying about what histories-of-disciplines say is "proper" work." In other words, it is "undisciplined" (p.13).

2.3 Learning without territory

Bremner and Rodgers mapped in detail how much disciplinary design was impacted by digital media. The authors standing deepens the perception that the division of knowledge is as artificial product of human action. Knowledge is not disciplinary but resulting of realms of information acquisition and processing, and therefore the (un)discipline of design is viewed as a "ground zero" condition for the open relation between disciplines.

However, already in the 70's, Papanek (1985), alerted that "with new processes and an endless list of new materials at his disposal, the artist, craftsman, and designer" is exposed to "the tyranny of absolute choice" (p.33). Considering that Bremner and Rodgers' diagnostic gives room move between art and science, the problem now is how specifically, learn, make, teach, share without disciplinary definition. Thus, to the nowadays light, the issue raised by Papanek further gains pertinence under the argument:

> "when everything becomes possible, when all the limitations are gone, design and art can easily become a never-ending search for novelty, until newness-for-the- sake-of-newness becomes the only measure." Papanek, 1985, p.40

Brenda Laurel (1993) advocates a similar point of view regarding a novel interactive technological environment. As a designer, she tackled the same problem when first addressing a then ubiquitous new media, the personal computer. Laurel used Aristotelian notions of drama seeking foundations to orchestrate action in the context of interaction. Laurel was interested in the role that tragedy had in Greek culture, which more than "entertainment" was a way to publically discuss important issues, like ethics, morality, government, or religion (p.40). But also acknowledged that in the realms of science or art the Greeks were discovering and inventing a world. Revisiting Aristotle's *Poetics,* Laurel identified drama's formal structures and concluded, for instance, that the sense of completion of a work, or an effect of *catharsis* depends of constraints. Constraints are necessary to design in an open context (Laurel, 1993).

Like then, the same challenges are posed given current state of undiscipline design. Thus, defining tools in the context of design exploration within the open possibilities of emergent technologies is one of the requirements. Defining a navigation becomes imperative.

As such, inspired by Peter Hall's design critique, mapping becomes a helpful method, where the idea of navigation in time and space is prevalent (Abrams & Hall, 2005). Thus, current research is first, inspired by critique taken from design studies. Mapping retrieves concepts of navigation, prevalently used as a tool, visualizing process of thought and concepts

The navigation process was inspired by Deleuze and Guattari (1998), that ground, define and identify a thought process helpful when tackling experimental territories. Concepts like immanence planes (Deleuze & Guattari, 1988) inspire creating charts, instead of a linear research process.

Research under the scope of U.C., has materialization as a condition *per se* that introduces the need to use practical research methods. As such, it becomes of interest to tackle, the difference between media (the object) and content (what gives meaning to the object). This distinction aims to reveal insight while designing new physical devices that are animated by software or by other technological possibilities such as smart materials.

2.3.1 Conceptual mapping

Deleuzian (Deleuze & Guattari, 1988) philosophical approach is widely discussed, open to several different interpretations. However, regarding design methods, offers a perspective on a particular presumption as "being in between without beginning or end", instead of a sequential, one dimensional and linear route. In particular, a non-linear approach brings forward practices which better relate and define human condition (Coyne, 2008), which is in a transient state, but also in tune with human sensation.

For instance, if considering a methodology as a storytelling technic, present research approach could be said to be *In media reas*, this is, it can start in the middle (e.g. disciplinary definition). This allows presenting a route, instead of a linear working logic, that has a beginning, a middle, and an expectation of an end. This is more in tune with an experimental approach and realist in contextualizing the field of U.C. within design.

Pursuing the singularity as a moment of discontinuity is a derisible outcome and part of research and scientific discourse. In fact, as a goal refers to a specific mind-set that seeks for originality. Deleuze, considers achievement of "the singularity" as one of theoretical systems approach prospective outcomes, but one that does not oblige to consider the design of systems aiming for totalities, as closed, definitive results. Instead, Deleuze and Guattari's system of thought was inspired by quantum mechanics as opposed to Newtonian physics. As a system becomes an useful tool to translate dynamic concepts.

Deleuze and Guattari's thought logic, offers a disjunctive synthesis. This means that uses injunctions (AND), over disjunctions (OR), avoiding the (it is). For instance, this mindset allows to force and think of reconnections, as in science and art, not taking for granted any previous current definition. Furthermore, it helps to define a state of suspension of judgment.

The application of this system in current research is helpful to validate the injunction between Industry (AND) Academy (AND) Experimental Design. These are traditionally presented as fundamentally different. Furthermore, this system of thought resonates with intended Fallman's methodological definition of research triangle (Figure 3), where several disciplines and contexts are put in continuous relation. Thus, conceptual mapping allows to move between concepts, going back and forward, but also validates intuitions as contribution.

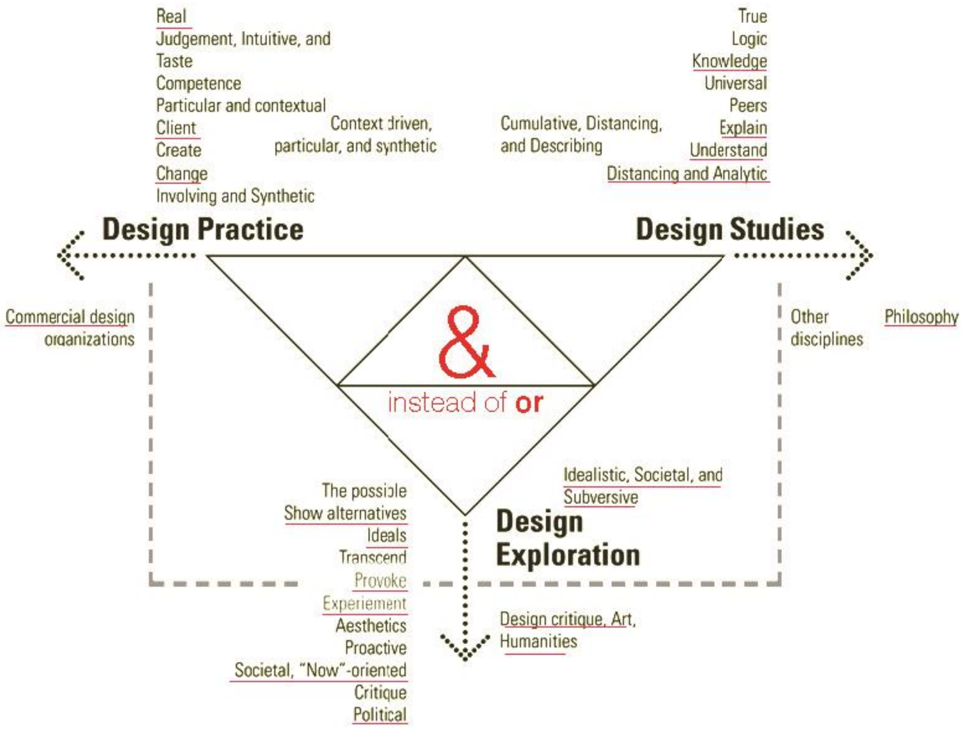

Figure 3. Fallman's research triangle

Following Fallman's map there is no contradiction in linking, idealism, with commercial design, or client driven research, with knowledge. The more prevalent concepts that drive current research, are underlined in red in the map.

Creating an emotional-conceptual cartography, by using diagraming, demonstrated in what is defined in Deleuzean terms, as a multitude, the effect of re-connecting and polinization (Figure 4). In this second map this effect is made visible: traditional disciplines that are applied in current research are directly referenced.

In this case they are: materials engineering, human computer interaction, philosophy of science, design critique, and art. They intercept, and offer an idea of nodes, and of interlinking territories instead of borders. For instance, the "real" validation of research is made in conferences and festivals, which are included in this map, and are distributed, between experimental design, practice design, design studies. (e.g. SuperMirror was presented in CHI, Paperbot in FILE and PLUNC, and design studies were presented in DRS2016, CitySkin was presented in

Interaction16, and pele tumbler). This display of information clarifies the relation between them.

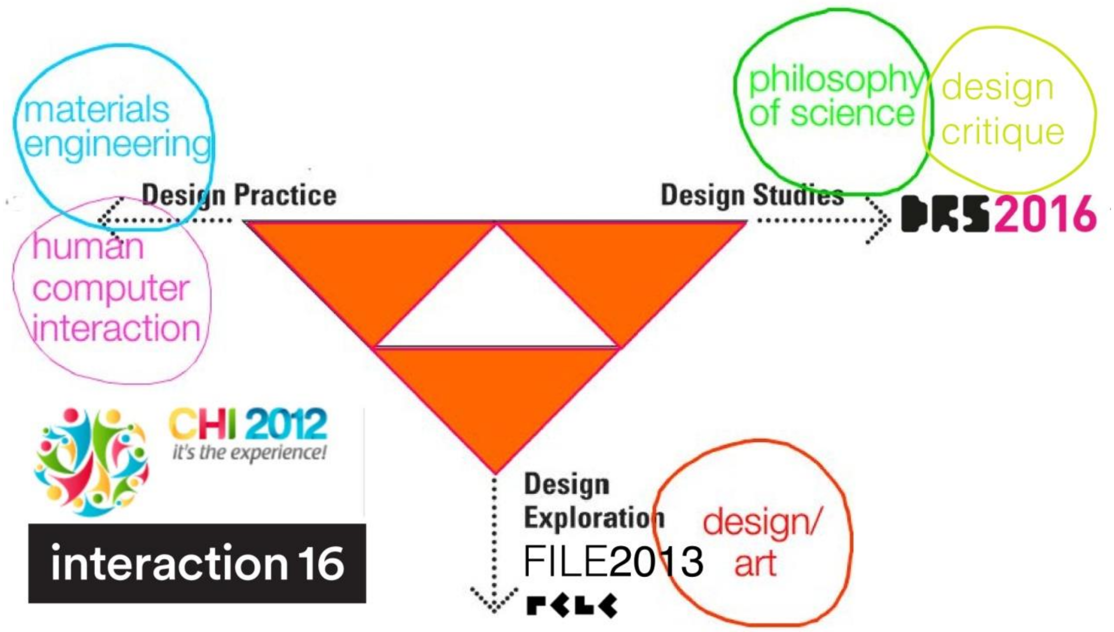

Figure 4. Design research and development map

Deleuze & Guattari's experimental empiric model integrates direct experience as life-vitalism, as an aesthetical experimentation. The emphasis is in creation without having previous assumptions. This is integrating *Kunstwollen* (Rajchman, 2000), the will of art, as a great contributor for invention based in a *Zeitgeist*, in the fleeting now.

2.4 Disciplinary perspectives

2.4.1 Computation and materials

In the 80's the dominant interaction model with computers was connected to the rise of the personal computers. Mark Weiser, a chief scientist at Xerox PARC in the United States considered this interaction to be complex, demanding too much attention, and isolating people. Personal computers were imposing objects on desktops and restraining people from other activities. (Weiser, Gold, & Brown, 1999). Solving these issues, meant to entail a new vision for the interaction model. An analytical look into trends of computers offers perspective on the relation to humans. Starting by the early 40's, the mainframe computer demanded management of many people, passing to a one-to-one model with personal computers, Ubiquitous Computing (U.C.) would finally project a one person to many computers relationship. The computer for the 21st Century would be integrated within a range of environmental contexts aiming at augment, aid or complement human capacity in a most natural and unobtrusive way. Technology should serve as an enhancer, instead of a disrupter of life, and the paraphernalia of peripheral devices (e.g., mouses, printers, screens...) would no further be necessary. This is a scenery where computers would be invisible, and the process of interaction would achieve a desirable calm (Weiser, 1991).

2.4.2 Approaches to Ubiquitous Computing

Weiser's main objective in computing is having humans at the center of research. In fact, UC is a concept that proposes "a very difficult integration of human factors, computer science, engineering, and social sciences" ("Ubiquitous Computing," 2015) thus getting insight stemming from several disciplinary backgrounds. During 1988's the Ubiquitous Computing program in the Computer Science Laboratory (CSL) at Xerox PARC, evaluation methods taken from Anthropology were integrated into research. The use of participatory observation enabled researchers to perceive a radical difference between how people used technology from the way they claimed to (Weiser et al., 1999).

The incorporation of social sciences brings yet additional advantages to research. For instance, it acknowledges the susceptibility for "confirmation biases", that is, researcher's inability for not influencing results. Thus, results are presented *as* a *perspective*, a hybrid mutable point of view. Furthermore, social sciences methods consider the gap between information and hard data, the qualitative versus the quantitative. As Weiser stated, the point of view of social sciences was a determinant changing step to drive computing research "from atoms to culture". Therefore, the disappearing of interface emphasizes culture(s) as a value from which research could start from, and design for, and posits computing purposes to achieve a human-to-human interaction, instead of human-computer one (Weiser et al., 1999).

Currently, divergent views have been held on Ubiquitous Computing. The overlapping concept "internet of things" is a model that proposes to design everyday objects - such as domestic appliances - connected to the Internet. These devices range from wearable to any surface that might be embedded with electronics and sensors. The main idea is having an object-to-object communication able to sense the world that can dynamically adapt to variation without direct human intervention (Kellmereit & Obodovski, 2013).

David Rose's version on UC suggests creating "enchanted objects", i.e., "instead of having a conversation of media, having a dispersion of intelligence in several objects" (Rose, 2014).

This is a case where a constrained degree of technology is embedded in things. Research stems from firstly i) identifying core human values and desires from which a relation to objects is noted, and ii) intensifying that relation through technological features. Technology would work like magic, looking less for efficiency, than for affectivity, expressivity, and appearing as a symbolic manifestation in objects coming from an imperceptible source. Rose maps human desires in relation to objects in six categories:

i) omniscience. the desire to know all
ii) telepathy, the desire for human connection
iii) safekeeping, to protect and be protected
iv) immortality, to be healthy and vital
v) teleportation, to move effortless, and
vi) expression, to create, make and play

An example falling under the category of safekeeping is an umbrella that will shine, and call attention to the owner, whenever there is a rain forecast. Or a bottle cap on a pills case that will let someone know the time for taking medicine by giving a shining clue. Thus, Rose proposal stems from a systematic analysis of cultural environment as to set the design outcome. It indicates a method that offers a solution open to critique, as values vary according to cultural contexts.

The "material turn" brings yet another take on U.C: "smart materials, ubiquitous computing, computational composites, interactive architectures, the internet of things, and tangible bits" are put into relation to each other, while the role that "non-computational materials" have in Human Computer Interaction (HCI) (Wiberg, Kaye, & Thomas, 2014) are simultaneously recognized. This means "making the digital real (again)" (Kitzmann, 2006), having computing and information re-imagined as just another material (Kuniavsky, 2010). As such, the material turn is an open perspective that builds research upon the materials as defined in the arts and humanities, science, and applied science. It foregrounds materials from interaction design, design practice - traditional and ancient materials as computable – and the notion of ''craft'', integrating groundbreaking achievements on materials and software engineering. Two approaches to this relation between new materials and crafts, are explored by Leah Buechley's in the low tech and high tech research group ("Leah Buechley," 2015), and by Catarina Mota's open materials, which presents new materials and traditional technics, as open source (Mota, 2015), and dislocates experimentation from the research lab to a Do It Youself (D.I.Y.) setting.

2.4.3 From nano to macro

As mentioned, a definitive contribution to this technological dialogue was given by nanotechnology. The invention of the scanning tunneling microscope (S.T.M.) at IBM Research Division, by two physicists, Gerd Binnig and Heinrich Rohrer, enabled to visualize a new world of the very small. As Dr. John E. Kelly III, IBM director of research puts it, STM "opened new avenues for information technology that is still being pursued today". STM is a groundbreaking instrument that goes beyond the ability to image, and measure, and allows the manipulation of atoms and therefore the creation of new materials stemming from the nano scale (IBM, 2015). To put it simply, STM is an electronic microscope that applies quantum physics to reveal the surface of matter. Readings on material surface structures at quantum level are acquired by directing particles that, according to materials different atomic structure, give a specific electronic feedback. In this way, materials reveal the energy-matter bounding variation in permanent motion. The determination of the atoms' position depends on the computation of position and images are recreated from this reading. ("Tout est quantique," 2015). The microscope "observes" through data taken from a material (energy) interaction.

In fact, nano-technological revelations from materials engineering, physics, and mechanical research labs have "a direct implication on the historical processes of design" (DeLanda, 2004). The traditional paradigm of the genesis of form depends on "historical processes of homogenization and routinization that have promoted the "hylomorphic schema". Neri Oxman further adds that the modern program reinforces form (idea) over skills, and assigns materiality to a secondary role. Materials are, in this context, part of the discourse of a project, and not the source that serves the form (Oxman, 2010). The modern paradigm is confronted with nanotechnology and "new theories of self-organization" and "the potential complexity of behavior of even the humbler forms of matter-energy" (DeLanda, 2004). This notion is present in Oxman's perception of Nature's way of building, which is translated to this designer approach to making: "there is always a direct relation between matter and energy, between form and environment and between organ and function." (Oxman, 2010) Thus, applied quantum physics brings on a new relation between form and structure. The enunciation between matter, energy and environment as givers of form is set ("Tout est quantique," 2015).

Consequently, it is no longer possible defining design "from the outside on an inert matter" (…) "as a hierarchical command from above as in an assembly line". Indeed, form "may come from within the materials" which becomes something "that we tease out of those materials as we allow them to have their say in the structures we create." (DeLanda, 2004)

These achievements brought forth from applied science have potential to dislocate the purposes of design practice. When designing from a nano-scale level, materials acquire meaning while moving into the macro scale, i.e., to a human scale. Designing at this new scale is made from the matter (atom) to the idea, therefore from bottom-up (Figure 5). In fact this is a direct inversion of the top-down approach in which materiality is chosen to convey an idea, to serve a concept defined *a priori* and then imposed on materials.

Accordingly, these considerations on matter inspired new strategies and methods in design, such as enunciated by Oxman, to whom the main point is to "copy nature's inventions" intending to design while desiring "to survive on earth", that is, for sustainability. In Oxman's case by finding inspiration in biotechnology, biomimecs and biogenesis (Oxman, 2010) in material-based design computation processes. The materialization of these strategies has a broad expression, and only a glimpse picture can honestly be made to illustrate their wide range and impact, but above all their disruptive potential. In a simplified manner, biotechnology uses living organisms to create new products. An example could be given with the use of mycelia, to create bio-plastic, as applied to Lynn Rothschild's drone (2014). Nano-biomimecry suggests to mirror nature's witty behaviours into materials. An example of the latter, is self-repairing concrete (Brownell, 2010), behaving like self-healing human skin. And indeed, biogenesis intends to create life in a laboratory. Furthermore, these biological based methods have outgrown the science lab set, and inspired designers, like Suzanne Lee, who makes use of "bio-couture" to grow wearable fabrics by using yeast and bacteria (Grushkin, 2015).

The material turn proposes, then, to tackle the division between the physical and the digital. And, as described, a deeper look at this new approach to design reveals that this reconciliation transcends the translation of digital to physical environments of interface. As is the case of turning Graphic User Interfaces (GUI) into Tangible User Interfaces (TUI) (Ishii & Ullmer, 1997) , or by making screens into things. In the light of material turn, the initial statement on Ubiquitous Computing proposed by Weiser, expands the absolutes delimitations of design practice, but also, in particular widen out the notion of "ubiquitously of computation": materials reveal their own computable nature and a myriad of new possibilities arise.

Hence, smart materials and computational composites are visible product outcomes from nanotechnology research labs. They have been considered by Manzini as "the highest expression of the paradigm of tailor-made materials" (Ferrara & Bengisu, 2014), and consolidating a "contemporary third phase of the industrial revolution". Simultaneously, they define a vast array of high-performance materials, able to change color, form, dimensions, temperature, and move (Ferrara & Bengisu, 2014). In fact, smart materials displays materiality as having an embedded smart system, resonating with what was described by U.C. Indeed, smart systems typically combine (input) sensors, a data processor, and an actuator (output), which perform a specific action. The same interaction model can be identified in a smart material. An array of stimuli will trigger an atomic process, which in the case of smart materials configure a transformation as the output. One view that is supported by definitions such as: "smart materials and structures are those objects that sense environmental event, process that sensory information, and then act on the environment" (Addington & Schodek, 2005b).

However, an important distinction between a smart system and a smart materials was put forward by Varadan and Smith: "smart systems do not necessarily contain smart materials, so the ones that do contain them are properly called smart material systems (Ferrara & Bengisu, 2014). This is a fundamental difference to have into account, when considering designing a UC system. A responsive environment, for instance, typically rely on smart systems, and often present a hybridization between architecture and technology (Bullivant, 2006). But in the context of architecture a smart system refers to an intelligent environment, which might contain a smart material, but not necessarily. Art, design and architecture presents a perspective that has a strong tradition of humanism which humans and their bodies are the center and measure of all things.

2.4.4 Defining problems within design and computing research

Smart materials resulting from engineering research are effective systems, but their applications in life are less obvious. Often, smart materials are described as a "technology push", that is, materials looking for a problem resolution (Addington & Schodek, 2005). Interactive design in the context of architecture might give grounding insight to UC goals, by recombining materiality in traditions, but projecting future configurations in a dialogue with new materials.

The convergence of the subjects proposed by the "materials turn" clarifies how U.C. design scope can be spread. However, as demonstrated, the problems these systems intend to solve, as fundamental step to create meaningful experiences, is not obvious. The analyzes of UC discursive practice (Greenfield, 2006; Weiser et al., 1999), made by Dourish concluded that there is a frail relation between UC and social sciences and humanities (Paul. Dourish & Bell, 2011). Dourish specifically argues that design and art emerged as a H.C.I. recent interest, and was applied to entertainment and games. But despite this, perspectives that incorporate post-modern analysis or feminist critical theory, and others, as initially proposed by Weiser, have a residual presence in U.C. research literature. (Dourish & Bell, p.16). Weiser's literal suggestion to "start from arts and humanities: philosophy, phenomenology, anthropology, psychology, postmodernism, sociology of science, feminist criticism, your own experience " is still absent. (Dourish & Bell, p.14) Following this insight, the emerging "central element of UC research" appears to be that one shall first define how to design experiences that "start from arts and humanities" and secondly, to do so in order to include what Dourish refers to as the "messiness of everyday life" (Dourish & Bell, p. 22), or what Weiser considers as culture.

The big question for incorporating social-cultural values in UC research is related to its definition. It is a fact that, UC is described as a "platform for encounters between people and technology", proposing, fundamentally, a disciplinary "conversation": science and technology studies, socio cultural anthropology, and media and cultural studies might be particularly relevant when defining problems. However, Dourish reinforces that there is a the lack of trends in UC that focus on an "emancipatory and democratic information technology", visions of "involving people in public debates", and "issues of science and governance concerning climate change, environmental pollution, health care". Further absent is the acknowledgment of research outcomes "in the social sciences" "concerning, learning, participation, motivation, and behavior change". These are problems not in the scope of what UC is typically addressing. As such offers visibility for terrains for innovative exploration.

Defining what problematic terms such as 'social' and 'culture' might mean in the context of a UC research is the starting point for a new approach as regards the human computers interaction. The 'social and culture' can be related to the social settings - the workplace and factory, schools, domestic environments (Dourish & Bell, p.49), or the social impact, as is the case of considering sustainability issues. Culture is, indeed, a quite problematic term. As a subject of study, academic definitions are substantially different, varying according to traditions in both sides of the Atlantic. For instance, Dourish refers to a deep mistrust of industry in the US to applied work developed under an American anthropological setting arising out of the 1950, 1960's. This was the source of the consolidated divides between the social and science, and the industry and academy. The same divisions can be found when examining design "cultures" dispersed by disciplinary backgrounds (Paul. Dourish & Bell, 2011). Indeed, specifically for the concern of this research, culture will be considered as firstly i) a generative process, secondly ii) as a method of analysis that enables us to give an account of everyday phenomena, and iii) the "examination of information technology as a site of cultural production" (Dourish & Bell, 2011).

The symbolic value of materials would be tackled by an ethnographic approach. It would be equally useful to provide historical background to access on perspectives of different disciplinary of making, which is determinant to discuss and put into practice interdisciplinary methodologies. In other words, cultural inter-relations are acknowledged, and will be pursued, throughout the process of making, and not only from a disembodied theoretical framework. The main point of these relations are that, by putting theory and cultural perspectives in contact to the more common accomplishments of a UC, research outcome might access least explored realms. Moreover, cultural values enhance awareness that a research contribution will become part of a new cultural production, but also part of a legacy (Figure 5).

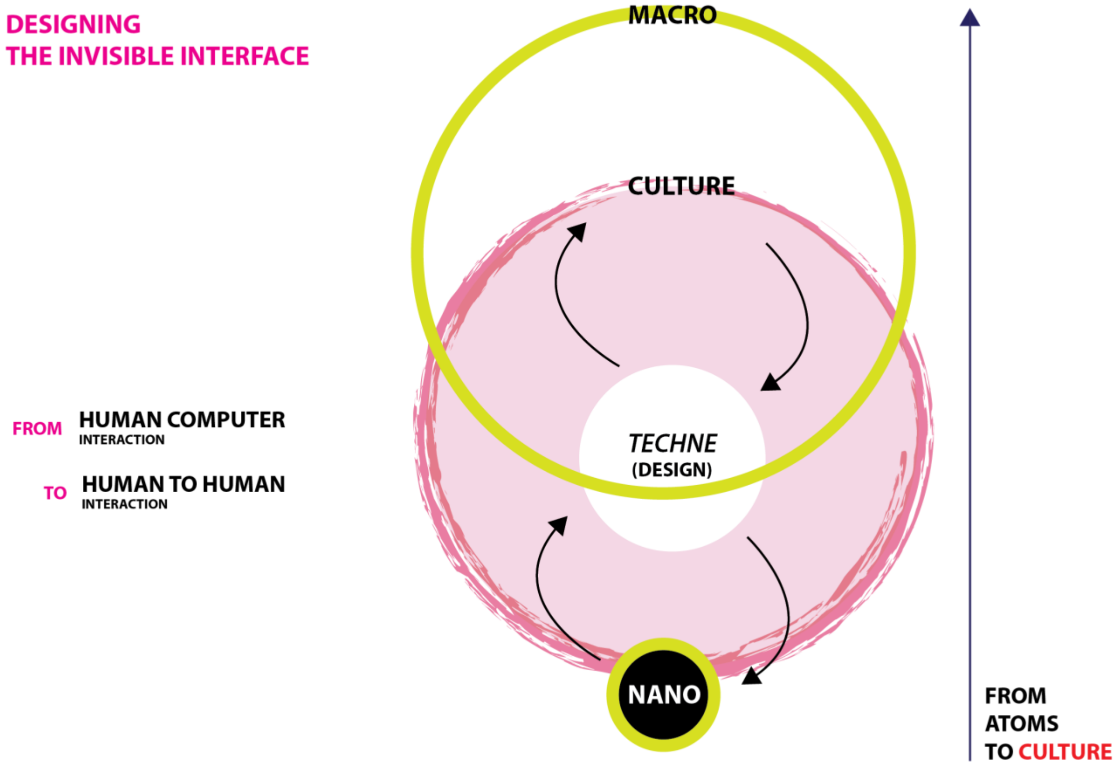

Figure 5. Research map inspired by Weiser, M. (1994). Creating the invisible interface: (invited talk). In *Proceedings of the 7th annual ACM symposium on User interface software and technology (*UIST '94). ACM, New York, NY, USA, 1-. DOI=http://dx.doi.org/10.1145/192426.192428

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Forget your ego, and leave your discipline behind.

Let's do this together!

Bill Moggridge, 2007, p.655

2.5 Collaboration in practice

Ubiquitous Computing research requires disciplinary interplay. Designing new computational devices rely at least on two guiding ideas: the need for collaboration and experimentation. These conditions were chosen to drive current practical research.

Collaboration can be thought happening not only outside a disciplinary field but also within its defined territories. As referenced before, this is the case when considering "design", where the acronym A.D.A., as an agglutination of art, design, and architecture, will be used interchangeably throughout the dissertation. The discussions on definitions, practice and theory within A.D.A. are not in the scope of current research. Weiser's proposal on computing design research assumes collaboration as a guiding inspirational factor. The scientist considers the need of working with contributions taken from different disciplinary backgrounds.

In previous chapter 2.4. U.C. was discussed as both a social and cultural phenomenon, beyond the explicit technological lead that engineering has gotten in the field (Dourish, 2014). The purpose of the following discussion will be to map relations, collaborative perspectives, conveyed by objects, but also by the associated disciplines that source them. Firstly, concerning computing science and secondly within A.D.A. The perspectives formulated inside each disciplinary field on the concept of collaboration and experimental design, can give insight to locate, evaluate results, but also further contextualize the methodological proposal of action.

The historical analysis method will be used, inspired by Actor Network Theory (Bruno Latour, Michel Callon and John Law). This approach specifically:

> "privileges neither natural (realism) nor cultural (social constructivism) accounts of scientific production, asserting instead that science is a process of heterogeneous engineering in which the social, technical, conceptual, and textual are puzzled together (or juxtaposed) and transformed (or translated). As one of many anti-essentialist movements, ANT does not differentiate between science (knowledge) and technology (artifact)" Ritzer, 2004, p.1

Actor Network Theory maps relations that are simultaneously material (between things) and semiotic (between concepts). Therefore, privileges collaboration-network to the individual authors of history.

The meaning of interdisciplinary collaboration varies according to perspective. Thus, possibly impacting outcomes, as well as methods. Therefore, the second concern of following analysis is to situate a speculative research. Specifically, defining the meaning of experimental design. This is problematic if acknowledging an approach routed in different making traditions, which furthers widens the scope of action of U.C. research. The intention is to situate the intersection between A.D.A. and science.

Therefore, specifically, next chapter will, firstly, present Computer Science using a selective history of the computational objects, in relation to creation of a multiplicity of disciplinary fields. These are, namely: cybernetics, computer science, human computer interaction (H.C.I.), user experience, interaction design. And from that, chart implications, achievements and limitations of the collaboration model arising from H.C.I.

Secondly, locate collaboration within A.D.A. (art, design, architecture). This will be done by discussing some contemporaneous topics of design: co-design (Sanders, 2008), design activism (Fuad-Luke, 2009), neo-futurism (Foster, 1987), design for sustainability (Manzini, 2015), sensory design (Malnar, 2004), design and emotion, speculative design (Dunne and Raby, 2013).

The role of the designer is discussed situating collaboration, in having co-design versus the expert view set-up. Sanders' mapping on design serves as route, to describe the shift between expert and non-expert perspectives and the implications on defining a collaborative model. As well as a distinction between a design led research or design research (Figure 6).

Sanders, created a second map where design is situated in four main areas: User Centered Design, Participatory design, Critical Design and Design and Emotion (Figure 7). The influence of cybernetics is discussed, in the case of systems approach to A.D.A., and by referencing to the wicked problems definition (Rittel, 1971).

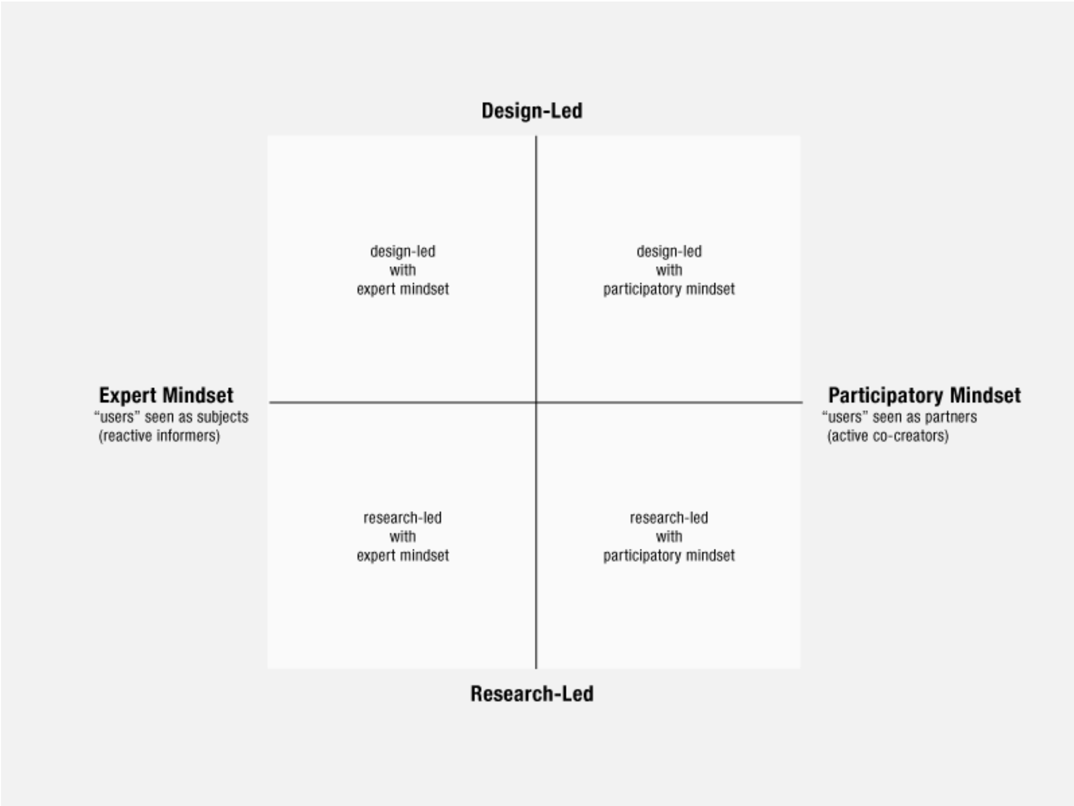

Figure 6. Sanders´ Design Research map

Research through *techne* describes the intersection between art and science The methodology is directed to create a final project. This object will be speculative, translated in a proof of concept.

This synchrony of practices as research will imply to move between studio art and the research lab. Thus, Fallman (2008), Buxton (2007), offer insight regarding methods. If the first, assumes that traditional design methods apply to different territories of action, the latter proposes hand-on approach to design exploration, by prototyping. Ashley Hall step-by-step practical research model, offers an experimental design method that mirrors the scientific method from a A.D.A. perspective. Thus, is in between science and A.D.A. Sanders situates co-design, regarding adopting a mindset, that allows to have the designer work as a facilitator. In this case, between disciplines and places. And Laurel contributes by conveying qualitative methods. The synthesis of research is cumulative knowledge about methods, applied in a final project demo. This project is the main research contribution.

2.5.1 Computing and Science

Human computer interaction (H.C.I.) emerges as a specialization from Computer Science in 1980's. As a discipline H.C.I. confines studies on the relation between Human Factors and Computing. As mapped by Sanders, within the field, other categories have emerged such as usability testing, user experience (U.X.), or user interface (U.I.), but also Interaction Design, a term coined by Moggridge (2007) at IDEO. The creation of H.C.I. as a discipline refers to the moment when computer science includes the humanities and becomes interdisciplinary, using a collaborative model.

The first documentation of this configuration within computer science happened in a workshop in 1984, focused on the concept of Computer Supported – Cooperative or – Collaborative Work (C.S.C.W.) - latter established as an open biannual conference. Computer science is discussed in relation to management information systems, information science, psychology, sociology, and anthropology. The conference concerns were wide with multiple vectors of approach. According to Falman's analysis, Grudin (1988) considered computer systems as a way to coordinate collaborative activities, Greenberg (1991) analyzed how the computer and related technologies affect group behavior and the modes of working together; Suchman (1989) addressed design computer-based technologies with explicit concern for the socially organized practices of their intended users and finally, Bannon & Schmidt (1989) made a meta-analysis, understanding the nature and requirements of cooperative work with the objective of designing computer-based technologies for cooperative work settings (as cited by Fallman, 2008).

Nowadays CSCW became the umbrella term to define an arena that allow people from a variety of disciplines to come together and discuss issues without any common ground about its meaning (Fallman, 2008). Thus, instead of configuring as a discipline CSCW is assumed to be an arena (Bannon,1998), which fundamentally marks the paradigm shift on the design of computer support systems (Hughes et al., 1991). The now ubiquitous "user centered research" emerges from the realm of computer science and has on CSCW the source which has influenced the prevailing paradigm on systems design. In fact, CSCW points at understanding the meaning of "user" in relation to computer systems (as cited by Fallman, 2008).

The emergence of the concept of "user" in the 80's is directly related with the spread of the computer as an object of personal use. During this period computer science research by bringing forward concepts such as "computer-supported cooperative work", opened room for social sciences input into the design evaluation. (Fallman, 2008). Human beings are transformed from neutral subjects of science into users (and consumers), that have feedback to be given to the system design. This is the original source of interaction design based in "user testing".

Moreover, CSCW aimed to recognize the social context of technology within computer science traditions. Therefore, CSCW research is also pioneer in applying concepts such as participatory design, in the context of computer science, further contributing to widen the scope built from a science tradition.

Participatory design is originally Scandinavian, where since the 70's have endured and developed approachable methods. Participatory design pays particular attention to social propositions and to the co-evolution of artifacts, practices and the influences of both users and designers in design processes (Shapiro, 1994). This is, the main objective of participatory design is to center on design work, rather than a specific technology. Another distinctive aspect is the interest on inclusiveness on the process of making (O'Day, et al., 1998, Laurel, 1993).

This perspective approaches technology and tools as representations of cultural history, mediators of knowledge and extension of human capabilities (Bannon and Bødker, 1991; Kaptelinin V., Kuutti K., Bannon L., 1995; Engestrom, 1994). Thus, adds a view of a network community research that develops beyond the technological ideology of innovation. Following Bannon and Bødker by taking these insights seriously, the study and development of artifacts over time achieve an essential focus of a design activity (O'Day, et al., 1998).

Currently, digital media brought an overwhelming presence of computation in life, applied in objects of daily use. These are an ultimate step of a gradual gain of social significance on computation that can be traced to origin of machines that calculate. Computers are artifacts with particularities, and are situated in relation to the history of computing.

The creation of computer science as a distinct disciplinary field is coincident with the story of progressive specialization. However, historically speaking, it can be said that H.C.I. is a cumulative step, built on the long connection between humanity the imaginary of calculus and the making of machines. As is the case of any other fields of knowledge, by the time disciplinary fields are set, there is already a long story, and the one of computing related to making of things is not an exception. For instance, it is consensual to identify the first computers as the mechanical devices that permit calculus. Thus, the abacus, the Antikythera mechanism or the astrolabe are artifacts that illustrate this story.

Calculus machines resolved limitations, as for instance, the constrained pace of computing when performed by human beings. In the beginning of the XX century, computing demanded time and people, whereas the quest to resolve these constrains is marked by several attempts to design computational devices.

This cumulative knowledge, results from punctuated achievements, for instance from the creation of the binary code by Leibniz, which was inspired by the I-Ching, to the first algorithm applied to a machine by Ada Lovelace. In fact, as was the case with Alan Turing and Konrad Zuse, some developments apparently emerged simultaneously in different places like Germany, United Kingdom or United States.

Fundamentally, it is the application of binary code that gave room to start digital computing. In effect, the velocity of calculus output as well as the amount of data that can be processed by the machine is radically improved. According to the Zuse Institute Berlin, the Z3 machine is the first machine that applied binary code. A machine was finished by Konrad Zuse in his parent's apartment in Kreuzberg, Berlin, and used an "on and off" state based on relays. The Z3 machine was destroyed in 1944, and it is stated that during the war it did not interest of the German political establishment. Zuse's machine was demonstrated to be first to have completed a Turing Test (Zuse, 1993). The big debate about the pioneering in computation is, possibly, unresolved.

Indeed, the exponential incremental step took place during the efforts of second world war, when computing reveals a profound usefulness in the realm of communication. Decoding the German machine Enigma, using a "Turing machine" made the scientist Alan Turing became a war hero.

However, building such machines had apparently other initial motivation. As one of the computing pioneers comments, the German Konrad Zuse admits that his urge for building the Z1 computer in 1938 was routed on frustration. Zuse was a civil engineer by training and desired to end the tedious calculations to focus on creating (Janusz, 2012). Distant in time by five decades, the motivational coincidence between Zuse and Weiser is rather informing. They both postulated to liberate human beings of a tedious task and imagined computation to be resolved by machines to gain time to enjoy life and creation.

Modern computation based in electronics begins a t the end of the Second World War. The invention of the transistor that allow to replicate the on and off state is also a story of materials science at the service of computation. The most efficient materials are the semiconductors Germanium and Silicon, which better allow controlling electric current. As such while looking to dunes of sand and to the abundance of Silicon, is also to find the name attributed to the high-tech industry Silicon Valley.

After the Second World War the term cybernetic coined by Wiener In 1948, describes a paradigm shift in the relation to computers. Cybernetics was concerned with the scientific study of control and communication in the animal and the machine (Wiener, 1948). Cybernetics offered a new focus on these new machines potential and marks the transition of the calculus machine into a device with interdisciplinary applications. Systems theory created at MIT, by Jay Forrester foregrounds a process (input, process, output) that coexists with a myriad of applications on the concept of cybernetics. Since then, cybernetics has been broadly applied to different realms of study. Systems approach integrates theories of different configurations, ranging from mechanical, physical, biological, cognitive, social systems, communication.

For the purpose of current research, for instance, in architecture, mapping human behavior patterns (Alexander, Ishikawa, Silverstein, 1977) has been used to configure a city as a system and help coordinate a better design. Also in ecology, the planet itself has been described as a magnificent system, the spaceship Earth, and is a concept that has influenced

Buckminster Fuller. In the realm of neuroscience, the brain research is considered to image a computing machine.

As a theory, the systems approach has ultimately influenced design methods. Buchanan (2001) describes the "distinct category system design" that offers a methodological approach to problems analysis. The system theory contributed to formulate issues as "wicked problems" (Rittel & Kunz, 1970). Wicked problems are the ones that due to its complexity tend to become overwhelming. On the other hand, system theory also presents computation as a mean to explain totalities, from the atom to the human gene (Andersen & Salomon, 2010).

Critics of cybernetics, address typically the pretense achievement of wholeness, and universality, by intended acquisitions of the whole reality, experience and life by mathematics. In is documentary work, the journalist Adam Curtis discuss the system analysis of the world that rely on organization of data (information), that is easily, translated into politics and life (Curtis, 2011). Curtis presents an example of the early concept of eco-system. Data did not convey the theoretical formulation of being a self-regulating system. On the contrary, hard data in fact, revealed a chaotic system, which did not correlate with the defined closed eco-system. For the concept to prevail, theory was forced on the data. Drawing from this example, Curtis goes forward to present the fabrication of results by science, to convey a theoretical (mathematical) model, as a more frequent event than expected. And in fact, what emerges from the tale is a prevalence of the humanity within science.

Quantitative analysis of the world has become powerful, and tends to be considered as true. Aligned with the argument, Tricia Wang (2015) states that measurement is not the truth. She invites to have look into history of mankind as political, using qualitative models that question the presentation of measurement as knowledge. For her, the map is not the thing, but a representation .

Already, physics correlated this approach since Heisenberg formulated the principle of uncertainty. Consider mathematics as a medium from each nature is analyzed but not being nature itself. Therefore, perhaps the core of systems thinking is that one is interested in complex 'wholes' with emergent properties, to which cybernetic ideas can be applied (Blackham, R. et all, 1991).

Ultimately, science is under the physics perspective, simultaneously the realm of human science and fiction yet to be proved. A realm of defying theoretical models that needs to be demonstrated, often apparently contradictory.

This realization, meets, hand-to-hand on the interpretation of results of H.C.I. testing, as absolutes, as happened in the 80's. This was the period when the best way to interact with personal computers was undefined. In fact, looking at the pioneers, alternatives views were put forward, beyond the pervading "personal computing". This was the case of computer design pioneers Brenda Laurel, and Alan Key. Steaming from two different backgrounds their positions illustrate alternative arguments to what was the pervading norm.

Laurel (1993) tried to incorporate an artistic and feminine perspective into computer science culture. Laurel approached the computer as media instead of a calculus machine, and therefore able to mediate any kind of emotional and artistic content. Her research applies Aristotelian concepts of drama, such as of *catharsis*. The concept of *catharsis* intercepting with machine, would have similar results to the effect of ancient Greek tragedies. The sense of completeness would inspire an emotional release. Purple Dreams, her company, was an attempt to positioning content targeted to a feminine audience, creating an alternative take in gaming in the market.

Computer science discussion, on the other hand, did not present a consensual view on the best design approach either. Alan Key (1987) presents some issues about the "absolute" value taken from interaction design research, regarding a computer and human relation. Key defends that coding represents a direct relationship with the machine, and should be considered as a language; with its own grammar, significance, to be learned by everyone. However, this view confronted with research results, which did not confirm appetence in people concerning coding learning. Despite this, Key believed that these results conditioned design itself, and creativity. In Key's perspective, Graphic User Interfaces (preferred by the user) had to some degree, removed the individual from a level of language and communication with the machine, which is algorithmic, not allowing to explore and be truly creative. In recent years, the appearance of *Processing* as coding language aiming specifically for artist and designers (Reas & Fry, 2007), would confirm the eagerness of non-experts to use software as a creative tool.

Looking to history of computing science, the huge design jump that happened with the ubiquitously of G.U.I., did not depend of earlier evaluation with users either. Instead, it was created in Xerox Lab, in a closed environment. Until the appearance of the personal computing, design of the computational machine had a particular setting, the lab. The early stage of interaction design happened between the scientist and the machine, and two paradigms emerged. A first, the mainframe, and a second one, object oriented paradigm, that culminated with Graphical Interfaces (Moggridge, 2007).

Apple Inc. applied G.U.I.s in a machine of wide distribution. Steve Jobs (Stanford, 2005) confirmed an incidental influence of typography. Fonts where carefully chosen. These realizations situate, to some degree, the role of having the user, as a non-expert or expert evaluator. For instance, designing machines for the office set-up, and having market as the paradigm of outcome, as a criterion, is not neutral, to results. The pioneer computers were expressive blue screens, with attached keyboard, and as Kittler discussed, a remediation of the typewriter (Kittler, 1999).

The history of personal computing had two paradigmatic paths. One, based on the blue screens and another on Graphic User Interface. The ubiquitously of the G.U.I. happens with Microsoft in the 90's. This gap was a relevant design issue. The emergence of the personal computer contributed to creation of the "design of interface", a discipline that could consolidate the discussion on graphics (Moggridge, 2007).

Moreover, it is my claim, that to some degree, the cybernetics route when applied in earlier computer testing allowed to create a positivist view on machine effects. Feedback loops prevailed as a paradigm of analysis, which eventually might had lead to a determinist view on research results. In the beginning of the 80's the cybernetic heritage was the exclusion of the indeterminate human factors (qualitative) in evaluation of human-relation. However, the introduction of social sciences worked more as validations of the design, than to define problems. Typically, social methods were called at the end of design.

Indeed, traditionally, user centered-design in computer science research was observed from an expert view, considering the user as a subject, and interpreting results from outside. This approach is present in U.S. first experiences in human computer interaction. Typically, in the test environment the user is passive and to perform tasks, while the scientist make interpretations. Research is also dependent, and constrained considering market performance. Thus, the experience set-up determines results. Fallman describes this realm of action as Design Practice, one that has to convey to certain constrains, as to be commercial.

In conclusion, humanities could be said that are still excluded from the process of making and analyzing results. This said, if considering the timing where qualitative knowledge is included, not as an evaluation tools (as is the case with H.C.I.), but as a definer of problems to be addressed by technology. This is not typically happening.

For instance, Manovich, stated that H.C.I. as a disciplinary field, struggles between the aims of becoming consistent and being original (Manovich, 2003, p.91), revealing a tension between the need to evaluate results according to metrics, and being creative. Mikael Wilberg argues that H.C.I should operate not only as a complementary perspective. In Wiberg & all's perspective H.C.I. must move out from its human science comfort zones to embrace all ways of understanding humanity. For instance, H.C.I., could get insight from material dimensions (Wiberg, 2014).

Perspectives on H.C.I. are divergent and put forward as different programs. Bolter (2007) identified important divisions regarding intellectual interpretation on H.C.I., uses and purpose. These vary according to the field origin, regarding references and methods that comply to the source of inspiration.

According to Bolter (2007), for instance, H.C.I. specialists that study digital media in the context of work and social life, support their research in literature, cognitive science, as well as social sciences technics. Communication researchers rely on vast literature, using a combined empirical and theoretical approach, and analyze digital media in relation to traditional media. H.C.I. in the realm of applications and games design, get information from the most popular and accessible media theory. And, researchers that work in traditional entertainment, such as Television and Cinema, read new media theory that respect the transition between media of origin into a new media. Finally, digital artists, offer a mix, of theory, critique and practice, without a determined agenda (Bolter, 2007).

In conclusion, user computer evaluation is fundamentally connected to business and market behavior. As such H.C.I. main field of action is typically designed to operate for that context. Therefore, a homogenization in relation to systems analysis is expected, instead of designing for specific divergence. Digital art projects, following other traditions, don't depend of user evolution to exist. However, these are not competing models, but are in fact contextualized differently, and complementary.

Dourish and Bell concern is that, typically, U.C. is being developed in Computer Science departments that are far removed from this conscientious placing. In fact, there are consistent obstacles that refer to power relations, that are sourcing from the dominance from engineering and computer science in U.C. research. Dourish and Bell refer that these have direct implication in funding models, support from the industry, and peer review practices. On the other hand, considering openness to critical thinking, Dourish mentions that there is a "persistent confusion on the part of the dominant engineering community on quite what to do with critiques and analyses from other disciplines" (p.189). Popper, presented the non-performative character of social sciences, as the main feature that support this avoidance. Popper critique refer to the often obscurant technics in language within the humanities, while explaining concepts, as more concerned with peer review than social transformation, this becoming an impediment on this dialogue (2009).

Dourish and Bell further noticed that, there are competing narratives, in Academy and Industry regarding U.C. This is the real state of the art, on the attempt to adapt to the rapid digital changes and challenges of consumers, government, and industry.

Current market oriented research agendas designate the practice differently. Dourish and Bell (2014) overview observes that Philips uses the term "ambient intelligence" (Aarts and Marzano 2002; Aarts, Harwig, and Schuurmans 2001; Zelkha and Epstein 1998) IBM, "pervasive computing", and focuses in mobile devices, these being phones, cars and homes (Ark and Selker 1999), and Intel uses "proactive computing", focusing in machine learning, data processing, and algorithms as well as personal experiences with digital technologies (Tennenhouse 2000). In academia, U.C. agendas present for instance, the Aware Home Research Initiative at GeorgiaTech (Abowd et al. 2000), Project Oxygen (Rudolph 2001), Internet of Things (Gershenfeld, Krikorian, and Cohen 2004) at MIT, and Project Aura at Carnegie Mellon (Garlan et al. 2002) (as cited by Dourish and Bell).

Currently the internet of things is in European Commission's Information agenda, is evaluated reaching $520 billion business (Columbus, 2018), incentive to research.

As discussed, the opportunity to witness innovative and emerging trends in the field is there: in particular, the take routed by the Humanities, focused in Art. Addressing problems sourcing from the diversity of places and need conveys local expressiveness.

2.5.2 Art, Design and Architecture

Traditionally, computer science approach to interdisciplinary collaboration (which brought the social sciences methods to research) uses hard data as results, and addresses human as subjects. Under a social science centered approach, user testing as a topic has taken a different turn, which could be part of what called the Human Center Design perspective.

Currently, participatory design and co-design, initially developed in the Northern European Countries, makes a deeper understanding in incorporating of a horizontal approach to human subjects. Human beings are perceived at the same level of knowledge and to some point also as designers. The process aims to be inclusive and try to eliminate the tendency of research biases, promoting design solutions and innovation that stems from identifying a wide range of real problems.

However, there are some identified problems in this approach. According to Steen (2012) designers can sometimes push a personal agenda and have great difficulties with human centered design proposes, while considering the designer's role. As described by Steen, human center design is a *fragile encounter* between *self* and the *otherness.* When confronted with these options, designers might have a tendency for closure instead of openness and moving toward *self* instead of the *other*. This shows a factor of resistance of the expert point of view. Design culture promotes the cult of the genius as an academic talent recognition (Rodgers et all., 2013) to the example of same expectation found in science. They are under similar values validation pressures (Popper, 2009).

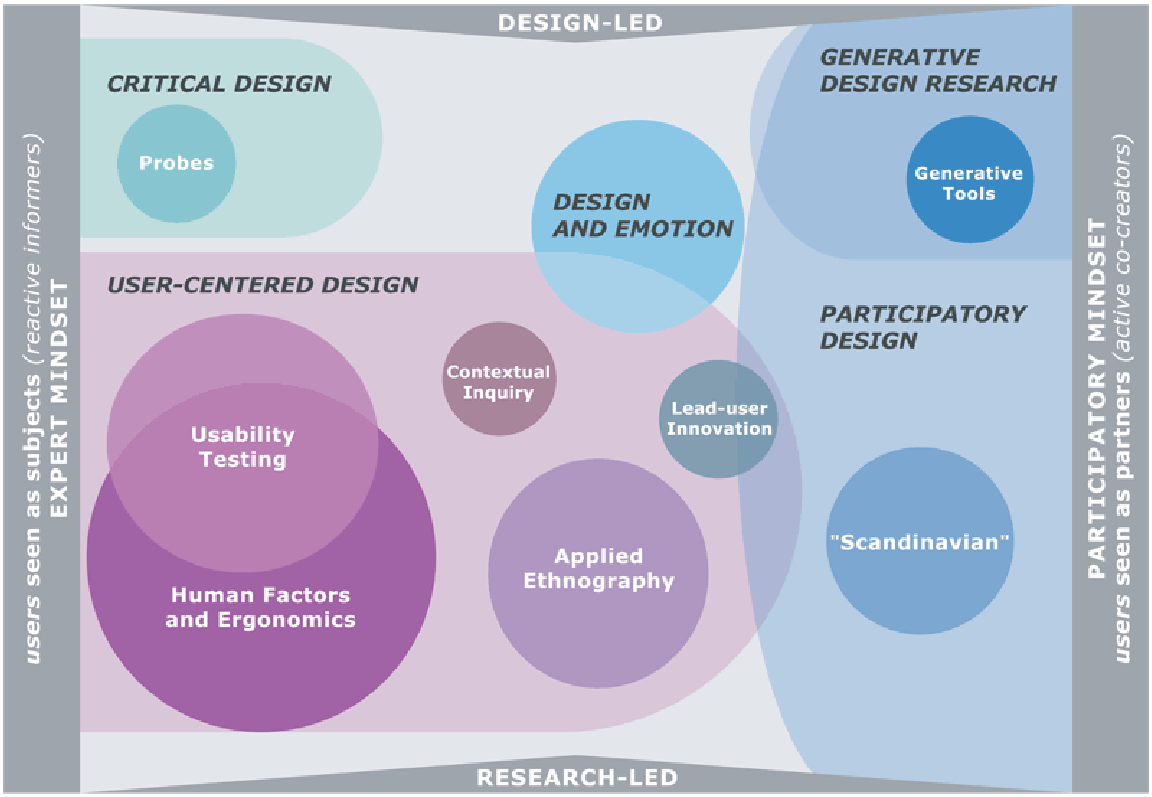

Figure 7. Sanders, E & Chan (2007) Emerging trends in design research.[pdf] retrieved from http://www.maketools.com/articles-papers/EmergingTrends1_Sanders_Chan_07.pdf

However, these tendencies on the expert view correlates with what art practice concerns, when discussing the concept of author or the current copyright discussion ("Creative Commons", 2017) but fundamentally reflect new definitions of design and acknowledge new relations with the other. This is, the other as potential collaborator.

Terms such as co-design, participatory design, design activism (Fuad-Luke, 2008) design for the future (Fry, 2009), reveal new concerns, and give awareness to social and environmental issues as design problems. Moreover, these thematic present major shifts on the perspective of the maker. The traditional expert view, that obliges to have a top-down approach to making is now confronted with proposals that frame a bottom-up approach, for instance, where people's (vernacular) knowledge or need is validated. Sanders (2013), a psychologist by training, proposes having a disciplinary dialogue, between organizations and people, while Manzini, coming from a design tradition background, address this sudden shift on the role of the designer, reframing it as becoming a trigger of change, a facilitator (Manzini, 2015).

Currently, design research territories are not consensual. In fact, it is fair to affirm that they are increasingly unstable. For instance, these can be presented as disperse and barely intercepting (Sanders & Chan, 2008, figure 7) or defined as going in a full intercepting loop trajectories between design meaning and other disciplinary fields (Fallman, 2008, figure 2), or even being in a total indiscipline and fragmentary moment (Bremner & Rogers, 2013). Sanders and Stappers (2013) presents their perspective on the state of the art on design using mapping. The diagram presents the discussed participatory design (which include generative process as tools), the user centered research (to which H.C.I. belongs), and further acknowledges distinct action in "critical design" and "design and emotion" bubbles.

Sanders and Stappers's model (Figure 7) reveal the user-centered design, as a big bubble, demonstrating that computer science environment includes usability testing. The map shows these developments with some overlap, but as an isolated area from other perspectives of design. Fallman (2008), on the other hand, coming from a computer sciences background, unifies making in a single term - design. The expectation is to have an interrelation between disciplinary areas, such as theory, practice and experimental. Typically disperse in action, they are presented in a dynamic interaction. Fallman (2008) refers to culture clash as an expectation, and Sanders and Stappers acknowledges the same issue and proposes models of resolution. In a very therapeutic manner, Sanders and Stappers considers that the problem relies on the solipsist perception on the role that each one has of his own discipline value in the world. Therefore, specialization is noted, as a cause and deliver of issues.

In the case of design, Buchanan (1995) adds some light to this permanent redefinition. Supported by a holistic and historic point of view, Buchanan presents how thinking and rationalization has significance in design manifestations in the world. Buchanan's analysis validates theory as having a fundamental role in practice, showing that it is not possible to design without being under some belief or theoretical framing. Consequently, each of the design placements have implications on the approach to making.

Specifically, Buchanan situates design origins in four moments: either with the creation of the universe, beginning of making, industrial revolution or the beginning of the twentieth century. Each of these placements will resonate in a different manifested design in the world. If design is contextualized with the creation of the universe, it is prone to relate to "intelligent design", framing possible correlations with mystical thinking (where sometimes Physics overlap); the second gives an anthropologic meaning to making, focusing in tools and artifacts; and the third and fourth placing relates design with creation of an autonomous discipline and the global market. Any of these origins determine an identity but simultaneously give an understanding to differences, not putting them in opposition, or under a hierarchical order value. For instance, an anthropological understanding of design gives room to include philosophical critique, and knowledge that arise from humanistic perspectives; while situating design on the rise of the industrial revolution puts design in direct relation to marketing and economics. Basically, Buchanan demonstrates that the concept of design is fluid.

Sanders refers to critical design, as another framework that situate apparent exclusive practices of design. Defined by Dunne and Raby at Royal College of Arts, this is the case of affirmative and critical design.

Dunne and Raby argue that when design is looked at as directly linked to marketing, can be designated as "affirmative design", and conform with cultural, social, technical and economical expectation. This would be the most common approach to design. "Critical design" gives room to create alternative views to these same social, cultural, technical or economic values, rejecting unique points of view (Dunne & Raby, 2001). Dunne and Raby (2001) claim that "critical design, or design that asks carefully crafted questions and makes us think, is just as difficult and just as important as design that solves problems or find answers" (p. 58), moreover "design proposals could be used as a medium to stimulate discussion and debate amongst designers, industry, and the public" (p. 65). These approaches tend to validate inclusiveness by considering multiple points of view as valid, instead to merely excluding each other.

Revisiting Sanders' map, becomes vivid the idea that the "User Centered Design" bubble depends of the market validation, thus being a case of "affirmative design". This is the framework where testing is relevant for market placement, while not being the exclusive perspective of design for contemporaneity. These are not presented as in competition, instead, they are contextualized differently, and potentially sourcing from each other.

According to Wahl and Baxter (2008) this dialogue contributes to a better definition on what transdisciplinary and collaboration could mean for design researchers and practitioners. In their perspective, the contextualization of a designer role offers a meta-perspective, which ultimately will be essential to creating holistic-integral perspectives.

As presented by Sanders, "Design and emotion", slightly intercept with "User Centered Design". Foster, alluded to this perspective on design, as Neo Futurism, this is, technology to the service of emotional relations with cities. The idea is to create a better urban quality of life, drive by eco-sustainability, ethical values, or using new materials.

Foster perspective was discussed in the context of 80's economical take, when referring to the rising "Telecommunity", the vast global network of networks, the merging of communications and computers (Foster, 1987), previewing a future relation between architecture and new media. The designated "neofuturism" acknowledges the circumstance where science is part of economic life, transcending limits between bodies, machines, nature and artifice (Foster, 1987).

Nowadays, after the liberation of the internet, digital media allows this project to become real. New architectonical categories have emerged, such as "robotic architecture" or "media façades", and public spaces are now regularly installed with art, conveying new concepts of enjoying the urban space.

Indeed, design for expression and emotion has spread to the multisensory. In what is allowed by technology, the aesthetical experience is no longer only focused on the visual senses, but also on the remaining sensorial realms: the haptic, audio, smell and taste. Design is covering the senses and being sensitive, in what has been labelled as "sensory design". But while new technologies mediate content, there is simultaneously, a proposed deceleration, as sensitivity to the expansion of senses as a design concern, is also to deal with the cognitive overload (Leone, 2017; Lehman, 2017). For instance, slow design, encourages a reduction on contemporary metabolisms, and suggest refocusing in serving basic human needs. Thus, designing for people, spaces to think, react, dream, and muse; balancing the local with the global and the social with the environmental; demystifying design, by re-awakening individual's own creative potential; and catalyzing social transformation towards a less materialistic, but fulfilling way of living (Fuad-Luke, 2002). For instance, taste, is one sense that is highlighted on what was defined as "Slow Food" design. This movement suggests looking at the simple pleasures of the aesthetical experience. In this case, returning to enjoying slow processes of manufacturing, and consumption of food. Thus, designing for active well-being and distributed economies with a local, connected, small and open scale (Manzini, 2007).

Design and emotion is a research route developed in Tu Delft University. One of the objectives regards the democratization of play, stimulating happiness and leisure enjoyment. Public spaces become canvas, arenas where projects can be playful, convey emotional experiences, beyond mere usefulness The interplay between play and knowledge, aims to design serving the creation of positive emotions (Caillois, 2001).

This is the purpose of the "emotional design" in the service of "smart cities". The availability of cumulative data, which is typically used in the context of monitoring and management can inspire design approaches. Data retrieval goes beyond what is manipulated on the screen (in fact data derives from the Latin, as something given), and is currently originated from common quotidian actions. But also, this data is directly created by people. For instance, Barela's analysis the tropes of culture, politics, economics, refers to the millennium generation use on memes for self-expression, as part of the overall circulation and production of information. The conclusion is that people are giving information willingly, perhaps following human beings desire to share (Barela, 2013).

The use of data as a material can serve the proposes of describing new ways to understand and design for cities. In fact, this is Information Age transitioning to the Experience Age. Innovative systems, driven by information and communication technologies, can become critical materials, in context of design exploration. These new projects can convey high levels of physical interaction and emotional involvement as design approaches.

Thus, "Responsive Cities" define urbanism as experience. In this scenery, emerging technologies merge with "design and emotion", a perspective that opens avenues for new paradigm of cities, as well as city-planning.

Cultural critics, as Hall Foster (2001) consider that the converging of playfulness with the liberal kind of subjectivity and culture, presents the erosion of hierarchies of culture. There is observable detachment from the once designated high, low culture and tech, kitsch and popular. However, there is still the need of having to provide culture with *Spielraum* (Foster, p.16). Foster comments, on the wholeness of the aesthetical experience as a factor of concern. In particular, the tendency for effects of *Gesantkunstwerk* (Foster, 2001). Now, there is a coincidence of intentions, as the hero of the modernism was the artist as engineer or the author as producer (Foster, 2001). And, for instance, opposition to total design, the "individuality expressed in every detail", has been source of Loos' critique in early modernism. However, for Foster there is one factor differentiating the new designer from the old modern: Art Noveau's designers resisted the effects of the industry, and there is not such resistance in contemporary design. In fact, "designers are delighted with post-industrial tech" (p.8).

Apparently, the convergence of need, market, art, with technological input is a constant expectation. And, nowadays, these same relations are in interplay. For, Gilles Lipovetsky (2013) the way that these relate, might be, a realm of permanent definition. In fact, the author notes that since the beginning of modernism, the infatuation of art with advertisement made this connection obvious. For Lipovetsky, the futurist and dadaists romance with the machine, consubstantiated in two pathways of art. One, an art-design link that is industry driven, and another, that created aesthetical discussions, criteria and terms of differentiation, coincidence and distance, in relation to economical values. Lipovetsky considered this to be phase two of design development. However, Lipovetsky highlights that during this period, commercial aspects of art are prevailing in both routes. According to the author, is only, after the end of modernism puritanical purposes, that a new time of emotional and diverse design emerges. Lipovetsky argues that now is a time of hybridization with art and economics.

Lipovetsky, assumes that "hybridization" of art and commerce is prevalent and current time is one of the democratization of art by economical means. For Lipovetsky art and commerce are incorporating, in a systematic way, the creative and the imaginary in sections of market consumerism. Furthermore, Lipovetsky considers that the aesthetic world is no longer a "niche sector" reserved for an elite. Instead, is a major value creator that has progressively caught attention from multinationals with considerable means. For instance, the typical exclusive realm of design, fashion and luxury, a world of placing of prestigious brands, have worked with contemporary artists. These collaborations are often seen as win-wins: for artists, these high-profile partnerships provide more exposure, and for fashion houses, having an "artist-in-residence" elevates their product above the High Street (Lipovetsky, 2013).

This is the realization of a random system of culture production, and of remixing. Despite all critique, as the prevailing economic wars continue (e.g. closed source open source tension), Lipovetsky assumes that the quarreling is creative. For instance, the author questions on how much, in fact, generative design was already influenced by some movements of technological democratization. And how much playfulness is reaching to a wider public with gamming.

Design and emotion aim to potentiate human well-being. Aligning emotions with the *other,* can be an useful requirement. Empathy (from *pathos*, passion in ancient greek), refers to when one feels the *other* emotional state, therefore, passions are shared. Steen, considers that a possible area for experiencing and potentiate empathy could be the market requirement (2012). In fact, considering that commerce is contact and communication, this place can be rethought, situating design as an ethical marketing discipline. This view is corroborated by Mike Hobday (2012), that argues that the historical and scientific based modern management, should be replaced, or at least, be rebalanced in favor of a creative, design-based approach to management.

This approach considers the market as a place that addresses the particularities of the *other* or *selfish* need. Other themes could range from cultural differences, social tensions, ethnicity, gender - male privilege -, environmental, handicap, inequity. This is to look at an open placement of creativity in the world. As such, if considering designing for positive emotions, contextualizing problems of the social and cultural nature, can use sensitivity and empathy as tools for the design of the future (Steen, 2012).

2.6 Experimental design

In current research the original concept "research through *techne"* situates the adopted methods between engineering and design (A.D.A.) . Collaboration between science and art in the realm of design has been addressed by several authors rising from both design and science tradition (Hall, 2011; Fallman, 2008; Laurel, 1993; Barret & Bolt, 2007; Key, 1987; Cross, 2008; Simon,1996)

Fallman describes design research separated by goals. In his case, these are commercial, theoretical, or exploratory realms. Experimental or exploratory design research is defined as a territory of design action: it relies on a specific methodology adopting common design methods.

Fallman adopts a model of interaction design research, defined in Umea Institute of Design, Sweden that includes practical design explorations as research. This research context connects common design methods to idealist, societal or subversive approaches, presented as a formal model. Indeed, offers a view in design exploration in close relation with critique within arts and humanities, and is a way to anticipate futures, where the possible can be formed.

The research model reinforces interfaces with other design territories, putting distinct disciplines in contact to originate interdisciplinary collaboration. This communication is a desirable process of experimental design.

According to Fallman, all territories of design share methods, technics and tools. However, one of the innovative aspects of the proposed model, concerns bridging perspectives on design action, without judgment. Therefore, resolving the resulting tension that traditionally arises from contact between them. Fallman assumes that these are activities that typically exclude each other, but, it is such contact, that can possible inspire novelty. Thus, instead of creating a mere difference, the territorial tension resolution, is a fundamental placement within design research.

Fallman (2008) suggests using three categories, conceptual movements, that illustrate the research process and might help in conflict resolution. First, "trajectories" makes the adopted design perspective visible. This allows to get information about stakeholders and quality measurements. Secondly, the concept of "loop" defines trajectories, which don't have "a beginning or an end", and essentially identifies freedom of movements between fields. Loops are notations used to think, plan, and explain these movements. The third category is "dimension" showing the outside take on the research outcome. This latter concept helps to visualize a continuum between different design fields. The dimension definition gives a holist view and ultimately the meaning of the research results.

The interactive design model proposed is a tool. The diagram visualizes design fields, that at first site might appear to be competing. The model allows to plan long term research, and to identify quality measurement according with a chosen design activity. Therefore, in terms of project evaluation, identifying adopted territories is part of the process that validates levels of success and satisfaction.

Comparing to other research models, such as Nigel Cross' or Friedman's, the inclusion of theory and the emphasis given to exploration is what stands out. These are presented at the same level of relevance. The inclusiveness of activity areas, and conceptual movements definitions (as back and forth) is distinctive from other research concerning designing interactive systems (Fallman, 2008).

Design explorations provides an interface towards society at large. Moreover, the author considers that there is power in materializing or "thingifying" one's ideas, sketches, and thought experiments into dynamic artifacts. The outcome, could whether or not turn out to be products, services, or spaces; or can communicate to academic groups and industry; or use whatever channels available, to become a voice in societal discussions and thus shaping the future (Fallman, 2008).

Ashley Hall (2011) concurs that creativity in industrial design depends on experimentation. This is a fundamental part of a design process, following actions such as imitation, differentiation, iteration, innovation, experimentation steps (Figure 8).

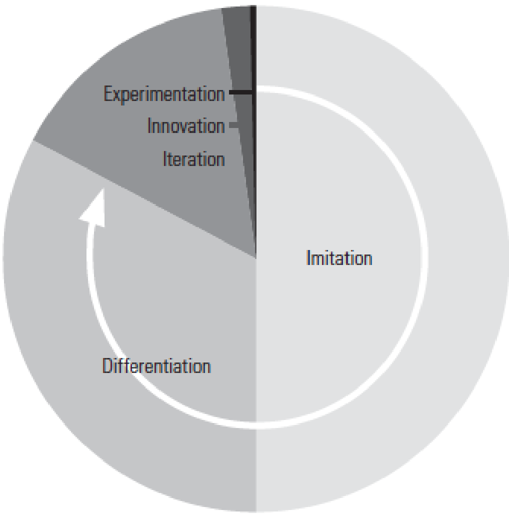

Figure 8. "How the world is made", retrieved from Hall, A. (2011) Experimental design: Design experimentation, *Design Issues*, volume 27, No. 2, p. 17

Technological and scientific developments are of high importance to experimental product development and market placement. According to Hall, there are e five-year phases of technological development to define these explorative products: first, in a five year period where the products are usually expensive and often in alpha or beta development format, a second phase, the product is in laboratories, and finally, projected to a time frame of 15 years. Experience in design would occur in the second phase, where it is possible to market innovation (Hall, 2011).

Ashley Hall (2011) argues that "design thinking" follows a model of parallel and interdisciplinary collaboration, combining science and design. However, he further states that the understanding of the experimental process is radically different between these two fields, having great implications on results and processes.

On one hand, science experimental process follows a linear, step-by-step model, building on previous knowledge and results. These experimentations, likewise, can be easily reproduced and validated, and are designed for that effect. On the other hand, design process is parallel, having experimental phases recombined and used throughout the process, and aims to have an original result. The reproduction of these results are not part of the process. Furthermore, design methods combine empirical and lateral approaches to decision making. In the author's perspective, to some degree, design methods recombine scientific approach to experimentation. This meaning, it relates to hard data and results, with a more abstract, soft experimental approach (Hall, 2011).

The addition of Ashley Hall (2011) methodology, taken from London's Royal College of Arts, with Fallman's model (2008), is observed to be complementary. Ashley's experimental method balances science and design approach to research (Figure 9). According to Ashley Hall, design studio based research will follow a practice as research method. It recombines traditional design methods, like sketching, scale modeling, materials studies, drawing, with inputs from scientific method (demonstrations, trials and testing results). The scientific, step-by-step model of experimentation will be applied to a step-by-step design projects driven to specific goals. This materialization of ideas in several projects answer to specific research questions.

In addition, the holistic approach gains another dimension: these small projects that answer to specific research questions can be followed independently, or not. The main objective of this practice as research, step-by-step projects outcomes, is to inform a stream of useful data to integrate in a final experimental project.

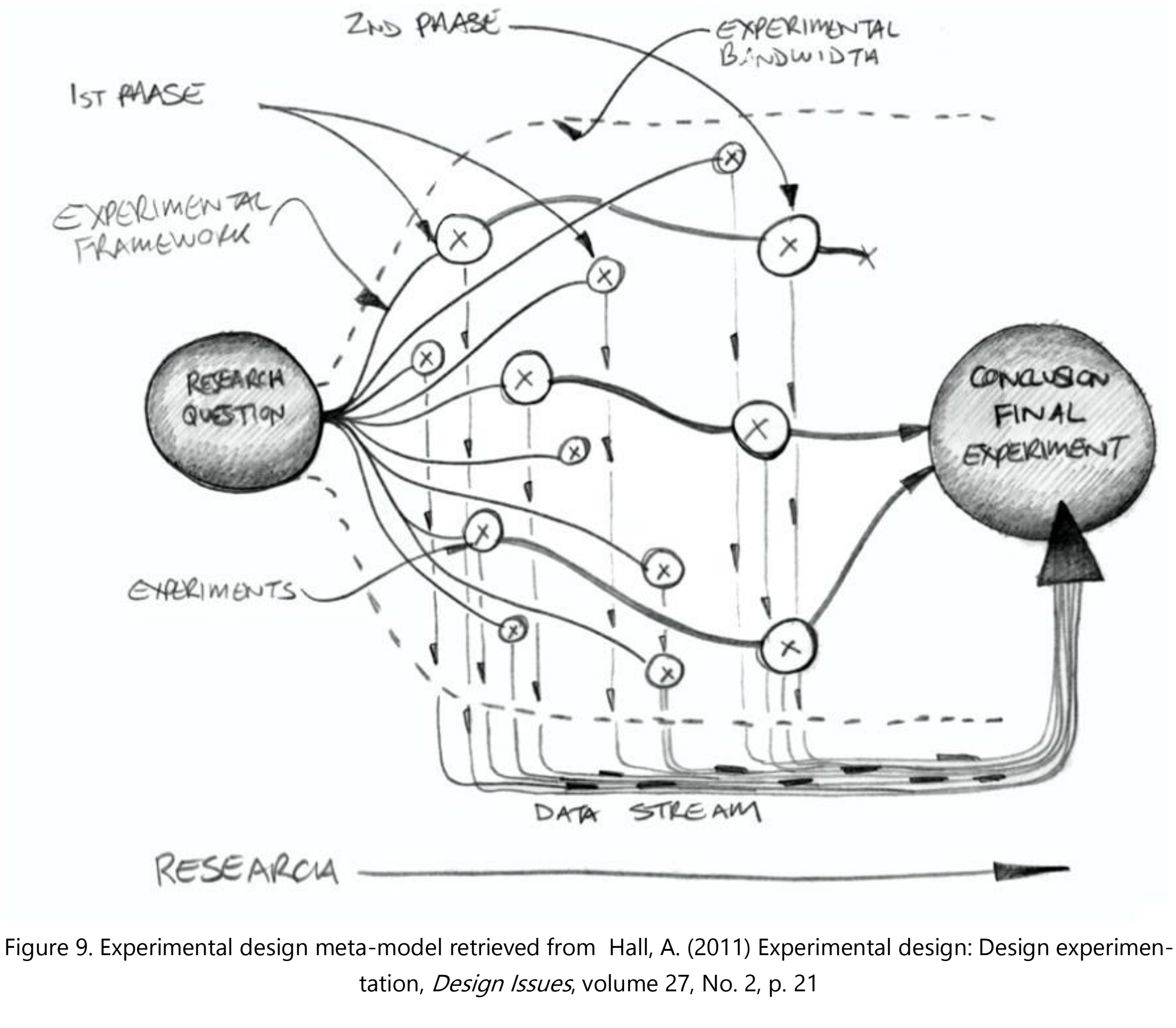

Figure 9. Experimental design meta-model retrieved from Hall, A. (2011) Experimental design: Design experimentation, *Design Issues*, volume 27, No. 2, p. 21

Both design and science based research have processes defined as an experimental method: scientists use laboratories to inquire; designers have studio based experimentation (Barret & Bolt, 2007). However, as much as these methods touch in purpose they can be fundamentally different. For instance, when pursuing collaboration, science and art based research tend to describe experimental process, purposes and the concept of innovation originality and knowledge contribution differently (Hall, 2011).

As stated by Hall one of the most important differences relates to the idea of innovation and experimentation. This translates in different practices, and attitudes concerning the idea of originality and associated ethical problems. While, results and demonstrations are important in engineering, the process exists to allow replicating results, and prove findings: copying is therefore a standard of proof. For instance, in engineering, patents wars are more prevalent. In design traditions, the process validates the design, thus the creative process validates originality. Therefore, the method is to be copied, instead of the replication of the result. However, Hall, notes how much copying/iteration is part of the process of innovation, this being, to learn about what is done, but also to find a specific incremental steps, that could be considered original. Hall argues that:

> "Iteration ensures that continual incremental improvements are made to enable increased performance and to keep pace with functional and technological developments. Innovation launches "new to the world" products, while experimentation sits at the very frontier of industrial output by proposing "future" offerings." (p. 17)

This comment resonated, with UT Design methods, fully acknowledging influences, and iteration as part of a process. As such precedents are assumed as influences, as part of a new body of work (described in state of the art chapter).

In sum, one of the purposes of this research is to first find, achieve and identify a hybridization of methods, demonstrated by prototyping. Moreover, following an experimental design, rationalization often comes at the end, and error, accidents, and constraints, become source of inspiration.

Specifically, current research blends methods like sketching, publishing, prototyping, addressing both the digital and physical experimentation (Buxton, 2007). This experimental methodology will build upon the definitions of skill (method) that can be described as *techne* – a broad perspective on the practical knowledge. Specific research questions are addressed, as cumulative data that informs the final experiment (Hall, 2001). Hall described this cumulative information as "data stream".

Thus, the experimental method adopted in current research mixes U.T. Austin design department methods, based in a pragmatic approach to design combining Fallman's, Hall's, Sanders', Buxton's, Laurel's, Steen's, described in full in the methods chapter. Further insight was gained in classes taken in Architecture, and School of Information, in UT, which contributed to finishing several prototypes and locating result in terms of (un)disciplinary territories. In conclusion, present research is a case of speculative design. It demonstrates a perspective of experimental Design in both fields of art and science, thus tackling ideology as a problem, and creating ground to an open and knowledgeable society by *techne*.

2.6.1 Evaluation

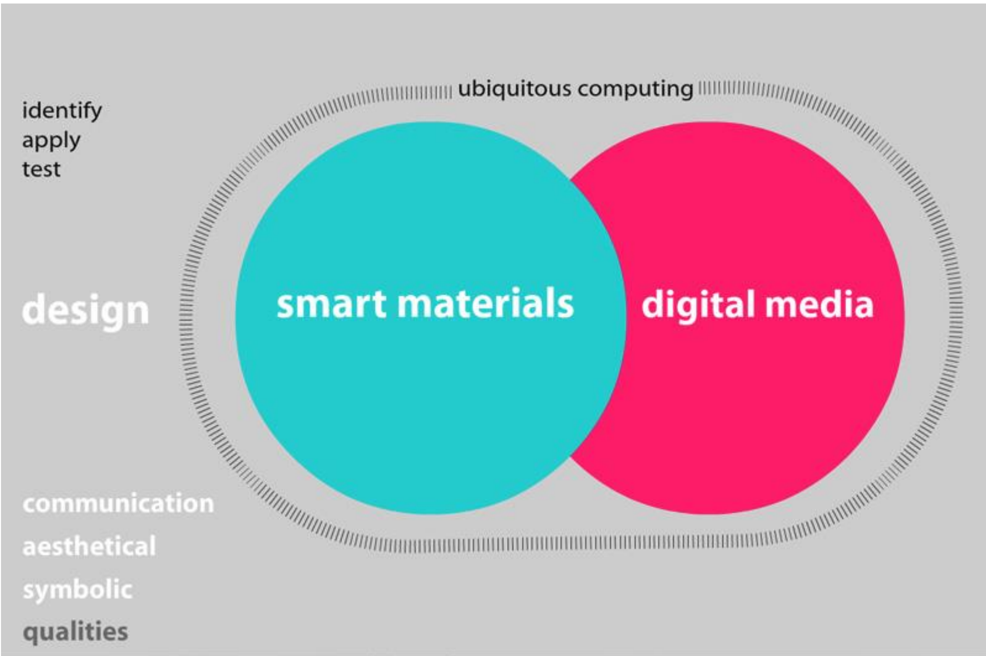

Figure 10. Research design broad objectives map, identify, apply and test, communication, aesthetical, symbolic qualities of (smart) materials and digital media within ubiquitous computing .

Current research adopts a speculative design approach. A set of pre-defined values drives the research into an ethical design. Latour (2008) describes a certain moral design that will beat the obscurity of the efficiency. In this case create a cross-disciplinary sustainable project, that responds to initial objectives.

The broad objectives can be framed by research map (Figure 10). They are to identify, apply and test, communication, aesthetical, symbolic qualities of (smart) materials and digital media within ubiquitous computing. And to consider the effectiveness of an interdisciplinary research.

Evaluations methods can reflect both disciplinary traditions within science and design. Under evaluation will be to what extend the final project, comply to the proposed objectives. But also the process that pursuits the inclusion of both traditions (science and design), and their definition on innovation. The synthesis defines what the ethical design for the future, combined with the idea of progress, could be. Ultimately making could work as a contribution to facilitate disciplinary transition. This would be one of the outcomes to achieve and be under evaluation.

Overall, the final analysis on the proposed prototype will depend on its performance. Here effectiveness (quantitative), the quality of response to defined schedule and design objective, and its aesthetic properties (qualitative) will be open to evaluation. Accordingly, achieving this qualitative versus quantitative analytical method would confirm if the main research questions were successfully answered by prototyping.

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" You never change things by fighting the existing reality.

To change something, build a new model that makes the existing model obsolete".

— Buckminster Fuller

2.7 Divining a sustainable future by *techne*

Divining the future persists on hunting mankind. In ancient Greece, divination played an important role in life and political decisions. At the Oracle of Delphi, dedicated to Apollo, the Pythias spend their life divining and answering pleas from Supplicants. "Pythia" was the name given to priestess, chosen for their psychic abilities, whose prophetic action lasted throughout the years that the Oracle was active. The prophecy was given through a Shamanistic ritual: a process that took time and involved both the supplicant as well as the Pythias.

As then, inaccessible, future is an incognita. And tackling one's future aims to control anxieties or find a sense of purpose. A s in Oracle of Delphi, the finitude that an answer grants, concentrates intense projections of imagination. Sorting this enigma is also to suggest.

In art, futuristic fictions have been summed by tales of a dystopian, or utopian nature. This divide presents emotional routes, with optimistic or pessimist outcome, giving light to a myriad of alternatives of science fiction and art genres. In the realm of science projections are also source of invention. Several scientific theoretical proposals are in fact fictions waiting to be proved. This is the case, for instance, of quantic physics superimposing fiction and a perspective of reality, when depicts hypotheses of time travel. In the past, the intuitive definition of the atom by Democritus, a mere fiction, was latter proved right, many centuries after it was imagined (Fara, 2009).

Thus, fiction has a fundamental role both in science and art, and might be the base ground of technological achievements. Dourish and Bell (2009) concurs, by claiming that "science fiction does not merely anticipate but actively shapes technological futures through its effect on the collective imagination" (p.1).

Dourish and Bell (2009) proposes to question to which extend the exposure to science fiction might, in fact, be limiting imagination of what is supposed to be designed. The authors refer to a techno-centric discourse, where Weiser's "dramatic computer" has the role of sociology and culture obscured. The authors are careful in acknowledging their non-expert condition regarding the science fiction genre. In fact, science fiction tales, convey a myriad of alternatives that extrapolate, mix, and overlaps several categories, as spirituality, society, and technology. For instance, the novel Solaris by the Polish author Stanisław Lem's, describes a planet that is a mysterious entity that can sense and perhaps manifest the dreams and anxieties of humans. Nevertheless, the authors clarify that the bases of their assumptions come from evaluating the objects that are presented in the science fiction visual culture, as is the case of cinema.

Dourish and Bell's argument asserts that "these questions are ones that arise not in the deployment of technologies but in the imagining of them – an imagining that arises before design" (pp.11, 12) and conclude that "cultural questions, then, are prior to, not consequent to, design practice (p.12)".

In sum, Dourish and Bell's critical view refers to implications on imagination of the future, and the impact that have in the present. Imagination is prior to materialization and as such is a critical moment that anticipates making. Therefore, if design results from what is imagined, the central question becomes, what are designer allowing themselves to imagine? For instance, do all designers dream with the same things? Where is the inspiration for desired innovation coming from?

Future-focused thinking inspired by science fiction have been discussed in the use of tools and conveying emerging technologies (Dourish & Bell, 2014) by Greenfield (2006), Bleecker (2009), Johnson (2011), and Lindsey & Coulton (2015). Indeed, methods sourcing on the genre have been designated as "science fiction prototyping" (Johnson, 2011), "speculative design" (Dunne & Raby, 2013; Auger, 2013) or "design fiction" (Lindley & Coulton, 2015, Sturdee, Coulton & Alexander, 2017).

Prototyping influenced by emergent technologies makes physical proof of such inspiration. As cited by Tiina Kymäläinen (2016) themes on practical research range from freewill (Egerton et al., 2011), transhumanism (Hales, 2011) or technological singularity (Callaghan, 2010). But the influence of science fiction on emerging technologies is also felt in in research areas such as Internet of Things, Ubiquitous computing (McCullagh, 2013; Kymäläinen, 2013b) intelligent environments (Kovalchuk, 2011; Kymalainen, 2013a) robotics (Johnson, 2009), augmented/virtual/mixed realities (Clarke & Lear, 2010; Ydreams, 2017), nano computing technologies (WU & Callaghan, 2011), brain-computer interfaces (Grian, 2011), natural language processing (Tassini, 2011).

2.7.1 Makers as problem

Nowadays oracles have complex issues to resolve. Perhaps the main difference from the ancient or even the early XX century avant-garde, is that nowadays, the dimension of problems and conscience of their impact is global. Nowadays problems range from the prevailing inequality, struggles with diversity and "otherness". These discussions find research focus interest within social sciences. One of the most superimposed pressures is to acknowledge that every one of these problems, happen in a world where resources are shortening. Under this scenery creating a sustainable future becomes basilar. Thus, solutions should combine a sustainable interplay between economics and technology.

Contemporary mythologies, storytelling and foresight reflect anxiety concerning economic and technological merging. From intelligent machines taking control of humanity, to the re-telling of Biblical myths of arcs of salvation, the narratives of doom are prevalent. Escaping from the apocalypse has two only options depending of human action. The map points either to getting out of the planet, versus, staying in the "spaceship Earth" and taking care of it. These perspectives are often presented as mutually exclusive point of views.

Technological hecatomb originating an unsustainable planet Earth, can be to a certain degree, associated to another continuation of an eternal tendency of imagining the near end of the world. The biblical tale of Noa of the big flood, is a Judaic-Christian hecatomb story, that is itself a retelling of a Mesopotamian tale (Gilgamesh). These recurrences reveal that this anxiety is something prevalent in human nature. However, one of the most important aspects of storytelling is that it imagines the future, this is, the narrative is part of the process of design. Thus, to oppose these manifestations of pessimism, design can serve an alternative, by imagining, and desiring to overcome fear, following an optimistic route.

Either way, the plans expecting a dystopia or utopic future, as a graspable next chapter, have a common factor: advancing will depend on *techne*. Thus, reiterating the continuity with Latin-Greek culture perception of *techne* (described in 1.1.).

Regarding the perception of time, the category apparently moving human beings into the future, further insight can be gathered from ancient wisdom. Ancient Latin-Greek culture discussed time as being circular, as opposed to what appears to be linear. The linear better future that is undertone of the ideology of eternal progress, and creator of an expectation that seams undisputable, is by beholding ancient believes somehow evaporating as a fact. The concept of circular time is simultaneously, a tool for questioning *techne* as permanent enhancement.

Carl Sagan (1985) subscribes the same notion of time by referencing Hinduism, noting a mystical coincidence between science and religion. Sagan considered that Hindu cosmology offered the best description of creation, by conveying the idea of cycles of time repetition, similar to scientific speculations on the origins and the future of the universe. Also, Oxman (2010) highlights that the nature way is sustainable for eons. Therefore, it is human being relationship with nature that is problematic. The evidence is that civilization is threaten by civilization. Indeed, a new geological age, the Anthropocene was popularized by Crutzen (2006) referring to the definitive physical transformation of the planet Earth by humans.

In ancient time the notion of cosmos is a more prevalent notion, as an organization that is opposed to chaos. Cosmos means acknowledging an order that differs from chaos. The discussion about the future of *techne*, cannot deny, that the cosmos still is the timeless, while the human that organize ideas, and imagine the cosmos is the transient. The only threatened element by *techne*'s outcomes are the makers, not the Cosmos. The eternal cycles will continue without Human beings.

For makers, revisiting Latin-Greek tradition is rewarding by finding that *techne* is inherently human. However, the ever-optimistic views on the powers of science, that trust in a progressive way of *techne* to always solving problems, can be problematic. As Popper advanced, this vision is in part, a fiction that projects an idea of science as a new religion, and that always achieving the good (Popper, 2009), serving as a spiritual guaranty. The problem resides in having the expectation for science, as an abstract entity, to project salvation. This view is shared with the *hubris* of makers, which are not in sync with the notion of need, but on the assumption of the domain of nature. Ultimately, this perspective on science gives all responsibility to scientists to solve problems created by their own action, and to consider ethics.

In fact, state of the art science is used in war objects. This is an often overlooked issue regarding design history. For instance, Papanek was denied presenting a gun, as an object of design, in a context of design exhibition. Nevertheless, the invisibility of design for violence and unease to which is met, has been started to be regarded. Design and Violence in MoMA exhibition, curated by Paola Antonelli considers the history of violence as part of design's. Four different themes — "Hack," "Control," "Trace," and "Annihilate" tackle the act of destruction as a double-edged sword, and surprising, with consequences intended and unintended. Antonelli refers that this project goes beyond on the dominant voices that give perception to design, as strictly being read under commercial and aesthetic success. These projects demonstrate how design can address, sensible issues, conveying new territories of action.

Antonelli by documenting objects of war and aggression as design presents *techne* full discloser. To some degree, this visibility suggests an inquiring on the state of the art science. In fact, if it could be directed to nurturing as efficiently, as to destruct. This has been the perspective that Fuller's body of work aspired to achieve when dealing with war technology. Following Fuller, the persistence on a sustainable agenda, can be thought to predict results upon civilization. And fully acknowledging the creative potential of science. In sum, to some degree, starting by being aware of the notion of scale, and de(limitation) of their application.

2.7.2 *Techne* as solution

As Fuller anticipated (Fuller & McHale 1963; Fuller, B. R., 1964, Fuller, B. R., 1982),either way, future survival on or outside Earth, are now literally in the hands of makers. The novelty is only apparent, as the shape of things has always been dependent of *techne* as was in the past. Indeed, Earth unsustainability, have designers to blame and to be made responsible. Designer Victor Papanek (1971) corroborated this view with a critique:

> "There are professions more harmful than industrial design, but only a very few... by creating whole new species of permanent garbage to clutter up the

> landscape, and by choosing materials and processes that pollute the air we breathe, designers have become a dangerous breed…
> In this age of mass production when everything must be planned and designed, design has become the most powerful tool with which man shapes his tools and environments (and, by extension, society and himself). This demands high social and moral responsibility from the designer." (Papanek, 1971, p. ix)

Since Papanek presented his insight on design practice, four decades have passed. Back in 1971, this perspective was already consequence of an increasing awareness to the globalized environment crisis that started in the 60's. The same concern has moved Buckminster Fuller that "as early as the 1920's took the view that the earth was a closed system of finite resources, and the job of the designer was to reallocate those resources." (Hall, 2011, p.3)

Victor Margolin comparing Papanek's to Fuller's perspectives, concludes that while the first based design thinking in the low-tech approach to design, validating wisdom of indigenous peoples, in contrast, Fuller advocated the use of the most advanced levels of technology applied to systems as well as in objects (Margolin, 1998). Fallan (2014) further argues that Fuller considered the use of high-tech solutions to elevate the standard of living for all and could profit from the military-industrial complex.

Indeed, Fuller design suggestions and projects both covers technology as well as human need. This was the case of "Fuller's Dymaxion projection of the earth, made of 14 segments that could be rearranged to privilege a variety of views of the earth, minimizing distortion, also indicates the importance of information visualization to systems-based design" (Hall, 2011, p.3). This patented map, offer a view on the planet without a political center.

Fallan (2014) sustains, that under todays light, except for Papanek, Fuller and a few other critics and visionaries the sustainability discussion within design lacks studies of a broader scope. Designers have not been able to envision a professional practice outside of the consumer culture. As Margolin notes (1998), Papanek's view was always marginal, and design continued to have the market as the only viable outcome.

Tony Fry (2008) corroborates on the persistence of the problem. Fry's evaluation criticizes current role of designers, which lack "a sense of how design makes or breaks worlds "(pp. 25–26). Currently, sustainability lies often within the realm of technology (p. 199) and even though some designers engage in sustainability issues, the result often is that "the unsustainable gets sustained" (p. 53) due to the designer's limited understanding of consequences (p. 121) and lack of accountability (p. 26). Fry's critique introduces a sense of tech illiteracy, in relation to economics, or even history of tech as a problem. For instance, technological illiteracy can be the cause of an unawareness on e-waste caused by digital media (Slade, 2007). In fact, digital media is all but immaterial. But how can a designer/ engineer engage critically their action either including or not this discussion?

Techne practitioners, either being engineers or designers, are by training taught to make, and expected to innovate. The challenge is to be disruptive, inventive, and to contribute to a body of knowledge. As discussed in Chapter 2.4. disruptive and innovation pressure is expected in the engineering research. While in design, originality is pursued, benefiting from a contact with soft sciences. However, both makers are expected to serve the market inside of that follows an economical paradigm. For instance, to apply the product life cycle, which is the euphemism for the planned obsolescence.

Planned obsolescence means technologically or even deliberated planned to fail, aiming to put new product replacements in the market. Markus Krajewski, professor of media studies at the University of Basel, in Switzerland, discusses programed obsolescence when first introduced by the Phoebus committee in 1924. These were the first regulators of the lifetime of an object, in this case, the light bolt efficiency (Krajewski, 2014). In fact, the Shelby Ohio lampbolt, in use for 100 years, demonstrate how a product could work under the concept of technological full efficiency.

Obsolescence can be directed either to a technological or aesthetical features. To some degree even force engineers and designers to redefine values of what "good design" and efficiency could exactly be considering this economical requirement. However, the aspect of obsolescence that relates to aesthetics (styling) or technological features, has the fad and the boredom of quotidian life as a motivating factor. The activation of excitement by the new is a fact of life. It cannot be contradicted that is a system that incites creativity and promotes human ingenuity.

However, a look into the original problem that obsolescence was trying to solve can trigger some insight. Following the great recession of 1929, Bernard London, first described planned obsolescence as an economical solution to put products in circulation, as such:

> "After the allotted time had expired, these things would be legally "dead" and would be controlled by the duly appointed governmental agency and destroyed if there is widespread unemployment. New products would constantly be pouring forth from the factories and marketplaces, to take the place of the obsolete, and the wheels of industry would be kept going and employment regularized and assured for the masses." (London, 1932, p.6)

From London´s proposal, stands out the idea of death of the object, and a sequential treatment. Thus, it can be asked, when an object dies, where does it go? Considering that designing, testing, acquiring the new, is part of human ingenuity, where are the governmental agencies to destroy objects as suggested by London**?** Can destruction of objects be obliged to be part of a design project?

Considering original definition on planned obsolescence, the proposal of systems of destruction is as important as creation. Moreover, instead of planned to fail London seems to suggest planned to die. This is a concept adding a new gear to his proposed system. Nowadays biodegradable materials are self-destructing, and might allow this plan to be implemented. In fact, planned obsolescence can be focused with planning to rebirth, or transition. These questions illustrate paradigms that sketch principles of a “circular economy".

Designers and engineers are taught in Academia techniques to address economical demand by briefing, and working for a market definition of need. And attempts to introduce eco design values have fallen systemically under a minority stand. For years, these attempts were dismissed as political agendas, or delusional readings of the economic reality. This is an allusion to continuous growth as the base of the economical movement of the late century, that is prevalent today. However, the contradiction of terms only now appears be demonstrated by visible damage. Contradiction resides in realizing that this continuous growth is not possible, considering the planet resources being finite.

This is an argument for reflection on economics. Reinterpretation on the use of cycles of matter that are part of nature resources, and of the circulation of Energy, can make the key tone fall on the circulation of materials and energy renewal. This is one of the underlining definitions of “circular economy “model that is put forward as an alternative view with implication on the design practice and industry.

2.7.3 Sustaining and nurturing

The sustainable agenda give to makers, as a base of production of applied concepts, responsibility. Furthermore, the lack of environmentally friendly behavior, extend responsibility to people. This observes sustainability as a problem that is profoundly social.

Having to some degree the guilt attributed, sustainability problematics can assume a moral character. For Latour (2011) this moralist approach seems to aspire to an happy return to the sublime admiration of nature, where, again Human beings, could be morally superior to the magnificent destructive capacity of nature.

However, Latour (2011) puts the moralist standing somehow slightly dissolving when accounting the scientist view in relation to common people. This is “one disconnect we don't have to share: we don't have on one side the scientists benefitting from a globally complete view of the globe and, on the other, the poor ordinary citizen with a “limited local” view. There are only local views” (p.6). Despite the cosmopolitan tone that science aspires to have, the scientist is also local.

Latour (2011) undertakes a critique to the moral standing by observing daily life. That is, for him it is in fact useless to be an activist trying to shame the ordinary citizen, for not being aware or thinking globally enough, or having a feel of Earth. “No one sees the Earth globally and no one sees an ecological system from Nowhere, the scientist no more than the citizen, the farmer or the ecologist —or, least we forget, the earthworm (p.6, 7)”.

As a concept, localism, is part of the discourse of emergent discipline “transition design” (Tonkinwise & Irwin, 2015) aspiring to discuss the transformation of design research at

Carnegie Mellon University (2015). Engagement with social and environmental concerns, build upon the redefinition of design discipline, as “design for service,” and “design for social innovation”. These culminate in the latter vision of “design for transition” situating design according to contemporary imperative. Concepts like “Futuring” postulates that radically new ideas and compelling visions of sustainable futures are needed. Connected, for instance, with “cosmopolitan localism” (Sachs, 1999), give focus to the emerging scenario of the small, local, open and connected space aiming to tackle issues of a global scale, with local resources. (Manzini, 2015).

On the subject Tony Fry (2008) offer other solutions. For Fry there is the need to consider convergence, and to register a specific mind-set. Fry’s first suggestion is to cut loose from developmental capital logic of perpetual growth; but still recognizing the unavoidability of the dialectic of sustainment (meaning that entropy/ unsustainability/ destruction are unavoidable); but fundamentally register that our being is finite and that our collective existence is directly related to the sustainability of our future actions.

Peter Hall (2011) comments on the practical effects that such critic have on designers when confronted with sustainable pressure. Hall observe that designers are often in an internal struggle with the voice of conformity, regarding two conceptions of design. One related with the appropriation of ethics and its application, and another related to a personal project of self-transformation. For Hall the imperative is in retelling the story of design, in order to ease this struggle, forming complex ideas, that that “negotiate between seemingly conflicting interests (e.g., capital versus human need)” (p.2). This meaning reformulating an apparent identity related with a unique view of the discipline.

“Material Ecocriticism” might offer a contribution to such a project. As a concept proposes to act in a post-ideological world, where an historical account would relate objects and tech with people. This is one of the key- points of the “material turn”, distant from postmodern and post-structuralist thinking that puts forward a “dematerialized” world of linguistic and social constructions (Iovino & Oppermann, 2012) As such, presents cultural theory reflecting on insights taken from natural sciences and politic economy. In addition, considers a relation of thinkers influenced by the Actor-Network Theory, quantum epistemologies, and authors that constructively deal with matter (Deleuze, Foucault). Finally questions the boundaries of agency, in order to rework the human–nonhuman mutual “infiltrations” in ways that take into account matter's ”inherent creativity” (De Landa,2000, p.16)

For makers, the rationale behind a circular economy offer inspiration and ground some basilar concepts. Indeed, Margolin (2002) considers that the question posed to designers is to widen design’s traditional sphere of action from manufacture to a more proactive involvement with the problematíque of the Club of Rome other groups who are concerned with the world situation (p.89).

The sustainable agenda, has since the 70's applied the concept of waste hierarchy. Political agendas implemented the tree Rs policies, putting forward campaigns that proposed to reduce, reuse, recycle, defining recycling, as a derisible behavior. In the context of makers, upcycling, reacts to this idea, proposing a shift on the point of view. Upcycling proposes to have a pro-active attitude, this is, to reuse products or materials creating a product of higher quality or value than the original. One of the example of upcycling, is *taskchair, evolve*, (Figure 11) by designer Lindsey Culpepper (2012), resulting from research Project at University of Texas Austin Design. In this case, new furniture is created by repurposing existing chair bases.

Figure 11. *Taskchair, evolve* by designer Lindsey Culpepper (2012). *Design and the Qualities of Craft*, MA report, University of Texas, Austin

Biosphere's rules inspired Unruh to propose "materials parsimony" as a desirable requirement into design practices. For Unruh, nature manufactures products that are fundamentally nontoxic displaying a wide range of sustainable materials, and part of renewable value cycles. Mirroring nature, making the selection of materials a priority, combined with a model of perfect efficiency is a feasible outcome of design concern (2010).

Sustainable practical design research has been inspired by visions and several solutions. Fabrizio Ceschin and Idil Gaziulusoy (2016) present a systematic analysis into the specific take on Design approaches for Sustainability. The authors present a systematic critique on contributions and also limitation on these models. Potential future research directions are also observed. The authors situate an evolutionary review starting in the 90's, discussing the concept of "green design", finalizing in contemporary proposals on "Design for System Innovations and Transitions".

Approach, focus & main contributors	Limitations	Potential future research directions
PRODUCT INNOVATION LEVEL		
green design Lowering environmental impact through redesigning individual qualities of individual products ***Burall (1991); Mackenzie (1997); Fiksel (1996)***	**Lacks** depth, promotes green consumerism (Madge, 1997); Focuses on single-issues therefore does not provide significant environmental gain.	Exploring potential synergies with other approaches
ecodesign Lowering environmental impact focusing on the whole life-cycle of products from extraction of raw materials to final disposal ***Tischner and Charter (2001);*** ***Binswanger (2001)*** ***Brezet and van Hamel (1997);***	**Lacks** complexity, focuses only on environmental problems and disregards problems which cannot be accounted for in life-cycle assessments (Gaziulusoy, 2015); Associated efficiency gains did not resolve the impact due to ever increasing consumption, has a technical perspective with a limited attention to the human related aspects (e.g. user behaviour in the use phase) (Ryan 2002; 2003; 2013a; Bhamra, Lilley and Tang, 2011).	Exploring potential synergies with other approaches
Emotionally Durable Design (EDD) Strengthening and extending in time the emotional attachment between the user and the product ***Van Hinte (2007);*** ***Mugge et al. (2005);*** ***Chapman (2005);***	It is particularly challenging to effectively stimulate product-attachment: the same product can generate different meanings and different degrees of attachment on different individuals (Mugge, 2007); Product attachment determinants are less relevant for some product categories (e.g. utilitarian products) (Mugge et al. 2005);	Undertake studies exploring product attachment during the whole lifespan of a product (Mugge, 2007); Test the effectiveness of EDD strategies in different product categories; -Investigate the role of culture and user values in product attachment (Mugge, 2007).

Mugge (2007)	For some product categories extending longevity beyond a certain point might not be environmentally beneficial (Vezzoli and Manzini, 2008); Manufacturers might be averse to implement product attachment strategies because this might lead to reduce sales (Mugge et al. 2005).	
Design for Sustainable Behaviour (DfSB) Making people to adopt a desired sustainable behaviour and abandon an unwanted unsustainable behaviour *Lilley (2009); Lockton, Harrison and Stanton (2010); Bhamra, Lilley and Tang (2011)*	**Ethical implications** of applying DfSB (who is entitled to drive user behaviour?) (Brey, 2006; Bhamra, Lilley and Tang, 2011); **Lack of metrics** to measure the effect of DfSB strategies and a lack of evidence based examples (Niedderer et al. 2014); **Business stakeholders** might not be incentivised in implementing DfSB strategies because this might not be counterbalanced by financial gains (Lilley, 2009; Niedderer et al. 2014).	Development of assessment metrics and techniques for analysing and evaluating of DfSB cases (Niedderer et al. 2014); Test the effectiveness of DfSB strategies (Niedderer et al. 2014); Develop a more accessible language and tools for professionals (Niedderer et al. 2014).
Cradle-to-Cradle Design (CTC) Emphasis on a regenerative approach by the industry and closing the loops; focus on non-human species and future generations *McDonough and Braungart (2002)*	These emphases remain at a **rhetorical level** and, despite its inspiring vision, CTC **design is technically not well justified** (Bakker et al., 2010; Gaziulusoy, 2015).	Improving its underlying assumptions; Exploring synergies with other approaches.
Biomimicry Design (BM) Mimicking nature in design of forms, products and systems by using nature as model, measure and mentor *Benyus (2002)*	Claiming that innovation resulting from mimicking nature is sustainable is misleading (Volstad and Boks, 2012) for isolating a principle, structure or process from nature and imitating it does not necessarily yield to sustainability (Reap, Baumeister and Bras, 2005); Technologically-optimistic (Gaziulusoy, 2015)	Improving its underlying assumptions; Exploring synergies with other approaches
Design for the Base of the Pyramid (DfBoP) Improving the lives of people who live at the base of the	Targeting the poor as consumers has raised criticisms: in particular, moral dilemma that BoP approaches do not differentiate between satisfying	Better explore the application of Product-Service System design to the BoP (Ceschin et al. 2015).

pyramid through market-based solutions *Kandachar et al. (2009); Jagtap and Kandachar (2010); Gomez Castillo et al. (2012); Jagtap et al. (2013)*	essential needs and offering non-essential goods (Karnani, 2007; Oosterlaken, 2008; Jaiswal, 2008).	
PRODUCT-SERVICE SYSTEM INNOVATION LEVEL		
Product-Service System design *PSS design for eco-efficiency:* design of product-service propositions where the economic and competitive interest of the providers continuously seeks environmentally beneficial new solutions. ***Brezet et al. (2001); Manzini et al. (2001); UNEP (2002); Tukker and Tischner (2006)*** *PSS design for sustainability:* as above, but integrating also the socio-ethical dimension of sustainability. ***Vezzoli (2010); Vezzoli et al. (2014)*** *PSS design for the Bottom of the Pyramid:* as above, but applied to the BoP. ***UNEP (2009); Moe and Boks (2010); Schafer et al. (2011); Jagtap and Larsson (2013)***	Not all PSSs result in environmentally beneficial solutions (UNEP, 2002); PSS changes could generate unwanted environmental rebound effects (e.g. increase in transportation impacts) (UNEP, 2002); PSSs (especially in the B2C sector) are difficult to be implemented and brought to the mainstream because they challenge existing customers' habits (cultural barriers), companies' organizations (corporate barriers) and regulative frameworks (regulative barriers) (Vezzoli et al. 2015).	Better understand what factors influence user satisfaction, as well as how to measure and evaluate this satisfaction (Vezzoli et al. 2015); Develop a deeper understanding on the process of introduction and diffusion of sustainable PSSs, and how this can be designed, managed and oriented (Vezzoli et al. 2015); Identify effective strategies to transfer PSS design knowledge and know-how from research centres and universities to companies and designers (Vezzoli et al. 2015).
SPATIO-SOCIAL INNOVATION LEVEL		
Design for Social Innovation Assisting with conception, development and scaling-up of social innovation ***Manzini (2007);*** ***Manzini (2014);*** ***Meroni (2007)***	Criticisms have been raised about the **naiveté of designers proposing superficial solutions** and high cost of design services (Hillgren et al., 2011); A sole focus on social innovation is not likely to achieve the levels of change required in large socio-technical systems meeting society's energy, mobility or housing/ infrastructure needs.	Further explore the role of designers in social innovation processes, particularly in replication and scaling-up (Jégou and Manzini, 2008; Manzini and Rizzo, 2011; Hillgren et al., 2011); Develop social innovation toolkits (e.g. Murray, Caulier-Grice and Mulgan, 2010);

		Research about how to **change professional culture and improve design education to support social innovation.**
Systemic Design Designing locally-based productive systems in which waste from one productive process becomes input to other processes. ***Bistagnino (2009, 2011); Barbero and Toso (2010)***	The approach is mainly focused on the production aspects, without addressing the issue of reducing individual consumption **(Gaziulusoy, 2015).**	Exploring synergies with other approaches.
SOCIO-TECHNICAL SYSTEM INNOVATION LEVEL		
Design for System Innovations and Transitions Transformation of socio-technical systems through (strategic) design ***Ceschin (2012); Gaziulusoy (2010); Joore (2010); Irwin et Al. (2015)***	Too "big picture" and need to be supported by approaches that focus on development of products and services that can be part of new socio-technical systems.	Developing theoretical insights and practical tools to linking micro-innovation with macro-innovation; Investigating how other DfS approaches can support design for system innovations and transitions.

Table 2. *Retrieved from* Fabrizio Ceschin and Idil Gaziulusoy (2016) Evolution of design for sustainability: From product design to design for system innovations and transitions*, Design Studies 47*

Fabrizio Ceschin and Idil Gaziulusoy analysis demonstrates that the sustainable agenda often raise tension. An extended network of interests, beliefs systems, or even life-styles, can be the cause of reaction, rational or emotional, against implementation of measurements that comply with a balance relation between economics and nature. Environmental need and design, are in fact better defined as a wicked problem (Rittel, 1972).

Social interdependencies emerge as a great challenge: user habits that are reflected in everyday work, and consumption practices, as well as sociotechnical systems, such as road transit, energy system, technology interlinkages, standards, massive sunk costs, legislation have tight interlinked dependencies (Schot & Geels, 2008; Hoogma et al., 2002). Attempts to change, are often met with observable resistance strategies (Shove, 2012).

Latour (2011) further adds observing the disconnection between people, scale and need. For the author, "there is no path leading from my changing the light bulbs in my home straight to the Earth's destiny" and further ask: "All assemblages need intermediaries: satellites, sensors, mathematical formulae, and climate models, to be sure, but also nation states, NGOs, consciousness, morality and responsibility. Can this lesson of assembly be followed? "(p.7)

A clear definition of choice between responsibility or morality versus fun, and lifestyle somehow, raises unquestionable cynicism and resistance. Changes are often associated with loss of freedom. However, are these really a disjunction?

Margolin thinks that designers can have a major role through the art of demonstration to reconcile the best aspects of the sustainability and expansion models. For Magolin, this could be a fruitful contribution to be made. Address the wicked problem that the threaten life on Planet Earth entails is to be part of the design prospecting futures. (Margolin, 2002).

An example tackling the wicked problem was put forward by Thackara (2017). The author vision on the "next" economy is based in small projects around the world, and addressing habits and needs of daily life such as moving, eating, clothing. For Thackara, people are not waiting for a big idea or even to part of a movement to do stuff. In fact, people are continuously doing things to meet needs on daily life. As such sustainable solutions are happening around the world. Thackara vision, includes the periphery in the equation and as part of the solution (Thackara, J., 2017).

Lipovetsky (2013) offers, yet, another a point of view. In this author perspective art integrates a new ethical dimension - the respect for the environment or the sustainable development - but without renouncing the aesthetical dimension (hedonism, ludism, beauty, image, and creativity) as a consumer logic. As in Fuller's anticipatory design proposed, this transition can be made through science revolution (Fuller, 1963; 1964; 1982). Current state of the art scientific development might have the potential to be added to the equation, as source for reconnection on these apparent disjunctions.

2.8 Chapter Synthesis

2.8.1 Research through *techne*

The concept "Research through *techne*" offers a perspective on practical research that synchronizes art and science. The adopted point of view refers to indiscipline of knowledge. It also describes digital media influence on the dissipation of disciplines. "Research through *techne*" formulate a design-engineering research perspective.

2.8.2 Interdisciplinary research

Interdisciplinary is a required condition for innovation, including an empirical (hands-on) approach. These relations are relevant when the purpose is to create a prototype, an invention. However, problems arise when designing, in fact, without territory. As such, assuming this lack of territory, action is defined from a philosophical framework. As put forward by Fallman charting a navigation by applying concepts of mapping, allows to define a research route (Figure 4). Furthermore, the multitude of disciplinary understandings, critical points of view, approaches, requires defining a strategy, which is routed in preliminary considerations.

Proposing to make a "new media", this is, a physical outcome out of research, follows preliminary considerations such as:

- use of practical **synchrony** of **A.D.A.** and **scientific methods**, resulting from a combination of materials studies, and step by step projects
- do a **deconstruction of ideologies**, and design beyond and despite them
- identify **fields** of action
- use **synchronous** process of thinking and making
- pursuit a **disciplinary discontinuity**, inspired by new technologies
- focus on the concept of **skill as knowledge**.

2.8.3 Ubiquitous Computing and Design

The initial challenge is driven by addressing U.C., which has greater development in the fields of science. This choice assumes this as one of the most exciting contemporaneous inspirations to take on design. As such, sourcing inspiration from design might be one perspective on computing that is vital to survey, anticipating that this option might bring contributions for both field of studies.

Moreover, following Weiser's suggestion on research within U.C., personal experience is assumed as factor that might, and should influence research on computing. In this case, complementary research at social and hard sciences universities (FCSH UNL, FCT UNL), allowed to convey prototyping routed by humanities and art. Ultimately, the challenge was achieve an "human-to-human interaction", inspired prototype; In particular, human-to-human relation pertains designing invisible media. The approach followed speculative prototyping.

To answer to this call, the "material turn" research in U.C. discusses the reification of computing as hybridization – of the physical and digital - but fundamentally consolidates a relation with several disciplinary perspectives and culture(s) of materiality (e.g. high tech, low tech). Furthermore, opens perspective to incorporate knowledge acquired by disciplines as architecture, art or design, which are fundamental when considering intelligent environments or traditional materials.

As such designing the future of computation is also taking a look into the past, or heritage. Or as Dourish suggests, consider the [...] "importance of holy landscapes, storyscapes, ecoscapes, and other ways of understanding the relationship between the land and cultural practice." (p. 200) But, in addition introduces Bolter's concept of remediation, revealing *technê* (making/ skills/ knowledge) as continuity, and much more of repetition of contents and strategies of visibility, than absolute novelty (Bolter, 2000).

Thus, incorporation of socio-cultural considerations in the realm of high tech materials is to serve them with communication (symbolic) values. And, as Dourish realized, and as defined by Weiser, defining problems having cultural-social considerations would be fundamental for the scope of UC making/practice. However, they might be at miss. In other words, it is a desirable outcome, and a concern of present research (Dourish, 2011, Weiser, 1994).

Designing for future generations starts in by speculating solutions, and projects in the now. Therefore, creating under sustainable parameters is a guiding beacon.

2.8.4 **Sustainable strategy**

2.8.4.1. "Materials turn" in ecology

The "materials turn" in ecology and digital media contribute with three basilar ideas to design: first, they contrast with theories of immateriality (the virtual) of media, second, they focus in sustainable material choices while inventing new technology objects, and finally, tackle the product life cycle. This is, create durable design practices conveying circular economy principles.

2.8.4.2. Adopted strategies

2.8.4.2.1."Materials parsimony" (Unruh, 2010), means choosing materials having sustainable new materials and traditional materials (e.g **case of cork)**, for high tech proposals. Materials that die, this is change state (e.g. biodegrable electronics). Thus using *techne* combining **natural materials with engineered materials**

2.8.4.2.2."Hybridization" as design experiments (Hall, 2013), originality might be achieved from cultural hybridity, for instance from connecting high tech to low tech. But also mixing on the qualitative and quantitative methods.

2.8.4.2.3. "Glocalization" (Hall, 2013) and the concept of "cosmopolitan localism" tackles sustainability as global problem, defining it as a local problem, involving social-economical factors. Remixing concepts drawn simultaneously on local and global (e.g. cork.) introduce the role of Global cities (Sassen, 2005) as hubs for distribution of ideas (e.g. Lisbon, Porto).

2.8.4.2.4. Focusing on "Energy efficiency" of a system.

2.8.4.2.5. Tackling the concept of product life cycle, anticipating the "death and rebirth of the technological object". In the case of current approach, concerns, are related to creating emotional durable design strategies. Add narratives, that put these materials to rest or are revitalized, following the premise "evolve me and I will change"

2.8.4.2.6. in sum, materials are the source of inquiry conveying U.C. research. Designing considering Portuguese Industry offer further grounding. This contextualization allows, simultaneously to comply to the notion of cosmopolitan localism when considering sustainable practices.

3

METHODOLOGY: PRACTICE AS RESEARCH

3.1 Experimental Materials Studies: inquiry through play

The method proposed in UT Austin Design Department suggested to contact with materials of choice, and to perform experimental transformations. The material studies were described to be a mediation between the hand and tangible materials. The proposal was to experiment with a material through a non-goal oriented investigation that provides the opportunity to "think without thinking" (Olsen & Lee, 2011).

These experimental studies were required to be done with a suspension of judgment and a detachment from concepts. The purpose was to design without history.

In this Spielraum of design, every fault, insecurity, error, could be manifested without expectation of judgment. The hands on contact with materials would become joyful and a without a priori criteria, premise or initial purpose. An a posteriori rationalization is suggested to be made through critique studio environment, where ideas, would be openly shared between every student and professors.

As such, materials were the starting point for a hands-on exploration. This is a bottom-up experience, where meaning was absent, and the form / informal setting of contact with materials was emphasized. Latter, a proposal created by hybridization of materials was pursued.

3.1.1 Biodegradable materials

3.1.1.1 Paper

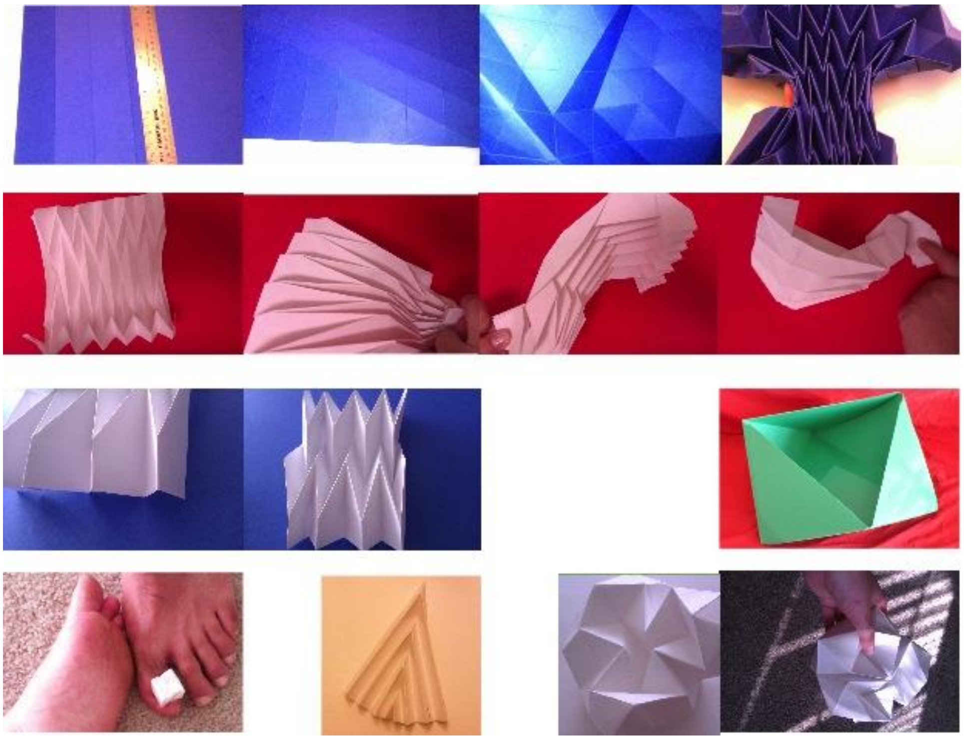


Figure 12. Playing with paper: origami

3.1.1.2 Edible materials

Figure 13. Playing with food, as ink, as lettering

3.1.1.3 Cork

Figure 14. Playing with cork: as structures, textures, cork powder ink

3.1.2 Smart Materials

3.1.2.1 Shape memory alloys: flexinol

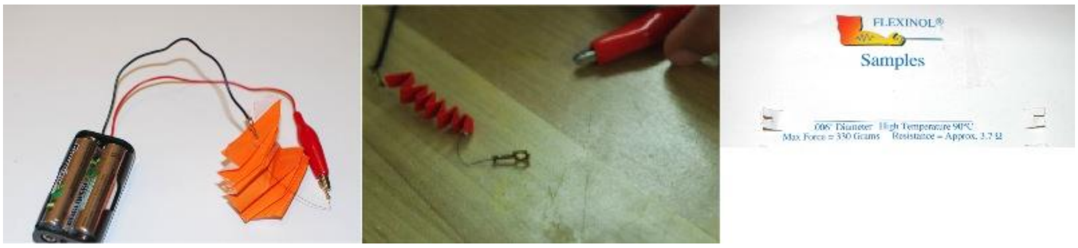


Figure 15. Playing with SMAs and paper

3.1.2.2 Smart Ink: thermocromic/hydrochromic

Figure 16. Playing with color changing as information

3.1.3 Hybrids

A second phase of experimental research took the shape of hybrids (Olsen & Lee, 2011). As such, results from open experimentation, where combined between them, but given light to a more structured outcome. As such, for instance structural studies with straws were now inspired by Buckminster Fuller dome, by testing the tensile properties of triangles in the context of a surface design.

But also first combinations of crafts and bits where tested. As such PELE project, an computer vision project, had transmutations from digital to physical in printing in several materials (plexiglass, textile, wood) (Figure 17), as to considers first test on inking. Latter, the same project was tested with thermochromic inks and digital fabrication. In addition, experimentation with cork and flexinol made the pieces of cork move (Figure 19) (Paiva, 2022a).

3.1.3.1 Crafts and bits

Figure 17. Hybrid (left to right): digital interactive application, silkprint on plexiglass, textile and wood

3.1.3.2 Structural studies

Figure 18. Hybrid: triangular structures, hard and soft wire with plastic

3.1.3.3 Cork and SMAs

Figure 19. Hybrid: Playing with cork and flexinol

3.1.3.4 Origami nad beet

Figure 20. Hybrid: Playing with beet ink on paper folding

3.1.3.5 Thermochromic ink and wood

Figure 21. Hybrid: testing thermocromic ink on wood

3.1.4 Conclusions

These explorations suggested the use of techniques such as sowing, cooking, ink fabrication to new techniques such as digital fabrication. The approach adopted was hands-on experience, conveying experimentation between science and art materials. In conclusion, materials studies allow to progressively convey symbolic meaning. In particular to initiate and imagine criteria, part of a responsive surface, as is the case of cork and flexinol.

3.2 CitySkin, a mobile data visualization tool.

Figure 22. Driving 60 minutes, CitySkin image output

This chapter discusses an experimental mobile application named CitySkin. The application uses mobile phones for data retrieval and mapping, to design an invisible skin of a city (an output map) following a user journey at a given moment in time. The project explores relations between subjectivity and raw data by combining hard data with visual mapping. Cities and their intrinsic diversity can be compared. Slightly different input variables can present greater changes in a recurrent path. CitySkin records the mood of a specific dérive and prompts consideration of the cultural implications of computing and the design of its ubiquity

3.2.1 Introduction

The concept of Ubiquitous Computing (U.C.) aims to create "a calm computing" achieved by having computer disappear (Weiser and Brown, 1996). his is made possible through the integration of computing in the built environment. It is argued that U.C offers a perspective that emphasizes human and social aspects, presenting computation as an open definition (Denning, 2011) challenging its terms, significance and appearance.

U.C. discussion translates into projects that combine research and life. For instances, contributions can be observed given by the progressive miniaturization of sensors and actuators, as to the exploration of smart materials (Coelho and Zigelbaum, 2010) but also by applying natural structures to design (Oxman, 2010) as well as Maeda's bits, atoms and crafts (Maeda, 2018). These relations inspire hybrids of form and nature. Moreover, some authors (Kim, 2010) argue that we are fully living in a U.C. era, considering that this ubiquity of computation is made real with the use smartphones.

The CitySkin research project acknowledges this last statement and aims to contribute with a proposal that tackles the hybridization of art with science.

In the last decade, mobile phones have become a common tool for communication in both post-industrialized (Castells et al., 2009) and developing countries. When analyzing the spread of mobile phones use in a globalized world, a significant factor in their appearance is the emotional tie and social connectivity given by a personal object. But on the other hand, the inequity regarding access to different mobile phone features, and quality network coverage are definitive factors that differentiate audiences. It is relevant to say that smartphones are still a "first world" tool, which translates to contextualize CitySkin in terms of accessibility.

Smartphones are tools that combine computing, mobility, and mapping possibilities. Beyond having an exponential computing power, smartphones commonly have features such as WI-FI, 4G and 5G network connectivity, GPS, accelerometers and high quality cameras. These particular features offer a realm of possible combinations.

The CitySkin project, addresses consequences of digitalization of information and big data. Tools such as smartphones have created an exponential ability to collect and store massive amounts of information. On one hand, this information generation has highlighted the need to improve its readability. The exponential growth of information has found in graphic visualization a model to simplify the interpretation of data complexity. Data visualization not only improves reading, it creates rich aesthetic experiences, adding new perspectives to visual and cultural discussion while conveying digital information. All these solutions have been made possible by mutual contributions arising from computer science and art. Examples of these prevailing collaborations can be found in current definition of design made by institutions such as NY MoMA, in the Design and the Elastic Mind or Talk To Me exhibitions (MoMA, 2011) commissioned by Antonelli or in the Linz's Ars Electronica (Ars electronica, 2017) a festival where, since the 70's, science and art collaboration is discussed and celebrated. Data Visualization is also a prevailing visual experience distributed in Internet under several categories and by a myriad of authors.

CitySkin's conceptual design is inspired by these approaches and uses computation to measure and visualize routes inside the city. It references mapping, data visualization, and digital art critique (Crampton, 2009, Tufte, 2006, Hall, 2006) but also makes a contribution to the shifting concepts of computing. Cityskin visualizes to hard data by tracking a literal and psychogeographic journey, considering human subjectivity, in an implicit invitation for dérive, surprise and improvisation (Debord, 1958)

3.2.2 Related Work

A background to this work in experimental mobile applications is to be found in the context of digital art. Since the beginning of the public internet, terms like "internet art" attributed to extended nomadic networks have emerged and have been explored by digital artists. In this context, the particular designation of "software art", described work that referenced formal outputs given by computational instructions.

Since the 90's, artists like Golan Levin have created interactive software that allowed the manipulation of visuals and sounds in real time. Telesymphony project extends Golan's work to nomadic devices. Sound is generated by the ringtones of audience's mobile devices (Paul, 2008).

Mapping became an excellent conceptual tool to understand and cope with urban landscape information. Considering U.C. and Data Visualization strategies, cities that dwell at the interchange of massive quantities of information, are becoming progressively U-Cities (Hwang, 2010), meaning Ubiquitous Cities. MIT SENSEable City Lab ("MIT Senseable City Lab", 2018) has contributed to U-Cities research with several projects. One of these projects, Trash Track ("trash track", 2018) attaches sensors to discarded objects and maps their national and international journeys. The output map gives awareness to the existence of long trails, as opposed to a more efficient proximity system, indicating waste of resources in an immediate way. Projects like Pedro Cruz's Lisbon blood vessels (Cruz, 2016), uses veins in circulatory system as a metaphor to visualize, with aesthetic appeal, Lisbon's traffic flow. This method can also give real-time valuable information to drivers.

A growing number of designers and researchers are using data visualization techniques for artistic expression, but also the particular features on mobile phones as survey machines. GPS, wi-fi, embedded camera, computation, in addition to mobility, are presently used and mixed in different approaches. MobiSpray by Jürgen Scheible, for example, uses mobile phones as an artistic tool to paint digital graffiti. Scheible created a client server application that uses mobiles as gesture-control (Scheible, 2009). Mobiles are used as pointing mechanisms drawing on a video-projection, thus, creating digital public art. Large scale drawing using mobile devices is another example of GPS being used for artistic expression, and a concept presented by several artists ("gpsdrawing", 2018).

Travelling inside a city deals with relations between time and space, i.e. geography, time measurement and a less obvious category, a degree of fun. Enjoyment is addressed by Mark Shepard's experimental mobile application Serendipitor (Shepard, 2011), and Atau Tanaka and Petra Gemeinboeck in "Net derives" (Tanaka and Petra, 2006). Serendipitor is part of a broader project, Sentient City, which tackles with design of the city of the future. Serendipitor is part of a broader project, Sentient City, which tackles the design of the city of the future through an i-Phone application that invites the user to explore different paths in a city map. It calculates alternative ways to get to a particular part of the city, with inherent proposals to diverge. "Net derive", also follows the concept of the dérive (adapted from the post-war situationist practice), transforming the city in an instrument. Mobile phones, using GPS position, camera and microphone, exchange information between spectators in a gallery and three participants in the streets of a city. Sounds and pictures from the streets become information to visualize and sonificate locations.

Finally, two experimental mobile applications from Japanese company Aircord, show how playfulness can be aesthetically relevant and simple (Aircord, 2018). The first virtual free runner is an animated man who reacts to the accelerometer with a tap to jump button, to be used with a projector.

3.2.3 Design Principles

3.2.3.1 Art concept

Describing time visually has been a concern with clear practical implications in human life since Ancient times. Current time measurements have implicit computations based in sky observations. It is relevant to investigate history of science and math. These time divisions originated from complex computations made in the beginning of civilization, 4000 years ago, in Mesopotamia. Surviving Babylonians' clay tablets records show cumulative data from sky observations that throughout time allowed predicting celestial phenomenon with precision. For instance, it was an ancient civilization that gave 7 days of the week.

Figure 23. Part of a clay tablet, 3 pieces, Neo-Assyrian. A copy of the so-called venus Tablet of Ammisaduqa (detail) The British Museum, retrieved from https://www.britishmuseum.org/research/collection_online/collection_object_details.aspx?objectId=314745&partId=1

The number seven had a mystical significance to Babylonians. It was associated with the seven heavenly bodies: the sun, Mars, Mercury, Jupiter, Venus and Saturn. As such, the measurements of the week that are still in use today are based in astronomical observations made in ancient past.

Mesopotamians were great mathematicians and created a 60 base system, which allowed defining the sixty minutes in the hour, and the 360 degrees of the circle (Fara, 2009). The Sexagesimal system is useful to measure angles, geographic coordinates, and time. Mesopotamian representation of time was created from a circle division, having different attributions to year, month and day. These divisions of time were also based in astronomical observations. For instance, the month division correlates with the observation of the moon. To some extent, and considering some alterations, this system created by ancient mathematicians is still used embedded in our high tech life, and use in the apps in our mobiles phones.

This historical background provides an understanding of the cultural implications of time division, but also indicates a clear relation to direct observation of natural elements. These divisions depend on interpretation and record of celestial moving objects and therefore have an implicit design (Figure 23).

CitySkin is also inspired by the convention of time measurement that relies on observation. Using mobile cameras as a metaphor of the eye, and giving direct relation with geographic space, by GPS location recording, CitySkin provides visual maps of travels that connect locations and time. It uses a predefined computational model (based in the number 60 as a direct quote of Babylonian measurements). The result is a graphic map that will give an impression of a particular city at a given time.

3.2.3.2 Prototyping

The prototyping studies for CitySkin began by physically travelling the city by car, and defining a path. First trial was a crossing over Tagus River, from the South bank, the city of Almada, to Lisbon, in the North Bank (Figure 24). The journey took 44 minutes.

Figure 24. Prototyping Journey

Throughout this journey, one photo was taken roughly each of the 44 minutes using a mobile phone.

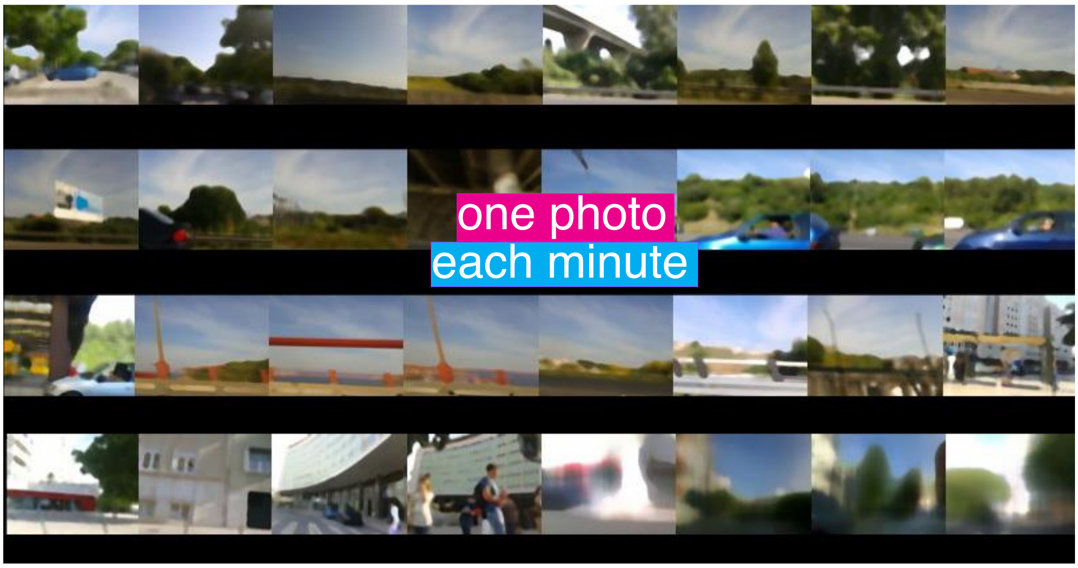


Figure 25. Prototyping: taking one photo each minute

These photos were used to output map studies, by stretching, adding filters, and searching for a visual result that was focused on color. Mainly, achieving a map of colors predominance within a specific trip (Figure 26, Figure 27).

Figure 26. Output color map number1 test using photos from figure 25

Figure 27. Output color map number1 test using photos from figure 25

3.2.3.3 Design

The application design follows the prototyping results. The final graphic map (skin) results from photos taken during an up to 60-minute journey, by foot or in a vehicle. Cityskin takes a photo each minute and has its location recorded. The difference between position A and B will define the velocity and this value determines each photo final length (

Figure 28, Figure 29). A median filter is applied to each photo, in order to emphasize color, and its length is compressed or stretched according to the velocity variables. These images are lined horizontally, and a white space is kept between them. The white space adds readability to each picture, but also becomes an editable input text space.

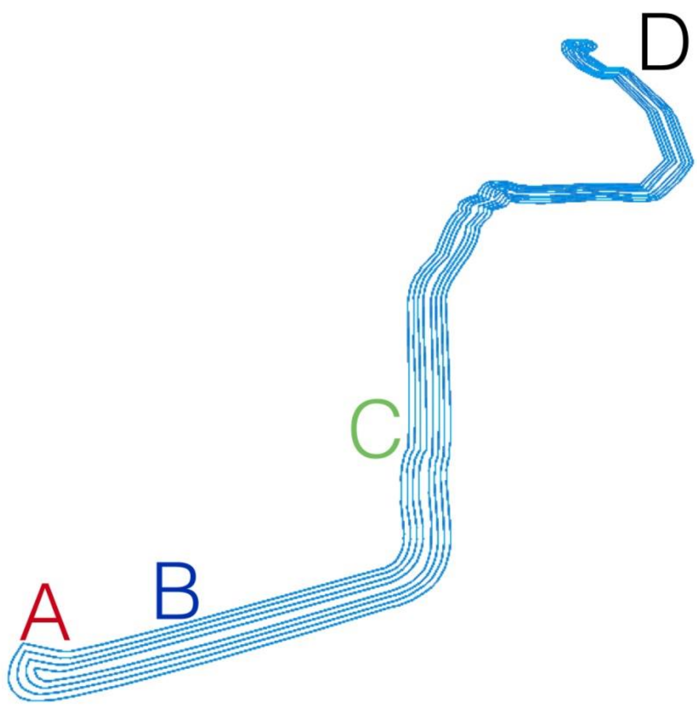


Figure 28. Example of a route diagram: relation between time, velocity and location. A-B, B-C, C-D, are distances travelled during a minute.

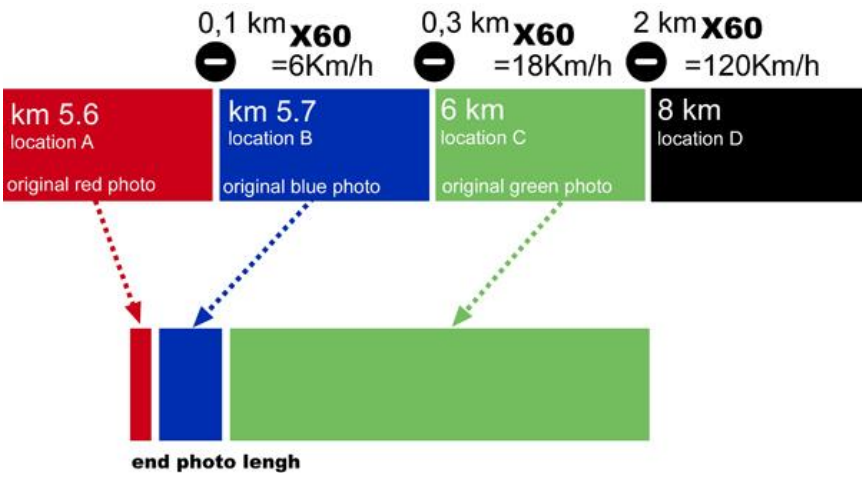


Figure 29. Image length computation

GPS coordinates are presented as default text between stripes. The users are allowed to substitute this geographic information by editing their own text labeling in each white line (Figure 30). The final map results from a representation of hard data and open variables related to movement and color – visual impressions, time, type of transportation and user input.

The final map will be presented as a stripe of colors, showing long stripes when the user is moving faster, and narrower stripes when the user is moving slower.

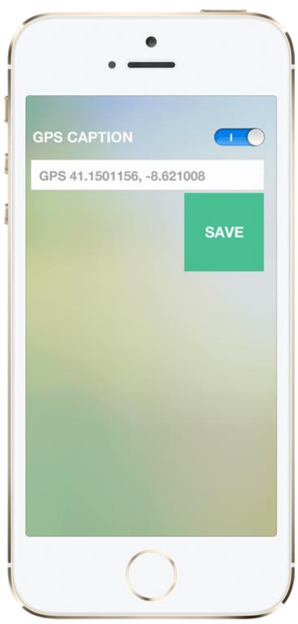


Figure 30. U.I. input text screen

3.2.3.4 Technology

The first implementation test was made for iOS. CitySkin output corresponds to a single JPG image file (Figure 22), containing the GPS coordinates of each of the images captured, with photos taken each minute. The final image directly represents the path taken by the user, synthesizing the user perspective and the particular variables associated to the travel.

This final skin output can be shared. The jpg format image is aimed to either be published in socials networks or sent via e-mail.

3.2.3.5 Designing relations

3.2.3.5.1 Objective: derive

Quotidian journeys are often a routine experience where landscapes blur into oblivion. CitySkin can provide insights about different layers of perception, and a singular perspective on a common urban status. The application invites the user to find different maps around the known but also unknown places.

The measurement method is inspired by Babylonian direct observation of celestial phenomena. As such, Cityskin is offering an interpretation on data given from visual cues. CitySkin can visualize and find interesting differences, coincidence or patterns on journey maps.

It becomes possible to compare visuals from different cities, but also to compare the subjective variables given by an individual journey. These changes can be given by time spent in different locations, or even provoked by the user's imagination.

CitySkin was designed considering that identical paths would provide completely different maps accordingly to the use, emphasizing the differences around the experience found in routine.

3.2.3.5.2 Sharing images

Figure 31. User Interface: share screen

One of the main features of the CitySkin application (Figure 31) is the ability for users to share outputs. This feature is designed to support a ritual of communication, this being, according to Mikko Villi (2010) often more important than the photographic quality itself. Also, it has been noticed that photo sharing rituals are followed by text message practices, i.e. often images do not substitute texting.

CitySkin combines image and texting possibilities, and opens directions and opportunity for experimentation concerning the combined use of jpg images and texting, as a common way of communication.

3.2.4 Algorithm flowchart

CitySkin's algorithm is presented by the flowchart (Fig.32). The start menu allows to access to an information button. The application suggests to answer to the question of "what color is your city?". The next screen offers the possibility to choose between "walk" or "drive". This allows users to adapt an average velocity, for either scenario. The application will then start taking a photo each minute. During the process it is possible to edit a CitySkin´s GPS position by text, and return back to the picture taking mode. The process can be stopped at any time. At this point, it is possible to share or restart. Sharing allows one to save to the phone gallery, social media, or go back. The button "save to website" is drawn and refers to future work, but is not yet implemented.

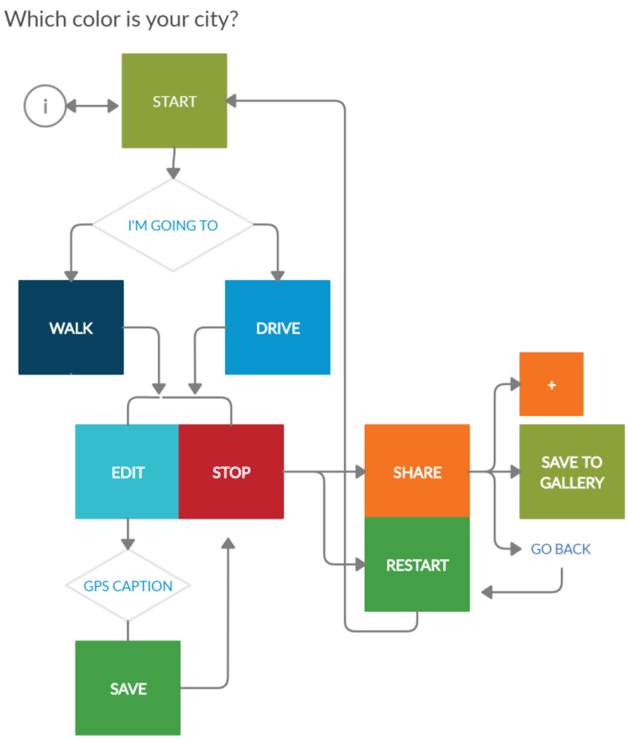


Figure 32. Algorithm Flowchart

3.2.5 Issues and Solutions

3.2.5.1 Human variables and algorithm

CitySkin's visual variations depend on velocity, which determines each stripe picture's length. This variation, however, brought the necessity to distinguish walking from a vehicle journey, as velocity has implications in the final design (Figure 33). Accessing two different algorithms solved the issue with the user input determining velocity, either walking or travelling in a vehicle.

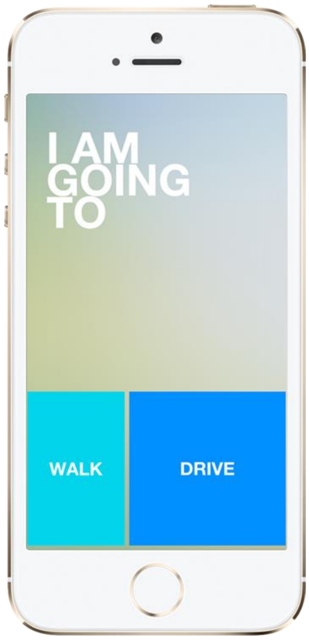


Figure 33. U.I. drive or walk screen

3.2.5.2 Identifying location

CitySkin's computation depends on a correct identification of location (Fig. 34), using GPS by default. It was noted that GPS referential location has problems. It is common for mobile phones to lose their signal indoors, making GPS based projects only suitable for outdoors. The lack of accuracy is also observable.

CitySkin invites users to test the application in fair conditions. When that is impossible, the geographic information can be manually inputted as referenced. In the absence of the user labelling, CitySkin will use an average measurement.

Figure 34. GPS default graphic aspect – CitySkin in Helsinki (GPS: 60.173294, 24.936304)

3.2.6 Future Work

CitySkin is a work-in-progress project. Next steps will include system evaluation aiming to refine the user experience. Also, after the initial iOS prototype, it will be made accessible to other platforms, such as Android and Windows. Also we aim to integrate the distribution of Cityskin's output in the website.

3.2.7 Conclusion

The Cityskin project tests relations between computation and art, acknowledging the incremental step toward computational ubiquity allowed by mobile phones. Ubiquitous Computing is addressed by this application, considering the city's intelligence. In a broad sense the project proposes to test playfulness and a sense of discovery, thus, giving focus on the user experience. The project also aims to challenge the dominant discourse of the "smart city", with its tendency toward quantitative data (traffic flows, phone data, revenues, etc) which arguably leads to an impoverished sense of the city as experienced by its users. Might smart cities instead learn from the post-war practice of the Situationist derive.

CitySkin produces outputs which give visibility to invisible layers present in quotidian life, adding a cultural impression to design and computation.

Each image reflects the point of view of a user along a path. There will be differences in colors and distortion on the output image (skin). Each skin will be unique and will reflect the singular point of view of the user's time, place and playfulness.

CitySkin also provides a means to compare and experiment with different times of the day or year of a specific place, but also between different cities. Furthermore, this application allows recognizing patterns of time. Finally, the information presented in the final map, can give the user a visual and immediate way to evaluate activities that relate to routine and movement.

This information presentation benefits from a comparative evaluation, like for instance physical activities or by visualizing traffic jams. Cityskin is a tool to measure the quotidian qualitatively and quantitatively.

Capturing the experienced sense of time, which has periods perceived as blanks or non-places, as opposed to measured time, is ultimately one of the useful contributions of this application. Is this case, the challenge is to re-capture the perception of fleeting time, specifically showing variables that are not obvious to the user. Thus, add a sense of wonder or fun, to an often called draining, empty experience that is commuting, or even register layers of perception while travelling un/familiar places. Finally. CitySkin suggests to slowdown, and embrace contemplation.

3.3 Super Mirror

Super Mirror, a Kinect-based system combines the functionality of studio mirrors and prescriptive images to provide the user with instructional feedback in real-time. This study, developed a working prototype of a system, which records ballet movements (also called "positions" and "poses"), capturing live motion, and showing the difference between the two.

3.3.1 Introduction

Mirrors are commonly used for dance instruction. They provide real-time feedback, but do not indicate what the dancer should do. On the other hand, reference
texts such as *Classical Ballet Technique* (Warren, 1989). It contains step-by-step illustrations of individual movements. The fundamental purpose of the Super Mirror is to render the useful features of mirrored reflection and modeled instruction in a clear and informative way.

3.3.2 Related Work

There are many dance-related applications of motion capture technology. Most of these applications, however, were not developed as tools for dance instruction, but rather for use in performance and choreography (DeLahunta and Bevilacqua,2007 Meador et al., 2004), and entertainment and gaming (Raptis et al. ,2011, Usui et al. 2006). One exception is the system for ballet e-learning, developed by researchers at Motion Lab, which supports the automatic composition of ballet sequences based on the specific parameters inputted by the user. The system's GUI represents the resulting choreography through its performance by a virtual ballerina on a rotatable, 3D stage (Umino et al. 2009). Although the intended users of this system are individuals interested in learning about ballet—not necessarily aspiring dancers—this application is structurally similar to the Super Mirror: both depend on a collection of motion_data, elements of which are retrieved and synthesized_according to user input and programmatic definitions of_specific ballet steps._The apparent lack of motion-capture applications for_ballet instruction is surprising, given the important role_of mirrored reflection in traditional ballet training_sessions. While it has been the object of criticism, the_use of mirrors in dance practice—its effect on learning_and on dancers' self-perceptions—has not been_rigorously studied (Dearborn and Ross, 2006). Moreover, the development of systems that use 3D camera technology for other purposes—e.g., learning to play a musical instrument (Ng, K. C.et al. 2007), sports training (Hämäläinen, 2004), and physical therapy (Chang, et al, 2011). —_suggests the potential usefulness of a motion-capture tool in the ballet studio. Similar to studies of these applications, our research is focused on questions about the user control of the system, system recognition of position data, and user feedback. We took a bottom-up approach to these questions: our purpose, in developing and evaluating initial Super Mirror interfaces, was to identify the requirements of the proposed system and support subsequent iterations.

3.3.3 Design

In order to evaluate the Super Mirror system, we developed and tested 3 successive prototypes, based on the following criteria: System performance: Which movements are accurately recognized by the system, and which ones are not? Which variables seem to cause errors?

User requirements: What features does the system need to support, for it to be a useful tool for dance students and instructors? Is the feedback provided by the prototype sufficient for evaluation purposes?

3.3.3.1 Technical Description of the System

In our prototypes, motion-capture is performed by joint skeleton tracking through a Kinect camera, and the transfer of input from the camera to the processor is mediated by the Synapse application (Synapse, 2012). The specific interfaces developed for our system use the Tryplex toolkit (Tryplex, 2012) a set of open source macro patches for Quartz Composer.

3.3.4 Comparing Real-Time and Pre-recorded Poses

In order to develop a patch that could provide real-time feedback for a live movement in terms of its resemblance to a predefined pose, it was necessary to establish a method of comparing prerecorded movements in terms of limb measurements, the system compares the angles of knee and hip joints. For each interface, a set of thresholds (minimum and maximum angle values) determines the extent to which real-time and prerecorded angle widths can vary and still be considered by the system as a match or, using our terminology, a “hit.”

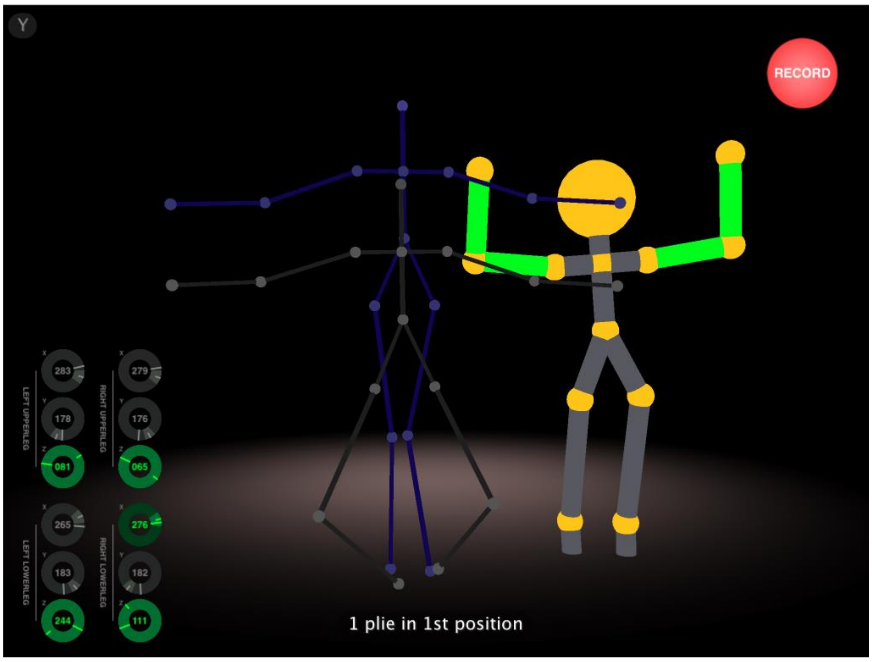


Figure 35. Both the wheel-like features in the bottom-left corner and the color-coding on the skeletal model indicate correspondence, or lack of correspondence, with a prerecorded poses. The two skeleton models in grey and blue demonstrate the correct final position and the movement that leads to this position. The grey figure with yellow joints is a real-time skeleton tracking of a dancer performing the movement.

3.3.5 Three Interfaces

The first interface juxtaposed an animated pose sequence with real-time skeleton tracking data. When a hit occurred, the color of the animation's legs would change color.

In the second version of the interface, two new features were added: a record button, which, when pressed, recorded a snapshot of the joint positions of the live dancer and stored this information in an XML file; and a hit icon, which flashed on the screen when the threshold requirements were met. These additions were intended to provide the researchers with more specific data, and make it easier to identify hits during the testing session. However, in practice, neither worked: due to an error in our workflow, pressing the record button did not result in an XML file, and the hit button was difficult to see.

Thus, a third interface was developed (Figure 35). In addition to correcting the problems associated with hit and record buttons, it also allows the researchers to specify the thresholds for a movement by setting the values of one or more angles. The graphical interface element, visible on the left hand side of the screen, displays the changing values of certain angles of interest in real-time in relation to the predetermined values for that movement. These features, in theory, will allow instructors to define a desired pose in contrast to the recorded pose, and/or change the level of precision required to achieve a hit.

3.3.6 Evaluation

Three rounds of system tests were conducted. In total, 5 dance major students at The University of Texas at Austin participated in the study (the number of 1621 Work-in-Progress CHI 2012, May 5–10, 2012, Austin, Texas, USA participants in a test varied according to the volunteers' schedules). During each test, the system's accuracy was measured in registering movements as hits or misses. Participants in the first and third sessions were asked to perform correct and incorrect versions of each movement; this allowed to evaluate accuracy in terms of false-negative and false-positive results. In pretests, the second interface returned no hits, which prompted to focus exclusively on the measurement of false-negative responses. The relatively large number of participants in the second session (which included 5 dancers, whereas the first and third included 2), and the unexpectedly large number of false negative results in the pretest, prevented from testing more than 3 of the 8 prerecorded movements (7 of which are represented in Figure 36). Following the second test, a semi-structured interview with 3 of the participants was held. Participants were asked to identify ways in which the prototype could be improved.

3.3.6.1 Error Analysis Results

Figure 36. These 7 poses, as well as the battement tandu side, were tested. Ultimately, we intend to implement a record feature, which would allow instructors and students to add new movements to their libraries, and a "play-list" option, which would allow them to select movements to practice in combination

Error analysis results from the second and third test sessions suggest substantial improvement in the system's recognition of specific movements. In the second session, only

3 movements were tested by all 5of the participants. Of the 30 *pliés* performed by the participants, approximately 7% resulted in hits; none of the 30 *passés* registered as a hit; and approximately 13%, or 4 out of 30, of *developpés* resulted in hits. Only two dancers participated in the third session. Each of them performed 3 "good" versions of a movement, and 3 "bad" versions of the same movement. All 8 steps were tested. The system accurately registered1 00% (or 6 out of 6) of the correct *pliés*, about 67% of the *elevés* and *developpés*, and 50% of

tandu fronts and *passés* as hits. However, it also inaccurately registered 50% of the "bad" *pliés*, and 50% of the *tandu backs*, as hits (Figure 37 shows the complete results from the third test).

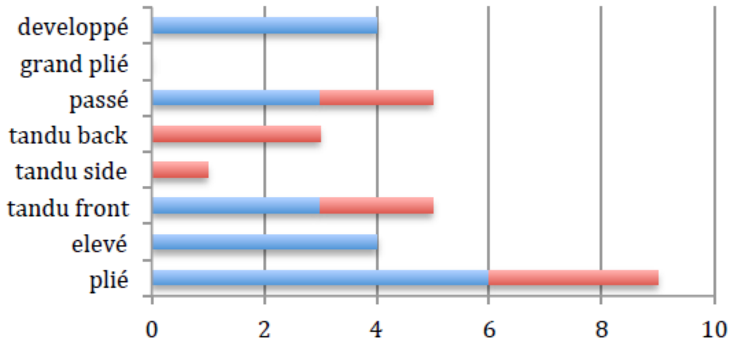


Figure 37. Blue indicates accurate hits, and red indicates inaccurate hits. The system appears to be better at recognizing the plié, elevé and developpé, and worse at recognizing the battement tandus passé, and the grand plié.

3.3.6.2 Interview Results

The participants recommended that subsequent iterations of the system provide the user with feedback that describes the transition between static positions.

All of them agreed that seeing a side view along with the front view would be helpful in, for example, correcting one's alignment or leveling a leg in the attitude position. They also noted that a summary of dancer's mistakes in a form of snapshots would be very helpful in correcting mistakes.

Participants suggested that the "playlist" feature, if implemented, should automatically contain basic movement combinations (such as tandu sequences),and be further divided by level: beginner, intermediate, or advanced. The subjects agreed that the ability to record additional movements, which could be added to the library and to specific playlists, would be a valuable feature for ballet instructors to have at their disposal.

They elaborated on this idea, noting that there are "many different styles of ballet" and "ways of movement that different choreographers have come up with," as well as "different ways to make the same movement."

Given this diversity within the domain of ballet, the ability to create dance sequences tailored to a specific school of dance or to a particular rehearsal setting would be useful—and possibly a necessity. Moreover, the participants noted that subsequent iterations of the system should address the diversity of dancers' bodies, and consider the effect of a dancer's physical proportions and musculature on his or her performance of specific movements. They also highlighted the importance of subtlety and transience to ballet performance—and suggested that future design efforts focus on the position of the dancer's feet and hands, and the transitions between poses.

3.3.7 Future Work

The current iteration of the system is limited in that it recognizes static poses as opposed to dynamic movements. In future iterations of the system, it is advisable to define each step as a succession of 2 or more prerecorded poses. Moreover, it is recommendable the use of the specific position data recorded during the last test session to refine the system definitions of individual movements.

In addition to the further refinement of movement definitions, the researchers plan to develop and evaluate:

- A version of the system that uses 2 Kinect cameras—to track dancers' motion from the front and side;
- A classification of movements according to how "recognizable" they are to the system (similar to motion annotation that uses Labanotation, cf. (Yu, T. , et al. 2005);
- A user interface for ballet instructors that would allow them to compile movement "playlists," record new movements and add them to the system's library, and edit movement templates by restricting or widening the range of values associated with different characteristics

"Any well developed tech will not be dissociated from magic"
Arthur C. Clark

3.4 Responsive Tile

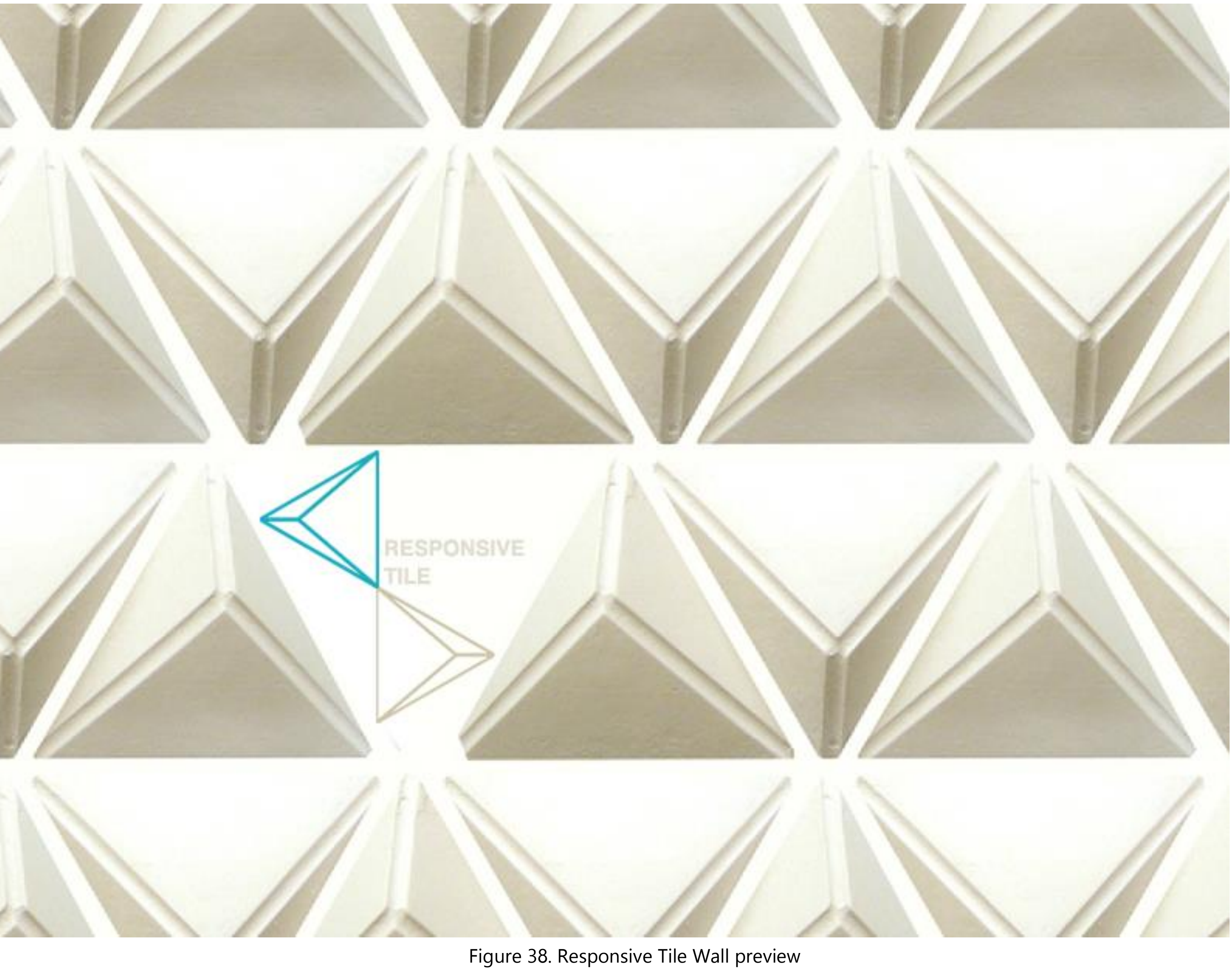


Figure 38. Responsive Tile Wall preview

3.4.1 Introduction

Responsive tile is a ceramic module that changes color according to weather conditions, specifically temperature variation. The tile is a low-tech/high tech-sensing artifact, which aims to convey awareness of water scarcity in urban contexts. This information is given in a playful manner, using reversible properties of thermochromic inks to convey content. The tile is module that behaves like a physical interactive device that can be assembled as a wall.

Each tile combines thermochromic and ceramic inks. The smart ink will respond to temperature variations. Thermocromic inks change color, and permits to display visual, dynamic and symbolic information that transforms a common tile in a responsive and communication device. The particular ink chosen in this project disappears above 32 ºC, and makes visible the Y shape. This is as a reference to a dowsing stick shape, the magic tool to find underground water. Thus, using symbolic cues, aims to convey a universal significance instead of referencing to a particular cultural view or language.

3.4.2 Experimental design

3.4.2.1 Collaborative Concept: Hybrid

Responsive tile results from collaborative design between Lindsey Culpepper and Isabel Paiva, developed in UT Austin in 2011. The engineer Rita Pontes, FCT-UNL, 2013, contributed with technical data, concerning implementation of the concept, materials and prototype testing.

The concept is a hybrid of two designers' research interests and specific personal projects. The project methods in use, reply to an initial challenge on "practical as research" collaboration.

The meeting between a Portuguese and American designer revealed that environmental issues was a problem of mutual concern. In particular water scarcity was visible both in Texas (and southern states of USA) and in Southern Europe (Figure 39).

Figure 39. Drought in Southern Europe and Texas, LUSA (March 2013). Poderá haver mais anos seguidos de seca no futuro, *Jornal Publico*, retrieved from http://www.publico.pt/ciencia/noticia/portugal-devera-ter-menos-25-de-capacidade-para-produzir-energia-hidrica-apos-2070-1587907; Picturing the American Drought: George Steinmetz, (November 2011). *Time magazine,* retrieved from http://time.com/3779679/picturing-the-american-drought-george-steinmetz/;

Indeed, as discussed in Chapter 2.7, sustainability extend beyond borders. This fact, drove research beyond a particular geography or culture. An irradiation, and temperature average maps (Figure 40) identifyed where drought could be more prevalent and clearly located the problem as worldwide. Under this light, this research projects is thought as site-specific, designed according to weather patterns, and geographic variation.

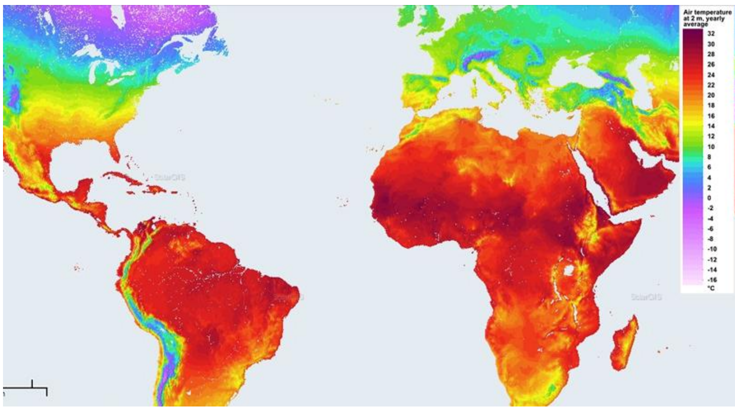


Figure 40. Air temperature year average map, retrieved from https://solargis.info/imaps/

A closer analyzes reveals that, despite drought being a problem with great economical and humanitarian impact, it is only visible, as dramatical changes occur in natural landscapes. This is, in rural areas. Therefore, water scarcity has a problem of scale and invisibility. Indeed, drought visible effects in the landscape are somehow inexistent in urban contexts. This common invisibility on urban environments creates a sense of distance and disconnection from the problem.

3.4.2.2 Conceptual method: hybridization

The hybridization method proposed invites designers to step beyond a comfort zone (Olsen & Lee). This meaning, adopt co-creating, specifically reflecting on research interests, but fostering future creative insight. As such, designers are invited to identify projects that best suit a personal research agenda, having these merged into a new project.

Designer Lindsey Culpeper chose project Hertzian Marfa, and Isabel Paiva's project Citykin. Each of these would be described in three criteria. The negotiation and common ground was taken from the total of six criteria, and synthetized in a project proposal. This hybridization of criteria should be materialized in a specific project. The conceptual work process took one week.

3.4.2.3 Project 1: CitySkin

CitySkin project, described in (chapter 3.2) was synthesized in keywords. The underline criteria identified was: mapping data from the quotidian, bringing the invisible into the visible realm, an extended skin that interacts and creates new layers of reality.

3.4.2.4 Project 2: Hertzian Marfa

Figure 41. *Hertzian Marfa* Lindsey Culpepper's , project image courtesy from the designer

Hertzian Marfa is project that Lindsey synthesized in three criteria: communicative device, reaction to a place or location, personal accessory

3.4.2.5 Project criteria hybrid

The hybridization of research interest and criteria taken from both projects (CitySkin and Hertzian Marfa) was expressed in keywords that defined a new project and research objectives. These were: ancestral knowledge and beliefs, studying materials, ambient signal (low-tech), mobile device (to find water), humidity, data, playful, interactive.

3.4.3 Design and Research

In a context of current design research, this is, creating an object that would convey a narrative aiming to address water scarcity, suggested the use of ethnographic methods. As described in Laurel (2003) research methods range from the spectrum of qualitative methods. These are focused in visuals cues, therefore, qualitative (Figure 42). Progressive evaluation of results is achieved with multicultural focus group and co-creation between experts. Thus, results and progressive corrections on the project were performed.

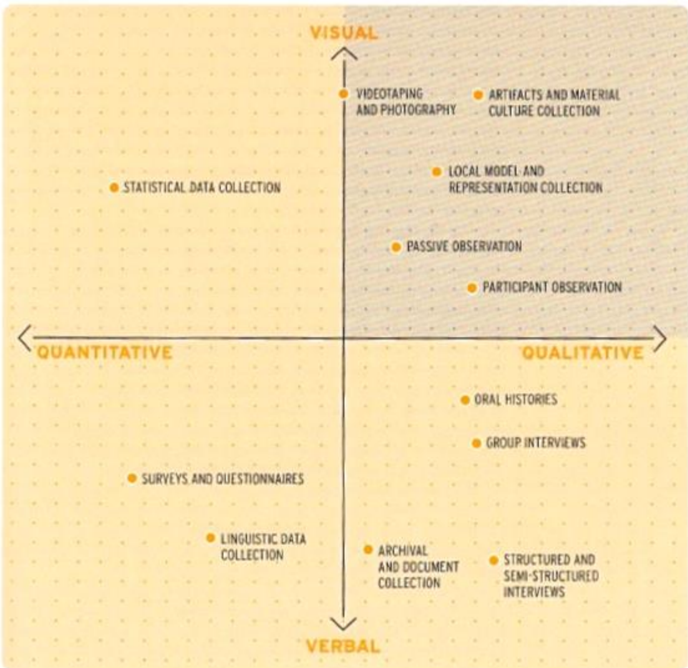


Figure 42. qualitative and quantitative research tools for conducting academic ethnographic research, retrieved from Laurel, B. (2003) Design research, methods and perspectives, MIT Press, p.33

3.4.3.1 Design Solution

The collaborative sessions resulted in a proposal to create a communication device that conveyed invisibilities. In particular, this project would refer to water scarcity, and aimed to suggest people to save water. The object would emulate nature response to drought; this is giving visual cues. Therefore, shape and color change according to the environment. Furthermore, design research focused in considering materials potential to tell a story.

Temperature serves as a marker, according with environmental variation. Thus, high temperatures are signalized by the Y shape. This create a visual sign and inform people to be aware and to save water. The communication strategy aimed to add surprising behaviors to a common object, in this case by placing it in the public sphere. The object interacts with the environment and acquires meaning complying with a specific sustainable narrative.

Placing an interactive device in public spaces aims to promote awareness in a playful and non-intrusive manner. In this case, this device could ultimately make people more sensitive to save water. Thus, this object would not use direct textual messages, but innuendos and symbolic language. The use of graphical information (e.g. drawing of an Y) allows the level of communication to become international. An ethnographic research drove experimentation with materials and prototyping, as well as, the symbolic object.

3.4.3.2 Object design proposal

Figure 43. Slide from personal presentation - UT Austin [pdf]

The inspiration for tile design was taken by revisiting tile surfacing traditions. In Mediterranean countries, tiling is an architectural cultural heritage. In this context, ceramic tiles can be used as particular weather adaptation into buildings. Indeed, tiles beyond having endless aesthetical potential, have isolation properties, and can refresh environments. Therefore, ceramics is a comfortable material in places where high temperatures are common.

Figure 44. (from left to right) Niemeyer ´s apartment building (detail) ; Keil ,M. (1958) *O mar* [ceramics], Avenida Infante Santo, Lisbon, image taken from Museu do Azulejo.

Two examples of worldwide use of ceramic tiles, with aesthetical purposes can be found, for instance in Neimeyer's architecture in Brazil, and as applied art, in murals, as is the case of Maria Keil's "O mar", 1958-59, (Figure 44).

Beyond function as an individual piece, the tile is a modular object that can be combined into a wall.

3.4.3.3 Storytelling with materials

Sustainability is a wicked problem. For instance, the challenge of designing cross-culturally, resides in connecting cultures, considering their difference, and political divisions. These tend to be a source of competition instead of cooperation.

The base inspiration for this project resolution is storytelling. Tackling a global identity and concern for our planet.

Storytelling is inherently human. Stories of oral source are nomad, as they travel with people. As such, orality is a precedent and prevalent way to transmit encoded knowledge. Oral stories work as embodied and coded mode of value dissemination, pre-mass media. Thus, storytelling offers a more prevalent common denominate, considering the global divide. This meaning, oral storytelling does not depend on technology, or energy supply, but operate changes of mood on the receivers regardless of culture or education.

Walter Ong (1988) analysis on the relationship between oral and literal cultures, identifies that they give different feedback concerning the experience of the world. The reproducibility of language with writing offer a reliable transmissible experience of the past. Literacy is based in the ability to access to this recorded knowledge. This being one aspect, where oral cultures fail, this is, on the precision and durability. As such, they are transient, and fragile.

On the other hand, Ong (1982), notices, that a preliterate cultures are performative, instead of based in accuracy. Thus, the experience of the world is different. For instance, poetic recitation is validated by its intensity, and not by accuracy. Dourish adds that, "indeed, to such a culture, accuracy would be viewed as a poor measure of aesthetic value" (Dourish, p.196)

Orality offers a particular process account of information, like it happens with "mouth to mouth". Performativity is source of reinvention and adaptation. Thus, in case of current research, intensities are pursued, instead of accuracy. This meaning, objects that tell stories, even that not being able to be evaluated in precision. Storytelling with aesthetic value and meaning, open layers of exploration when considering the use of interactive materials performativity.

3.4.3.4 Hydrographic objects

Ethnographic research looks to cultural identity through artifacts. Thus, the stories objects tell are often the source of inspiration and emotional connection (Turkle, 2011). Meanings are inherent to objects, in their, silent, physical manifestation.

Thus, first focus was given in collecting and analyzing objects that relate to water. Specifically, tools present in culture that search, find, or measure water.

The selected tools were: dowsing stick, weather house barometer, dowsing rods, water barometer, aneroid barometer, Fatima's weather prediction statue (vernacular design)(Figure 45).

Figure 45. Water related artifacts

3.4.3.5 Dowsing Stick

The concept of divining underground water prevailed over other useful related tools. In fact, radiostasy, uses a pendulum, while with a vedor, a dowsing stick indicate the water source. These tools of a non-scientific nature belong to popular knowledge, and are valued as an ethnographic practice present in several cultures around the world.

Durand describes an overlap, for instance, in France, where both dowers and hidrogeologist are hired to proceed with water finding companies even when there is not any relation between the two (Vale de Almeida, 1996). This contact between a dowser, a para-scientific practice and the scholar traditions, is described as symmetrical anthropology (Latour, 1991). Latour (1991) illustrates that it is not possible to stay at the margins of scientific production (meaning with folk culture), instead, it is simultaneously necessary to look at the center (science). This meaning not only looking into history of science, listening to what scientist say about their practice but in fact doing the ethnography of their quotidian practice. Observing science on how it is really done (Durand, 1996). Again, these illustrate the contact between a culture as measurement with culture as expression and affectivity.

For instance, an example of such overlap in design practice, can be found in "direct citing" of the dowsing stick in the context of a modern art exhibition. In this case, folk cultural appropriation is merging with a high-tech world (Figure 46), when observing a wi-fi dowsing stick (Antonelli & Museum of Modern Art, 2011).

Figure 46. Thought collider (2007). *Wifi Dowsing Rod*, by retrieved from http://thoughtcollider.nl/project/335-2/

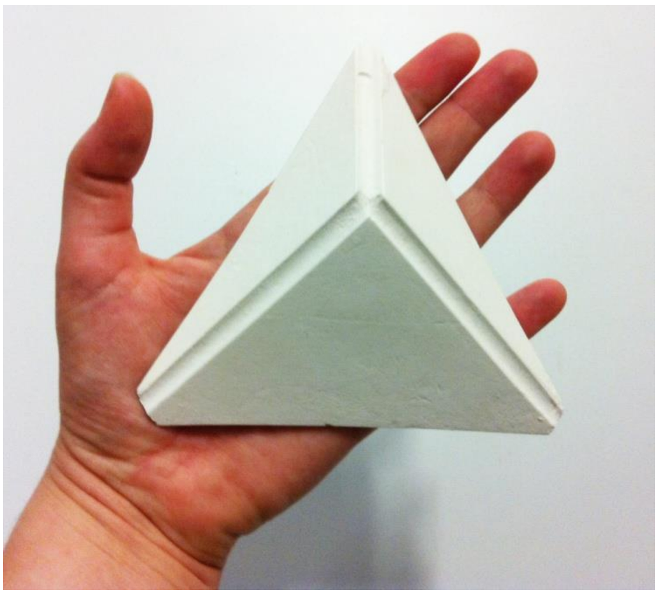
3.4.3.6 The symbol (Y)

From observing qualities on the objects related to water, the dowsing stick was chosen due to having the most potential. In addition, the multicultural focus group of UT Austin design colleagues recognized the tool. Dowsing sticks can be found in USA, Portugal, China or Iran. This culminated in founding dowsing for water as a practice that could be identified worldwide, and therefore, widely accepted as a trans-cultural tool. This fundamentally expresses a trans-cultural and trans-geographic concern in the quest for water. Secondly, the use of tool as mediation with the unknown, an invisible underground world.

The discussion on its real utility as a measurement tool, and accuracy was secondary. More prevalent was considering its magical function, as a mediation tool, that stimulates imagination, and having the potential to inspire re-linking concepts (as art and science). The object synthetizes the basic value that water has to life. Thus, the dowsing stick extends its significance beyond being a recognizable (tool), emerging as a symbol with potential to have an extended cross-border recognition. During prototyping it was decided to adopt its shape (a Y shaped stick) integrated in the design.

3.4.3.7 The tile shape design

The adopted final design took the shape of a triangular base pyramid (12x12x3cm). The tile was sketched from the Y shape. The 3d pyramidal shape was designed to better drive water to the soil though. Also, the Y, which is embossed in a negative space, is designed to drive water (Figure 47).



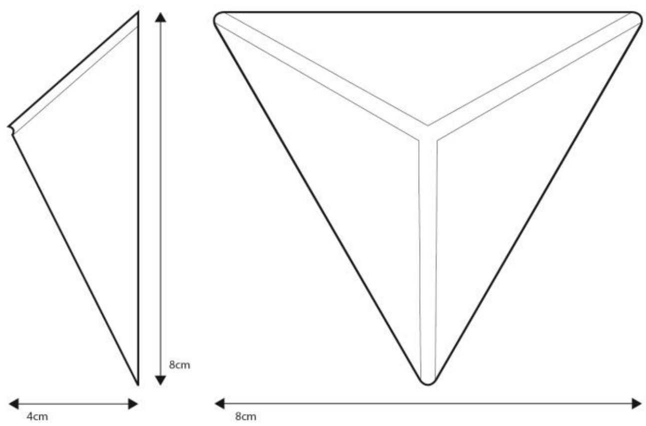


Figure 47. The tile

3.4.3.8 Inking

The experience and communication design proposal led research to test and identify specific technological features on inks. Accordingly with the concept, the interactive tile reacts to the environment and gives information by changing colors.

Initial color design studies was inspired by the Portuguese artifact Madonna of Fatima Chemical color reaction. Thus, the experience design studies aimed at capturing the mysteries of circulating water (hidden), the invisible water vapor. This artifact works as a chemical barometer by chemical reaction. To the naked eye the ink changes from blue to pink according to levels of moisture in the environment. This water triggers a chemical reaction with Cobalt-Dichloride. As such, the aim was to replicate this effect, this is, change of color in the presence of moisture. This reaction produces a reversible change between blue and pink.

Cobalt-Dichloride Free HI Cards were tested as a material study (chapter 3.1.). Cobalt-Dichloride Free Humidity Indicator (HI) Cards are used as in the context of electronic and semiconductor manufacturers. These cards offer information about the presence of damaging moisture during shipping or storage. The one tested was free of Cobalt-Dichloride, a chemical regulated under European Chemical Bureau (ECB) REACH directives, as being toxic. The possible use of an ink based in Cobalt-Dichloride was eliminated due to possible toxicity, but also due to practical constraints. Instead, we chose to search for a reactive manufactured ink that could convey the concept, and therefore adapt the reactive concept to change of temperature.

3.4.3.9 The ink choice

Reactive inks can have distinct activating mechanisms, reacting to different kind of stimuli, and outputting specific reactions. For instance, diverse smart inks can provide color variation as an effect. This is the case of thermocromic ink, which react to the temperature variation, hydrocromic, which react to direct contact with water, photochromics, which react to light or piezocromicas, which react to pressure. Fosfocromic inks absorb and stores light energy, and emits its own light. Other types of feedback can be provided with aromatics inks, which instead of offering a visual feedback, have olfactive output.

3.4.3.10 Thermochromic inks

A thermocromic ink that react to heat and is reversible was our chosen material to obtain the response mechanism. Thermochromic ink is a mixture of encapsulated liquid crystals. These substances (LCs) are a special state of matter with properties between solids and liquids, as the name suggests. This type of substances present special optical properties and are often used to modulate the light in electronics and day-to-day technology (for example in LCD-TVs).

Usually, the LCs used in these paints have a cholesteric structure. This means all the molecules are well-oriented in layers and this orientation rotates from layer-to-layer, around the optical axis.

The light passing through the LC suffers a Bragg diffraction due to each layer and the light reflected will have a well-defined wavelength, that corresponds to a spectral color, that will be observed.

Changes in the temperature will affect the space between the layers and, consequently, the wavelength reflected will also change and so does the color observed. Nowadays, it is possible to buy a great diversity of thermochromic inks from different suppliers. There are different colors and temperatures of transition available.

3.4.3.11 Thermocromic (reactive) plus ceramic (non/reactive) ink

Figure 48. Responsive tile interaction design

The tile interacts with the environment and gives information visually, by changing colors. To convey the concept it is used a combination of thermochromic and ceramics inks (Figure 48).

The visual effect is made possible because thr thermocromic ink change typically from a color to invisible or lighter color, at a given temperature. The ink temperature threshold can vary.

For this project purpose it was determined that the ink threshold temperature would be 32 C. In order to get a two-ways combined information device, the Y is painted with ceramic ink, and the side of the tile is painted in the same color but with a thermocromic ink.

Therefore, the design experience is defined by having the thermocromic ink disappear above 32 C. This becomes the moment that the Y (the dowsing stick shape) is visible. Thus, turning into a responsive tile, it works as a low tech sensor, combining aesthetical shifting properties.

For a first prototype the color adopted was red. However, this system can be made in a wide range of colors, depending of the tuning between the thermocromic ink and the ceramic ink (Figure 49).

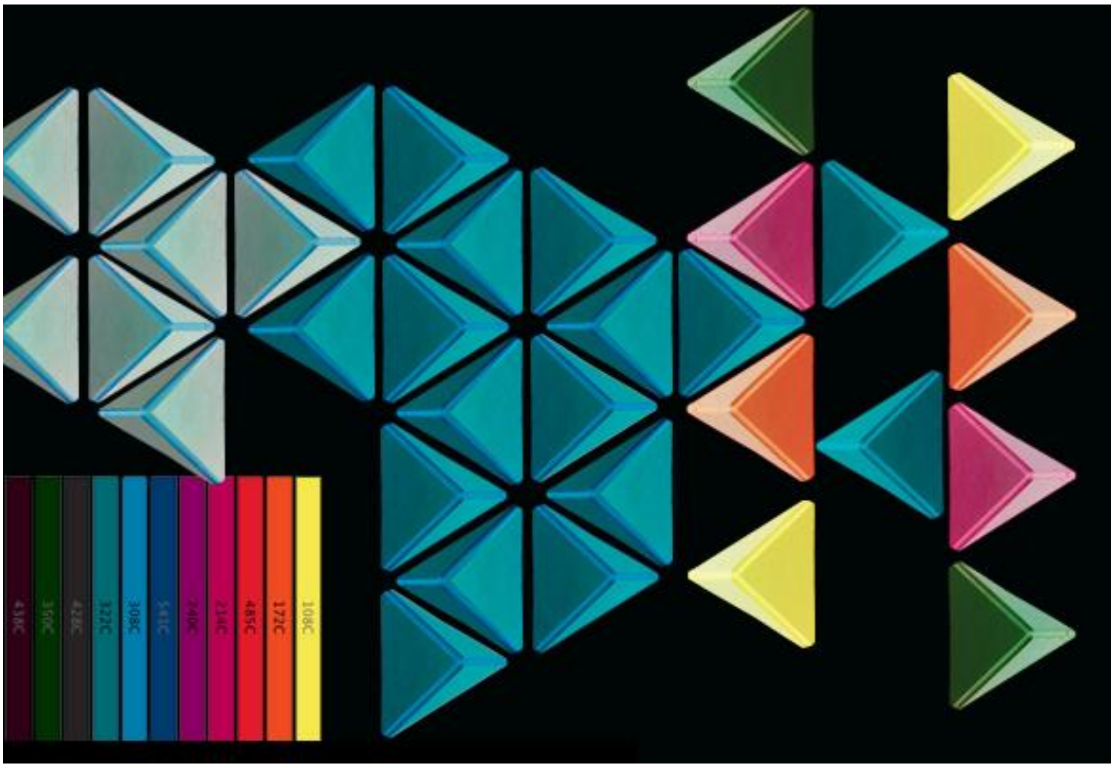


Figure 49. Responsive Tile color options by Matsui, CA

3.4.4 Making

3.4.4.1 Prototype production

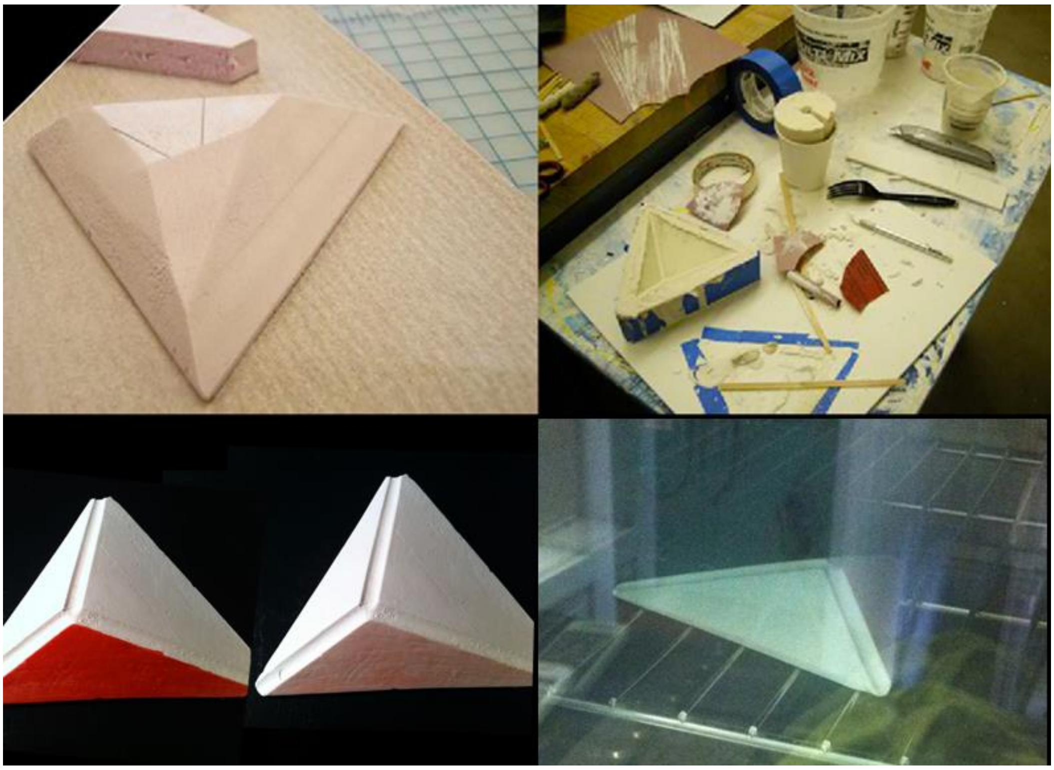


Figure 50. Making: casting, inking test, and oven finishing

Materials used in prototyping were styrofoam, silicon, hydrocal, thermocromic inks, ceramic ink, woven, abrasive paper, airbrush.

3.4.4.2 Manufacturing responsive tile

The settled design (12cm x 12cm x 3cm tile) was sculpted in styrofoam finalizing design details (for instance, the embossed Y). A silicon cast was made out of this shape. Hydrocal solution was prepared and added to the silicon cast. This solution dries without fire. Latter, the tile was taken carefully from the mold.

Hydrocal plaster is less durable than ceramic or porcelain, which would be the materials of preference for final production.

3.4.4.3 Ink application test

Thermocromic ink can be painted directly on the ceramic ink. The ink application was made using an airbrush and masking. This method allows to apply homogeneously the thermochromic and ceramic ink in the ceramic surface. In order to dry, the oven where the tile was set, was pre-heated at 200ºC during 8 minutes.

After cooling, varnish is applied on the surface. Depending on the amount of varnish used, there must be a waiting period of 3 minutes between each application. Drying times usually take never less than 2 hours.

The use of varnish is advisable in order to prevent paint degradation due to external factors, such as wind and friction. This way, the paint will last longer, as its properties are expected to degrade with time.

3.4.5 Conclusion

Responsive Tile performance depends on external factors. Therefore, these conditions have to be determined firsthand, in order to devise the placing for the product.

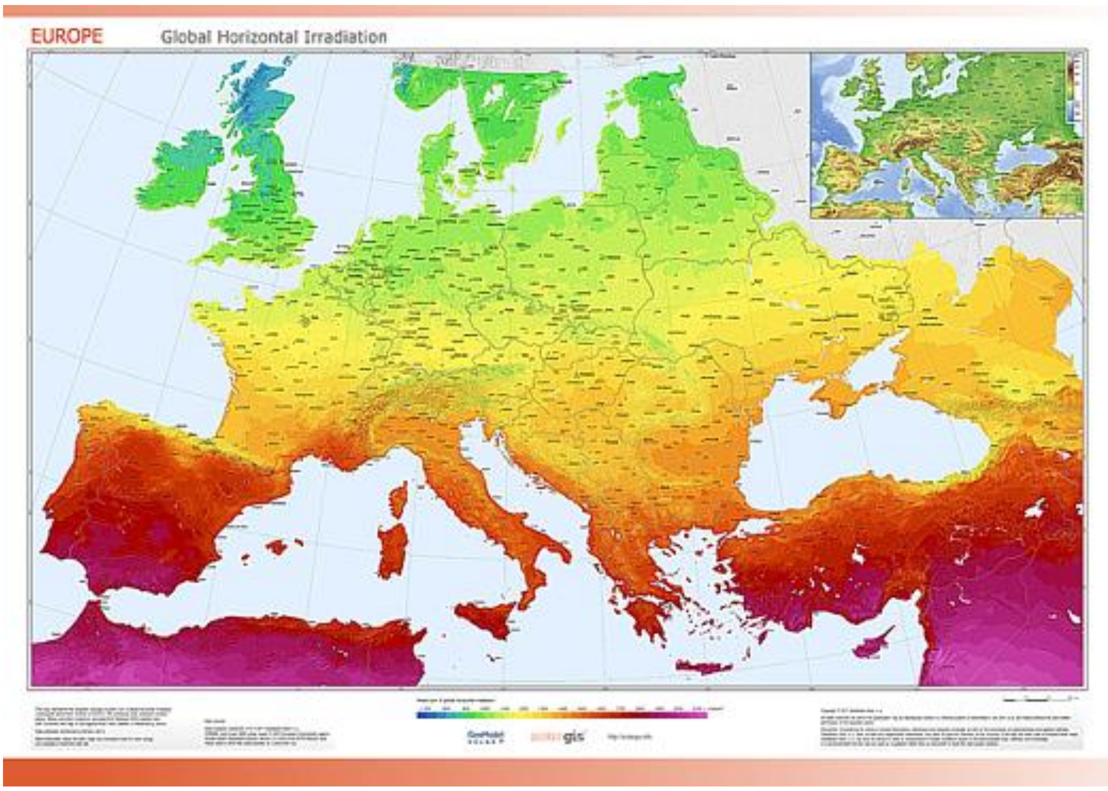


Figure 51. Irradiation and temperature maps (2018), retrieved from: https://solargis.info/imaps/

For instance, focusing only in Europe, according to a solar map, is made evident that countries in southern Europe have higher irradiation during the year and, consequently, higher air temperatures than other countries (Figure 51) Average temperatures in Portugal

(Temperatura média do ar, 2018) during the year vary from 14ºC, to maximum temperatures near the 40ºC in summer. Therefore, a thermochromic ink with a transition temperature of 32ºC would operate perfectly to indicate high values of temperature.

In contrast, in northern countries, for instance, (Finland Helsinki Monthly Climate Averages, 2018) has the maximum value of 30ºC during summer therefore, a thermochromic ink with transition at 32ºC would not convey the concept. These two examples demonstrated a relation between placement of the final product, and the ink typology. Future work can gain for the application of this idea to other perspectives, this is, to consider it as communication system that can be adapted to other weather conditions, and constrains, becoming site-specific (Irradiation and temperature maps, 2018)(Figure 51).

Responsive Tile is a common day object that give calm and subtle cues, as such, is a contribution to U.C. research. This is creating intelligent objects that are not intrusive or requiring full attention for the user, as well as power supply. This is a case of an object that tells story, embodying ideas or enabling communication. One that bring invisible variables to be part of daily life.

The advantages of a reactive surface made from chemical reactions is that they do not require energy. One of the disadvantages, is that they rely in chemical reaction on termochromic inks, and there is the expectation on the inks qualities to degrade. In sum, this experimental object requires further testing in order to become a product.

Insights gained for data stream:

• Successful collaboration, and making process (co-design) between design and science experts, and cross-culturally. A contribution from qualitative design research, and making processes into creating narratives within UC research with (smart) materials. Thus, demonstrating how to create content with materials. Telling compelling stories through materials and technology. Convey the idea of telling a story. Evolve and I will change.

• A speculative design project that was successfully tested: proof of experimental design process viability.

• A high tech, low tech dialogue, between smart and traditional materials: contribution for Portuguese industry (ceramics).

• Contact with technical constrains, that changed design initial proposal.

• Created a module that can become a wall. Designing a module, referring to an interactive surface.

• Learned about the inks qualities, and concluded that inks will not be the primal source of the final experience.

3.5 Paperbot

Figure 52. Paperbots set-up

All Watched Over by Machines of Loving Grace

I like to think (and
the sooner the better!)
of a cybernetic meadow
where mammals and computers
live together in mutually
programming harmony
like pure water
touching clear sky.

I like to think
(right now, please!)
of a cybernetic forest
filled with pines and electronics
where deer stroll peacefully
past computers
as if they were flowers
with spinning blossoms.

I like to think
(it has to be!)
of a cybernetic ecology
where we are free of our labors
and joined back to nature,
returned to our mammal
brothers and sisters,
and all watched over
by machines of loving grace.

Richard Brautigan, 1967

3.5.1 Introduction

Paperbot is an interactive device that reacts to motion or presence by moving paper foldings. It combines digital and physical computation, i.e., low-tech kinetic properties of materials, folded paper fibre memory, with mechanical actuators like found in LEGO midstorms. Paperbots are designed as D.I.Y. objects that can be easily built without requiring any previous knowledge in coding, mechanics or arts.

Paperbots are artbots that present an easy construction model and reproduction, tackling an alternative to mainstream perception of robotics. These qualities are being ephemeral, playful, and fragile. Thus, this chapter discusses significance of art in the context of robotics. In particular, framing processes of making and inclusiveness, and by positioning Paperbots as art objects in digital media exhibitions.

As such, these alternative views on robotics were tested and performed with different audiences and cross-culturally. Specifically, Paperbots workshops were directed to children and adults as participants. Thus, generative processes were tested, as well as co-design set-ups, at FILE2013 (Brasil), S.Paulo, Austin's Travis Heights elementary school (USA), and PLUNC (Lisbon).

3.5.2 Discussion

Robots are particular objects. Simply put, they combine computation with sensors and actuators. Software controls builds a system that typically output movement. Movement has qualities that address the senses having intrinsic aesthetical and symbolic value. Understandably discussion on kinetics range from sports, cybernetics, engineering, or cinema. Contributions given to robotics can, under this light, be expected to be of interdisciplinary nature.

A particular contribution from art emerges precisely from literature. The word "robot" derives from a Czech word Ro, which is first found in a play R.U.R created in the last century 20's by Karel Capek (Pappas, 2016). The imaginary of this science fiction story present a robot that turns against their human creators. Within this story plot, the creation of the machine that replicates human beings inspires terror, as it seems to embed sacrilege.

Indeed, robotic research find overlapping concerns with religions and with mystical knowledge, as it focuses in the creation of an intelligent entity. Authors like Christopher Mims argues that in Judaic-Christian Westerns cultures there is a prevalent notion of sacrilege inherent to robotics. The creation of robotics would be an act of hybris that eventually would have its consequences. And this is reflected in a deserved punishment of human beings for acting like god. In Eastern cultures, based in Buddhism, robots are perceived as things embedded with soul, and as such would be equals to human beings. In fact, Buddhists acknowledges that objects can have soul. According to Mims, these narratives have impacted the robotics design approach in American, and Japanese societies. While in one place state of the art robotic research prevails in the context of the military, in Japan, they are seen as personal assistants (Mims, 2010). Robot funerals, as happens with Sony Aibo "dog", illustrate a truly human behaviour (Brown, 2015). To mourn a robotic dog demonstrates affection, and desire of perpetuation of the memory of loved ones beyond death.

Looking back, becomes understandable that the desire to design these machines, predate current technological possibilities. Automation is documented from ancient Greece to Renaissance. For instance, Adrienne Mayor, in her essay bio-techne, traces links between Greek Myths such as of Hercules, Jason, Argonauts, Medea or Daedalus' and boundaries between human and machine (2016). But also, Leonardo Da Vinci, projected a mechanical knight, an autonomous machine. Shelley's hybrid Franskestein is part of the imaginaries of Techne's robotics. The scenery of automation culminate in the minimal representation of movement and replication, as is the case of cellular automata. The cell is described as unitary measurement of life.

The dawn of Cybernetics conveyed visions on systemic models on robotics that create cyber happiness on earth. Brautigan's poem, describes machines as gods that take care of humans need, creating an utopian environment where the mantra of the selfish gene (Dawkins, 1976) is resolved. Darwinian insight on the imperfection of competing animals is finally overcome by machine perfected justice.

In sum, robots bring forward the manifestation of beliefs, fears and desires, which translate in rather different understandings, and configuration on their shape and behaviour. Indeed, these are questions that hunt tech theorist Vilém Flusser, as a problem that should be of design concern:

> "…what should machines be like if their striking back is not to cause us pain? Or better still: if it is to do us some good? What should the stone jackals be like if they are not to tears us apart and if we ourselves are not to behave like jackals? Naturally, we can design them in such a way that they lick us instead of biting us. But do we really want

to be licked? These are difficult questions because nobody really knows what they want to be like. However, these issues need to be addressed before one can start to design stone jackals. And these issues are more interesting than future stone jackals and supermen. Are designers ready to address them?" (Flusser, 1999, p. 53)

Designing these new machines puts forward anxieties that reflect on a very "human" condition.

3.5.2.1 Robotic Properties

Imaginary automated machines predate technological ability. In current years, technology has allowed these intentions to become real.

Asimov (1950) anticipating the moment when machines achieve autonomy, prescribed three laws of robotics aiming to prevent a possible cataclysm. These laws previewed constraints on the software design of the intelligent machine. First, intelligent entities could not injure or allow a human to be injured, second, a robot must obey orders from a human being, except when conflicting with the first law. Third, a robot must protect its own existence, as long as it did not conflict with the first and second law. Current military robotics developments have demonstrated disregard of these laws. A challenge prevails as Flusser´s insight on the shape and action of intelligent things, as well as Asimov's ethics.

A robot combines software with hardware in a seductive dichotomy. One of robotics characteristic effects enforce a divide that refers to the Latin root Anima that means soul. Root both present in the word animation, as well as in animism. The latter refers to objects when are perceived as being infused with life. Language seems to suggest that robotics give a soul to machines.

In fact, the animism effect refers to a perception on machines by humans. That is due, in part, through perceived movement. The animistic effect is possible by transference of emotions to an object, and by the interpretation of movement as behavior. For instance, when movement is combined with an anthropomorphic shape – one of the branches of the quest on the shape of robotics – this perception is further reinforced. Anthropomorphic robotics are highly developed in Eastern cultures, and are designated as Androids. However, robots that resemble human beings are different from the definition of robot.

Anthropomorphic shape in robotics was found to be problematic. In fact, anthropomorphic robotics seams to posit a limit to positive emotional human connection. Masahiro Mori (2012) indicated the point of non-return in the affective connection with the robotic object, as entering the uncanny valley. This meaning, as closer as the object, the android, resemble an human, and some features not complying with a natural human being, instead of connection, in fact originates a sense of aversion.

Nevertheless, robots are expected to be social machines that interact with humans. Mirroring human relations, these robots intend to create reciprocated relations and a sense of attachment. In such scenery, humans would exercise empathic abilities with machines. As such these machines are designed to replicate behaviour that target human mirror neurons. In some cases, the attachment to objects is reinforced by exploiting shape, for instance, round shapes create a sense of cuteness. Or by giving visual cues to make the brain to interpret that an object is displaying emotions. This is the case with smiling. Moreover, reciprocity can be built by imputing "personalities" in the machine. Smoothly infused, software can be built into an object that reinforce a relationship by offering adequate replies to human need (Rose, 2014).

Both popular culture as research projected robots as companionship and as sexual objects. For instance, popular culture presented visions on these cases with the movie HER (Jonze, 2013), and Ex-machina (Garland, 2014). Like the myth of Pygmalion, the machines are human female like, and designed as male, heterosexual companionship. While in the movie HER the interaction model is from a software point of view, the lack of physicality is an issue at certain point to be resolved. In, Ex-Machina, the starting point on the robot is the physicality, evolving into a sentient being by improving an AI algorithm. Inevitably, in this story plot, the machine tricks a compassionate male.

These examples, taken from science fiction popular culture, illustrate a particular take on female-male relationships. These machines are imagined under a particular male gaze, where masculine, heterosexual anxieties are manifested. And to a certain degree there is a perpetuation on a particular view, on uneven power relationships, which with machines are presented as a normality. However, these readings on popular culture, are certainly a male point of view on robotics, and reveal a field where the feminine voice, and manifestation is often lacking. Could the popular imagination preview with ease, what these machines could be, as to, serve as female companionship? Danaher & McArthur (2017) discussed on robotic human interaction and sex social and ethic implication, compiling perspectives. These seem to be concerned in part, with identifying a norm of male sexuality to anticipate and justify design (Scheutz and Arnold, 2016). Moreover, the pressure in on the marriage institution (Adshade, 2018) as well as is on gender identity and roles. Thematics that has been a subject of inquiry from a humanistic point of view.

Under this light, can the term reciprocity really be applied to robotics?

Sherry Turkle discussed the implication to human beings on building this apparent intuitive automaton. Turkle believes that the distinction between machines and human should be preserved, so that the human attachment would not be in fact present (2011).

Kate Darling discusses on implications of current human relation with machines. Darling comments a military DARPA machine, a dog like creation, during a stability test. In a presentation video, the researcher hit the dog like creation with a foot. Darling argues that apparently, displaying violence on machines is not questioned, as they are objects. However, to some degree, the normalization on gestures that inflict pain, without reciprocity, consent, or critique, is somehow discussing the model defined of reciprocity. Darling reverses the question, as to find, in fact what, hurting a robot without expected reciprocity, does to the human (Darling, 2016).

Related work, present alternatives and comments on robotics sourcing from the arts. In fact, the concept of Artbot puts forward a discourse on robotics, that question the "mainstream discourse of robotic technology e.g. robustness, intelligence in software, autonomy, anthropomorphism, and the mechanical aesthetics related to mass production" (Jacobsson e all, 2012, p. 2020). A discourse taken in and appropriated by Ars electronic, as for instance presented in Berlin with "Meter crawler" (Figure 53) by Keiko Takahashi (2013).

Figure 53. *Meter crawler* by Keiko Takahashi, 2013, retrieved from https://makezine.com/2010/11/16/meter-crawler-a-robot-made-from-a-t/

The role of art in STEM (Science, Technology, Engineering And Mathematics) is discussed in education, as to include the faulty contribution from the humanities and arts, preparing the future generations within STE(Art)M.

3.5.3 Design and Research

3.5.3.1 Research questions

The project design adopted a hands-on, speculative point of view, aiming to gain insight through a material experience. Thus, the inquiry started by following open questions, building a sequential exploratory research.

As suggested by Flusser, the first question was to define shape. Second, to find a process. Finally, to define an audience with whom this concept could be explored. Robotics is a complex concept that entails a necessary dissection of the wicked problem (Rittel, 1972). Considering robots as "animated" machines, initial focus was given to the exploration of movement. In particular, the inquiry started by analysing materials kinesis, the combination of physical materials and coding which ultimately would control movement.

The first question was to determine what might look like. In fact, open ended materials studies predate the creation of Paperbots. Open ended materials studies (Chapter 3.1) assumed this role. Focus was given to a hands-on exploration of an accessible material, paper. Typically used in prototyping, the open exploration of paper suggested its animation. In sum, Paperbots resolves the question on animation of materials.

The next step was to make them proliferate. This is, to define an audience, and to teach a particular set-up in a workshop. For instance, questioning if the inclusion of non-expert voice in robotics is pertinent. In particular, to inquiry what paper robots designed by children or by non-specialists might be like.

Therefore, Paperbots workshops are created as generative design projects. They address these research questions, by using participatory design methods. Lastly, proposes to investigate poetics and arts robotic potential, by conveying and open-ended approach to computing and materials.

3.5.3.2 Conceptual hybrid: precedents

Paperbots was a project developed in UT Austin Design Department. Built on results from the materials studies, Paperbots concept derive from a combination of criteria taken from three precedent projects. First, "messa di voice" (Levin et al., 2003) highlights a particular Human Computer Interaction model. The performance combines coding that inspire a return to elementary visual communication. In this case, voice and sounds are turned into visual symbolic elements in real time. The second project that worked as a precedent was parietal paintings by unknown authors as found at Lascaux Cave (Figure 54). The first human artistic manifestation had nature as inspiration.

Figure 54. *Lascaux cave*, detail, France

Finally, Neri Oxman's (Oxman, 2010) research redefines the concept of nature as a model for making. Oxman research moves design beyond symbolic representation, and is inspired by nature processes to build physical structures.

The synthesis of criteria inspired a new project, Paperbots, specifically focused on dialogue between the physical and the digital. But is, simultaneously, a process of analysis on the concept of remediation (Bolter & Grusin, 2000) this is, designing mixing the contemporary technology, need, and Kunstwollen.

3.5.3.3 Hybrid materials studies

The materials studies (Chapter 3.1.1.) with paper offered perspective on the kinetic possibilities of the material. The process of folding beyond their aesthetical and mechanical properties, allowed to take note of the kinetic potential of the paper fibre. This last feature was made obvious through a hands-on approach, where the resistance of paper, suggest the use of the material itself as a lever force. Origami precedent work material inspired structural studies (Jackson, 2011, Vyzoviti, 2012, Gjerde, 2018) and multiple applications as explored by Robert Lang (2018). From this background, the materials studies suggested the use of two type of folding. Thus, for Paperbots was selected a construction using a triangle and a chevron based structure.

The actuators are designed with LEGO pieces and motors. The mechanical structure is adapted on paper shapes. The code that activates the motors is composed according to the limits of the paper structures and the attached LEGO mechanics. Therefore, Paperbot is built around the material specific properties and constrains. As paper can easily tear, a balance is achieved by combining the malleable instrument and the fibre resistance. These latter features were shown as useful when designing kinetic objects

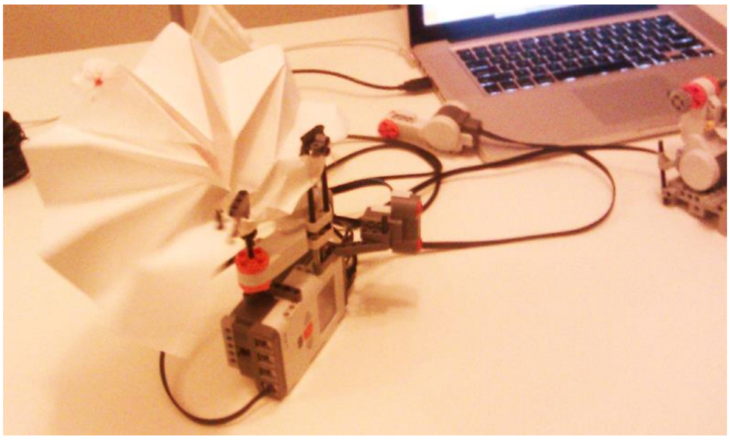


Figure 55. Paperbot, First study material activation with Mindstorms, 2011

One of the observable results from this interplay is that each Paperbot becomes unique, site-specific, and personal. Therefore, self-expression is possible by the combination paper, Lego, and software exploratory potential.

In sum, this set-up, gives evidence to the typical role that paper has as a prototyping tool, and expression. Furthermore, introduces Lego Mindstorms coding and mechanical accessibility as a prototyping tool for interaction design. In this case, useful to explore dynamics on the combination of different media and software.

3.5.3.4 Animation on materials: a moving pixel study

As a prototype tool for designers, the combination of software and Lego (sensors, actuators, and mechanical pieces) offer an intuitive and accessible method for prototyping with physical materials in the context of interaction design.

Lego Mindstorms allows to mix physical materials and coding. In this way explores material kinesis, this is, the transitions of an immobile material to its animation. Thus, the Paperbot, is an animated paper pixel. This paper moving pixel could eventually be replicated, and as such, turned into a surface. The identified moving physical pixel study proves that animation of materials is possible. The animation of paper reassured its potential as prototyping tool.

LEGO Mechanical structures allows to test rapid prototyping considering movement of physical materials. The actuators are activated by motors and controlled by software. This makes possible to test several solutions of mechanical and aesthetical nature. As software controls movement, nuances on their different features, aesthetical and mechanical, are possible to change easily. This was the case, for instance, in applying “easy in”, and “easy out” features, on paper movements, or different velocities according with folding aesthetics. Variation on input can be explored by the use of different sensors.

3.5.3.5 Paperbots

Paperbots result from the cumulative development on the idea of testing three-dimensional animation. Lego Mindstorms set-up served essentially to get insight regarding motion control. However, its set-up imposes some constrains. There are four input devices available (sensors), infra-red, color, sound and a push button, and as output there are motors. In addition, the connecting are made with physical wires. These are attached to a computer brick. Each of these computer brains can connect to up to three motors. Therefore, in the case of this project, three independent Paperbots are possible to activate simultaneously per each brick.

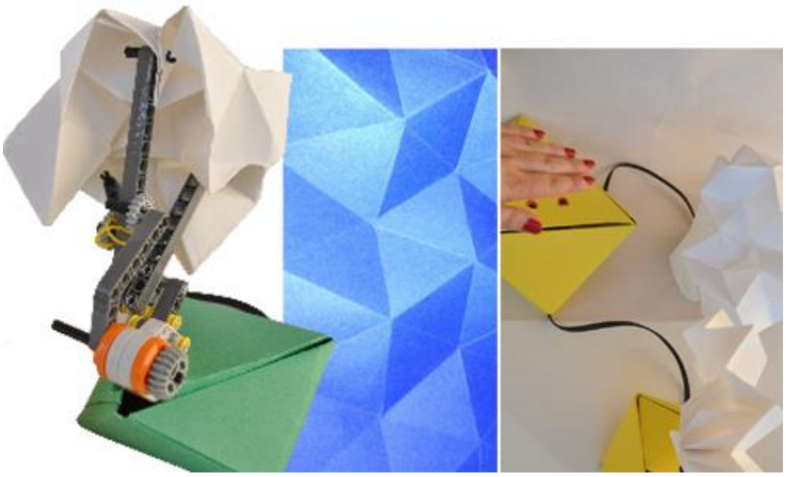


Figure 56. From left to right: Green Paperbot, triangle shape origami (paper materials studies), Paperbot Set-Up (Green and Yellow paperbot, Brain Box)

The human computer interaction model is defined by an input that triggers movement. Feedback is motion of paper that happen during the period of time that the sensor is active. Different visual effects are given according to different paper folding.

Each of the Paperbots' animation on paper is coded individually. The basic program is a loop, which is active while the sensor retrieves information, and completes the loop. The infrared sensor, designed to measure distance and detecting physical obstacles, is in this case, is used as a motion sensor. This setup, sensors, control brick, and motors are integrated in folded paper boxes, as an aesthetical option. The wires connected are visible and part of the visual set-up (Figure 56).

Figure 56 and Figure 55 demonstrate the first Paperbot set up (2011), presenting two Paperbots. These were designated generically as "yellow" and "green" Paperbot, identified according to the base colors that contains the motor. Indeed, beyond the simple desire of attribution, the animistic effect that this set-up stimulates, lead to naming things individually.

3.5.4 Education

3.5.4.1 Workshop set-up

Sanders' Generative Design toolbox research (2013), provides perspectives to use workshops as research ground. These are aimed to co-create through exercises with people, constrained by time. Thus, both participants and the facilitator are part of a learning experience. To achieve this effect, to have participants as collaborators, a particular mind-set is necessary.

A generative design process was applied having as main objective to co-design new Paperbots. The designer role was to facilitate, teach a building sequence, stimulate creative practices, and generate new approaches to Paperbots design. Thus, Paperbots workshop are presented as open source set-ups combining notions of science and art. In the case, coding, and origami folding. The general questions that these workshops were addressing were: What new kinds of Paperbots could be generated from people's input? Would Paperbots workshop be cross-age?

Paperbots collaborative sessions were presented at FILE S. Paulo 2013 Workshop Series (Figure 57) and in Austin School (Figure 58), Plunc (Lisbon) resulting in 5 new Paperbots. Results are described using a participatory observation method.

3.5.4.2 FILE S.Paulo Brasil

Figure 57. FILE workshop, 2013, Brasil

The Paperbot workshop was the first public presentation of the concept. Thus, experimented on premises mainly on the common perception on what a robot might be.

Thus, the exercise with participants emphasized the least explored qualities on robotics, such as ephemeral, but also fragility, and playfulness. These qualities would be revealed through the building process with Lego Mindstorms, as a tool for robotic construction and replication. Uncommon materials and technics (like drawing) that are not typically in use within robotics were added for experimentation. The overall idea was to convey an alternative view, to the majority aspects of techno scientific perspective that robotics tends to put forward.

The workshop was first presented in Brasil at the International Digital Media Festival, FILE, in a 2 day session of 4 hours. The audience was restricted. Participants were invited to contact directly with coding and folding techniques. The proposal was to build a Paperbot and to test the concept as a D.I.Y. project. Therefore, to animate a participatory design workshop, encouraging individual creativity. Thus, create, and make a personal contribution to the realm of robotics by the proliferation of new Paperbots.

Two new Paperbots resulted from the workshops. One first, emerged from a collaboration between two participants, and the other as an individual creation. The two Paperbot were baptized by their creators. Paperbot "concha" (meaning shell), and "pulmão" (lung) (Brasil). Results from the workshop were published on-line (Paiva, 2013).

3.5.4.3 Austin's Travis Heights elementary school

Figure 58. Paperbot workshop children version, digital invitation, 2014

Paperbots workshop was selected to be part of Travis Heights elementary school, young artist workshop in Austin. The 2 workshops set up was about 50 minutes each. The audience, up to with 5 children, 6-8 years old, each from different backgrounds and ethnicities. Some children had previous experience with origami, and mindstorms. The set-up allowed to build paperbot sketches, in a collaborative manner. Due to the limitation of time, only one Paperbot was made, from a chosen origami animation. All children participated in folding (the chevron), and only one code sequence was used.

A collaboration model was implemented. One of the aspects with working with children is that they can get easily distracted, so waiting for each other make them lose focus. Working with children demand an one to one attention.

Children displayed impressive learning skills. Despite the differences and the diversity of knowledge required to attend the workshop, children did not detect any cross/disciplinary issue regarding Paperbots construction.

3.5.4.4 Plunc Lisbon

Figure 59. White Paperbots exhibition set-up, PLUNC 2015, Lisbon

Plunc is the international festival of digital art and New Media (2015) that merge art and technology, in Lisbon. One of the objectives of the Festival, was to promote the dialogue between public and creators. Not only by process of work but also through creation process of work. Therefore, a workshop and an exhibition set-up was proposed.

Paperbots workshop set up proposed to follow the same criteria as in previous exploration, this meaning, to delve into animation of materiais. Therefore, the workshop one more time, tests the combination of papers folding, mechanics and software, specifically Lego Mindstorms.

However in this case, the resulting paperbots were open/ended results to be presented in the festival exhibition, in Cais the Sodre, Lisbon. Therefore, the workshop was divided in two sessions, at FAB LAB Lisbon. During two days, work was directed to the exhition set-up as one final objective. In this context, Paperbots are presented as an ephemeral art instalation, projected specfically for Plunc. The result would be documented (Figure 59).

Therefore, designer works as a facilitator to create devices for exhibition. Some contrains were defined *a priori*, such as colors in use (an agreement between participants). Total workshops of 8 hours were extended into time for the exhibition set-up.

Naming papebots result from collaborative dicussion. Movement and folding new Paperbot were called: Bailarina, trovador, pisces (Figure 59). The names created from the suggestion of movement: the yellow papebots looked like a “Bailarina”, while “Trovador” derive from the bowing it made. “Pisces” was inspired by the shape.

Figure 60. Paperbot Bailarina (Dancer), Trovador (troubadour), Peixe (Pisces)

The set lasted 4 days in the places of exhibition. Participants manifested concern with the fact that Paperbot could tear with time. It becomes interesting to acknowledge physical changes through time: they are mutable and ephemeral. At the end, Paperbots resisted the test and were disassembled.

The exhibition put forward a dialogue between art and science as complementary fields, but also, presented a collective author. In this case, demonstrated that Paperbots are all different, unique and co-created. They are not just art artefact but are ephemeral objects.

3.5.4.5 Results

Paperbots are all different, and unique. In fact, the exact reproduction of a specific Paperbots set-up is harder, than to obtain potential expression of materials. One of the requirements inspired by people was to have a sequence to follow. However, folding demontrated how much the process can become random and expressive, which was met with surprise. This became in fact one of the workshop requirements. The challenge was to copy a set-up but adding something different and original. The outcome was 5 Paperbots resulted from workshops in Austin Elementary School (USA), FILE (Brazil), Plunc, (Lisbon).

Deriving from participatory observation further results were as following. Lego Mindstorms sets have one computer brick, which allows to connect and activate three motors. As such, due to the technological configuration, three Paperbots per set, are possible to make. As each Paperbot shares the same brick (computer) this particular feature transforms Paperbot Workshop in a collaborative tool. As such, team work, negotiation, and agreement is required to build between one to three Paperbots.

As each of the Paperbot depends on a singular folding, mechanical attachment, as well a software variation. These projects became tools of self-expression.

The workshops audience were diverse in terms of age, and background. Specifically, from sports, art and engineering, and children. The level of interest, and background and the subject influence the expectation and relation to the theme. It was observable that people tend to do what are more comfortable with, according with their background, and cross-boundaries on subjects must be facilitated. For instant, contact with the art of origami, was met from several participants with anxiety, worried about not complying to aesthetical requirements. These initial comments were resolved practically, by moving forward with an one-to-one presence, and hand-on help. Handling paper requires gentleness, and care, as to avoid tearing. There is a learning curve, that eventually was overcome by all participants. All participants eventually folded their own origami.

Performance anxiety and evaluation was also present concerning coding. Some of the participant, admitted not being able to think about coding. Lego mindstorm visual coding, and the simplicity of the program allows to explain basic coding programming, and this issue was resolved with ease.

Therefore this set-up allowed to adapt to the number of people and to a concept easy to build. It works better in an individual attention to each of the participants.

The exhibition at PLUNC, presents Art and Science collaboration, but also, the collective author. The uniqueness of Paperbots, and ephemerality was highlighted when in the exhibition context. They are not objects but temporary concepts. They also wear, and tear with time. It becomes interesting to acknowledge that these objects change through time. But also, the places of exhibition can change their meaning. In sum Paperbot workshops instigate discussion concerning robotics, inclusive practices, and learning by having fun.

3.5.5 Conclusion

The promise of cybernetics to provide the leisure society without labor has been the narrative that that is yet to happen. We are not still all watched over by machines of loving grace. Even in this utopian scenario, robots are imagined taking the burden of labour, and perform tasks that are useful. The question that Paperbot finally ask is, should robots be useful? The best relation between human and robots is an open question.

Addressing wicked problems, like robotics, is adequate when considering separating it in small problems resolution. This approach allows to have non-experts to convey ideas, as in the case of set-up participatory workshop, under a non-expert mind-set.

These exercises in time, with people, followed a generative design process inspired by Sanders` toolbox, and became part of the design research

This is an example of conveying a concept and getting surprising results from playful educational practices. Furthermore, it became evident that the robotic objects, as any other, must comply to creation, and destruction cycles. And the attachment to objects, in this case Paperbot was to some degree reproducing the animistic effect that these object provoke in people. A system death and life of the object emerge vividly.

Indeed, during all Paperbots workshop the animism effect was prevalent. The attachment to the object was systematic, but also, a sense of ownership, and authorship. Naming paperbots was part of this process of giving an identity to a thing. As such, disassembling Paperbots, felt, in many cases, as killing of a thing. In other case, the attribution, as in art creation, raised some awareness to the qualities of a supposed artistic ephemeral object. These objects are transient. In fact, they deteriorate with use, which is opposed to the idea of conserving valuable art objects.

Moreover, assembling and disassembling Paperbots brought closeness to robotics simple features (input, process, output) and therefore achieve grounding for insight concerning participatory creative practices in the realm of Human-Robot Interaction. But also previewed what obsolescence and limitations, possibilities of the robotic design could bring forward.

The mixing of tradition with innovation was given with combination of two materials that are typically from different backgrounds. Therefore, it is a successful hybrid, of high, low tech combination.

Paperbot are not part of the mainstream discourse of robotic technology. As described by Jacobsson et al., (2013) they are all but robust, intelligence in software, autonomous, anthropomorphic, or have a mechanical aesthetics related to mass production. But intend to be part of robotic discourse and be beyond this mainstream view. The claim of this project is that, in fact, these proposals can bring novelty to the discussion. Also, demonstrate that this least explored path, having a better ground of expression in the field of art, is nevertheless relevant.

In sum, Paperbots are artbots. As a device they present robots with no evident usability as to give a sense of playfulness. These effects can be taken from the building processes as well as from the result. Indeed, Paperbots are designed as D.I.Y. objects that can be easily reproduced, without requiring any previous knowledge in coding, mechanics or arts. Secondly, these objects have a limit life-time, due to the nature of the set-up. The third, there is a collaborative nature of a device. They share coding as well as depend on lego pieces, therefore, must be disassembled. Thus, they are ephemeral, fragile, and useless, which is are not the qualities that are popular associated to robotics. However, these devices demonstrate how these qualities can be part of robotic vocabulary.

Furthermore, the ephemeral qualities on the device, allows to convey on concepts like obsolescence and limitations, possibilities of the robotic design

. Beyond outputting new Paperbots, the workshop led to the following conclusions:

• Inclusiveness is possible, this is, contact with code in a fun way, by non-experts,

- Contact with art, folding, by non-experts.
- Contribution to the discussion of robotics by non-experts.
- Teaching the new generations.
- The particular properties of Paperbots, conveys building and destruction practices, which give to design as creation, a tone in also previewing the dead of the object.

4

SUBERSKIN: STATE OF THE ART

4.1 Introdution

The final research project explores the link between digital and physical materials: Suberskin module mixes cork, flexinol (smart memory alloy) and electronics, in order to create a responsive surface. The state of the art reflects on research options, focusing in traditional (low-tech) and smart materials (high tech), and precedent projects.

Thus, the state of the art is separated in three distinct parts. First, precedent projects directly related to Suberskin proposal; second, projects concerning responsive surfaces under Art, Design and Architecture category; third, on the specific materials in use: cork and flexinol (smart memory alloy).

The first part focused on "the materials turn" and in interactive surfaces, within ubiquitous computing and A.D.A. State of the art for experimental design projects is extensive, and therefore a selection was obliged to be made. The criteria used aimed to give understanding to three moments of Suberskin research: first, what was inspiring for the project initial proposal, second, what contextualizes research outcome, and finally how to prospect future directions.

Initial objective was to combine a low-technological material, as is the case of cork, with a high technological material, illustrated with smart memory alloy, flexinol. Cork is a natural material, while flexinol results from laboratorial work. Materials are discussed moving from nano (physical properties) to a macro scale, this is, addressing both technical features, as well as, the acquisition of meaning inside culture. Therefore, the overview on cork, and smart memory alloys, describes practical applications, either within A.D.A. or scientific research, in interplay with socio-cultural, historical, and economical factors.

Finally, the state of the art on materials, and A.D.A., situates Suberskin within speculative design.

4.2 Art, Design and Architecture (A.D.A.) and Ubiquitous Computing (U.C)

4.2.1 Surfaces and media *façades*

Within architecture and design explorations we find research on process and materials (D Pham, 2001, Mori, 2002, Van Onna, 2003, Lefteri, 2003, 2007, Thomas, 2007, Mcquaid, 2005, Stacey, 2006, Reiser, 2006, Beylerian & Dent, 2007, Seymour, 2008, Brownell, 2008, 2010, Corser, 2010, Deamer & Bernstein, 2010). In particular, addressing digital fabrication (Mitchell & Mccullough, 1995, Rocker, 2003, Iwamoto, 2009), as well as proposed break-through prototypes of smart surfaces (Klooster, 2009) or media façades (Haeusler, Tomitsc and Tscherteu, 2013) some with animated form (Lynn, 1998, Moloney, 2011).

The creation of surfaces, with applications in architectonic façades depends, as described, of modular based structures. In the context of new technologies, façades that define new models of communication, have the basic unit, the pixel, emerge as an element of design. When blending space and pixels, new concepts have been put forward. This is the case of "Spaxels", a pixel that is not fixed to a two-dimensional display (Hörtner, Gardiner, Haring, Lindinger, & Berger, 2012).

Architecture as interface behaves like living skins. Thus, admits that the future of architecture is becoming malleable and increasingly collaborative (Hall, 2006). Peter Hall comments:

> "Clearly, architects cannot produce buildings that transform themselves in response to a data feed without intense collaboration with artists, designers, programmers, and engineers. And for these collaborators, the building offers a decidedly public canvas on which to see their creations come alive." (Hall, 2006, p.8)

Looking back, Hall, situate futurists like Kevin Kelly, that in the 1980s, imagined a neo-biological era of manufactured hybrids, living silicon polymers and mutating buildings.

> "As buildings gain the capacity to communicate, the potential arises for mutations that are useful, dramatic or, perhaps, downright mischievous." (Hall, 2006, p. 8)

The term media *façade* describes interactive façades that are digitally activated, creating moving images in architectural surfaces. This is the case of Ydreams', *Light Creature* interactive *façade*, in S. Paulo. In this case, the interaction model, beyond reacting to the environmental factors, is also supported by a gaming experience, where a user input taken from a mobile phone makes the *façade* change aesthetical properties (Requena, 2015).

Christian Moeller and Ruediger Kramm's *Kinetic Light Sculpture Reactive façade* at the Zeilgallery in Frankfurt, uses a media *façade* with a diverse interaction model. In this case a reactive façade changes color distribution according to weather conditions. The façade is composed by screens of perforated aluminum that hide 120 floodlights that fade from blue to yellow. A visual vocabulary is composed displaying variations on yellow and blue. Data is motorized in a weather station on top of the building that is translated into images, visualizing factors as ambient temperature, wind speed, rain, and street noise. Yellow patches velocity and direction represent wind. Rain causes the yellow patches to move vertically. In the upper area, a graphic line, visualizes the noise in the street in real-time (1992).

One of the early paradigmatic expressions of Media Façades was designed by Archigram architect Peter Cook and Colin Fournier in collaboration with realities:united studio. The Kunsthaus Graz is an early example of merging the historic site with the modern. The building is shaped as an amorphous form of a blue bubble made of semitransparent acrylic glass. A computer controlled light systems, of 930 light sources are located under the acrylic skin, which are controlled individually. This technological hybrid is able to create a display forty five meters wide and twenty meters high that enables the museum to communicate with its environment. This building outer skin generates power through integrated photovoltaic units. The interplay between technology and tradition in the historic center on the bank of the River Mur offers a balanced dialogue between traditional architecture, and transitional technology (Cook and Fournier, 2003).

Emerging technologies shapes todays architecture, conceding new concepts, regarding materials and processes. For instance, the case of robotic architecture can refer to a building process, this is, by having robots that build large scale 3d printed houses, but can also take form of modular robotic surfaces. For instance, FESTO's interactive wall (2009) is defined to convey autonomous materiality.

Figure 61. FESTO corporate (2009) *interactive wall*, Germany, retrieved from https://www.festo.com/cms/en_corp/9651.htm

In the case of FESTO’s interactive wall the structure changes physical characteristics in response to human input. Movement is inspired by fins of fish through water and the skin can change in appearance dynamically. Following the authors own description, it's an interesting step towards the idea of emotive architecture, where the environment comes alive around you.

4.2.2 Sustainability and high-tech

Usability of sustainable facades are unquestionable. In fact, design methods for high-performance building envelopes, have been edited by Aksamija (2013). Materials engineering and design research cross from application of materials based computation to grown materials (bio-fabricate). An example of the latter the first fully algae-powered architecture developed by Splitterwerk, Arup GmbH, B+G Engineers, Immosolar (2013). The *Bio Intelligent Quotient (B.I.Q.)* Building, is built in Hamburg.

Figure 62. Splitterwerk, Arup GmbH, B+G Engineers, Immosolar (2013). *The Bio Intelligent Quotient (B.I.Q.)* Building, Hamburg, Germany

Its *façade* is built with 0.78-inch thick panel - 200 square meters in total. These panels display a bright green color as they contain algae taken from the Elbe River and pumped full of carbon dioxide and nutrients. These panels beyond using the aesthetics of algae, use their natural performativity potential. The sunlight hits these "bioreactor" panels, and photosynthesis causes the microorganisms to multiply and give off heat. The warmth is captured for heating water or storing in saline tanks underground, while algae biomass is harvested and dried. Furthermore, these can either be converted to biogas, or used in secondary pharmaceutical and food products. Residents have no heating bills and the building currently reduces overall energy needs by 50% (Figure 62).

4.2.3 Art and Technology companies

Environmental experiential graphic design combines disciplines defined as graphic, architectural, interior, landscape, and industrial design, and stabilizes a relation to visual aspects of wayfinding. Environmental experiential Graphic Design has been a context that progressively adopts new technologies. It concerns communicating identity and information in space, creating experiences that connect people to place. As such, the areas of practice range from wayfinding, placemaking, exhibition design, public spaces, research to master planning.

Emergent technologies allow to create dynamic digital content and promote exchange of content between an user and place. As information is becoming progressively dynamic, static elements makes a progressive transition to digital interfaces. Thus, design for public places evolves to support smart cities.

Complying to the concept of smart cities, and serving the citizen comfort the experience of the urban place combine art and technology. Precedents were set by companies like ART+COM studio (Germany) which is specialized in spatial communication with new media. This company that started as an art collective (Manovich , 2003), created *Symphonie Cinétique*, *the poetry of motion*, an example of a kinetic composition of music and mechanical motion in a space.

Studio Roosegaarde (Netherlands) is another company which focuses in artistic centered research, where technology serves the concept. Roosegaarde claims that this combination allows to create highly innovative and emotionally appealing solutions. An example of a reactive project is *Lotus interactive wall* (2011) using shape memory material.

4.2.4 Interior design interactive objects

Interior design has been progressively adopting new interactive technologies as another expressive material. In Milan Design Week, examples of this transition to interactive objects have been progressively presented as part of design discourse. Considering interactive objects typologies, two projects highlight the particular mix between natural materials, and electronics.

The demonstration chosen, offer insight regarding a vertical and a horizontal surface application, this is, an interactive wall and an interactive floor. A wall *tu luz*, was designed by Stephanie Brenken and Viola Kressmann and an interactive floor, *light up the wood* by Sophia Bischoping and Laura Pausinger.

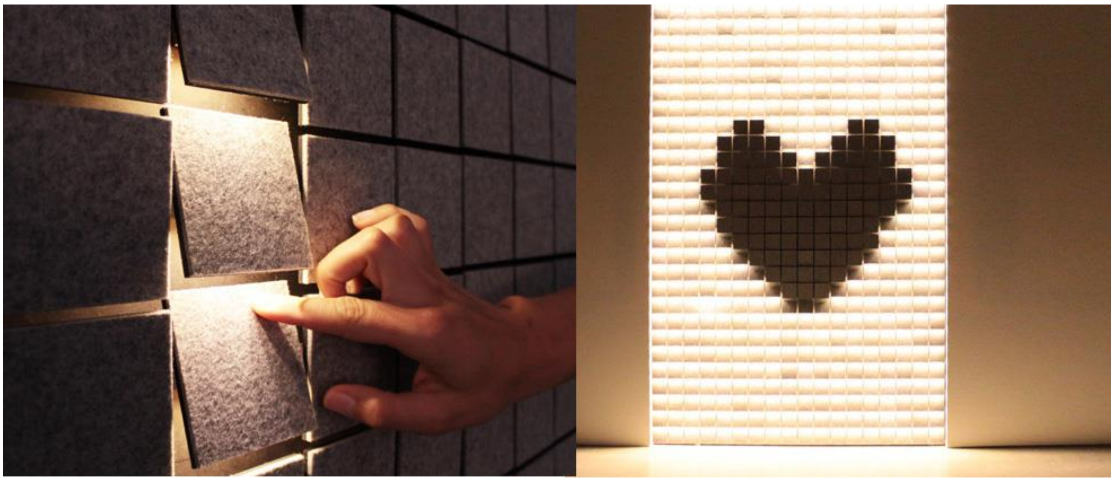


Figure 63. Stephanie Brenken and Viola Kressmann, (2014), *Tu luz*, Milan Design Week.

Tu Luz is a vertical installation that creates different atmospheres. The square element, the pixels, are operating light switches. These are designed in order to project light upwards or downwards. The lighting moods can vary according to positioning and brightness (Figure 63). In the case of *light up the wood* the pixels are wooden floor elements containing LEDs. Each of these pixels are triggered by pressure. The design concept aims to encourage playfulness, togetherness and stimulate communication. The installation reacts (the LEDs change brightness) according to the number of people, adapting to the individual step of the user.

Figure 64. Sophia Bischoping and Laura Pausinger (2014) *light up the wood,* Milan Design Week

4.2.5 Shape

4.2.5.1 material pixel

The translation of digital pixel to a physical form, in particular when movement is applied to the pixel, creates a new vocabulary. Physical user interfaces terminology look at shape changing surfaces. For instance, the novelty of the subject led to define a taxonomy for material interface (Rasmussen, Pedersen, Petersen & Hornbæk, 2012). Another case, on the transitions to a physical 3D lattice, the digital units are called voxels (Hiller, J. & Lipson, H.,2008). Moreover, the Spaxels bring, yet another designation for pixels that are part of space (Hörtner H., et all, 2012).

In the case of drawing in large scale *façades*, materials are often used as pixels. Moeller & Kramm created a digital *façade* which changes color distribution according to current weather conditions (1992). In another work, *Quill* (Moeller, 2014), uses pixels that do not require the use of energy. Instead, it is the environmental placing that inspired the use of 20.000 reflecting discs, that work as a display. During the day the disc convey an image, and at night they reflect passing by car lights, becoming a project of public art.

Figure 65. Urbana Architecture (2012). *Dynamic facade system*, Eskenazi Hospital Parking Garage, Indianapolis, USA

Studio urbana architecture designed the installation that creates a dynamic façade in a hospital parking structure. Situated in Indianapolis, this façade made of 7,000 angled metal panels, articulate in an east/west color system (Figure 65). These allow to create unique visual experiences depending on the observer’s perspective (Caula, 2014).

4.2.5.2 Module

The overall mathematical considerations that tiling imposes is built upon ancient traditions. Modular design can be traced back to the Babylonian period. Tile design have offered solutions that are still is in use in today's architecture. The overall question behind tilling is to resolve the quest on how to occupy a surface, with elements, without space in between. In fact, tilling oblige to tessellations - repeating of patterns of specific shapes. Indeed, the word "tessellation" comes from the Latin "tessella" meaning "small square" - which the Romans used for making mosaics and tile designs. Mathematicians in middle ages have answered these questions, with geometry, expressed in multiple shapes in ceramic tiling.

The term module is an indicative of order. It should represent a conceptual framework to operate in, rather than a specific dimension or grid. Any design concept used to enclose space requires continuity of both structure and enclosure. The interplay between module, proportion, symmetry and rhythm was discussed for instance by Gyorgy Kepes, (1966) Modelar design is a quest that with new technics, and software, have open new possibilities. As Catarina Mota states,

> "The idea of modular objects often evokes a limited vocabulary of basic shapes and thus a limited number of variants that can be created with those units. However, with parametric digital designs, modularity does not require a predefined vocabulary and therefore does not imply a reduction of the number of forms that can be created. On the contrary, as Manovich (2005) points out, if pre-digital modularity leads to repetition and reduction, digital modularity is capable of unlimited diversity" (Mota, 2014, p. 146)

Software like SketchChair, Similarly, Pop-up Workshop, JavaGami and PePaKuRa offer design environments for generating polyhedral 3D objects. Regarding cork tiling design, generative and parametric design pushes forward on the traditions of tiling, as is the case of projects like Gencork (2015).

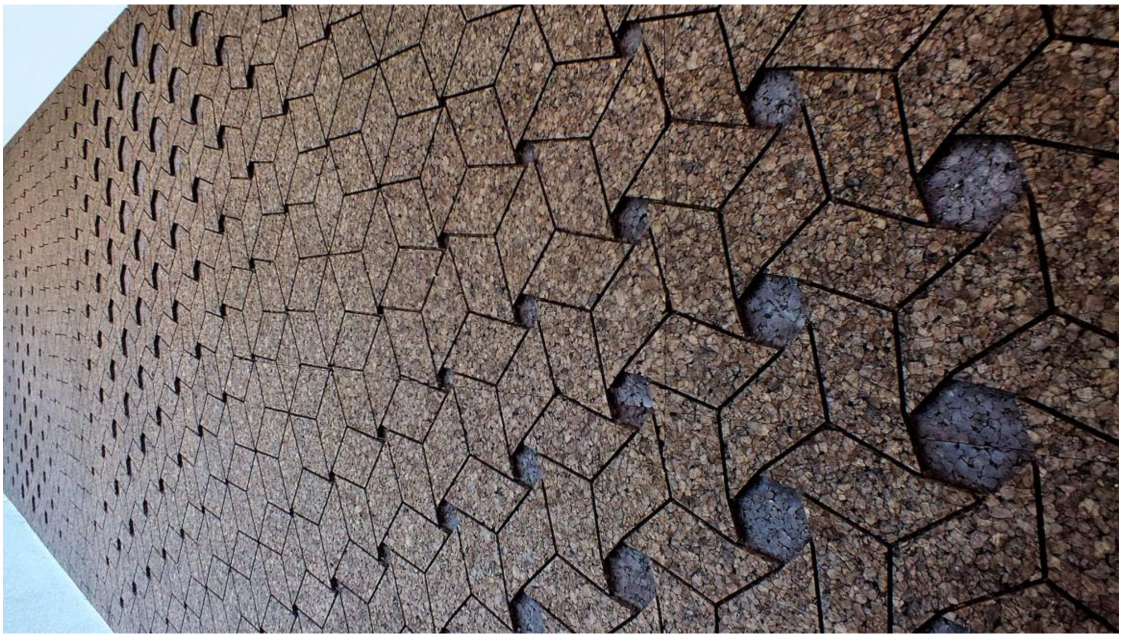


Figure 66. Gencork (2019) *generative wall,* Portugal retrieved from http://www.gencork.com/site/

4.2.6 Suberskin project precedents

Smart surfaces explore specific features of materials. Two strategies are possible and relevant to identify regarding the approach to technology. One, using emerging technologies and another exploring the interactive potential of traditional materials. On a high-tech level, the use of materials that work as sensors and actuators are common ground. This is the case of materials that can monitor weather conditions, activate protections, or provide data, transforming intelligent surfaces in devices. Such surfaces, for instance, can retrieve data and allow evaluations at different scales e qualities (Sauer, 2010).

However, there are responsive surfaces found to use low-tech. Thus, bringing traditional materials into the vocabulary of smart surfaces. This is the case of the *Biomimetic Responsive Surface Structures* developed by the Academy of Art and Design of Offenbach, that uses wood natural conditions to trigger movement. The wood would curl and make openings in the structure when reacting to moisture (Figure 67).

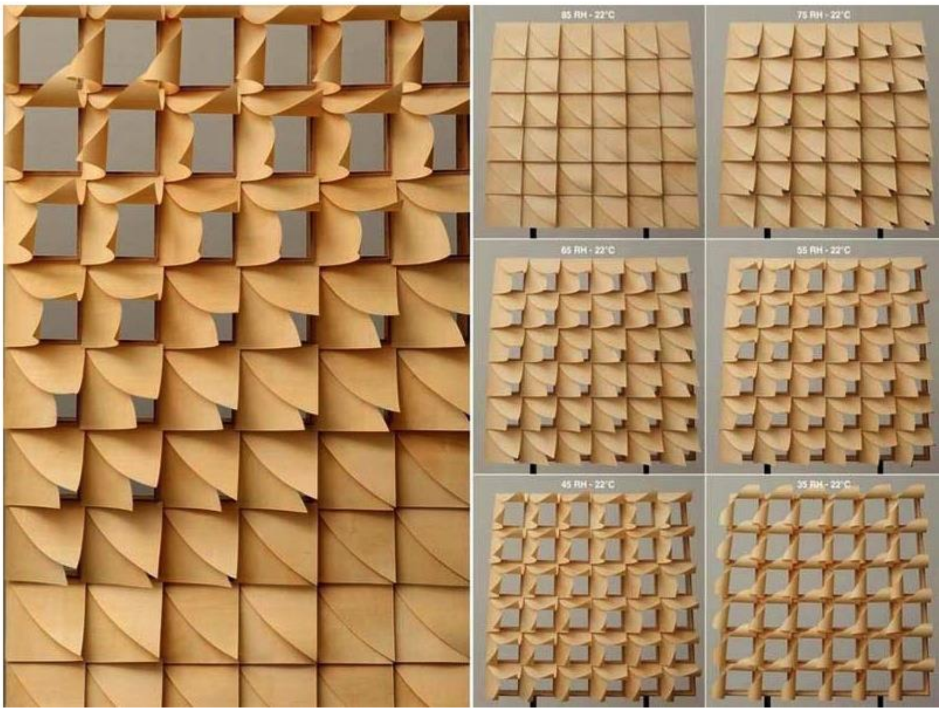


Figure 67. Academy of Art and Design of Offenbach (2006) *Biomimetic Responsive Surface Structures* retrieved from https://icd.uni-stuttgart.de/?p=5655

Another physical installation, *Windswept* (Figure 68) works as intelligent public façade. In this case 612 freely rotating directional arrows move with the wind, and thus transforming this façade in a wind mapping tool. The advantages of these two surfaces are that they are completely self-sufficient in terms of energy, whereas intelligent digital surfaces systems require to be powered by an electrical power source.

Figure 68. Charles Sowers Studios (2011) *Windswept.* Randal Museum in San Francisco

Interactive walls and installations are now common in the digital realm, either in art or commercial applications (Bullivant, 2006, Klanten, Ehmann, & Hanschke, 2011). The systems ability to convey content, therefore, meaning, have either digital or analog images as output and a variety of input data.

Figure 69. Golan Levin, Zachary Lieberman, Jaap Blonk, and Joan La Barbara (2003) *messa di voce* [performance]

Visualizing information in a wall shaped device has been part of several art projects. Pioneers like Golan Levin and Zachary Lieberman created *messa di* (2003), a digital wall that translates visual interpretations of the invisible voice in real time. Levin and Lieberman's system uses sound as input, and outputs real time digital images according with voice variation. Their work established a link between drawing and the digital representation.

However, the use of physical materials in an interactive surface, can be noted to be less common. Daniel Rozin's art installations are pioneer work in the use of wood, metals, mirrors, as pixels (e.g. wooden mirror installations). This author's work is an inspiring precedent for using kinesis on intelligent walls. It is an example of surfaces that uses movement to convey images and information. In this case, Rozin uses a myriad of physical materials to make moving images. Each piece of material is used as a pixel that is activated by a mechanical structure. In the case of *Wooden Mirror* (Figure 70) the moving pieces are made of square shaped wood and that reflect light, allowing to convey gradient shades.

Figure 70. Daniel Rozin (1999) *Wooden Mirror* [installation]

Wooden Mirror explores the boundary between digital and physical, using a warm and natural material such as wood to portray the abstract notion of digital pixels. The experience design is based in a mirror set-up. The viewer watches a real time reflection of self. The input is made via a camera and a computer vision *algorithm* translates the captured image to an output of wooden pixels.

Rozin's projects are contextualized as interactive art, and *Wooden Mirror* was presented in an art gallery context. Latter, the concept was installed in a hotel lobby.

A deeper analyzes on technical and materials options taken on this oeuvre notes that: each piece of wood reflects light, which allows to control gradients and shades. The interaction offers a real time aesthetical feedback combining image and sound – due to movement of the pieces of wood, and the motors that work as actuators, the system has noise as output – which is part of the whole experience.

In sum, the particular feature of Daniel Rozin's instalations is the application and testing of several typologies of materials as pixels. The use of a natural material (wood) as a pixel is relevant to situate design research, conveying natural cork as pixels. The interaction model and technology (computer vision and server motors) offer reference to the system and user experience design.

Rozin's design process is documented in Open University website. The first prototype and process is discussed, as well problems resolutions. In the Figure 71, Rozin presents the first tile prototype.

Figure 71. Prototype tile wooden mirror (video still) retrieved from https://www.youtube.com/watch?v=nv4yQGw7dmg,

David Bowen's, *Tele-present water series* also uses physical materials as output. In this case, a flexible composition of bamboo, moves according to digital coordinates. David Bowen's physical interactive art installations conveys a telepresent interaction model (2011). *Tele-present water* was presented in National Museum in Poland and resulted from a collaboration with a National Oceanographic Atmospheric in Pacific Ocean. The installation used live data taken from a Microsoft Kinect, installed in a sea front, and the output reproduced live physical movements of waves in the bamboo structure.

Recent developments made by MIT Tangible Media Group, investigates physical interchangeable devices. *Transform* (Vink et al, 2015) results from this team effort to devise what could be interactive furniture, or physical objects that change shape from digital remote input.

Interactive surfaces can be built from mixing smart with traditional materials. For instance, smart materials can be found woven into textiles with electrical conductive fibers, but also to work as displays, through the use of electrochromic coatings, thermochromic or photocromic pigments. These would be incorporated in inks that change colors. Shape memory alloys are typically used adopting its reversibility properties to activate small elements or to change textile length.

The combination of crafts with SMAs as an actuator is demonstrated by Yvone Chan Vili's research, when applying kinetic properties to textiles (Ritter, 2006). The same model interaction model is found with Marcelo Coelho's *Shutters* (Coelho & Maes, 2009) or Jie Qi's work with self-folding paper (Qi & Buechley, 2012). These last projects have a low-tech, high-tech approach, that reveal crafts design prototypes combined with complex materials, as a viable mean of expression.

4.2.7 Process and presentation

4.2.7.1 Speculative prototypes

Responsive architecture results from a process of gradual experimentation. Speculative work has devolvement phases presenting demos and prototypes. This was demonstrated with discussed project Wooden Mirror, where Daniel Rozin's builds from pixel, to a tile, to finally have a wall installation.

Contributions to the field of highly speculative design, often present early modular prototypes. This is the case of three students at Barcelona's Institute for Advanced Architecture of Catalunya. This is the case of Ece Tankal, Efilena Baseta and Ramin Shambayati's, are creator of *Translated Geometries*. The collective concluded a modular component that expands and contracts reacting to temperature variation.

This project offers a contextualization of present research. First, by presenting a collaborative research. And, secondly, by combining material studies with smart materials. Third, by demonstrating a territory for architectural research. In this case, the presentation takes the shape of a prototype that demonstrates the structure reactive quality (Figure 72).

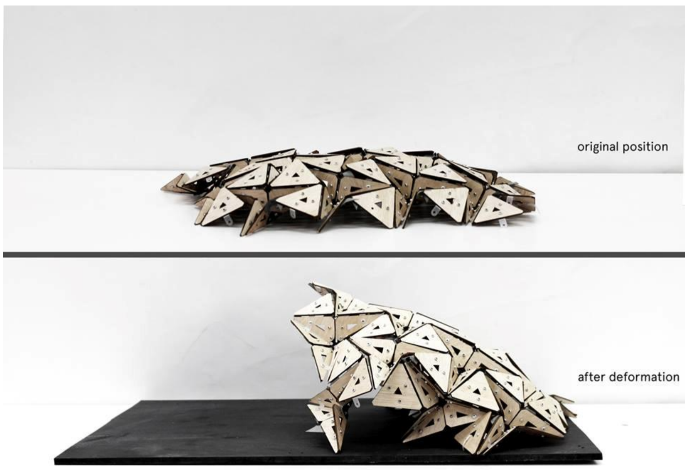


Figure 72. Ece Tankal, Efilena Baseta and Ramin Shambayati (2014) *Translated Geometries*, retrieved from https://iaac.net/project/translated-geometries/

4.2.7.2 Tile demonstrations

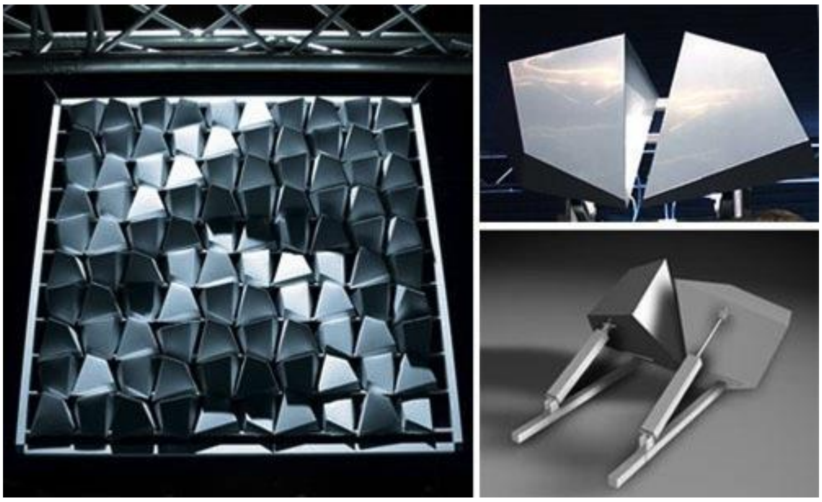


Figure 73. studio WHITEvoid (2012) *FLARE-facade prototype* retrieved from https://www.white-void.com/#/main/architecture_spaces/flare_facade/description

Other example of highly speculative exploration and presentation are media façade modules. Interactive art and design studio WHITEvoid introduced their FLARE-facade prototype at the NEXT art & technology exhibition (Figure 73).

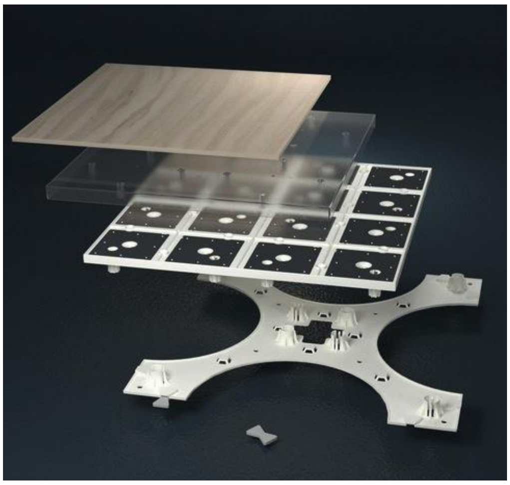


Figure 74. Sensacell (2019) retrieved from http://www.sensacell.com/

Sensacell is another module combines traditional materials and technology. This tile is an interactive sensor surface, that can have any size or shape. The single module sensor is scalable, to 1000’s of square feet, and detects objects through materials such as glass, plastics, wood. According to the company, Sensacell modules consist of 4 non-contact sensors and a LED lighting array, capable of bi-directional communication with other modules and forms of distributed intelligence. The module can be applied in interior and exteriors, within context such as smart architecture, entertainment, or interactive physical computing. The system's network can also interface with a computer for control (Figure 74)

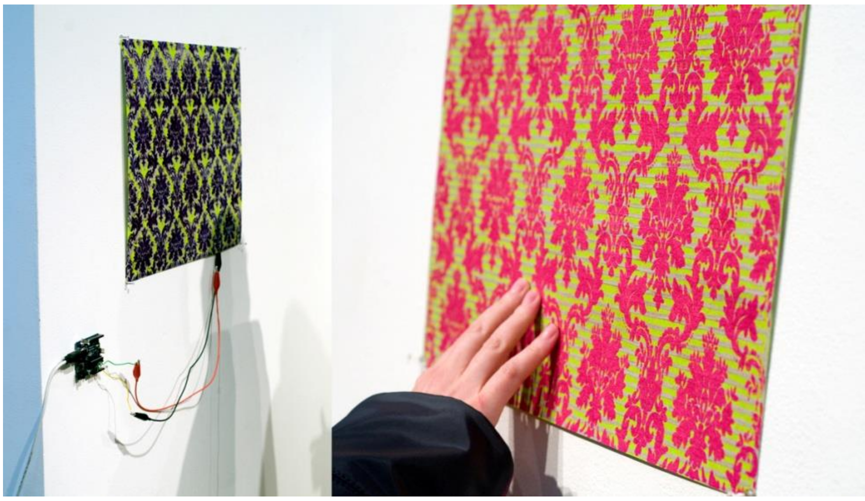


Figure 75. Kirk Mueller (2014) *interactive wallpaper* retrieved from https://www.flickr.com/photos/kirkmueller/3108810596/in/photostream/

Kirk Mueller, a new media artist, created an interactive tile, made of paper. This interactive tile combines arduino, smart and conductive inks, and presents a concept of decorative silkscreened wallpaper into dynamic, pattern-changing skins (Figure 75).

4.3 Low tech material: cork

4.3.1 Material Characteristics

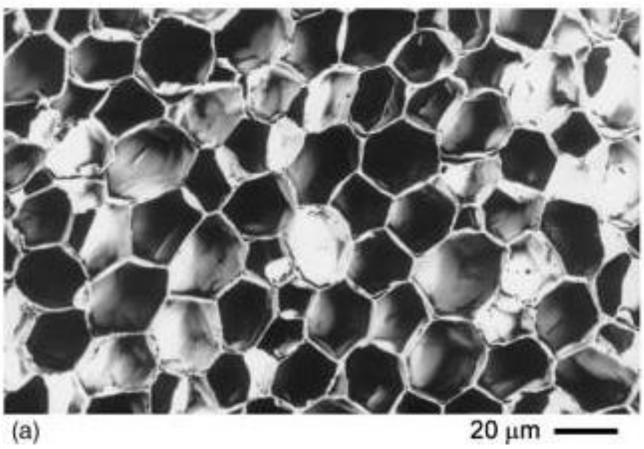


Figure 76. *Cork Hexagon nano-structure, Scanning Electron Micrograph, tangential section*, retrieved from Pereira, Helena (2011). Cork: Biology, Production and Uses, Elsevier, p. 37

Cork is a material with a vegetal origin. Precisely, cork is the wooden tissue that grows from the bulk of a tree, the Cork Oak.

The skin, that stands out, can be said to be a wit of nature, resulting from the tree's adaptation to the environment. The natural distribution of the oak tree is restricted to the western part of the Mediterranean basin and the adjoining Atlantic coasts (Pereira, 2011). The woody tissue below epidermis of a plant (designated as *suber*) is exactly what is emphasized in the Latin name given to the tree, *quercus suber.* The Latin name, suber, explains branding options on the research project.

The feature that makes this oak differ from others offer protection in the environment where it grows. The "montado" (group of Cork Oaks) is exposed to Mediterranean weather, with high temperature amplitudes. In Winter the tree is subjected to mid-moisture, and in Summer temperatures can reach 104 F, 45 C. These dry and high temperatures conditions often lead to forestall fires. The skin thickness provides temperature resistance, elasticity, fungal protection, and is a fire retardant. Cork material, once removed, maintains characteristics that actively serves the tree.

Figure 77. Debarker and cork, retrieved from http://www.apcor.pt/

The Cork Oak takes 30 years to grow into a young tree, and 9 years to grow its first bark. The first and second bark, virgin cork, cannot be used in natural cork wine stoppers, however it has an applicability if granulated. The tree's bark only becomes productive to utilize in cork stoppers when reaching 50 years, for a period of 300 years, throughout its lifespan.

The Cork Oak must stay healthy to produce material with good quality. Costa & Oliveira (2015) have discussed the relation between the stress produced by debarking, and the maintenance of the tree's health. Debarking must follow specific rules to overcome the aggression, for the tree to maintains the equilibrium, and growing back her coating. According to Apcor the preservation of the Cork Oak, within the Portuguese forest is estimated to absorb 14 millions of tons of carbon dioxide (2018).

The transformation of cork, before becoming cork stoppers, undergoes an industrial process. Stripping of the cork oak is an ancient process. Currently this is done by specialist labours, the debarkers, which make specific cuts preventing damage to the tree (figure 8). The curved cork planks are boiled and flattened. This shape allows to cut slices of cork, and from them, wine stoppers, are finally cut in shape with different calibers. Leftovers are used in composites and for fuel (as is the case of powder). It's estimated that 85 % of cork industry is used from leftovers.

4.3.1.1 "Warm" and natural material

Natural cork is impermeable, elastic and compressible. Cork has low conductivity of heat, thus works as thermal insulator. The material displays fire retardant qualities. Cork absorbs noise and vibration and is resistant to abrasion, offers qualities for acoustic isolation. It has hypoallergenic properties and a non-intrusive odor, an haptic felling which is reminiscent of dry wood. Cork s naturally uneven surface gives textural possibilities that vary accordingly with the finishing. It is 100% natural, fully recyclable and reusable. Cork can be granulated endlessly. The use of agglomerated cork has been used in a side industry, with application in flooring, and walling.

As it heights 0.16 grams per cubic centimeter cork is very light and can easily float. These properties are more prevalent in the natural cork, than in composite materials (Apcor, 2018).

In sum, cork, a natural material, is bark taken directly from a living oak tree. Cork, as material, maintains properties that result from the tree's natural adaption to environment. For the tree, cork wide skin offers fungal protection, excellent thermal isolation, and works as a fire retardant. These characteristics, which serve the living tree well, are kept in cork once removed and transformed into non-living material.

4.3.1.2 Material applications

Cork is traditionally used as wine stoppers when cut out initially from the whole bark. Earlier sources as far as 3000 BC refer the use of cork for fishing tackle, floats, stoppers for casks, women's footwear and roofing materials. If grained, the cork can be transformed into tiling and wall coverings.

Mestre (2011) selected seventeen cork materials available in the cork industry and registered patents.

Cork materials	Manufacturing process
Natural Cork	Cut through cork planks
Granulates	made by grinding scraps, parings, virgin cork, cork pieces or stopper production waste
Black / Pure / Expanded Agglomerate	Made through an agglutinating process of crude virgin cork granules. No synthetic agents are used. It is a product with excellent ecological characteristics
Sandwich of Black Agglomerate with Natural Fibres or other materials	panels of black agglomerate are used in a sandwich with other materials such as coconut and neoprene.
Regranulates	Produced by using the waste from expanded agglomerate. These are essentially used in walls, terraces and coverings, and may be mixed with concrete.
Densificated Black Agglomerate Boards	The black cork agglomerate densification is a completely natural (without glues) process. These agglomerates do not have any problems of possible toxicity presented by other agglomerates. The production process involves compressing boards of ordinary black agglomerate
Agglomerate Composite with Natural or Synthetic Resins	This is made from waste products from the transforming cork sub sector, adding value to waste and an excellent opportunity to recycle (used cork stoppers) or re-use cork products. The most widely used in industry is white agglomerate.
Agglomerate of Cork Powder without addition of glues	agglomerate manufactured from cork powder, with the possible incorporation of other components, without using glues.

Agglomerate Composite with Rubber (RubberCork)	Rubbercork or CorkRubber is a type of cork agglomerate that have different formulas. They can be made by mixing and agglomerating cork granulate with natural or synthetic rubber (in powder or small particles) and other agents (vulcanising agents, anti-oxidants, polymerisation accelerants, colourings).
Agglomerate Composite with Tetrapak® cardboard waste packing	The production process of composite agglomerates includes a combination of particles deriving from the shredding and/or grinding of Tetrapak® packaging, optionally including other materials.
Cork Polymer Composites (CPC's)	Can be produced with cork powder (50% wt.) and mixed with polypropylene (PP), polyethylene (PE) or Polyurethane gel by pultrusion with the purpose of preparing cork-based composite by compression molding. The aggregation of the particles (and in some cases the adhesion of the covering particles) is due to the use of different kinds of thermoplastic binder.
Cork Fibre Reinforced Plastics (FRPs)	Provide series of alternatives in the realm of technologies for reinforced plastic composites, which may be used in industrial applications, such as trains, ships, buses and aeronautics. The use of natural loads (in addition to cork) in new composites has been considered, providing the mechanical requirements of the materials and market demands.
Sandwich of Agglomerate with laminated sheets of MDF, Wood, Aluminium or others	This process can use a great variety of base materials, namely sheets or panels of wood, MDF and aluminium. The sheets of cork are glued and pressed on to the selected materials.

Cork Gel	A compound of silicone with natural cork granulate. Adhesive, absorbs shock and impact, is comfortable, resistant to heat, water and sweat and elastic. It is produced and sold in the form of tape in different colours and nishes.
Cork Fabric and Paper (also known as cork leather or cork skin)	Produced from laminated sheets of natural cork (usually with a thickness of 50-500 µm) or agglomerated cork glued on a textile or paper base. This fabric has a long durability and its texture is that of cork, which can be felt on touch.
Cork Wool	Different application purposes, as in packaging, mattresses, pillows or sofas, due to inherent properties: absence of toxicity, compressibility and power to recover, durability, lightness, impermeability and insulation. t is cited as being able to eliminate certain sleep disturbances.
Cork Powder	Residue deriving from cork transformation sector. A series of chemical compounds may be obtained, for different applications, for instance, for medical purposes or as an energy source. Combined with thermoplastics allow to create a new cork-polymer composite (CPC) materials with interesting properties provided by cork. The impact, hardness, water absorption and acoustic properties are being investigated to create new products with high added-value.

Table 3. Mestre's table of cork application

Cork research has typically addressed material properties by enhancing or combining with other materials. In recent years, there has been research into cork composites that take advantage of cork features to create new materials and applications; one application is the use of rubercork in parts for NASA space shuttle (Apcor, Amorim, 2017). This is also the case with bio-composites like patented Lifocork (cork particles and thermoplastic PVC, that can be molding injected), Vinnex (polyvinyl, acetate-based, free-flowing powder), Thermofix (composition of 30% Cork flour, 30% Coconut fiber and 40% PVA resin), suber3 (injected molded cork, mixed with acrylic resin, plant fats and water) (Peters, 2011). The hypoallergenic properties have been researched in the context of medical applications.

Crafts-led approach has contributed with further innovative solutions. This is the case of British designer Yemi Awosile, which blends knitting skills with cork, creating cork-textiles.

4.3.2 *Ethos* of cork

> "Mexer nas coisas, "meter a mão na massa" (como proclamaram movimentos contemporâneos nos EUA — hands-on! — ou em França — la main à la pâte), tem contra si séculos de cultura de educação retórica e burocrática e o medo "de classe" de trabalhar com as mãos, atavismos esses particularmente enraizados em Portugal"
>
> Entrevista a José Mariano Gago por João de Pina-Cabral, (2011) *Análise Social*, vol. XLVI (200) p.402

The *Ethos* of cork extends from historical-cultural to social-economical values. The choice of cork as a material was led by a purist approach to materials, aiming to highlight raw aesthetics, and use the least mixing possible. This aesthetical purism also complies with sustainable practices, as is the case of materials parsimony (Unruh, 2010). In the context of the research project, creates an expectation of the use of its most neutral expression. Thus, attention is directed cork physical properties, its natural features combined with digital, emerging with potential plasticity.

The insight gained with a neutral scientific analyzes can possibly imply lost in terms of context and qualitative evaluation. To address cork, conveying physical properties, implies the removal of the material from its social-cultural context. However, the meaning given to the project tends to recover the original provenience: cork is evaluated inside a culture, and Portuguese Industry. This research effort tried to be removed from addressing expectations. The composition between a S.M.A. and cork is a hybrid, and a tentative of creating a mutant material, and therefore to be innovative in the context of cork.

However, one of the problems of using cork as a material is the fact that is not neutral in terms of social-economic and cultural background. Meaning changes according to the point of view, and the information of the subject. From an ethnographic point of view this transformation of the object itself by the cultural and individual filter of the viewer, cannot be totally avoided. Therefore, this effect is pertinent to acknowledge first hand, as well as identify variations and the possible ways they might interfere in a final evaluation.

Considering identity and legacy of cork, a problem arises immediately with the assumption of historical objectivity. Despite of existing abundant documents that registers history there is still differences between story and narrative. One of the issues arises specifically with cork, when we are talking about recent history of people, and this, might eventually resonate in the material itself. However, ANT offers a point of view that allows to distance ourselves from a very near object, and consider the thing, instead of the authors of the history. This is the approach that was tried to be followed.

4.3.2.1 Historical and social-economical factors

Figure 78. cork factory, "escolhedoras", XX century, retrieved from "mulheres cocheiras", 2010

Cork, as a natural material extracted from a tree has a source geographically referenced and limited. The tree physiognomy is an adaptation to an ecosystem, and therefore, it is understandable that the Industry coincide with the countries where cork is abundant as a raw material. This is the case of Spain, Portugal, France, Italy and the North Africa - Morocco, Algeria and Tunisia. The remaining share market, focused in trade and industry, is distributed through countries from East European Union, Japan, Switzerland, Germany, United Kingdom, Latin America, India and United States of America. The Iberian Peninsula has 75% of production (Pestana & Tinoco, 2009).

The history of cork is directly linked to the history of Portuguese industry, that extends from the XIX century to nowadays. Nevertheless, the world knew about cork early on, before Industrialization. The first Portuguese references of creation of the monopolies are from the xiv century, attributed by the king D. Dinis (planks and derivatives were sold, etc..). Records referring to cork are across the world, taken by Portuguese navigation. One of these early records appears in England, in a text book in as particular contribution to science made by the British Robert Hooke (1635-1703). Hooke when observing cork with a microscope identified hollow structures that he named cells (from the Latin, *Cella*, meaning small room), a designation that since then have been applied by cytologists to define structure of biological materials (Figure 76, Figure 79). His findings were published in *Micrographia* (1665).

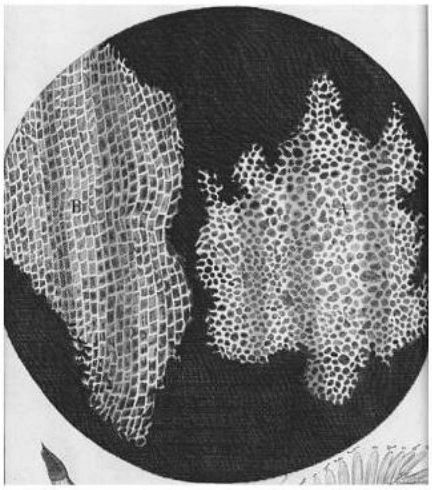


Figure 79. Hooke drawing reproducting cork structure seen in the microscope, retrieved from Pereira, Helena (2011). Cork: Biology, Production and Uses, Elsevier, p. 34

The first standardized cork wine stopper appears in South of France. Some references associated this to the creation of Champagne Cork, for the D. Perignon bottle, by the Benedictine monk D. Pierre Perignon. Associated with standard cork is the creation of other tolls, as is the case of the corkscrew. This is an example, on the direct relations between objects prevailing as tangible observable documents in history.

Since the XIXth and throughout the XXth century the transformation of cork into standardized cork stoppers, offers a view in relation to the history of the Portugal and the world of industrialization. According to Pestana and Tinoco (2009), the first documented industry in Portugal, have labors arriving from Spain (Catalunia) traveling to Montijo, closer to the main source of the material (Alentejo) south Portugal, to teach the craft. Nowadays, the industrial cluster that located in the North. The motivation to place the Industry in Portugal is related to the demand caused by Port Wine success.

Considering the described factors, like the location, and abundance of the raw material, Portugal offers perfect conditions to create innovation using cork. However, this happened in countries that have a more mature Industrialization. For instance, the agglomerated cork is patented in the XIX century in the United States. The same happens with the Industrial transformation machines. The first machines are imported from France.

Portuguese sociologist Barreto argues that in the beginning of the 30 of the late century, Portuguese economy was one of the further behind in Europe. This situation continued until the 60, shaping the social and economic evolution in Portugal. As a result, the society was paternalistic, and polarized in terms of classes.

During this period, Cork Industry rose from bottom up, creating side vernacular applications in crafts, and an incidental industry from left-overs. Throughout the XX century cork Industry establishes its lead in Portugal with Amorim and others industrials.

The Industry makes an extensive reuse of the material. Leftovers when grained are applied to other products. This allowed the industry to consolidate a side product industry, with agglomerated cork. The reuses of leftovers become an incidental industrial sustainable practice, having a local, hands-on approach in relation with a material.

4.3.2.2 Collaborative design

Co-design (a bottom-up point of view), assumes that actors or users can participate and contribute to the design process because they are "experts of their experiences" (Visser F. S., Stappers P. J., van der Lugt, R. & Sanders E. B-N, 2005). Thus, this is a democratic view on design.

However, the tendency to overlook the voice of people, referenced as source of need, and not, as source of knowledge, maintains. The data on education in Portugal (2012) still confirms a wide gap: 62% of adults do not have upper secondary education. This gap has decreased, there is 38% of adults with at least upper secondary, but this is still low as compared as the average for OECD countries, where 75% of adults have attained at least this level (OECD, 2018). Portuguese are keener in adopting social reproduction strategies than mobility (Wall, Aboim, Cunha & Vasconcelos, 2011). This data show that Portugal is an unequal country. Thus, the environment is not typically favorable for discussions supported by critical view. In fact, patents sourcing in academy and the industry are still at low level in the UE. Further research regarding these processes could be done.

Cork has shown appreciation in foreign markets throughout the XX century. Portugal is currently (2019) the biggest exporter of the material 1 billion of revenue, and creating 60000 jobs.

Therefore, in Portugal the Industry cork has a social economical impact, expressed in exports expected to reach EUR 986 million in 2019. Cork has become a material that supports a community that ranges from the extraction of the material to its transformation into products (APCOR, 2019).

Considering the background, a focus group in UT Austin with 5 nationalities was adopted testing assumptions on cork, without a frame of reference (Paiva, 2012). An unbiased reaction was expected and reactions were annotated. The material inspired curiosity. The neutral reaction to the material further consolidated the possibility to address cork with experimental design.

In the case of current research, of interest is to analyze the contact between traditional economics (scarcity based) and new digital economies. For instance, in the case of cork, as is a bottom up industry, has social-cultural and political dynamics – these are, after all, part of Portuguese history – and part of the production of value.

4.3.2.3 Sustainable factors

Cork is 100% sustainable due to two general factors. First, debarking does not affect a tree's health as the bark grows fully back every ten years; this in turn has the side benefit of giving the tree protection from human harm as it is embedded with social practices and relevant economic revenue. Second, cork is endlessly and continuously reusable. In fact, cork can be thrown into the soil as a fertilizer: it is 100% biodegradable.

As such the protection of the cork tree prevents the soil erosion, retaining CO2. Also, contributes to the use of the autochthonous flora. Other cultural practices, as is the use of nutritional qualities of the acorns contribute to the tree's multifunctionality. The use of acorns were typically associated with lack of alternative food. As a practice this has been recovered, recently, through a display of culinary applications.

4.3.3 Academy, Industry and experimental design

Flusser, a philosopher provably inspired by working in his father in law factory in Brasil, comes to mind:

> "the Basic error of the Platonic and the Romantics is becoming clear for us to see. As long as the school and the factory are in fact separated and look down on one another, industrial chaos is the rule", Vilém Flusser, The Shape of Things, p. 49

Despite existing throughout the XX century several public policies, concerning the industry, the divorce between industry and academia, specifically referring to research of new products, only recently had been dealt with.

On one side, Cork industry has as entrepreneurship program, and includes research program inside the industry. One of the first results is the" Portuguesas" sandals, with cork sole. An encounter between design research and industry happened in 2011, with Ynvisible Network.

This Lisbon based consortium concluded a first round of innovative products addressing the Portuguese Industrial traditional materials (paper, cork, cements…), but also research materials (smart materials). The aim was to development of new products, process, and systems for the invisible computation.

Internet of things research is happening in CENTI Cork Nanotech, or the Smart Cork. proposed in University of Aveiro, using an integrated chip RFID to qualify wine (Universidade de Aveiro, 2014)

These political proposals reveal that nor the academics are looking down to Industry, or the Industry to the academic. The paradigm is to create jobs based in innovation, addressing locally, a global need. This research is a timid contribution by replying to this call, while focused in two materials—cork and SMAs. This is, to build a novel device.

The scope of this research becomes multidisciplinary. Efforts were directed to include art, in the discussion of materials and software engineering. The announced new industry offer insight on the opportunity for investment on the internet of things. Raw (traditional) materials are not the most explored take as part of this discussion, and my aim is to include cork.

4.3.4 Cork design precedents

This project research retrieves influence from personal work "SuberBowl" (Universidade Aveiro, 2001). This project shape is inspired by cork crafts, specifically the "cocharro" bowl. This is an artisanal natural cork bowl taken from convex surface of the tree. This cork shape as it is useless for the industry allows the craftsmen to create a bowl that is used in rural areas as a drinking recipient.

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Figure 80. Suberbowl, personal project, 2001-2007

The material hypoallergenic properties are highlighted by the use of cork as a drinking vessel. However, SuberBowl (Figure 80) is a craft-industrial product that combines cork with ceramics, taking advantage of cork's thermal isolator properties. The cork pieces can be detached from the ceramic bowl, and this way, adding further functionality to the set.

This precedent work grounds current research, concerning cork *ethos*, and branding. The overall purpose of this precedent was to rethink cork, suggesting new shapes, meanings and applications. Since 2001, the prove of the growing and recent interest on the use of cork is found on new projects and objects.

After analyzing cork precedents these were divided in three categories: the crafts (tradition - innovation), the industry (tradition - innovation), the outsider gaze, design with new interpretations (design - top-down innovation). This is the case of new views on the industry traditions with Sofia Dias' *Wall cork,* were the application of color adds new aesthetical features and meanings to traditional cork tiles. And Daniel Michalik's *Cub Children's Chair*, which uses cork absorbing impact properties in projecting a chair. Olariaalgarvia and craftman Antonio Luz collaboration resulted in a lamp combining cork and ceramics demonstrating how crafts are also approaching cork with new solutions (Figure 81).

Figure 81. Cork precedent by context of making typologies (from left to right) Sofia Dias' *Cork Wall* for Corque Design (Industrial), Middle, Olariaalgarvia and Antonio Luz's lamp (Crafts), Daniel Michalik's *Cub Children's Chair* (Design)

The final research project will use the "suber" brand (Figure 82). This identity works as a logo image that references the particular tree feature - suber.

SUBER
SUBER
SUBER
SUBER
SUBER

Figure 82. Suber Brand, logo Studies, academic work, Universidade de Aveiro, 2001

The Cork Oak Latin name makes an immediate connection with cork and without crystallizing to a particular language or territory. This designation gives an international tone to the brand. This communication approach witnesses the reunion of thought and need of contemporary culture, with the *ethos* inherent to empirical knowledge of a place (when the tree identifies with Portuguese culture).

Indeed, the material also has an ethnographic value. Cork is linked to ancestral influences and to numerous actors that are partially responsible for what is recognized as Portuguese culture. Evoking this can convey originality as distinguishing factor (the otherness). However, it is my objective to detach from a closed conceptual definition of ethnicity, but to refer to a "cosmopolitan localism" perspective. The purpose is to give new contexts to cork, valuing a conscious identity in open shifting territories of meaning (identity) that revisits and reinvents itself.

4.4 High tech material: smart materials

4.4.1 Why smart materials?

Current research explores materials linking digital media and smart materials. Consequently, contributing to Ubiquitous Computing [U.C]. One of U. C. goals is to achieve "calm computing" (Weiser, 1996) by introducing intelligence into surrounding environments outside the human body. U.C is as conceptual turn on computation, re-centering human and social relations as a main focus for design. This is made possible assuming that computers will progressively disappear from human eye scale, following understanding that computation is exponentially becoming smaller and powerful (Moore's law). This enlightens the existence of intelligence in progressive smaller scales.

This tendency to miniaturization where the calculation is built in, eventually affects physical but also peripheral devices as sensors and actuators, and ultimately materials potentialities. It is possible to envision those smart materials are embedded with some form of computation. Moreover, the concept of Ubiquitous Computing, has been absorbed into culture assuming different understandings, and showing how experimental in fact, this research topic can be.

4.4.2 Materials embedded with intelligence

This chapter presents a broad description of smart material typologies. Moreover, the aim is to demonstrate and understand the link between computation and materials and how this ultimately builds into the definition of intelligence. Particularly, the focus is on identifying Shape Memory Alloys (SMA) aesthetical properties, their information qualities, as well as their specific limitations. This study addresses nano-scale as a fundamental issue concerning smart materials, giving understanding of mechanical process which occurs beyond the human immediate perception (visual or tactile). These critical questions would inform how to hybridize different typologies of materials and how this could be applied to U.C. concepts.

Intelligence is assumed to be a human characteristic. As a non-visible characteristic, immeasurable - there is no consensus about human intelligence measurements - and immaterial, one can assume that smart materials visibility is given by a response to stimuli. Therefore, intelligence can be manifested by behavior. When applied to materials, this feature has to be computable in order to mimic these same behaviors recognizable by human reasoning. Manipulation of materials properties allows to introduce atomic modification, which are translated in terms of human language as movement, color changing, and on meaningful actions often inspired by nature or life. The latter, illustrates a principle that underlines biomimecry. However, one should consider that the concept of intelligence as applied to materials can be problematic (Shahinpoor & Schneider, 2007). This is understandable, when considering applying a human concept to an inanimate thing. On the other hand, the mechanical properties of materials, which simulate behaviors, are far from being able to mimic biological life.

However, these new conditions of technology allowed tech theorists, like Flusser (1999), to predict that next design revolutions at this scale will be biological. Furthermore, that the human body is a shapeable material. This perspective introduces both ethical and also particular design issues. What is pertinent in this studies scope from the philosophical critique is to realize that shape determines meaning, and the way it is embedded and found is never totally rational or neutral (Latour, 2008, Flusser, 1993).

Moreover, finding how this nano design, where the human eye cannot reach, can influence human scale, is still and again a problem of design. Flusser (1999) identified this question addressing design of the new biological machines as a design problem.

Nevertheless, materials can solve urgent problems like environmental or energy crisis. The direction given to the application of knowledge is a design issue to consider. The broad field of smart materials is able to create specificity in wide range of stimuli, which can address specific necessities using clear reactions.

According to Newnham (2000) smartness on materials can be differentiated by a classification of its role on sensing, actuating and signal processing. Their function can also determine how materials smartness can be perceived. These are possible to make by controlling phase transformations.

For instance, the ones that respond without a signal processing, (Newnham , 2000) are classified as “passively smart”. In the cases where the material analyses a signal, they could be named “actively smart systems”. “Very smart systems” designation is reserved for materials able to learn and to tune functions. “Intelligent” materials would integrate control systems with sensors actuators. Moreover, Newnham, alludes to Flusser’s problematic, when predicting that wise materials could be someday manufactured evolving into a living system. In his forecasts, future world cash would disappear, robots would be more intelligent that humans, voice will drive furniture, smart houses, gene replacement, automatic gardens. Newnham envisions a myriad of desires and possibilities.

4.4.3 Typologies of smart materials

Smart Materials are classified following the type of reaction that can trigger, as an actuator, but also the type of *stimuli* that are sensitive, as a sensor. According to Newnham, there are four major families of smart materials: piezoelectrics, electrostrictive, magnetostrictive and shape memory alloys. Piezoelectrics react due to a relation between stress and electric variables, electrostrictive, change their shape under the application of an electric field, on the magnetostrictive the mechanical deformation is induced by a magnetic field, and shape memory "remembers" their shape. Some of the most used shape memory alloys are nitinol (initially used in the US navy), terfenol which is a mangestostrictive actuator, (change shape in the process of magnetization), and flexinol.

4.4.4 Engineering form: shape memory alloys

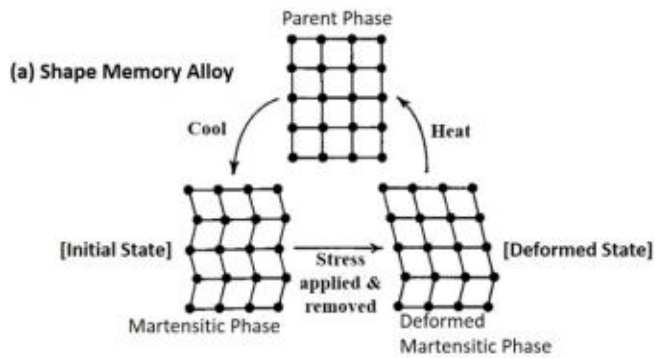


Figure 83. Schematic representation of the shape memory process, retrieved from Uchino, Kenji. (2016). Antiferroelectric Shape Memory Ceramics. *Actuators*. 5. 11. 10.3390/act5020011.

4.4.5 Shape memory typologies

A shape memory alloy "remembers" its original cold-forged shape and returns to the pre-deformed shape. There are several alloys with this mechanical proprieties, which can be found extensively, like in many copper-base alloys, as well as silver and gold, NI-ti (nitinol – nickel titanium alloy), among others.

Shape Memory Alloys [SMA] can be thermally or magnetic activated. They can also be one way or Two Way Shape Memory (TWSM). The martensite phase on the material – which is a hard state of steel which is formed by rapid cooling - is crucial to undergo this SMA transformation. According to Tamura:

> "the martensitic transformation is a shear-dominant diffusionless solid-state phase transformation occurring by nucleation and growth of the martensitic phase from a parent austenitic phase. When an SMA undergoes a martensitic phase transformation, it transforms from its high-symmetry, usually cubic, austenitic phase to a low-symmetry martensitic phase, such as the monoclinic variants of the martensitic phase in a NiTi SMA". Tamura and Wayman , 1992.

SMAs martensite transformation can be reversible which show an interesting mechanical behavior. This feature is due to "a stress-induced martensite phase", which forms themoelastically, and is crystallographically reversible. Typically, SMAs are in a low temperature martensitic condition that when heated gain its original shape. The nature of its mechanics is given by a single crystal of a parent phase that will transforms into 24 orientations of martensite.

> "As it is deformed, a single orientation of martensite results as a consequence of twinning and the movement of martensite interfaces. Twins which gives form and deform are other orientation variants of martensite. When a matensite-martensite boundary moves under stress, one plate grows at an expense of other, and a similar conversion results" Tamura and Wayman , 1992.

The end result is one remaining orientation.

In the case of TWSM effect an object will be deformed in the martensitic and regain it form after heating. With TWSM there is a reversible deformation, i. e. during cooling the object will regain its original shape. This can be obtained by training the alloy, i.e., using a stress cycle, or and stress induced martensite (SMI cycling). The two way behavior is a result of formation and reversal of a trained martensite and results of cooling process. Martensite transformation under stress, can be used to create a mechanical force.

SMAs are also notable for its pseudoelasticity behavior, which mean that there is a total recovery of a material when applied temperature, that were under large strain. There are two categories: superelasticity, where there is thermoelastic martensite transformation and rubber-like effect, that depends on the behavior martensite phase in itself.

4.4.6 SMA design precedents

The interesting kinetics properties of S.M.A. are both applied in engineering and art. In engineering S.M.A.s are used in pipe coupling, electrical connector, clamps, plugs, automatic greenhouse window, fire door openers, thermostatic devices and heat engines. They are also used in dental application. S.M.A.s, and more precisely, Nitinol - which is resistant to corrosion and fatigue and allow flowing movements - have been used as an artificial muscle. Nitinol is also used to cause a shift in resonant frequencies in bridge structures.

In art and design context smart materials are beginning to gain attention. Recent initiatives in art institutions have progressively been reactivating the connection between art and science. The design curator Paola Antonelli at MoMA follows a profound interest on science application to aesthetical and meaningful contexts, as it can be seen on the exhibition Design and the Elastic Mind (Antonelli, 2006), and Talk to Me (Antonelli, 2011). Projects framed in art or engineering were presented side by side. That is the case of the Nitinol based *Softbot* (Trimmer, 2006) from Biomimetic Soft/Bodied Robots project (figure 84) which takes inspiration in adaptive mechanisms of animal movement – in this case of a caterpillar (Trimmer & all, 2010). Another example can be found in Marcelo Coelho, *Shutters*, that is a curtain using embedding SMA into a textile (Coelho, 2010) (Figure 85).

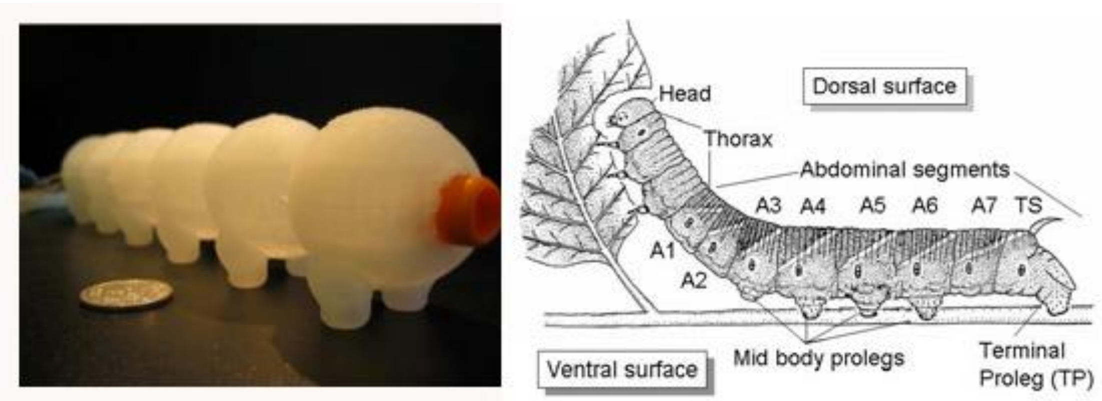


Figure 84. Soft Bot - Biomimetic Soft/Bodied Robots retrieved from Trimmer et all. (2006). Caterpillar locomotion: A new model for soft-bodied climbing and burrowing robots. *Proceedings of the 7th International Symposium on Technology and the Mine Problem.*

Also Jie Qi addresses the combination of high tech and low tech materials. In *Animated Vines,* Jie Qi , uses flexinol, paper and sensors in order to get movements induced by sensor (Qi & Bushley, 2012). Marielle Leenders (2000) in her *shape memory alloys textile shirt* applies nitinol wires into a fabric, creating textiles that can move (Figure 86). These works follow academic interdisciplinary research, testing with different applications on SMAs.

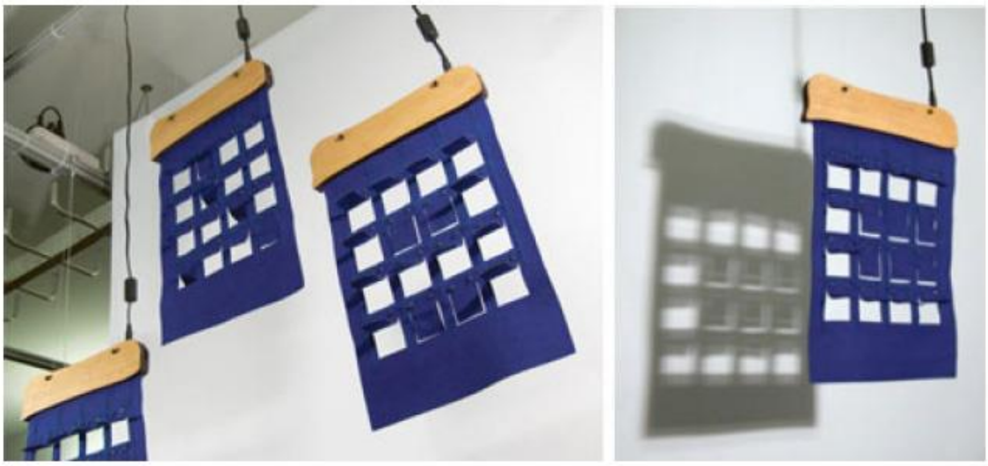


Figure 85. Coelho, M. and Zigelbaum, J. (2010). Shape Changing Interfaces, Springer, Pers Ubiquit Comput DOI 10.1007/s00779-010-0311-y

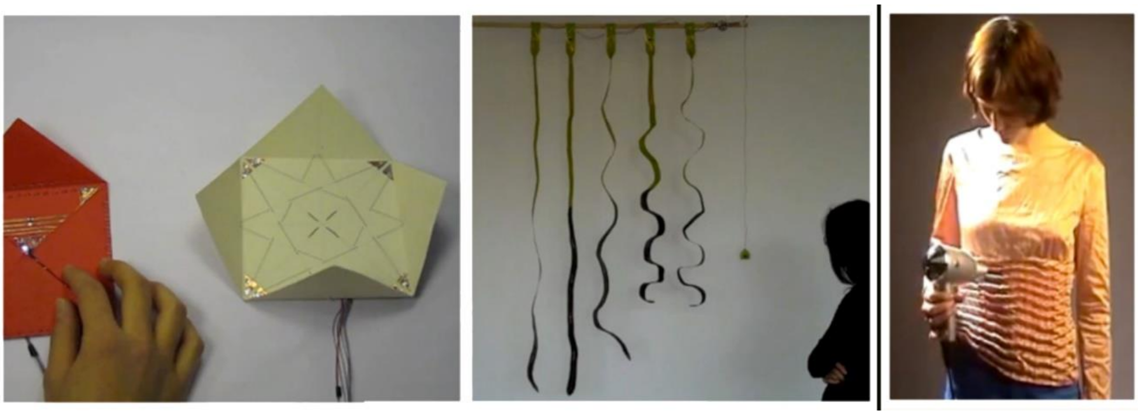


Figure 86. Jie Qi *Self Folding Origami Paper* and *Animated Vines* retrieved from Qi, Jie and Buechley, L. (2012). Animating paper using shape memory alloys. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI). ACM, New York, NY, USA, pp. 749-752.; Marielle Leenders *shape memory alloys textile shirt* retrieved from http://photorepeats.com/en/work/shape-memory-textiles/shape-memory-textiles-3-woven-2/

4.5 Suberskin: the hypothesis to be proved

4.5.1 Project proposal

Suberskin complies to "skin" as a symbolic conducting metaphor. This criterion beyond being a guiding beacon, becomes evident throughout process, and guides an experimental research.

The project proposal Suberwall (2012) describes an interactive wall combining cork, a low-tech material and shape memory alloys, a high tech material. The wall would be composed by several interactive modules. These would visualize graphic information by moving each piece of a physical material (cork) as pixels. The information presented would result from remote data input. As such, the initial aim was to define these data input that takes the shape of a low-res tele-drawing, as an output.

The prototype (a physical device), linked to a web site using a telepresent model defines the user experience. The anticipation was creating a physical data visualization screen, a cork wall, eventually giving a sense of presence by displaying a telepresent drawing, inserted from a remote location.

Indeed, the first and imperative objective was to contextualize research within the A.D.A. field. An initial inquiry inspired by Skin metaphor started at UT Architecture department. Specifically, aimed to situate the use of shape memory alloys applied to low-tech, or traditional materials. Secondly, to identify particular modular structures, that ultimately were in use as reactive surfaces. In particular, question to which degree the use of reactive natural materials could have application in architecture. These lead to explore symbolic applications having nature as inspiration, as is the case of biomimecry. The third and last criterion was to find how the *stimuli* of a haptic sense, a referring to skin, could be done from a visual point of view.

Architectural critical thought contributed to the discussion on the state of the art chapter. Moreover, this contextualizing allowed to situate the final research project proposal.

This research project combines cork, digital technologies and smart materials. SuberTile is an interactive module which synthesizes materials research. The module can be expanded into a full cork interactive surface, SuberSkin. SuberTile is the cork made device thought as part of an integrated system. The design experience proposes to have human input given by using a mobile application.

Moreover, the general research objective is to be a cumulative step in cork tiling design. As such this motivation is, firstly, expressed and grounded by cork industry and crafts tradition of wall surfacing. The industry has typically developed research in variants of cork tiles, with architectonic application. Secondly, the design research exploration, give focus to human factors, this is, defines as the starting point premises that might contextualize a user experience in relation to a final product. Finally, this research aims to be a contribution to the material turn approach in ubiquitous computing research.

4.5.2 Process: Hybridization

The concept for SuberSkin was possible to put forward by combining methods: inspiring precedents taken from experimental material studies, projects, and a hybridization of criteria. The following description will further discuss methods in use. First, a practice as research approach allowed to collect what Ashley Hall defined as "data stream". This data results from insight taken from each of the Extended Skins projects, namely CitySkin, SuperMirror, Responsive Tile and Paperbots. Secondly, inspiration was collected from the hybridization of projects precedents (following Design Department, UT Austin Methods). Finally, building upon personal work, namely, suber (2001, Universidade de Aveiro), and interactive videos (Pele, espelho meu, software facilitated by Ydreams, 2009). The combination of information resulted in Suberwall project proposal, as a cumulative step. The project viability was consolidated by having preliminary proof of concepts resolving specific issues, as is the case activating cork with a SMA.

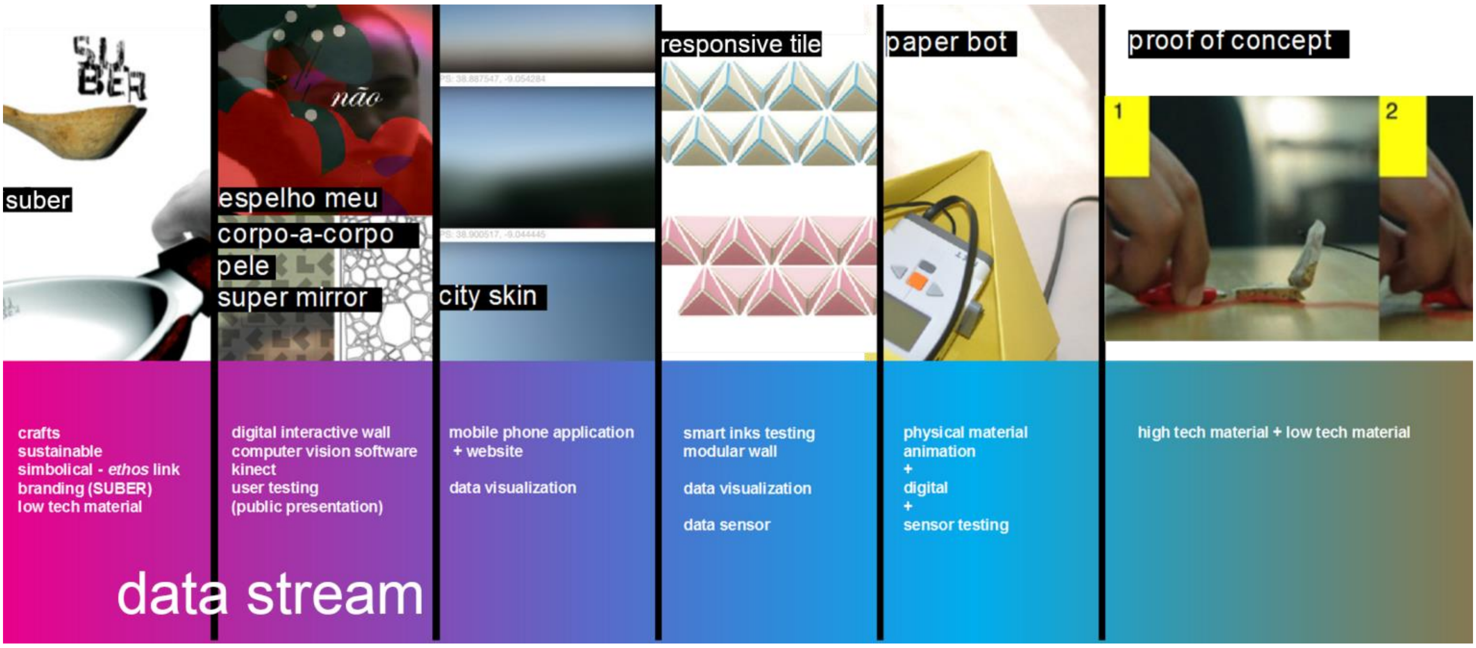


Figure 87. Suberwall proposal: Data Stream, adapted from Ashley Hall

The period spent at Design Department, in critique studio at UT Austin, originated a step-by-step process of Suberskin proposal (Olsen & Lee). First identify project precedents and proceed with hybridization. Specific criteria are put forward as most relevant (discussed in State of the art). The precedent projects that allowed to identify particular features on

SuberWall proposal, are: first, *Shutters* by Marcelo Coelho and *pixelskin* by Oragevoid. These projects are particularly relevant as they present Smart Memory Alloys applications in the context of surfaces. Secondly, *telepresent water* is a telepresent physical installation. The system translates data in real time that is taken from a remote place. It offers reference to the system set-up. Armikhan Abdurakhmanov's living room wall project *Change It*, reveals a moving wall that conveys information in a common context of a living room. Lastly, the suggestion of haptic visual sense given by materials, was given by Christian Faur's Portrait projects.

This method not only assumes that there are influences in design process, but in fact, reinforces this evidence by assuming them as part of a method. Furthermore, by quoting projects directly, there is a close relation to the process of quoting, as in the case of theoretical discussions and research. Considering the case of research by practice, position the meaning in making and projecting, on features and significance, or what is highlighted by having languages combined.

This is the case Orangevoid studio in London, that created *pixel skin* as a conceptual wall using movement to convey information. In their first version, *pixel skin v1*, the structure was activated by mechanical element. On a latter version a smart memory alloy was used as an actuator (Figure 88).

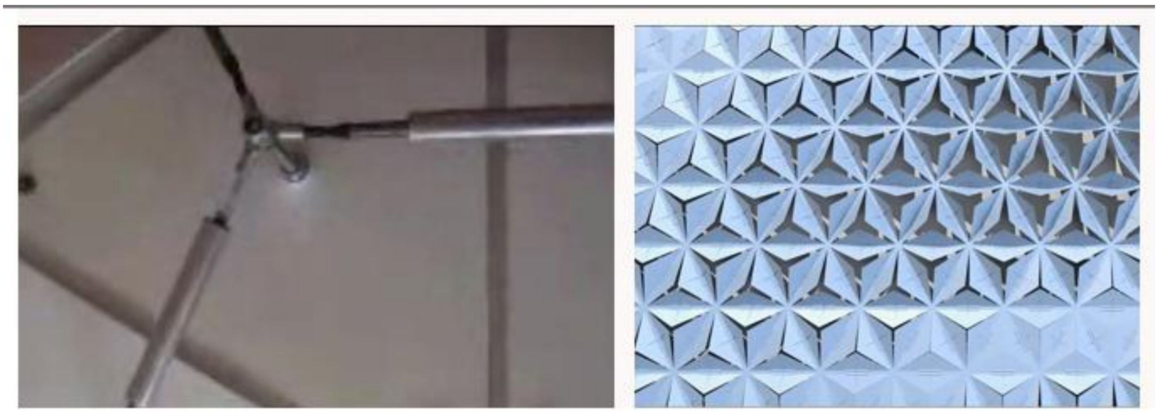


Figure 88. Orangevoid : *Pixel Skin* version 1 and version 2, retrieved from Brownell, B. E. (2008). Transmaterial 2: a catalog of materials that redefine our physical environment. New York, N.Y: Princeton Architectural Press.

David Bowen's *Tele-present water series* are digital to physical interactive installations (2011). First presented at National Museum in Poland, this installation got live data from a

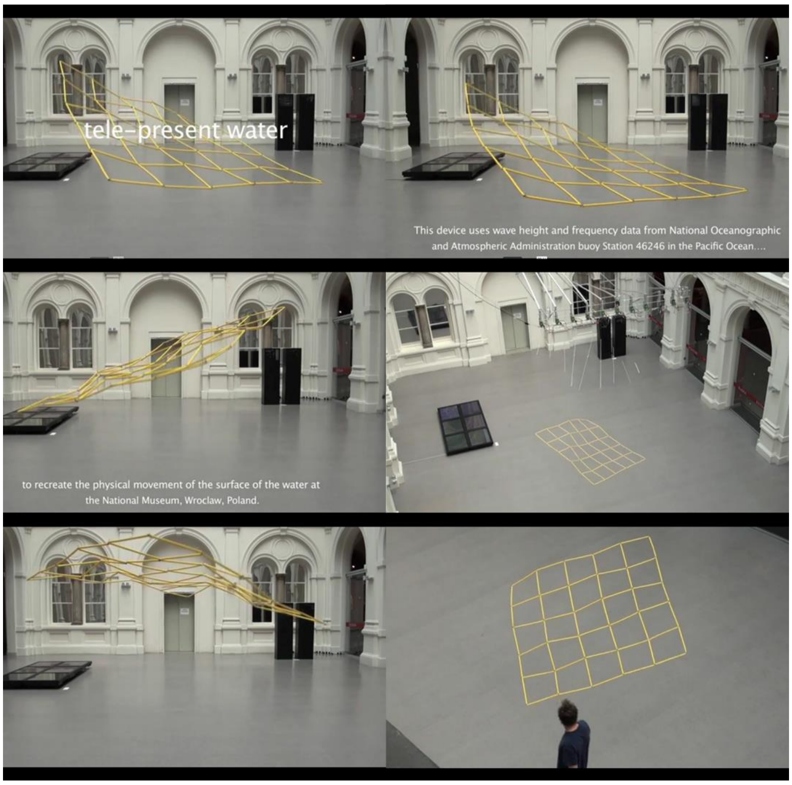


Figure 89. David Bowen's Tele-present water series is a digital – physical interactive installation (2011), video stills

National Oceanographic Atmospheric in Pacific Ocean, allowing a physical structure to reproduce live movements of waves (Figure 89)

Figure 90. Armikhan Abdurakhmanov (2011). *Change it* retrieved from https://www.archdaily.com/115529/change-it

The idea of a moving wall as decorative element yet simultaneously working as a display was explored by Armikhan Abdurakhmanov. In this case the moving pieces are activated by mechanical movements, as illustrated (Figure 90).

The use of a physical material to draw images can be found on the particular and similar effect achieved by Christian Faur's work. In this case the image is built with common crayons, acquiring a haptic visual sense (Figure 91).

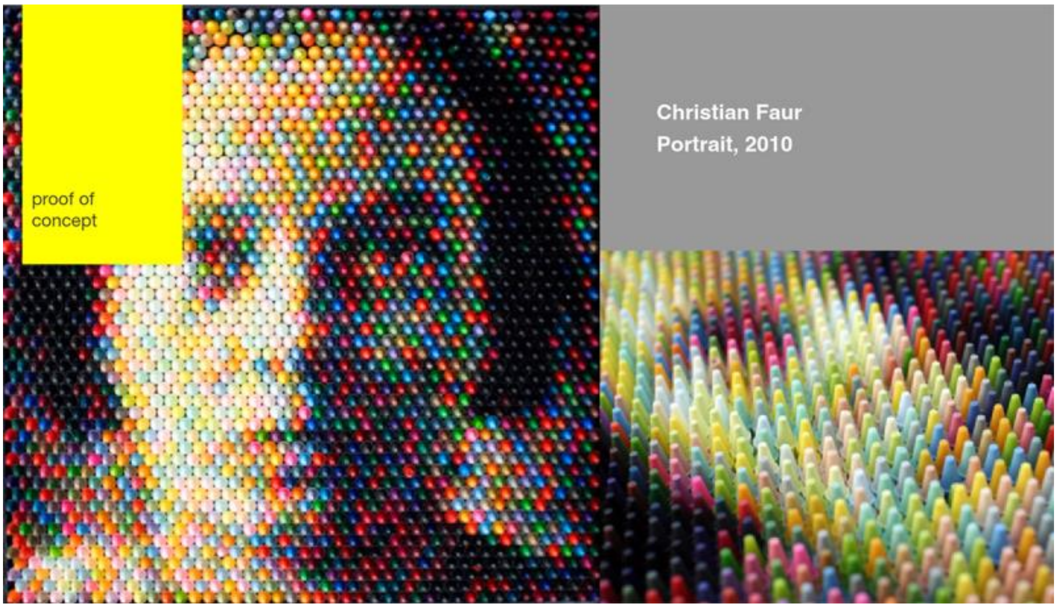


Figure 91. Christian Faur (2010) *Crayon Portrait* retrieved from https://www.christianfaur.com/NewSite/

4.5.3 Suberwall description

The initial research proposal describes SuberWall as a responsive wall that works as a screen. The suggestion of an haptic visual feel is given by choosing a natural material, in this case cork. The exploration of aesthetical effects is focused in visual properties – using high contrast between natural cork colors, dark and light brown. The proposal is highly experimental, and ultimately, aims to explore potential routes on cork research, and to recreate, transform the material in an intelligent surface.

Thus, three criteria drives the initial iteration. Firstly, use cork aesthetical characteristics focused in visual properties, secondly, test S.M.A.s as actuator on cork, exploring a high- low tech material interplay, thirdly, to search for new layers of aesthetical experience concerning cork.

The user experience proposed, is defined having a telepresent physical manifestation – movement - on cork as an interactive content. Walls are the perfect and accessible canvas for graphics, and home environments are ideal setting to have surfaces conveying dramatic content. The anticipated end result is to have a conceptual prototype that could open routes to a practical application.

4.5.3.1 Research Question

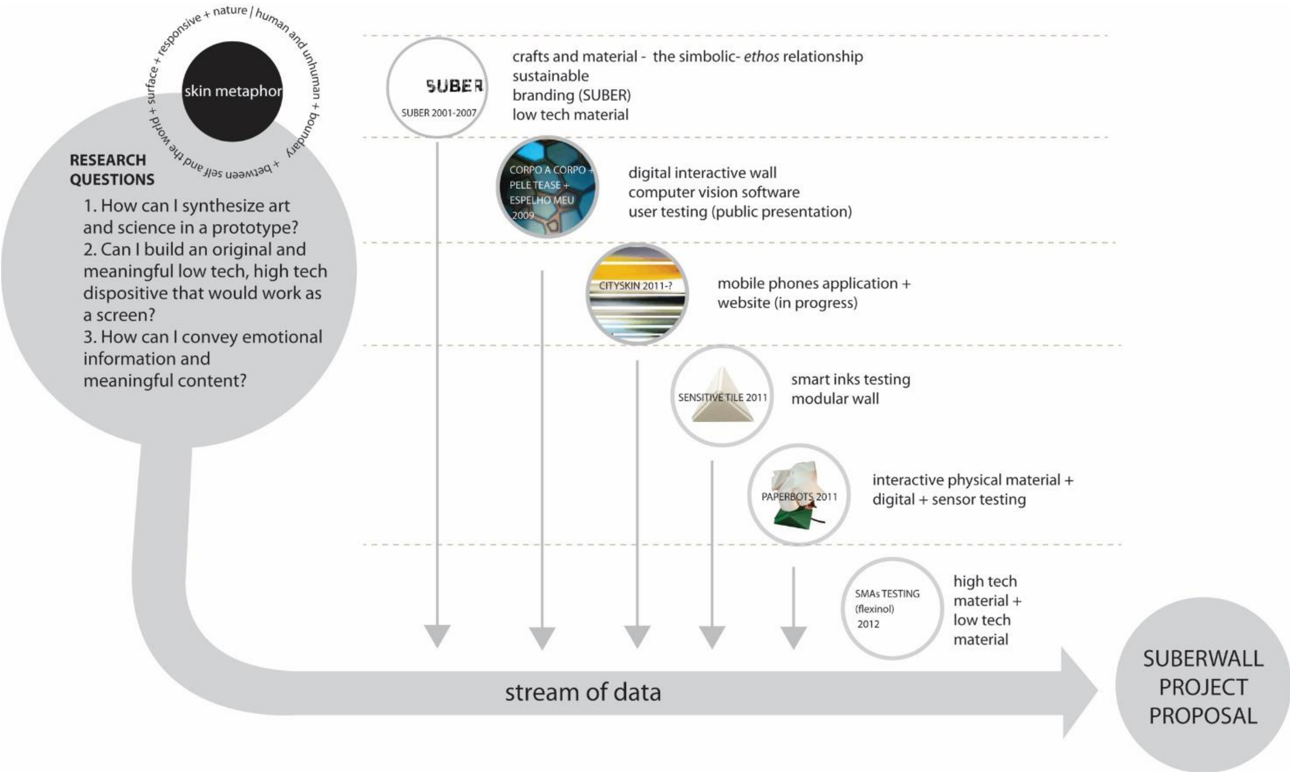


Figure 92. Research question and data stream taken from projects, background, and proof of concept, informing suberwall proposal.

The practical nature of this research aimed to create an original invention. Therefore project Suberwall research acquires a practical tone, which is reflected in the research questions. Driven by skin as metaphor (image), suberwall, works as one final “extended skin” exploration, as a synthesis of previous experiments. As such, the initial research questions were enunciated in the graphic below:

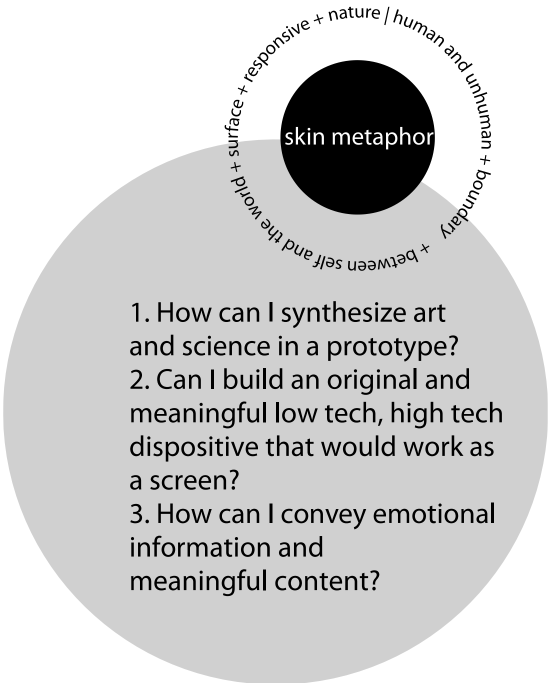


Figure 93. research questions

Aristotle, in Poetics, defines metaphor as the application of a word that belongs to another thing: either from genus to species, species to genus, species to species, or by analogy. (Poetics, 2) . Here "skin" is the application of a word, considering that the final project, is the last of the "extended skins" explorations. Inspired by skin as a metaphor (Figure 93), the research questions resolution is focused in practical design.

A responsive skin research project is a synthesis of previous experiments that aims to comply to the skin metaphor criterion. These analogue projects create a constellation of meaning. The anticipated outcome is to create a surface that conveys concepts equivalent to skin.

Initial ideation considers that skin responsiveness is directly inspired by nature. The porous boundaries, skins, serve as a shield and as a communicating surface. This device, having the shape of skin, a surface, will also have qualities that are similar to behavior. This meaning, be responsive to the surrounding environment. In this case, serve as a medium tackling human and inhuman barriers. Therefore, this abstraction on metaphor is the first sketch on the design experience. This device would convey content, putting human factors in interplay, as to convey relations between the self and the world. To identify, what this content would be, is one of the research questions to follow.

Suberwall project proposal is supported by mirroring precedents and results from exploratory projects (data stream). The relation of concepts can be visualized by keywords: shape memory alloys, data visualization, telepresence, interactive walls, physical computing, speculative design. Suberwall is anticipated to be the vertical application of an interactive cork surface that could work as a screen.

4.5.4 Technical aspects

4.5.4.1 Diagrams

The following describes design, mechanical, S.M.A.s and cork testing. Considering the highly speculative nature of the project proposal, these proof of concepts intend to demonstrate the viability of SuberWall.

The first step is to constrain the proposal to build a cork module: a prototype of 6 pixels by 6 pixels, with a total of 36 cork-pixels. In a posterior phase, this module would allow to build a wall by composing a structure (Figure 94).

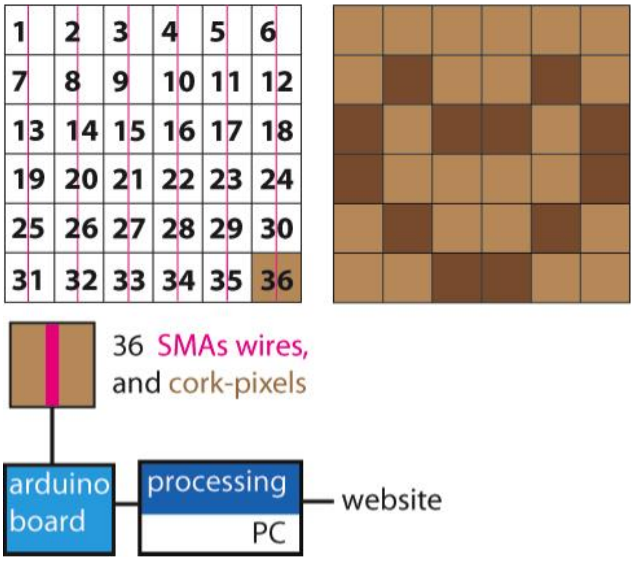


Figure 94. Module circuit diagram

This module works as the output as part of the design experience. The prototype will visualize drawings that can be either sent by a mobile phone (the input) to the wall from a website (via website server). The goal is to achieve the effect of a telepresence drawing - a manifestation of a distant person in a physical output device (Figure 95).

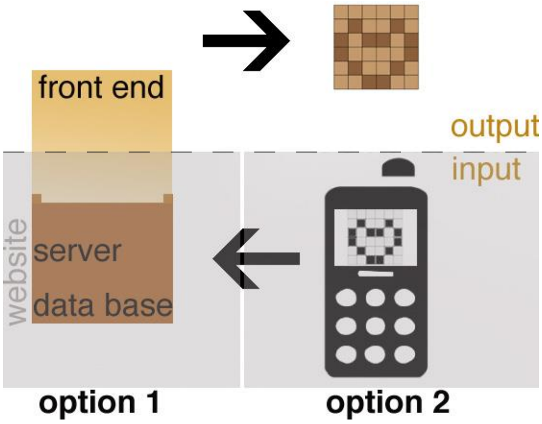


Figure 95. User interface diagram

4.5.4.2 Sketching

Sketching as a method of exploration, can be thought outside the traditional definition of pencil and paper (Buxton, 2007). Low fidelity sketching allows to explore with material aspects and speculative ideas, by testing what can be simulated as an aspect of design, in a phase where the only consideration is to materialize an idea. In this case, the aesthetical issues that can be explored are of a specific nature, such as kinetic properties. Despite being instantiations of a specific design low fi prototypes and sketching are different as they relate to different stages of the process. Sketches related to a very first moment of experience, while prototyping syntheses already resolution and insight. Therefore, sketching must be quick, timely, inexpensive, disposable, minimal detail, suggest and explore rather than confirm, and strive in ambiguity (p.136).

The first sketching of the concept an interactive physical wall can be found in Figure 96. This physical sketch allows designing graphics, with the possibility of displaying lettering. The mechanism that allows the physical wall to move is illustrated by a paper mockup. The simple movement consists of on-off state, which will lift the physical pixel. Each of individual pieces of paper represents, in this case, a physical pixel. Using this principle was possible to write the word “HI”.

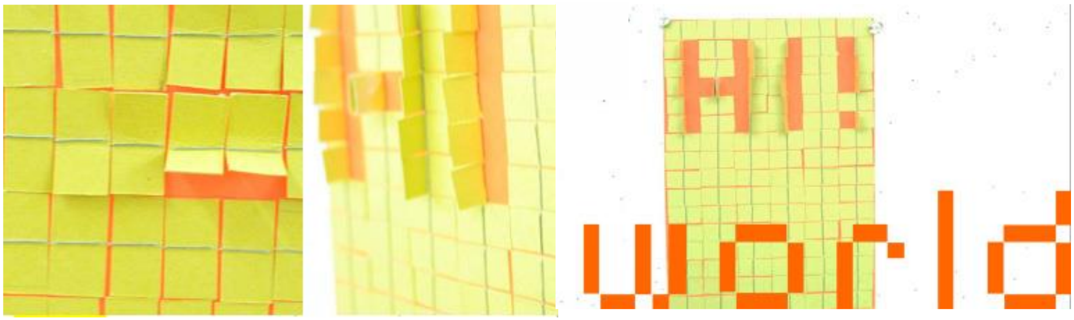


Figure 96. Low fi movement prototype

4.5.4.3 Color contrast

Cork natural qualities, such colors and contrast were openly tested in the materials studies (Figure 97). Cork based material studies allowed to explore different aesthetic solutions, either by combining cork textures, or arranging different patterns. These envisions future aesthetical alternatives to the square shape pixel. A cork based ink was created and tested on paper.

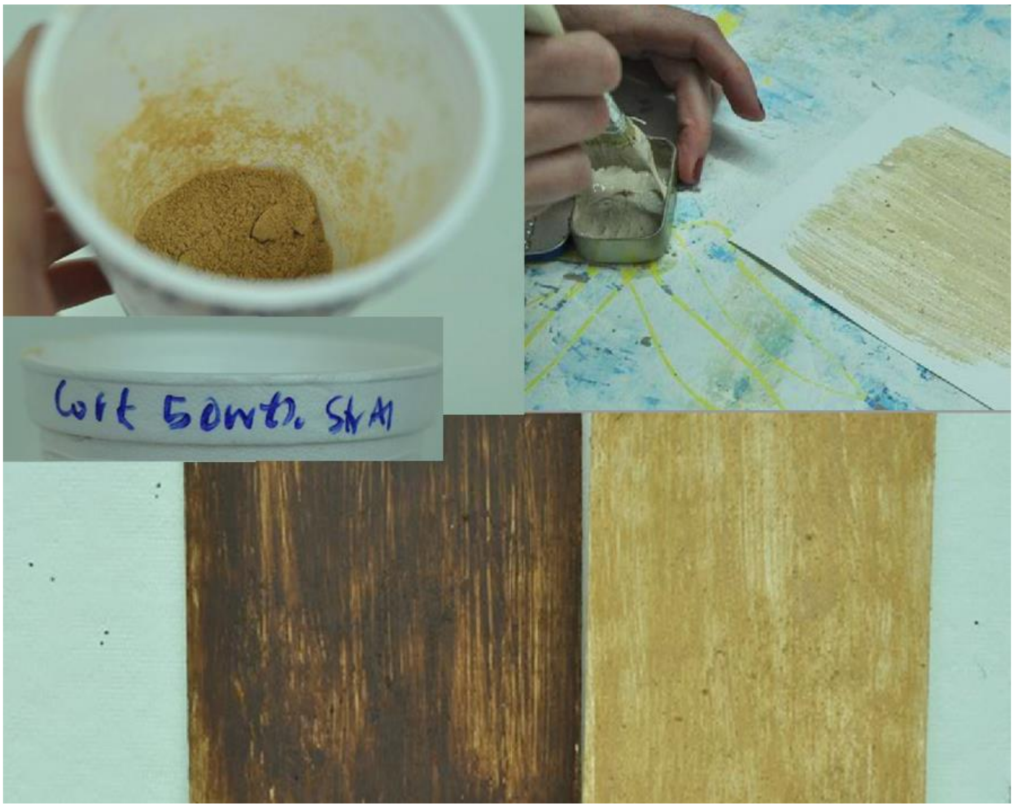


Figure 97. Cork color contrast

The proposal for the first module is described as having S.M.A.s wires connected to 36 light brown cork pixels. The initial proposal states that the upper pixel moves, giving visibility to a darker brown cork surface underneath. The initial intention is to augment complexity by adding modules together. Also the resolution improvement is anticipated, but as incremental steps on the physical system design research. The effect of physical pixels on a wall, conveying drawings, is achieved by using high contrast colors of a material. This system is illustrated in a sketch test made with sticky notes (Figure 98.)

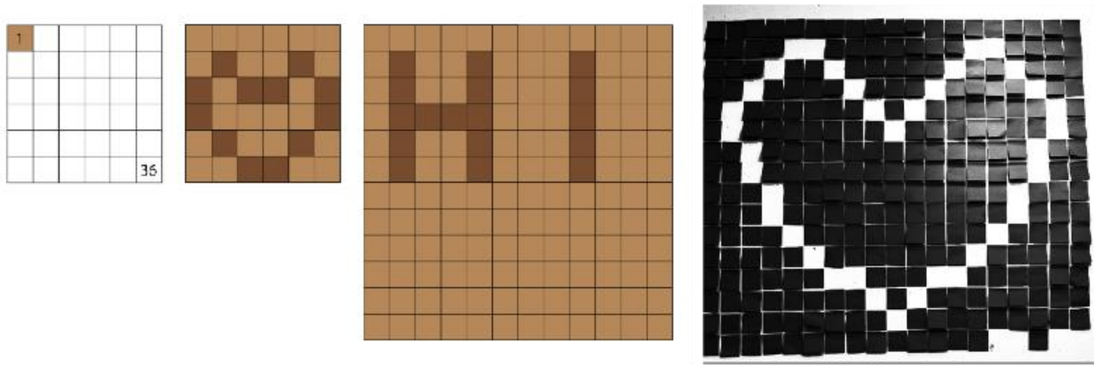


Figure 98. Cork Module, low fi drawing

4.5.5 Preliminary proofs of concept

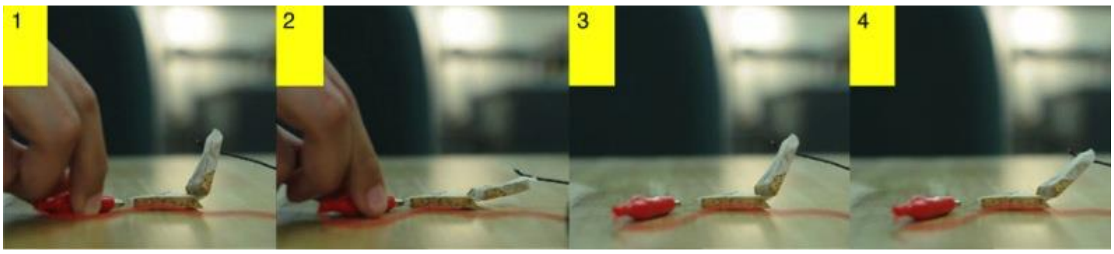


Figure 99. Proof of concept, flexinol on cork

A test on a smart memory alloy (flexinol) application on cork was made (Figure 99). The images sequence demonstrates how movement is possible. The test consisted in one cork pixel reaction to an on-off state, this is with having electricity going on or off. When electric current goes through the SMAs the heat will change its phase and therefore its shape, which eventually makes it move. On state 1 the flexinol wire is compressed, and when electric current goes through, it stresses, allowing the cork to move. This test also showed how efficient a SMA is as an actuator on this material. The main advantage of cork that emerged in this context was its lightness (low density) which will decrease the SMA mechanical force necessary.

To coordinate each individual movement of the cork module pixel, the use of an Arduino board is proposed. The activation of each pixel is made by an electric impulse to be switched on or off. For each pixel there will be SMA wire that will work as a movement actuator on cork - taking advantage of natural properties of this material lightness, color and texture.

4.5.6 Project suberskin and ubiquitous computing

SuberSkin project was directly inspired by Mark Weiser's (1996) vision of ubiquitous and calm computing [U.C.], which is obtained by inserting computers into environment and making them invisible (Weiser, 1996, 1999). The output in the context of this exploratory project is an original contribution; this is an invention – a new interactive object made of cork. This object uses U.C. principles referring to the humanities and design perspective designated as "materials turn". This perspective in U.C. recognizes traditional and ancient materials as computable and therefore interactive while also acknowledging code as a material (Wilberg, 2014).

As such the method presented will be practice as research: experimental approach that bridges the differences between design and engineering methods.

To summarize the initial project proposal consisted in:

1. **building a 6 x 6 px module combining cork (aesthetical material), Smart Memory Alloy (actuator) and digital media**
2. **coding a 6x6 px module**
3. **translating a "drawing" into the cork module**
4. **get data output from an application**
5. **create a telepresence output - reproduce a remote low-res "drawing" (Arduino)**
6. **increase complexity by combining several tiles**

5

SUBERSKIN: IMPLEMENTATION

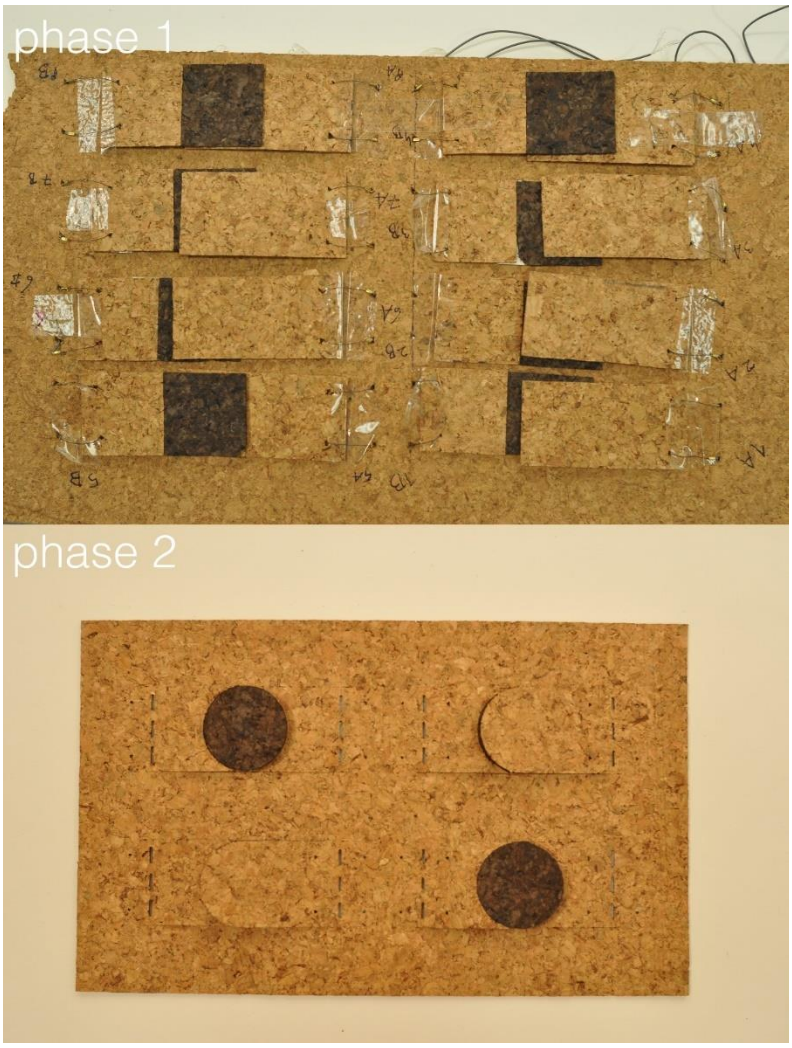


Figure 100 - Subertile

This chapter describes the development of a reactive surface combining cork with Smart Memory Alloy (S.M.A.), flexinol. This is materialized in SuberTile, a modular cork tile, that dynamically changes shape triggered by the smart memory alloy. The next description presents the device development.

The process was divided in two phases: phase one, research was developed in collaboration with Nova University (Faculdade Ciências e Tecnologia), Portugal. Research was focused in laboratorial experimental work and implementation of a mix between the digital and material. Phase two was developed in collaboration with UT Austin, exploring aesthetical and engineering considerations of an interactive prototype.

Phase one results were translated in a functional system, that worked as a proof of concept. Specifically, this phase consisted in creating the dynamic cork pixel (SuberPixel), application (SuberApp), and system (activating the pixel wirelessly). Design research culminated in the combination of the digital and physical device, having one functional pixel activated wirelessly by a mobile application.

Phase two, consisted in the extension of the proof of concept one, into a first cork tile with 4 moving SuberPixels.

In sum, the following chapter describes the sequence of proof of concepts. The first, one cork pixel system, SuberPixel, and the second, cork prototypes of 4 pixels, designated as SuberTiles. Design variations are demonstrated. Finally, an interactive cork system is described, presenting the module as part of an interactive cork surface, SuberSkin.

5.1 Phase I, FCT-UNL: SuberPixel system

AMORIM

Figure 101. Cork sheets sponsored by Amorim

At the initial stage, exploratory work was divided in two separated routes: first, a “materials exploration”, and the second, the “digital exploration”. The analysis was focused in cork and S.M.A.s properties and issues regarding the combination of both materials. These inspired the definition of the user experience and interaction design. The “material exploration” used materials sponsored by cork industry combined with crafts, hands-on technics (Amorim, 2014) combined with high tech exploration in smart materials, in the current case, flexinol (Tamura and Wayman, 1992; Dynalloy industries, 2018).

The initial premise was to explore aesthetical visible characteristics of cork, and to make them mutable. This made the initial focus to constrain to natural colors of cork properties (no added ink). Therefore, color became a first quality of cork to be explored as dynamic. Initial exploratory research was focused in creating a moving cork pixel.

Preliminary studies with a smart material as an actuator were aimed to change color properties by mechanical means.

As described in chapter 3.1, the method consisted on a systematic and exploratory analysis of materials. Insight was taken from identifying natural witness of cork itself. These ideas taken from a hand-on approach were part of the exploratory process throughout the work.

5.1.1 Materials exploration

Three typologies of cork were tested: recycled cork taken from wine stoppers, sheets of agglomerated cork (sponsored by Amorim, Figure 101), and natural stripes of cork.

The agglomerated cork had black and natural colors. These sheets of cork had 1m by 0,50m and were cut in 3 thickness sizes, 1, 2, 3 mm (Figure 102, Figure 103).

Figure 102. From left to right, recycled cork, agglomerated cork sheets, natural cork stripes

Figure 103. Dark and light agglomerated cork, 1, 2, 3 mm cuts, sponsored by Amorim

5.1.1.1 Exploring Shape

Throughout materials studies sessions, three relevant issues were pursued: defining the shape, the interchangeable colors mechanism and the S.M.A. wire attachment allowing movement. To define the shape, several cuts on cork, rectangular, squares, triangular were made, and an array of attachment mechanisms (Figure 104, Figure 105). The first cork shape to test with SMAs was a rectangle of 2 cm by 4 cm (Figure 106).

The first design evaluation was to use actuators exploring cork ductility. Moreover, Smart Memory Alloys with 0.004, 0.006, 0.008 inch diameters sizes were tested during materials studies. Specifically, relevant was to find the wires length, according with the amount of force needed to apply on cork, and the attachments that could create movement. To consider were variables regarded to S.M.A. diameters and length size in relation to different cork typologies.

After iteration, the final shape was defined inspired by the square shape of a pixel, and inventing an exchangeable mechanism of two pieces of cork.

Figure 104. Attachment and flexinol wire studies

Figure 105. Double side cork explorations

Figure 106. interchangeable mechanism studies

5.1.2 The Pixel shape optimization

5.1.2.1 Interchangeable mechanism

The solution for further testing was an interchangeable mechanism. One of the advantages of this mechanism is the energetic efficiency. This is, for the pixel to be on, as it is activated physically moving between contrast dark and light cork, there is no need for energy supply during the "on" state. Energy is only required to activate the switching. This finding suggested further exploration.

Research was directed to defining an optimal pixel shape. As such densitometry test on cork typologies were made. The focus was to define the best relation between cork weight to be raised, and the S.M.A. length and diameter. These last features, beyond requiring measurement, had direct implication with the amount of current needed to activate the wire, and thus, directly constrained the physical design.

5.1.2.2 Densitometry chart according to cork typologies

Density measurements were made on natural cork, agglomerated cork, and black agglomerated cork. The volume of the squares samples of each of the cork typologies was measured with a micrometer (thickness assessment) and a vernier caliper (length and width). After getting the value of the mass for each of the samples, it was possible to determine the density for each kind of cork. Natural cork is the less dense. This would imply that the S.M.A. has to apply less force to make the pixels exchange. Furthermore, natural cork has better resistance to flexion, thus, this would indicate it as best choice for the purpose at hand.

The main objective of measuring cork density was to determine the maxim size of a pixel, in relation to the alloy strength. The manufacturer table (Dynalloy, 2019) was used as a reference, stating that the alloy with 0.008 inch can pull until 891g. The measured density value led to the conclusion that the 1mm thickness cork could be a square with the maxim side of 144cm. In a practical sense this value is an absurd, however, according to verified tests there is a safe margin, in terms of size variation for each of the pixels.

5.1.2.3 Cork plus S.M.A. testing

The main objective of cork and S.M.A. system's assembly testing was to determine the most efficient relation between Cork and S.M.A.s, concerning the potential of flexinol to make cork move. Three factors were addressed: first, the diameter and the transition temperature of the S.M.A., second the pixel’s geometry, and finally, the attachment method of the S.M.A. wire from pixels to the cork substrate.

Tests were performed with 0.004, 0.006 and 0.008 inches of diameter alloys applied to rectangular shape cork (Figure 107). The observed results, registered that there was no movement with the 0.004 inches S.M.A. The 0.006 inches alloy could provide some movement, however the force applied by the alloy when activated was never enough to raise the cork sheets. The last experiments were performed with 0.008 inches SMA. These raised cork to an appropriate height in most tests.

Having set a pixel size and the alloy diameter selected, it was noted that the attaching mechanism had a major role in successfully switching the pixels. The material used in testing was duct tape.

Initially, the duct tape was placed lengthwise. After that, tests were made with a new configuration in which the adhesive tape was placed perpendicularly to the length of the pixel, working as a rotation axis. Another important aspect was the way tape binds each pixel to the cork substrate. The observed results demonstrated that the cork pixel could not be excessively restricted but, on the other hand, the duct tape must be placed in a way that the rectangular cork were almost sustained before activating the alloys.

The set-up worked properly in the initial stage. However, the progressive use of device causes the tape to lose adherence. The heating leads to local softening of the duct tape. In conclusion, this was probably an ideal system for testing, but could not be a permanent solution. The durability of this type of attachment proved to be a major obstacle.

Another concern on the use of shape memory alloys was the system's degradation due to fatigue phenomena. However, the number of cycles performed during the tests were not high enough to reach the fatigue limit in any of the alloys. This led to the conclusion that this phenomenon might only be important in long term.

5.1.2.4 SuberPixel design

In sum, the “material approach” research was a sequential step-by-step aimed to design a preliminary cork pixel: SuberPixel.

First, the pull force and mechanics ratio between the SMA actuator was identified, second, a physical proof concept, a cork-pixel that changes visually mechanically by changing the position of materials was successfully achieved.

These conclusions, lead to the optimization of the cork-pixel. The proposed shape was a pixel of 2cm x 4 cm. This would be composed by two parts: a black, and light cork side, and a light cork side (Figure 107).

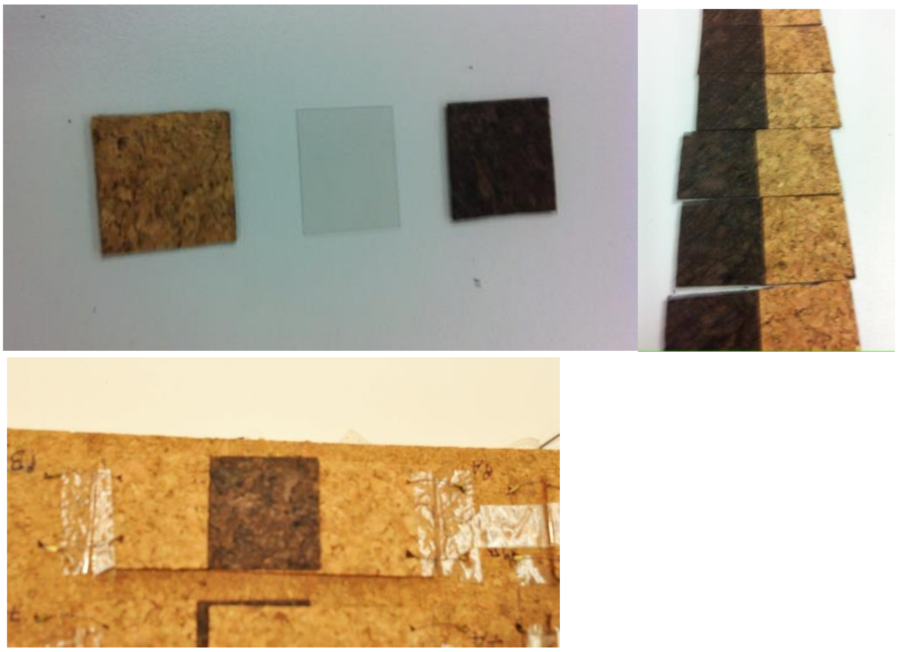


Figure 107. Suberpixel

5.1.3 SuberApp design

The “digital approach” refers to the digital system that dynamically triggers the physical output. That is the case of yhe physical SuberPixel. The set-up reveals the nature of the system giving significance to the output.

This phase of the research consisted in the defining a design experience, this is, creating content for a totally new display; moreover adding human factors, creating a valuable experience for the user. Thus, the system was implemented, and thought as a sketch of a telepresent device. An android mobile app establishing a wireless connection with SuberPixel and the user.

The initial issue with the app interaction design was to create a connection with an physical object that did not exist. The interaction design has changed drastically throughout the process, reflecting on the failures, and achievement of the physical object. The initial statement was that the output would be of 36 pixels and therefore this was the base for the first app design.

U.I. interface, uses skeuomorphic design, with cork squares refer to each of the pixels. The icon design inspired by brand Suber uses cork textures. In term of functionality, this first design sketch, reveals problems, in terms, of adaptation of the pixels, to buttons size. There were problems of usability (Figure 108).

The application design conveyed the assumption on having a screen as output. Thus, allowing the user to choose between two scenarios. The interaction map refers to scenario A, at home, or scenario B a public display. Issues regarding these scenarios, have relevant problems considering the system design input.

Figure 108. Application interface design

5.1.4 The System proof of concept

5.1.4.1 System design: the app and pixel integration

After testing the Suber application, it was decided that the interaction should be focused in activating one pixel within a contextual system (Figure 109). Design issues, were resolved by simplifying the ouput screen to a 4 x 2 prototype (Figure 110, Figure 110).

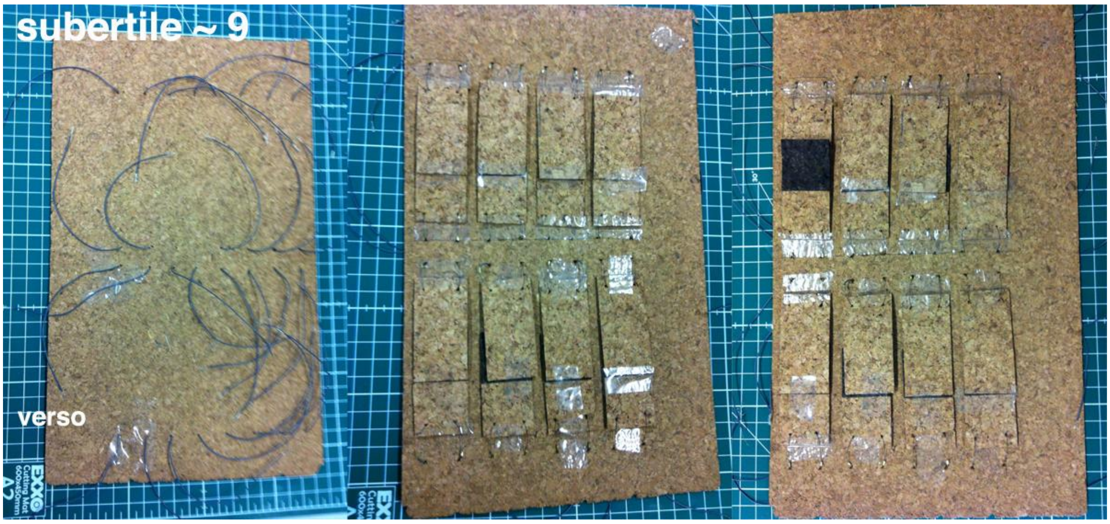


Figure 109. Subertile testing, pixels and S.M.A. wire assembly, square and rectangular shape pixels

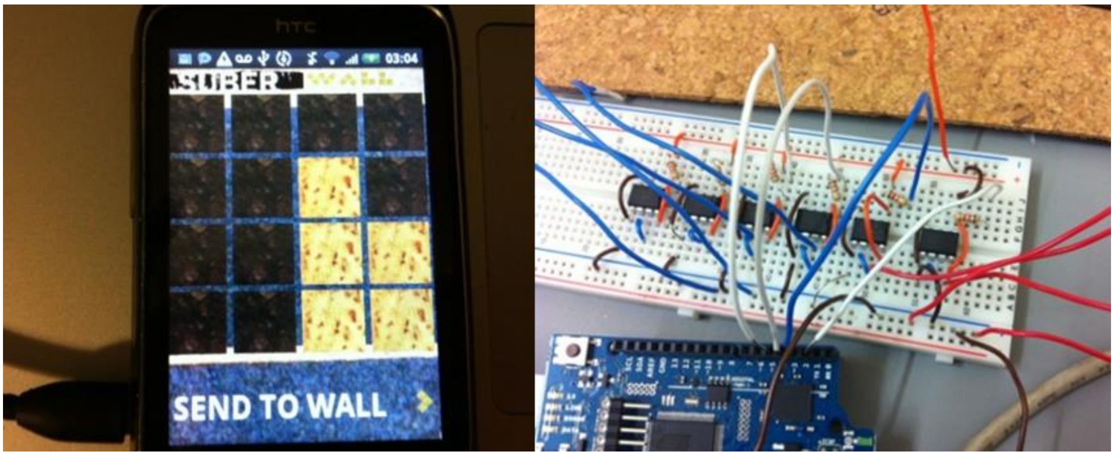


Figure 110. Suberapp 16 pixel tile (4x4 screen), plus one pixel system activation electronics

5.1.4.2 Electronics

Initial testing used component Farnell's MCP 1407 drivers as high current drivers to power the alloy wire.

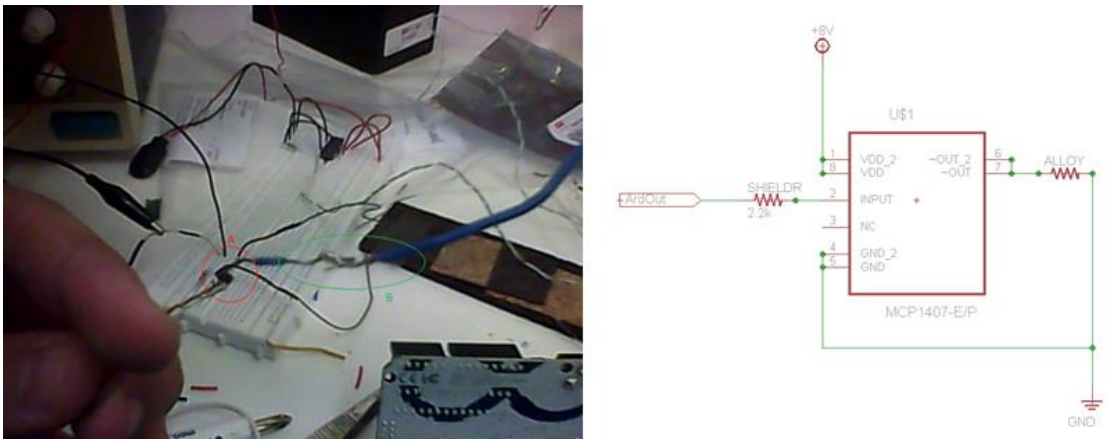


Figure 111. Suberpixel, and one subpixel electric diagram

The component role is to enable connection to the voltage source, when activated by the Arduino pinout, which must be connected to the component's input. A good logical level definition is necessary for stable behavior and, in that sense, the Arduino must share the same ground with the power source.

The power source, in this configuration must be able to supply up to 8 V DC (the voltage used was 7.8V) and up to around 1.5 A (Figure 111), for when two alloys are activated. In case of the system scaling, and the need to increase the number of alloys activated simultaneously, the supply source current output must also increase, by the amount of current needed for an alloy make the transition. Currently is a little below 0.7 A for the 0,008 inches alloy. However, the amount of current will depend on the alloy used, especially due to the impact of geometric factors, like the alloys diameter and length in the resistance.

Above, it can be found the circuit schematic used to drive each subpixel (Figure 111). This structure was replicated for every subpixel, which means there are 2 per pixel. The Arduino's output is connected through a shielding resistor (which is there to protect the arduino pins in case there is some current peak) to the input of the MCP1407, which has 2 supply pins that were connected to each other, and 2 grounds, according to the device's datasheet. The device also has 2 outputs that were both connected to the alloy, which from a eletrical standpoint is only a resistor (although it's resistance actually varies when the transition happens). Finally, there's a pin, NC, which is not connected.

5.1.4.3 Arduino and Android Software connection

The physical set-up is designed with an Arduino with an attached Wifi Shield. This shield allows to connect to the android mobile phone. The final test, the connection between arduino and android, was made in a controlled environment constituted by a router without security. After it is connected to the network it is possible to find in the Serial Monitor the arduino IP needed for the Android application.

The software uses two variables that represent the time delays that refer to the subpixel up and down states. These times are variables, to adapt to the physical variation of the pixel. Therefore physical pixels need to be optimized, in order to have an equal performance.

In the loop function the Arduino waits for the Android communication.

5.1.5 Design evaluation: time calibration in order to expand tile

To better custom fit SuberPixel rise and fall their activation times can be optimized. The timing depends on the physical pixels assembly. Also, for the reduction of the total transition time of the whole wall, the activation of different, sequential pixels, can be made in a smooth transition process.

For each pixel activation is required the following sequence: activate one first subpixel, then have a waiting time for the subpixel to go up. This is followed by the activation of the second subpixel, followed by the deactivation of the first subpixel . Then have the deactivation of the second subpixel.

To assure optimized times, the activation of the first subpixel of a pixel can be made during the deactivation period of the first subpixel. And consequently the activation of the second subpixel of a second pixel could start as soon as the deactivation of second subpixel of the current pixel starts. This sequence allows for significant reduction of the total transition time without activating simultaneously a large amount of alloys, which would "demand" a huge amount of current output, interfering with the power source.

Activation and deactivation times are currently quite different, accounting for the described process. Furthermore, this calibration considers not stressing excessively the alloy. Thus, avoiding a faster degradation of its properties. This optimization could also be interesting from a user point of view, as it would lead to a quicker response from the system and greater sense of sequence for the user, reducing the waiting time.

5.1.6 Conclusion

Creation process, "important to keep in mind, is that for the process to work, we must generate and discard more than we keep"

Bill Buxton, pag. 147

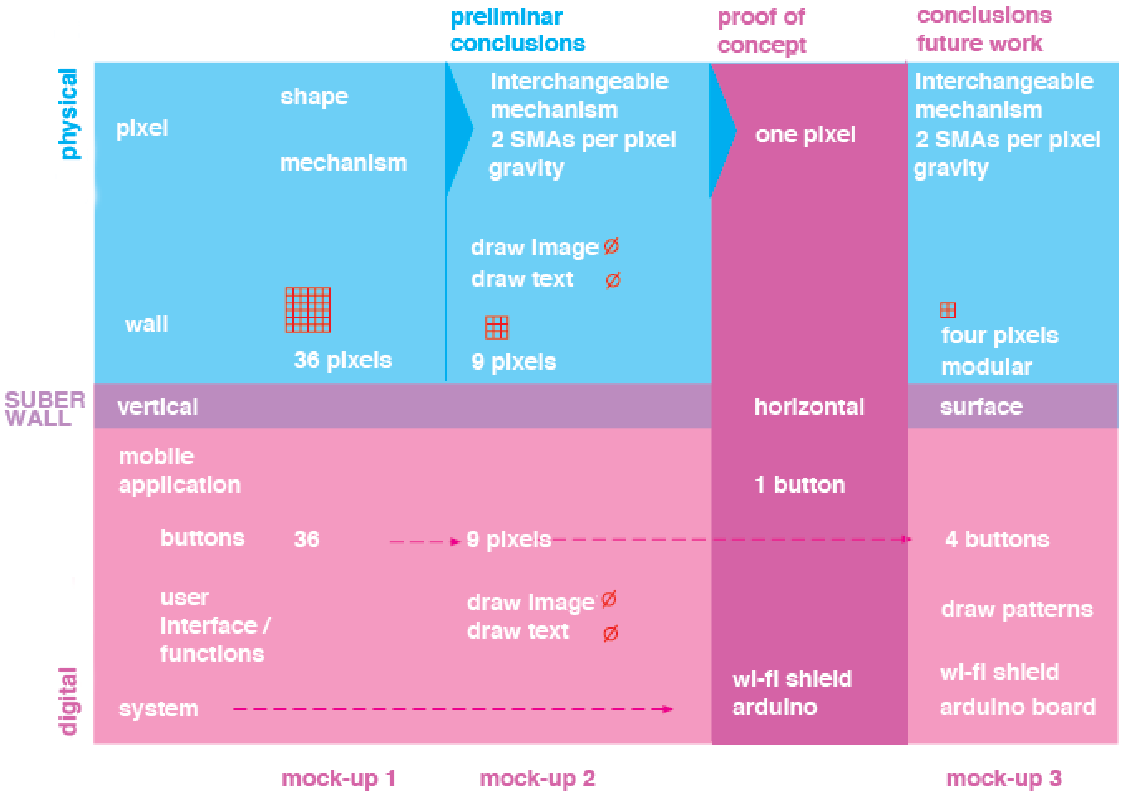


Figure 112. Results controlled convergence chart, based on Bill Buxton's, *Sketching User Experiences: Getting the Design Right and the Right Design (Interactive Technologies),* Morgan Kaufmann; 1 edition, p.150

Bill Buxton chart offers insight about work stages, from the idea to its implementation, using sketching, materials and mook-ups (Figure 112). Initial proposal, aimed at designing a 36 pixels wall. Functions associated to the design interaction module changed through the process of development. Moreover, the project changed from considering a high-fi output with images and text in a wall, to the simply activation of one pixel. Therefore, exploration on material properties determined software design and U.I. For instance, coming from an initial objective of having a 36 pixels module, this was reduced to 9 pixels (theoretically maintaining a square shape 3x3), and finally 4 (losing the square shape to adapt to final SuberPixel testing shape, and into an ideal number, 2x2 pixels.

The final proof of concept was a system of one fully functional pixel. This led to conclusions and insights. Moving back and forward the aim was to simplify the interaction. Another advantage of this simultaneous and collaborative design, was to find that the physical module, offered constrains to U.I. design. For instance, the number of pixels implied on the usability testing, had constrains associated to the user finger size. In a digital application highly speculative design the usability issues still exist, and therefore, less is more. These results benefit from cross-referencing and sequential design stages.

Software design determines soul of the experience, this is, how the system will work.

Considering movement activation, an animistic perspective arises as to define the meaning of the experience. User experience discussion concluded that the meaning of the system, this is, purpose and application depends on the scenario. Therefore, software and physical design had to constrain, accordingly, to scenery A, a private use or B, public use.

Both scenery A and B, follow a telepresent system approach. This was inspired by Bowen's physical interactive art installations. Being more in tune with a public display, the project aims to build a vertical application of the system, the Wall. Purpose A, considered the use in a private setting, where emotional messages, could work as an output. Ideally, the wall would convey images, as to design text and leave messages in a wall. However, at this point of research, the proof of concept is a sketch that inspires a the module in movement.

In sum, results on the first phase were (Figure 113):

- an assembled first cork tile prototype "**subertile**" with integrated Smart Memory Alloys wires.
- built an Android app – **SuberApp** - activating one pixel.
- functional **system** using an android application, arduino board and wi-fi shield, using a private wifi-network
- **functional demonstration** prototype "subertile" with **one** functional pixel

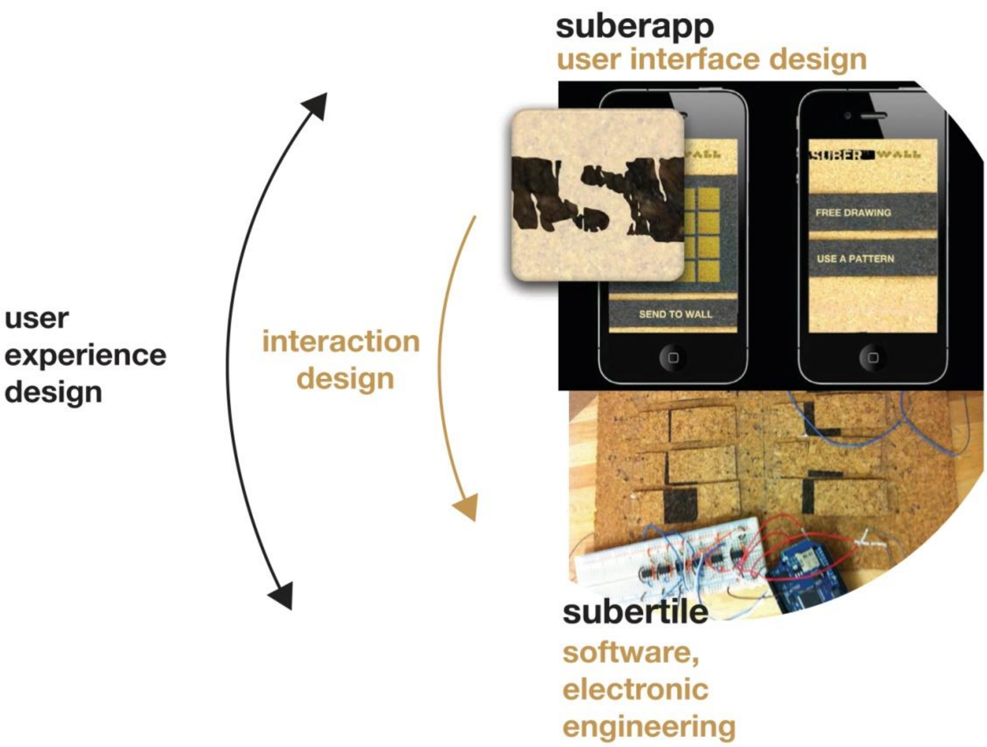


Figure 113. results diagram phase I

5.2 Phase II, SuberTILE: the cork module (UT Austin):

As part of a larger scope on the PhD research, "cork modular" studies continues previous investigation. Essentially, this study aims to redefine aesthetics, kinetics, mechanics of a low-tech material, cork, combined with high-tech material. In this case, the use of a smart memory alloy of 0.008 inch diameter. In particular, this study aims to define a modular design or pattern that can work in an on/off mode.

The main objective of these experiments is to converge into a reactive system. Solutions were focusing on what is allowed by the material in different stages to determine specific visual effect – as a visible and invisible interplay, with moving elements. Critical questions were answered by combining digital fabrication and traditional hands-on methods, crafts techniques in order to pursuit patterns and a prototype.

5.2.1 Design systemic approach

The material studies (Chapter 3.1) and previous laboratorial testing (phase I) permitted identifying cork properties in two perspectives: constraints and plastic possibilities. Physical constraints of cork, features such as low density combined with being an electrical and thermal isolator indicated to be specifically interesting, considering that smart materials have actuating properties that rely on electric stimulation. Specifically, relevant is the fact that to activate a smart memory current is needed to heat the alloy, and control the mechanism. As such, an assembly with cork, being an electric isolator, contribute for a safe user experience, and system efficiency.

The use of an actuator inspires the transformation of static properties of raw materials as dynamic. This combination creates the possibility of exploring it plasticity. This last premise became a design and engineering objective to explore altogether.

This insight propelled looking for the dynamic alteration of cork physical properties. As such, theoretically, exploring modifying cork physical qualities was pursued. By hypothesis, cork and SMAs combination resolves this premise.

Cork features were divided in four main categories: technical, aesthetical, social/cultural, and environmental. Technical properties are low density, thermal isolator, electric isolator, acoustic isolator, mild elasticity, and flexibility, hypoallergenic, water-resistant, stain-resistant. Aesthetical as to having a natural scent and variable natural colors (with no ink added). Environmental, 100% recyclable, sustainable, and serving as an economic, social and cultural symbolic value in Portuguese society (Apcor, 2014). These identified properties are determinant starting points for design approach of cork as new digital product.

Technical	Aesthetical	Social	Environmental
Low density	Natural scent	Economical value	100% recyclable
Thermal isolator	Variable natural colors	Symbolic (protected tree)	Endlessly renewable
Electrical isolator	Variable natural textures	Cultural ethos	Biodegradable (natural)
Acoustic isolator Absorbs vibration		Comply to circular economy principles	Comply to circular economy principles
Mild elasticity		Historical	
flexibility		Industrial value	
hypoallergenic			
water resistant			
Stain resistant			

Table 4. Cork properties

This chart presents a systemic point of view cork properties (Table 4). These allow to map design territories of exploration and combination properties. Therefore, SuberTile exploration, beyond constraining to aesthetical properties, can for instance, explore functional variations, like is the case of acoustic. Accordingly, these features will comply to refine pixels applied to a cork made device. Therefore, Table 5, describe “subertiles” possible explorations, in three ways. These address cork properties projecting design solutions according to technological constraints and function.

SuberTile	exploration	design	function	research
Suberkin (ground zero)	surface	Movement	Visually Aesthetically pleasing,	material, gravity or on/off state,
“Hi world” tile 	screen	Change color Movement	Aesthetically pleasing, convey visual, graphic information	material, gravity or on/off state transition vertical application

3D Cork Acoustic interactive tile  	3d chevron shape	Movement Sound	Control sound, modulation formal, aesthetical	material, gravity or on/off state, sound design, aesthetical vertical application

Table 5. Testing tiles, projecting design solutions according to technological constraints and function.

5.2.2 Design studies

The SuberTile assemblage are part of a system that gains meaning progressively, from a pixel, a tile, into a surface. Subertiles have an one way and two ways mechanisms. Indeed, concerning tiles and surfaces, hands on testing from paper to cork were performed. It was used hands on and laser cutted paper mook-ups on shape of the module, ways they fit together, attachments push-on and off mechanisms (Figure 115, Figure 116).

Research was guided by exploring natural material properties. The question was to verify if these qualities could be enhanced or have a built in variation. The smart material to be applied as an mechanical actuator, could manipulate properties in real-time. Beyond pixel shape, studies were directed to design tile shapes and qualities, like the levels of acoustic variation (Figure 114). This research route was abandoned, having the inquiry focused in exploring changing visual properties.

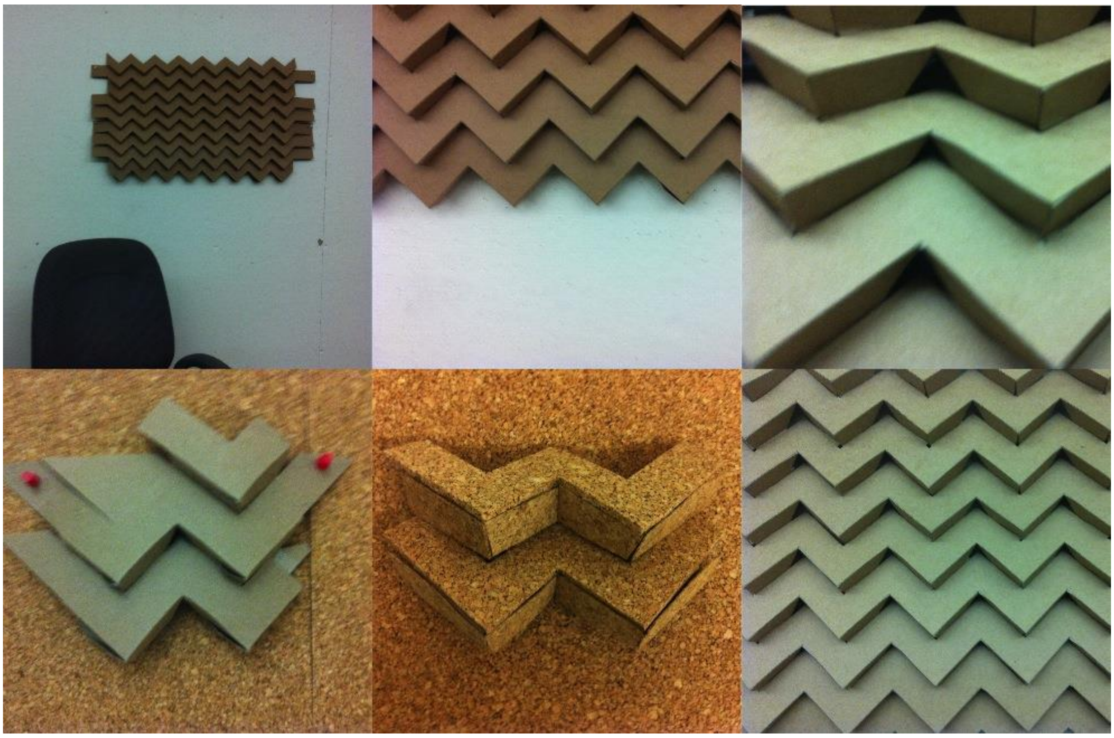


Figure 114. Accoustic tile 3d design exploration, module and Wall.

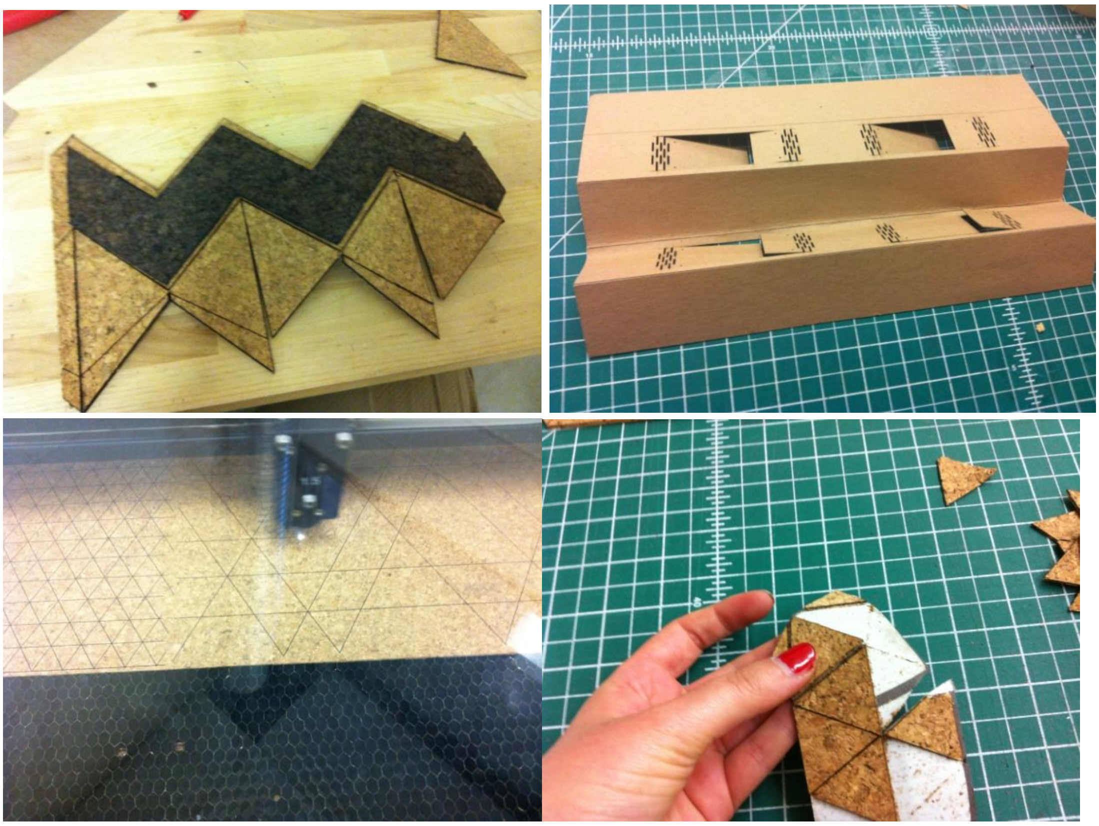


Figure 115. Surface design explorations (selected)

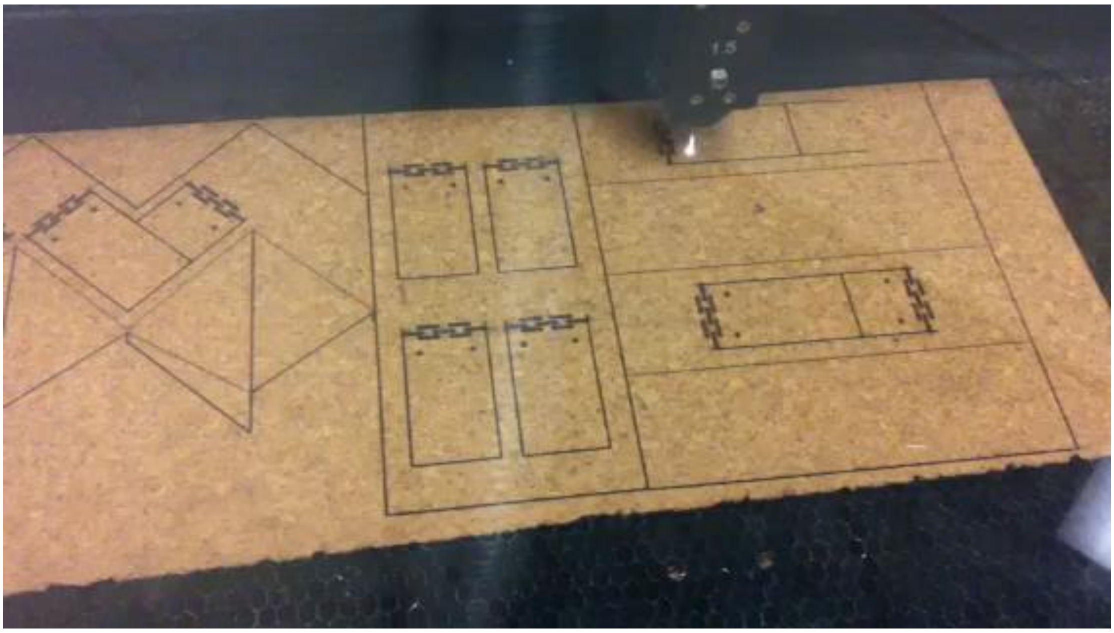
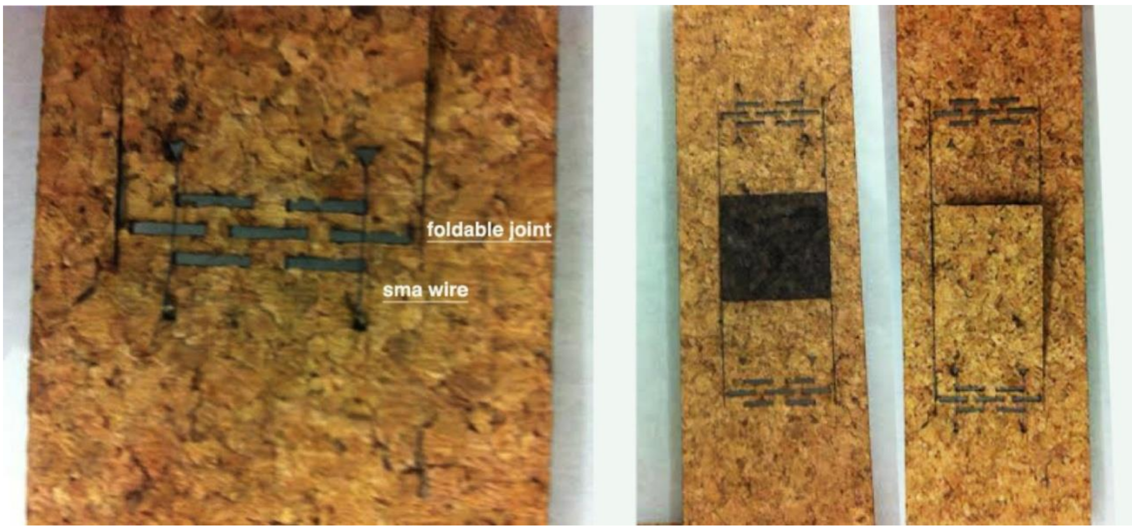


Figure 116. Laser cutting cork

5.2.3 From one to 4 pixels

After evaluation on results, the focus was to design a tile of 4 pixels. In fact, one of critical feature on the tile assembly concerned the foldable joint. Optimization of an expandable mechanism required joint optimization. The evaluation of a Sub pixel testing was made by sequential analyses on a single opening (Figure 117). Moreover, Von miss Stress tests were performed (Figure 118). Aesthetical variation as well as function was addressed.



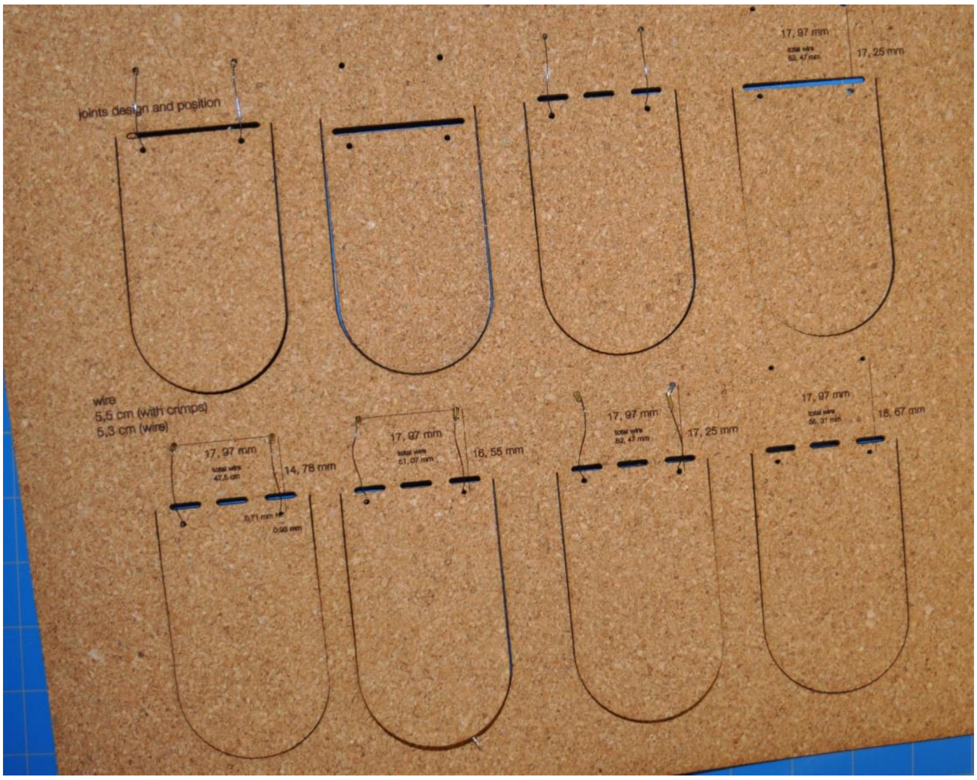
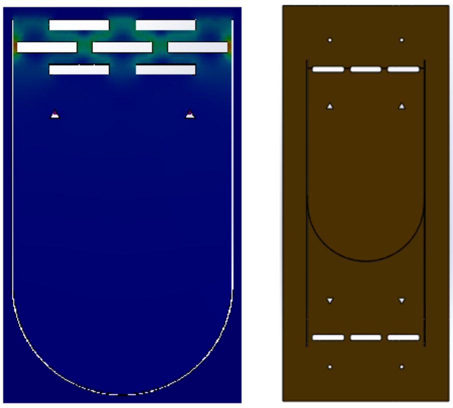


Figure 117. Joint testing



Von Mises Stress analysis on original living hinge design

Updated design as a result of analysis

Figure 118 pixel optimization

5.2.4 The electronic circuit optimization

Impendence tests were performed with flexinol, SMA LT 70 C, in order to design a better performance of the mechanism. The material with lower temperature transition was chosen in order to optimize the system, in terms of energy supply (Figure 119).

A final working test was performed with the new joint design, concerning the inter-changeable mechanism .

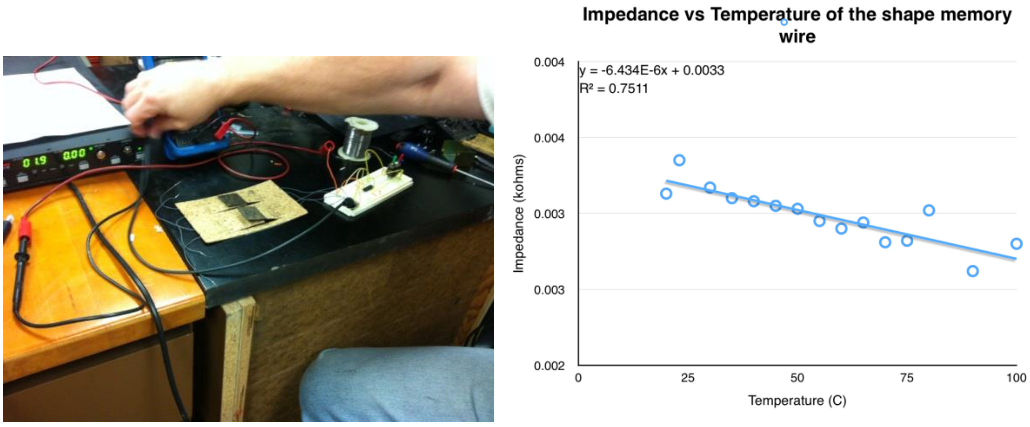


Figure 119. Pixel optimization

5.2.5 Digital Fabrication

Optimization of SuberPixel was directed to design improvement (Figure 120). Design focused on an exchanging mechanism, but also in one way mechanism. These two options, shared the same features, concerning design. Thus, a round pixel was proposed for evaluation. The wire positions on sub pixel were optimized accordingly. These improvements relating to the folding mechanism were digitally fabricated (Figure 120).

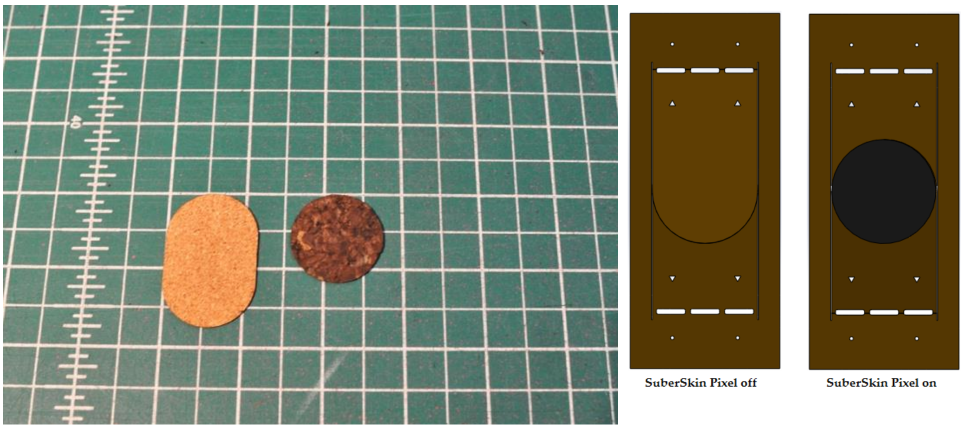


Figure 120. SuberPixel, two ways mechanism

The assemblage of parts and features contributed for an optimization of movement. However, the movement was slightly constrained, and it was not easy to fully replicate movement homogenously. Therefore, regarding lifting of cork, with the new design, tests were performed with the flexinol (Figure 121).

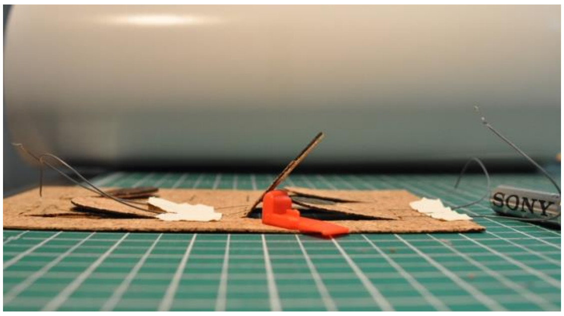


Figure 121. Suberpixel, two ways mechanism

A final digital fabrication of the final tile was made. Tests were performed sequentially, transitioning from paper to a final composition (Figure 122).

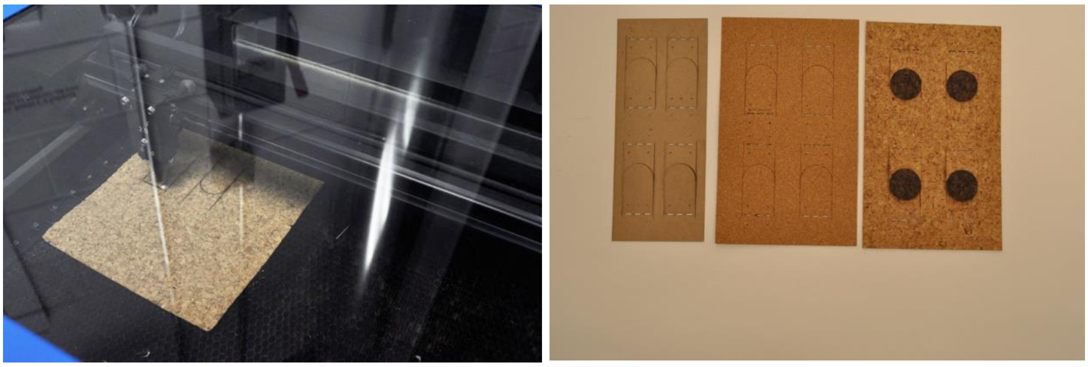


Figure 122. Laser cutting SuberTile, from paper to cork.

5.2.6 Hand made process

Transformation of cork into the cork stoppers, as a product, results from processes of skilled cutting. Cork can be both cut mechanically into different kind of products, but this can be easily done manually. Manufacturing current SuberTile, introduces a remediation of these traditional methods, therefore combining both mechanical (laser cutting) and manual input. The inclusion of electronics as well as the S.M.A. is obliged to be made by hand. A particular assemblage process is required to attach the wire to the cut-out tile. A process that could be translated as “weaving S.M.A.s wires into cork” (Figure 123). Craft work that require a highly specialized approach.

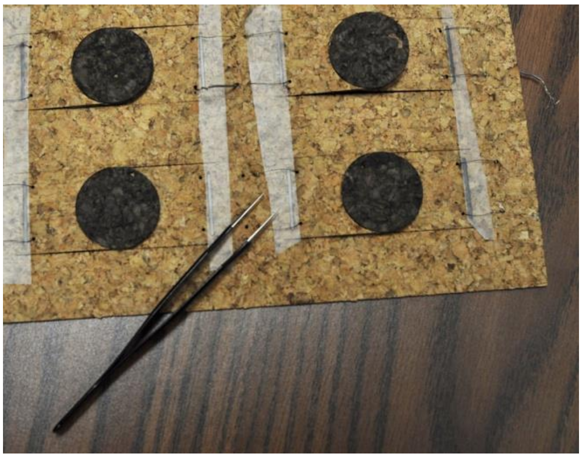


Figure 123. Subertile, hands-on weaving SMAs wires into cork

A second layer of cork is applied to the tile in order to have a contrast or continuous color underneath. In the case of the interchangeable mechanism the color is light cork (Figure 124). In the case of the one way opening mechanism, the layer beneath is dark cork. This second layer of cork of 2 mm, also give physical stability to the tile.

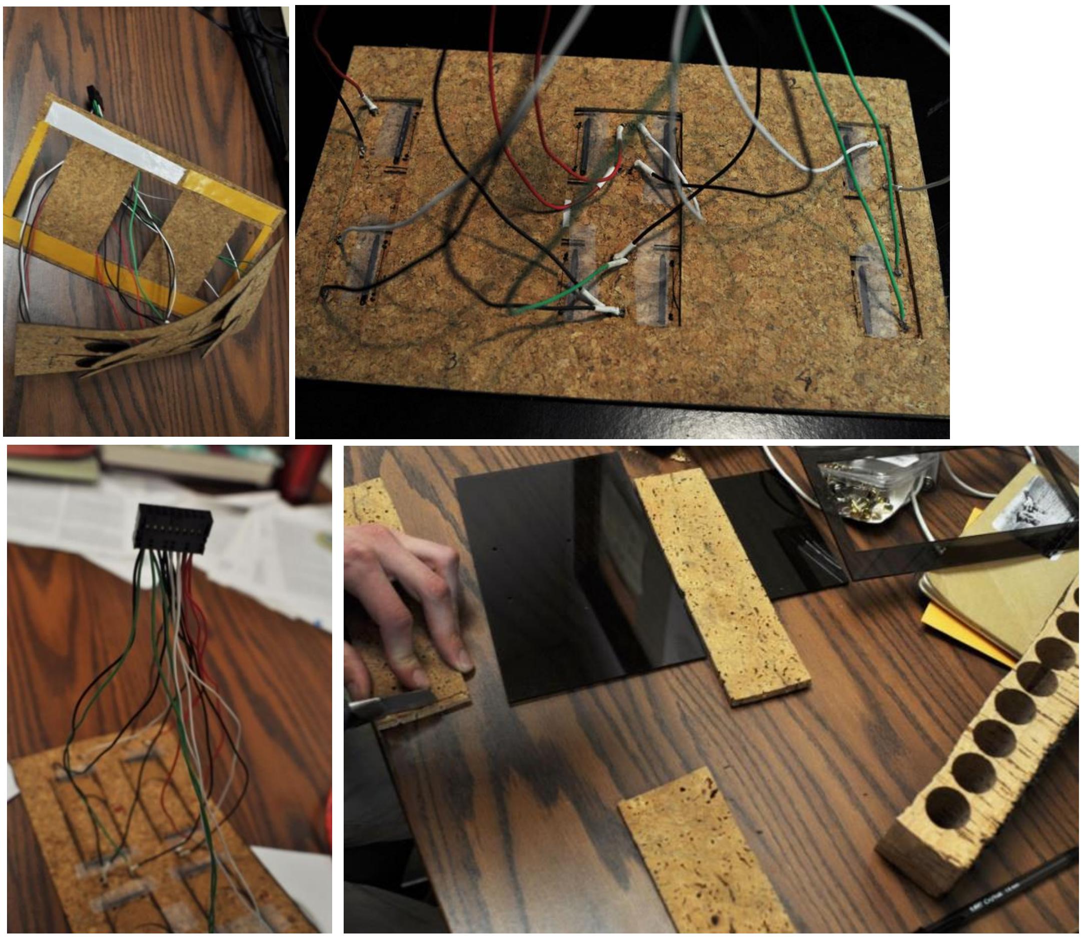


Figure 124. Subertile, assemblage

Additional wires are annexed to the tile, as well as the connector to the Arduino board (Figure 124).

Further improvements concerned the tile presentation. In this case to design a box to combine all components: the Arduino, electronics, wires, SMA wires and cork. The module attaches to a box. Thus, these fit together, but also detach, building an attached push on and off mechanism. This was simulated by applying a magnet to the structure, allowing the tile to attach and detach (Figure 125).

5.3 SuberTile: design results

5.3.1 Exchangeable mechanism, and one way mechanism

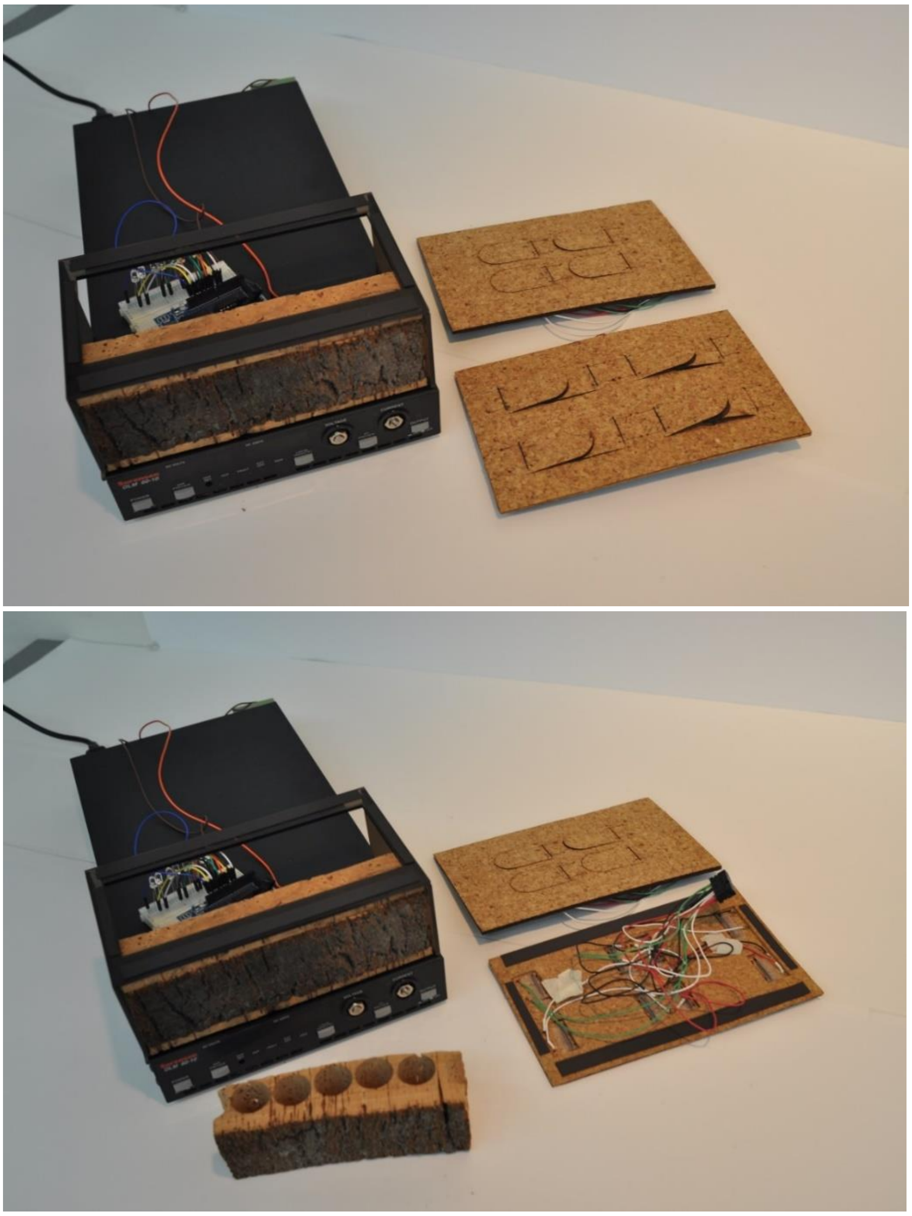


Figure 125. Demonstation Suber tile, one and two ways mechanism

The experience showed that with current software is possible to replicate a 4 pixel module in 16 states. The output are visual patterns made of movement (5.3.2.1. the wall configuration: mechanism 1 way; 5.3.3.2. The wall configuration: mechanism 2 ways pixel). But also several physical designs can be proposed. For instance, the triangular shape pixel, and using laser cutting to draw images on cork like found in Figure 126.

In conclusion depending of the mechanism two typologies of tiles are proposed: the exchangeable mechanism, versus one way mechanism. Both are based in a 2x2 SuberPixel tile. The demonstration can be found in Figure 127, hiding the electronic wires, and displaying a physical attachment from the SuberTile to the box. The one way mechanism is simpler, and the most functional tile. And this is the one explored in Figure 126.

The digital composition wall/surface visualization of the two ways mechanism is proposed. Both output movement options are presented in Chapter 5.3.2. SuberTile, extended to suberskin. The photo in FAB LAB UT Austin demonstrates a simulation of the "interactive cork system" applied to a location (Figure 128).

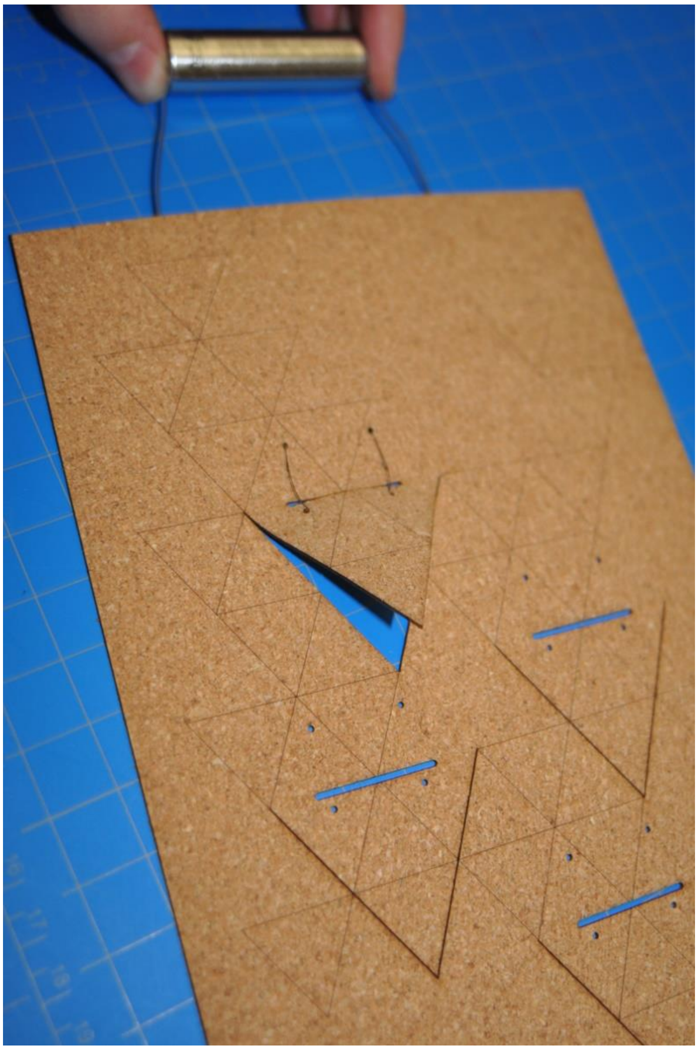
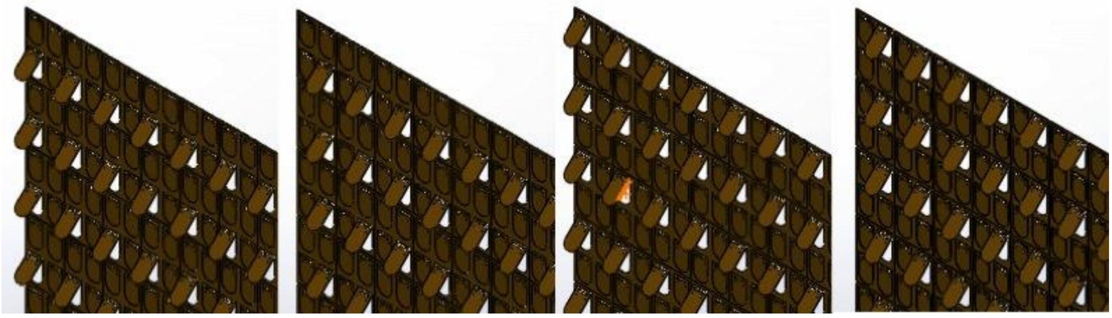


Figure 126. Subertile, design option, detail

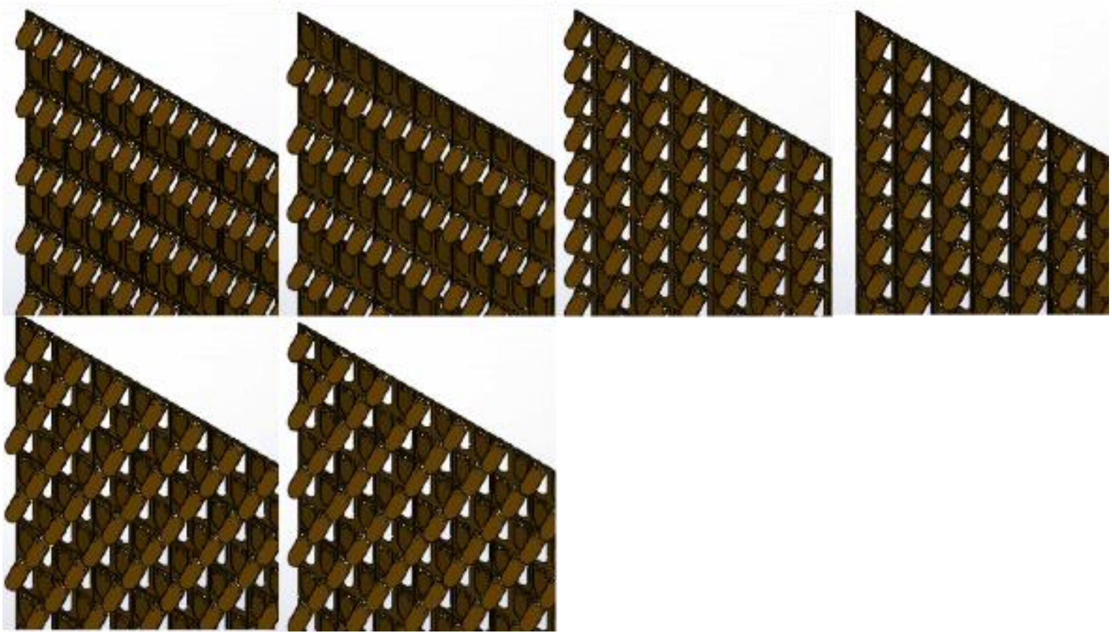
5.3.2 SuberTile, extended to suberskin.

5.3.2.1 the wall configuration: mechanism 1 way

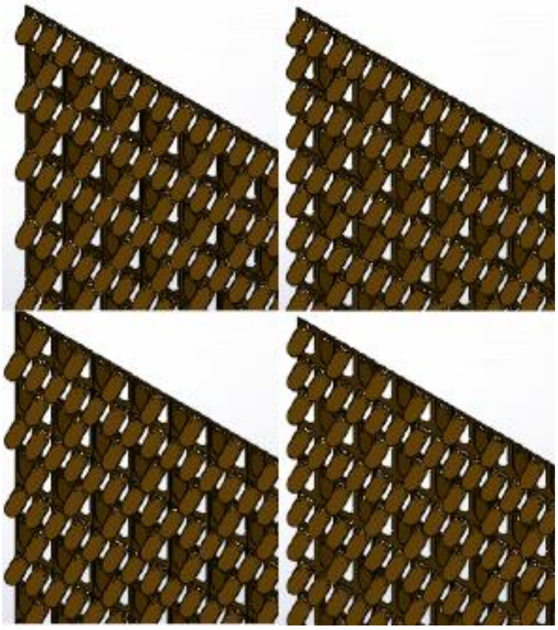
5.3.2.1.1 One pixel on



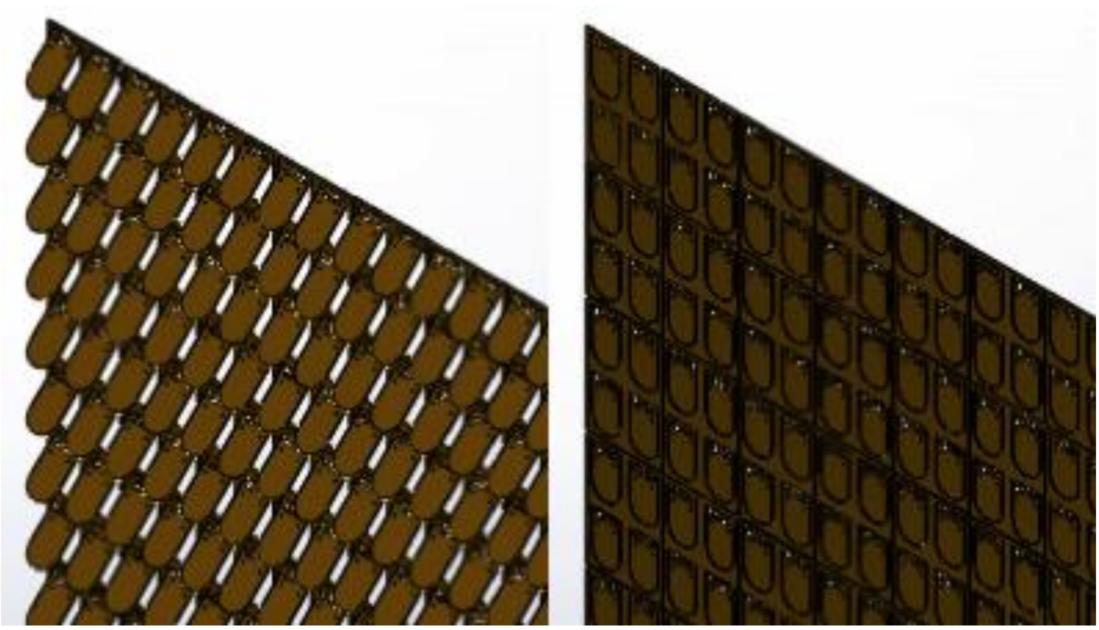
5.3.2.1.2 Two pixels on – Wall



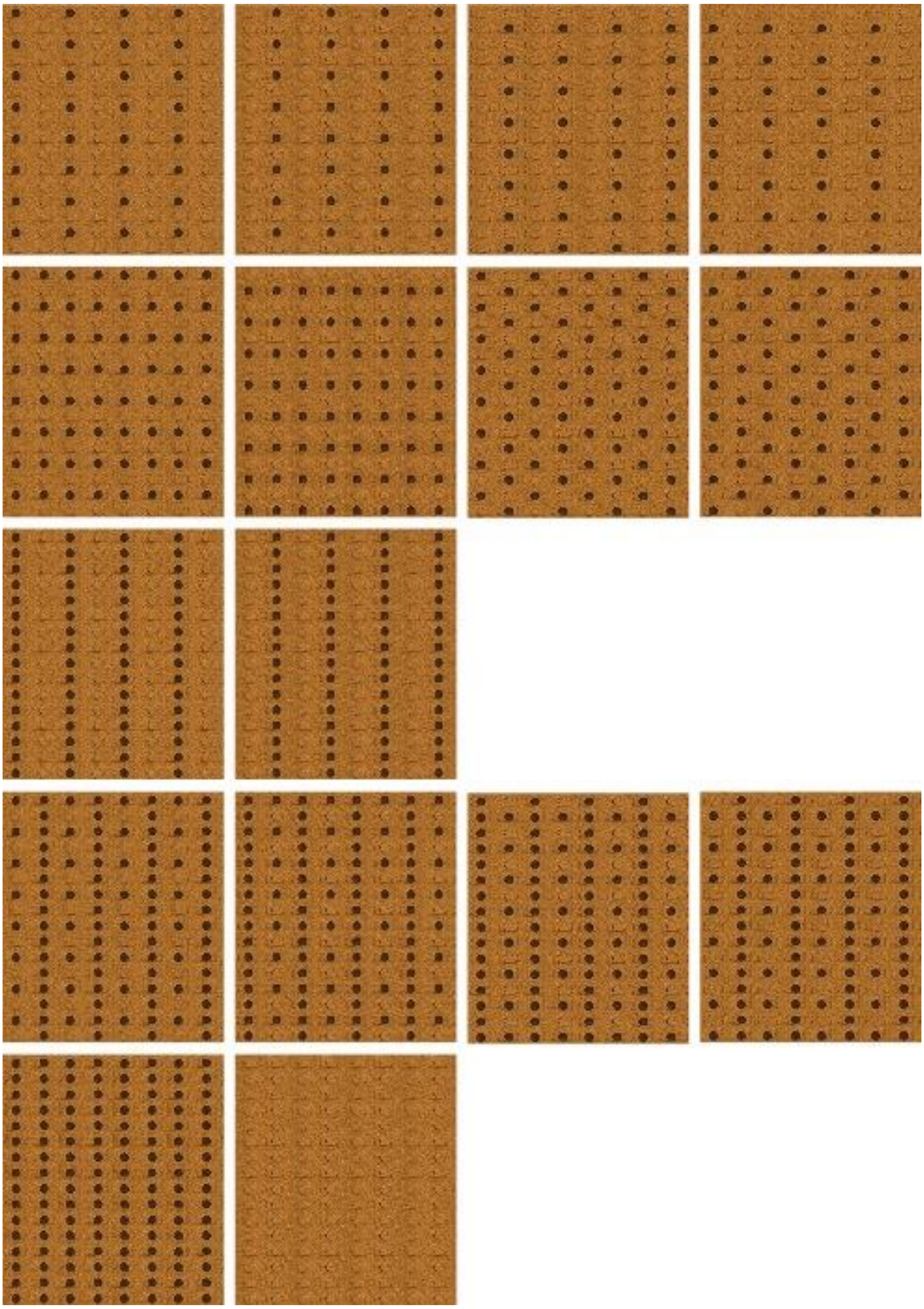
5.3.2.1.3 Three pixels on - wall



5.3.2.1.4 Four pixels on /off - wall



5.3.2.2 The wall configuration: mechanism 2 ways pixel



5.4 Prototype demonstration

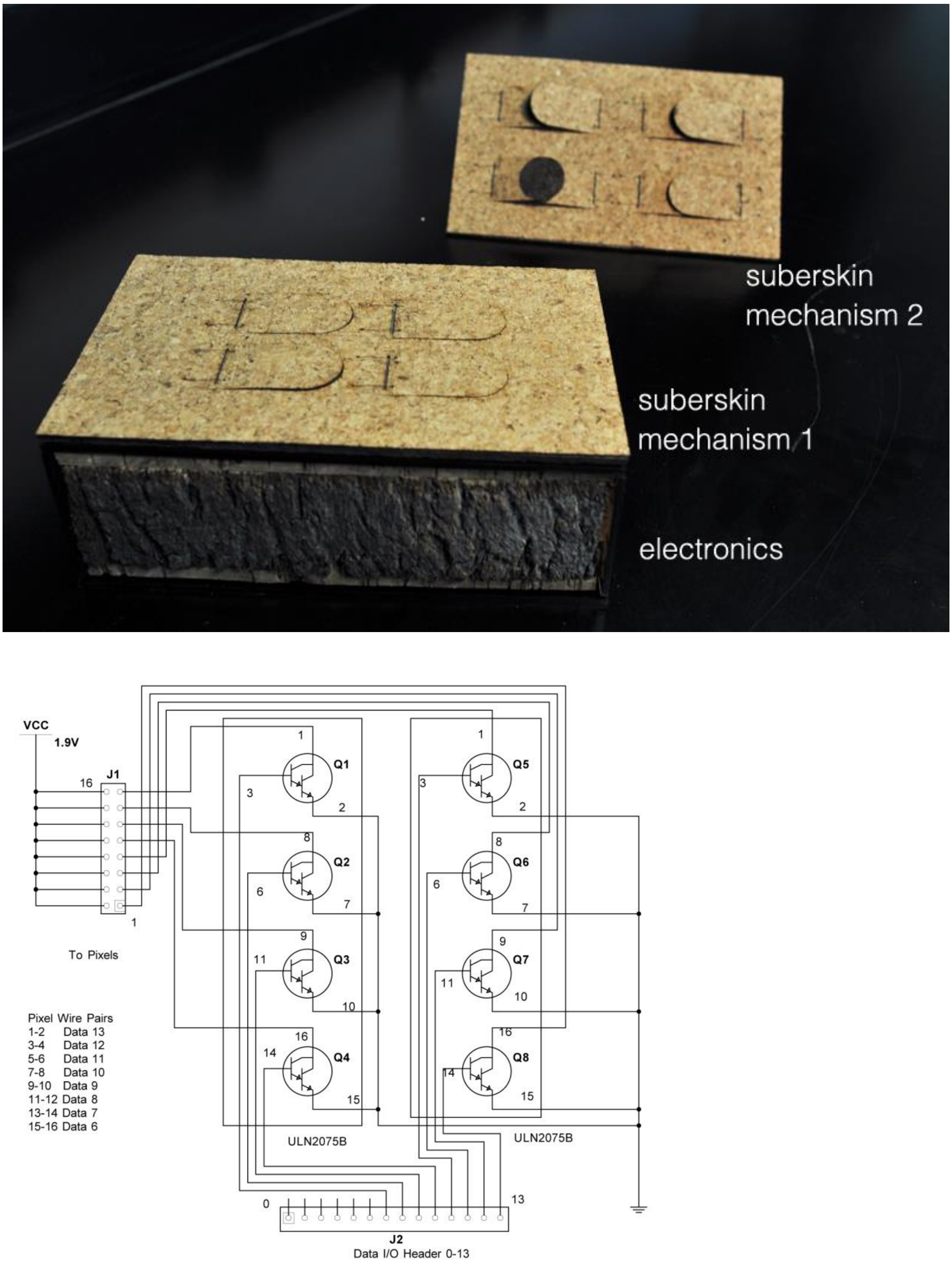


Figure 127. Demonstration and Electronic Circuit

5.5 Interactive Cork System presentation suggestion

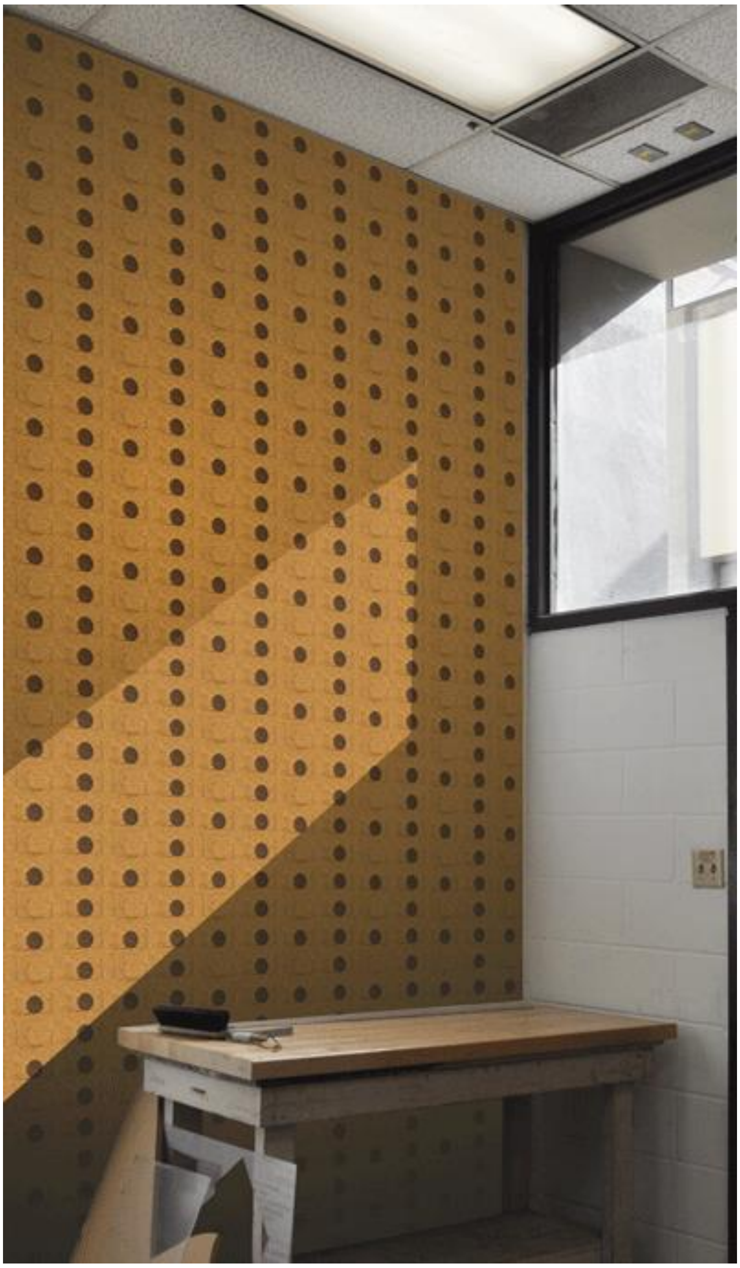


Figure 128. Two ways mechanism application to Wall – digital composition: original photo location FAB LAB UT Austin

The SuberTile, an original invention, is the interactive cork system module. An one way mechanism SuberTile demonstration (Paiva, 2022b) was presented and well as the SuberTile changing mechanism (Paiva, 2022c).

6

CONCLUSÃO

"In STEM, failure is a fact of life. The whole process of discovery is trial and error. When you innovate, you fail your way to your answer. You make a series of choices that don't work until you find the one that does. Discoveries are made one failure at a time. One of the basic tenets of design and engineering is that one must fail to succeed. ... The skills of the 21st century need us to create scholars who can link the unlinkable. ... Nurturing curious, creative problem solvers who can master the art of figuring things out will make them ready for this unknown brave new world. And that is the best legacy we can possibly leave."

Ainissa Ramirez's "Save Our Science: How to Inspire a New Generation of Scientists"

6.1 Contribution

Research contributions can be summed in three outcomes. Firstly, an original invention, the interactive cork system. Secondly, a methodology that integrates a A.D.A. perspective under the scope of ubiquitous computing research. And thirdly, the extended skins: Paperbot, Responsive Tile, Supermirror and Cityskin.

The problem tackled was to find links between Portuguese industry, academy, and sustainability as part of research project requirements. Therefore, the proof-of-concept merges technology, economy and innovation. The device combines cork, SMA, electronics and software in two SuberTile versions. The demonstration proposes a speculative scenario adding technological improvements that make the device fully sustainable. This device is described in future work.

The second outcome from this endeavor concerns demonstrating a methodology that situate "practice as research" as source of new knowledge. In particular, this thesis discusses a methodology that integrates a design (A.D.A.) perspective contribution under the scope of ubiquitous computing. The practice circulated between art and science spheres, which was resolved under the term "research through *technê*". Broadly, this original notion discusses the idea of innovation as hybridization and is fundamentally a theoretical contribution. This concept illustrates collaboration as an expectation and demand of current time, if concerned with having technology to the service of common good.

Thirdly, combining scientific and design methods. Experimentation with materials was inspired by new product research in the context of Portuguese industry. The choice was guided by traditional materials available in Portuguese industry (e.g. paper, cork, ceramics, food...). Thus, the designated step-by step projects method take on a design practice directly inspired by the scientific method. In fact, they apply results taken from initial material studies and the so called "Extended Skins" (Paperbot, Responsive Tile, Supermirror and Cityskin). These works are autonomous research projects.

The use of these combined methods have advantages. Research projects can be independent (thus generating constellations of possible results). This is a great advantage considering practical design research. These tangible sequential outcomes do not collide with the traditional design practices, in fact, they suggest moving further the disciplinary scope of action.

6.2 The interactive cork system: What is radically new?

As defined by Weiser, Ubiquitous Computing research objectives considers social, cultural, aesthetics issues but also personal experiences and history as determinant while designing intelligent environments. Project Suberskin answers to these requirements by being part of the effort to re-imagine H.C.I. from art and humanities point of view. Weiser also includes personal history in the context of research as relevant which for the designer, as defined by P. Hall (2011), motivates a negotiation between a process of self-transformation, while trying to contribute to society at large.

The choice of a natural material to design an interchangeable system met several objectives. Cork is associated to **environmental** but also with **social-economical factors**, which in terms of design program offers an added value. Moreover, the material being biodegradable allows to plan the object's death and rebirth, by complying to Circular Economy principles, as part of a system design. As such, this project not only approach nature as an ethical imperative but makes a practical demonstration of possibility, given light to a sustainable project that blends design, economics and technology.

This project is also **radically new** in the **context of cork research**. Firstly, research addressed natural qualities of the material as potentially mutable. Secondly, the combination of cork with electronics transcends the primary scope of use of the material. In sum, Suberskin: a "cork made" system media designed towards a human-centered experience, is a new device.

Within **cork research context** the use of an actuator combined with the material that previously did not exist. Furthermore, the particular use of an S.M.A. as an actuator, contrasts with precedent quoted **kinetic walls**. These walls typically use mechanical set-ups as actuators. S.M.A.s have aesthetical and physical advantages. For instance, they reduce complex mechanical structures to a simple wire, while conveying a silent actuation.

The prototype SuberTile changes shape by lifting SuberPixels. The module can be assembled into a **surface** or **wall**. This project can be understood in the context of an art-tech, design exhibition. However, it situates and draws lines to develop a product. Therefore, one of the objectives of the research is reached: it is a demonstration of a controversial but obvious connection between what was defined as art, design, engineering and industry.

Accordingly, SuberTile aims to **contribute** to the described current **H.C.I. studies**, dedicated to interactive materiality given by digital to physical convergence, crafts and digital computing mix.

Project Suberkin is **radically new** in **Ubiquitous Computing research context.** Suberskin presents an activation of a "dumb" material: displaying behavioral features linked to traditional materials that have expected stable properties. Therefore, it is a research project that demonstrates a systematic approach to natural materials considering and (potentially) manipulating its properties. In a broader sense, this project is included in **Ubiquitous Computing discussion**, appreciating cultural and social aspects, and interdisciplinary techniques as instruments for design. In particular, making use of "warm", historical, geo-referenced raw material. Therefore this system is site-specific, giving a re-interpretation of cork, and actualization of a local material, proposing a transition for the future.

On the other hand, considering the system design, this project advocates **the inclusion** of **cork industry** in **Ubiquitous Computing** discussion. This systematic approach to materials can be adapted to other cultural contexts, as site-specific advances in context of the new technologies, industries and computation.

Combining materials sourcing from high and low-tech contexts hybridizes different traditions and practices. The particular combination of S.M.A.s as an actuator on cork gave note to emergent advantages. The S.M.A. activation is silent, and cork is a sound isolator material. The S.M.A, while activated, (creating openings on cork), conveys variation on amount of sound isolation, therefore interfering with cork acoustic properties. This suggests that beyond changing physical shape, the fixed properties of the material could be controlled dynamically.

The smooth sound experience results from combination of natural features found in these two materials. These show an advantage regarding the mechanics traditionally present in kinetic walls (which are typically noisy). In technical terms, cork low density exposes further advantage in the use of this combination because there are excellent margins in relation to the actuator force. Cork isolator properties (electric and simultaneously thermal) further contributes to the system safety. These qualities can be adapted to address concerns regarding expected S.M.A. heating effects, and the user interface with the system.

Furthermore, regarding **physical shape**, the use of S.M.A. as an actuator creates a flat design. The mechanism that applies the movement is minimalist and a sense of simplicity is achieved into the tile overall design. In particular, this simplicity allows to save room for packaging. For instance, current SuberTile versions, including the electric wire attachments, can fit in a paper envelope.

Considering the overall context of research, the prototype Subertile can ultimately project a future product: an interactive cork wall or surface (described respectively as Suberskin, SuberWall). Therefore, the research results can be integrated in fields defined as U.C., internet of things, media walls, robotic architecture. Future applications could be anticipated in the context of smart home, art installations, or interactive furniture.

6.3 Future Work

6.3.1 Design and technical considerations

Movement aesthetical design possibilities are endless. The proposed protype makes evident that the quality of the performance depends on software. Cork and S.M.A.s ensemble depends on a constant ratio and influence directly the amount of power necessary for the system to work. Thus, technical aspects, as for instance cork-pixels resolution, have scaling constrains. Therefore, resolving these technical issues are a priority, and precede aesthetical options. Theoretically, scaling can be done, but according to observable limits between the mathematical possibility and the experimental results. Therefore, progressive testing is recommended.

The software of the system is designed to be disconnected from the cork tile. SuberTile, the physical device is detachable. Therefore, physical design, the tile, can be changed without affecting the physical setup system in the wall. As demonstrated, the interactive cork system can originate several physical designs (SuberTiles) sourcing from the same software. But also, different software can activate movement in a specific SuberTile in multiple ways.

Current demo relies on Arduino electronics. The replication of the Tile, into the wall, has, nevertheless, to address several factors. The scalability potential has implications in, for instance, considering a bigger surface combing SuberTiles. But also, resolution issues, will alter proportionally the cork-pixels ratio (pixel and wire sizes). Both have implications on the energy supply. The reduction of the electronics size is also requisite necessary to make in the future. For instance, in this case testing with printed electronics can be an option. In this in a future context, where some of the aesthetical properties, such as acoustic properties are expected to change.

Research on control of physical properties of a natural material can be followed. There is still work to create a sustainable product, demonstrating solutions to maintain 100% recyclability. And finally, aesthetical research on cork, can be potentially explored by addressing features expanded to other senses.

6.3.2 Suberskin speculative design

Considering Sanders' map on design, SuberSkin, can be integrated, and identified, as belonging to a specific territory, defined as "design and emotion" and "critical design" research. Thus, meaning a definition on what the project might be, the idea, comes at the end, and not at the beginning. This is typically an inversion on the design process, and it is related to what is defined as experimental design, much closer, as described, to the scientific method.

Project Suberskin is framed under Circular Economy principles, and therefore, can be proposed as a neo-futurist project. However, under the scope of circular economy principles, some features should be added in order to comply to environmental requirements. These improvements are referenced as future work.

One first improvement concerns applying "materials parsimony", and proposing the use of biodegradable electronics (Figure 129).

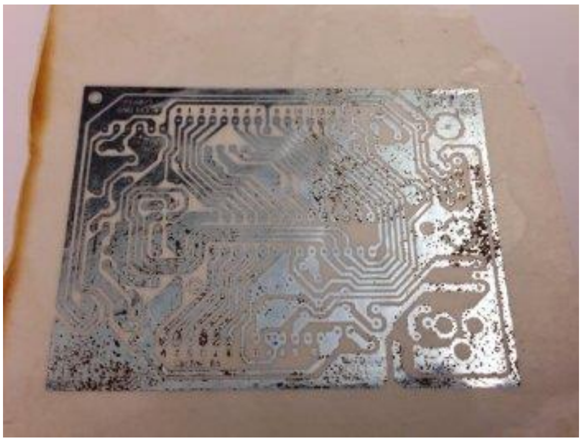


Figure 129. Biodegradable circuit printed onto material made of cellulose acetate, by Lynn Rothschild, retrieved from http://2014.igem.org/Team:StanfordBrownSpelman/Building_The_Drone

Secondly, one of the issues that define the circular economy principle refers to tackle the product life cycle. Planned obsolescence is, as discussed, an overall system of "birth" and "death" of the object. In the case of SuberSkin, a system of rebirth is proposed, designing an experience that allows the product life cycle to repeat complying with the circular economy principles

Design planning includes a product life cycle as an inevitable. I propose to include a system of activation of novelty. In this case, the death of the object combines with the product characteristics. Rituals are ideas to be included as a design dynamic, and engaging storytelling. This ritual of death and rebirth can be recognized in two ways: through the user participation and be a built-in characteristic of the product.

The end-consumer assumes a participatory role in recycling the Subertile. This interplay with the user, can be done regarding the actualization of software, but also of the physical tile. In one hand, taking part of a pleasured ethical ritualistic re-activation of the system: subertile can be used as a fertilizer. In other hand, actualizations on software can create new models of interaction with the physical device.

Therefore, the renewable and biodegradable materials are part of the design of experience. That is, it makes the existing product to be designed to die eventually. This means dissolving into the environment, not depending of the level of engagement of a user to recycle.

In sum, in the case of interactive cork, the system can be both, endlessly actualized by the software updates, as of the hardware. However, the use of biodegradable materials, and modular systems makes actualizing of the hardware, the thing, as cyclically possible.

The modular system allows to have replaceable tiles, as it is composed by independent modules. It can both serve the concept in terms of allowing an easy technical assistance, but promote new interactions with the system, by allowing changing physical designs tiles periodically.

Therefore, it is possible to activate the product life cycle, both physically, as the meaning without damaging the environment. Moreover, the consumer, can be allowed to fabricate his own tiles via a service provided. But in addition, due to its total biodegradable features, educational storytelling to engage with nature, and energy cycles are possible. For instance, burying a subertile to fertilize the soil.

6.3.3 Proposal for a sustainable future

As such, SuberSkin project can follow two directions for future improvement, and aiming to comply to Circular Economy principles.

Sustainable tile

Case of cork (a natural material) + biodegradable electronics (engineered material)	e.g. the ideal: you can return a product to the cycle, by simply burring it, as it is totally biodegradable. Design according to the example of nature own transformation cycles.
Design an open system (aesthetically pleasant)	The advantage of the flat design is both in transport, but also, allows to have a better interaction with an end user. It is possible to easily ship hardware actualizations and proposing meaningful, ritualistic reactivating of the new. The end consumer can change the tile design by themselves.

In conclusion, this proposal for the future, creates a highly speculative scenery. These, obviously, require testing. However, speculative design assumes the risk of failure of products that do not exist. As an idea it can contaminate, or inspire others, either by being copied, - as it is common in both academy and industry - or by quoting (referring sources and inspiration). Copying and remixing, when serving common good, in this case environmental issues, is welcomed. At the end, we all, present and future generations benefit from the proliferation of ideas that serve all. In case of interactive cork systems is the environmental crisis that is addressed.

6.4 Notes on the proposed methodology

Early research scope was motivated by the manifestations of instability in design practice influenced by digital media. However, the premise that design (making) is a synthesis of doing and theory led to situate research under the concept of "research through *technê*". The concept concedes a tranquil tone, regarding either common issues on disciplinary boundary or as recurrent pressure of disruptive "changes" presented by technology. Under the concept of "research through *technê*" these pressures are viewed as persistent, rather than new.

Furthermore "research through *technê*" offers a synthesis that tells the existence of common ground between practices and knowledge (e.g. there is knowledge obtained from practice). Under this light what was defined as science and art in contemporaneity has a more vivid understanding of open common ground of action. *Techne* resolves the binominal science and art.

In sum, to address research under the term *technê* is also to find particular interpretations of making and theoretical routes, that might be helpful to achieve a contemporary Renaissance between engineering and art. For instance, *technê* was nomad, concerned with practical knowledge, skill, as something that could be reproduced, that is, it could be taught. Moreover, since ancient Greece *technê* is regarded as a kind of knowledge that brings social mobility and change. In a time of highly fragmentary concepts, *technê* offer a wider scope of action, while stabilizing interdisciplinary research.

Research through technê further gives understanding that the hybrid is a norm of creation. Looking into the ancient Greece through *technê* is also a way of realizing that the Romans were already 'remixing' the Greeks, as the Renascence was doing with the Greco-Roman civilization. The rupture of a technological push [*technê*] might introduces in fact, an expected, (new) time of remixing, and as such, art and science would be, again, in a conscientious interplay.

Ultimately, *research through technê* presents the Humanities as a source of insight. In other words, contributing to dialogue and innovation in the realm of makers. Understanding making under the term *technê* introduces the notion of skill as knowledge, taking both engineers and designers action as complementary entities, as are defined by contemporaneity.

Understanding making from the perspective of skill opens a new (old) perspective of equal standing. Thus, having been trained in different skills, due to living under an intense disciplinary era, the makers, in both fields, have consciously or unconsciously built up a disciplinary skilled blindness, as well as blindness to *other* skills' value. Resistance to learn new skills and learn about its purposes is common in all disciplinary fields. My claim is that this apparent easy, safer and comfortable behavior, tend to be expressed in a defensive manner, of what is known. In fact, resistance to risk, that of being of ridicule, failure or disciplinary ostracism, often result in conveying to peer pressure. However, the claim of present research effort is to give the understanding that these attitudes are less prone to create innovative environments. So, what can motivate inter-disciplinary discussion? And how to listen to the *other*? These became imperative questions to be tackled as a future need, displaying an urgent problematic.

The unquestionable role of *technê* in transforming the world, also opens room to acknowledge continuities. These being on making, or of expected biased perspectives. The quest for the next industrial disruptive revolution, is one of those. The assumption that the impact of *technê* does not benefit from humanistic critique, is contradictory. This is one of the final contributions this thesis aims to make. Technological (control), this is, directed for agape (common good) cannot be achieved by technology only, but through *techne.* This being by the contributions and collaboration with the Humanities and Arts.

Current thesis discussed contemporary disciplinary division under the light of *technê* as described in ancient Greece. *Technê* reactivates the vital relation between art and science. Thus analyzing current work scope through *technê* contextualizes the empiricist route taken in research. Considering science and art as *technai* helps to reveal a relation that is in fact inherent when designing in contemporaneity. The ancient insight presents the vivid link between art and science as somehow omnipresent, but also one that reintegrates making connected to creation of knowledge.

6.4.1 Tackling wicked problems by "research through technê"

Wicked problems, as defined by Horst Rittel, situates the feeling that was initially a driving motivation. This means, asking big questions that are usually avoided by its magnitude and complexity. The expectation is not that wicked problems could be solved, but somehow, should not be avoided, despite their complexity. The realistic expectation is that these problems might be tamable.

Academic culture that is commonly focused in specialization and networks has addressed interdisciplinary research under severe derision. Therefore, the initial problem was to tackle this expected resistance. One of the most common arguments presented against is that results are disconnected and not belonging to any field of research – this lack of definition is a particular factor of concern. The historical theoretical approach taken on this thesis, discusses the particular perception on these divisions as real, and contextually relevant. But, also presents that these differentiations are human artifices, and often tend to create disputes and the emergence of power struggles. In fact, creating continuous victims, ostracism, instead of invention, creativity aiming for common good or cumulative knowledge. All these behaviors are documented and discussed typically within the Humanities. Thus, these negative (side) effects, are proposed to be interpreted as symptoms of the disciplinary division, and misunderstandings that can, and must be, potentially anticipated and resolved. This was done by relying in methodologies that have discussed this issue. In particular Sanders, Ashley Hall, Laurel, Steen and Fallman.

However, at the beginning of this inquiry, the overall interdisciplinary objectives, prospected a possible tragic ending. This is, to expect undisciplinary chaos. Instead, the approach was based in anticipating these results pursuing a continuous disciplinary **dialogue.**

Results were, firstly, demonstrating a practical methodology that can, and should be reproduced, copied, and secondly, successfully building a functioning prototype – responding to the research questions that had initially been proposed. Results are, therefore, a particular micro-cosmos – as a specific answer to the opposing chaos that interdisciplinary can easily entice. Ultimately, the research outcome can be presented as a system that can, and should be, applied to other contexts in case of interest. The replication in other cultural contexts is recommended.

Moreover, current research tackled the future of design challenged by combining nanotechnology (as high tech material explorations) with design traditions. As an applied science field of research, nanotech presents a myriad of possibilities, and in fact makes, the so called, "technology push": materials waiting for a problem to solve (Addington & Schodek, 2004).

Nanotechnology as *technê* proposed new takes on design, expanding, if not totally disrupting traditional methods defended inside design as a discipline. Nanotech is in fact a disruptive step in the "culture" of materiality, revealing new perspectives on interactivity and design. For instance, powerful outcomes arise from bottom-up, instead of the typical top-down approaches. However, turning these new materials into content, that is, making them become meaningful experiences at a human scale, oblige to invest their designed "functions" with culture. This is one of the problems focusing in smart memory alloys that present research tackled with. But it is also an identified opportunity to include innovative solutions into design practice.

Interdisciplinary research is about dealing with gaps, between disciplines, categories, social perspectives, people, etc. Tackling gaps, having a new invention as a synthetic answer is a demonstration of this possibility.

6.4.2 Hybridization as innovation

The quest for inter-disciplinarity was guided by what design better contributes into the world: skill (*technê*). The undertone was to apply common design skills progressively transitioning to the ubiquitous computing realm. For instance, the appreciation of the qualities of other disciplines from the Humanities, as is the case of having a philosophical criti, was helpful to ground an apparent unease research context. However, the best manifestation of design traditions in the world, is the body of knowledge based in making. Shaping projects by building, creating visibilities, and demonstrating ideas. Thus, practicing as research, and creation of knowledge through making.

An unengaged mind-set helps consolidate experimental design research methods. In the present case, rooted in a combination of design and engineering traditions, both fundamentally practical. Playfulness, program-less, as well as a suspension of judgment to research approach, in practical sense, made possible to have imagination leaps, projections and intuitions to become real. Research started with addressing engineering, contacting directly with materials and purposes without a previous project idea in mind.

From the experimental approach, several projects came to light. These were materialized in Paperbot, Supermirror, Responsive Tile, CitySkin. These experiences, not only pushed forward development of new specific skills sets, but created new knowledge, by answering to particular questions. These projects gathered progressive information to solve a bigger quest.

The advantage of using a hybrid practice as research method, was firstly, to demonstrate the continuity of the use of traditional design methods, but under a new mindset, resituate their relevance in the transient technological moment. This meaning, either by gaining new preeminent skill sets (knowledge), as to the contextualize *Zeitgeist* requests with ease – but disregarding how the discipline "is" defined.

The materialization of projects with particular inquiry in mind offer room to be followed through, latter, independently. As such, these projects could be thought as constellations of related objects (extended skins). As discussed, this method of practical inquiry, was designated as **step-by-step projects** and are an adaptation of the scientific method to design.

The synthesis of information consolidates a final highly speculative project proposal. However, the stream of data, offer grounds and support from previous findings. These methods of discovery, inspired by the scientific method, are typically foreign to design. Thus, this final research proposal demonstrates a process of transition between art and science. In sum, results from the combination of learned skills, namely the step-by-step projects outcomes, as first attempts, and sometimes detections of failures and error.

Collaboration is a necessity. Linking knowledge either coming from a high and the low-tech background. Building projects together is an excellent way to get to know new skills. This is, the experience of the other/skill, helps to build an embodied knowledge – and empathy. The idea of contamination between people, ideas, prevails as a problem solver. Thus, the end of the author/designer becomes also a truthful outcome. The question on who is the center, the central discipline, or the author, does not apply with so greater need, as the expert mindset is dissolved in a more horizontal and participatory practices. The designer is in this case a facilitator.

Finally, this research outcome, demonstrated a solution that does not privilege ideas over matter. In fact, the creation of concepts and projects, arrives from a suspension of judgment, and assumptions (idea of a project), and rises from inspiration taken from engaging directly with the often, and unease foreign knowledge. Hybridization comes forward, once again, as a producer of new combinations and novelty within the *zeitgeist*.

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