



Chair:
Prof. Lucia Rosa Elena Rampino

DOCTORAL PROGRAM IN DESIGN

Field of study

The Politecnico di Milano established a PhD programme in the field of design already in 1990. Based on this tradition, the current PhD programme in Design was established in 2008, resulting from a substantial review of how design was researched at a doctoral level.

The overall aim of the PhD programme in Design is to develop skills to carry out high quality research, reflecting on the overall nature of design, with its aesthetic, performance and meaning values as well as its capability of being an agent of social change.

The PhD programme in Design deals with various research strands, each of them carried out by a given research team within the Department of Design. All the teams cluster around three Sections:

- Design and Cultures
- Products, Strategies and Services
- Design for Environments, Landscape and Mobility

The programme aims at educating researchers who will contribute original knowledge to the field of design as an established academic field by tackling the problems and identifying the potential of contemporary society. Their contribution may be brought to bear in:

- creating designs, visions, and proposals (research through design);
- developing tools and methods for putting these into practice (research for design);
- developing critical analysis of design and its application domain (research on design).

The Programme develops project and analytical abilities, proposes different methodologies of research, promotes the attitude to collaborate, and offers working opportunities in universities and research centres, design enterprises and public corporate bodies.

Mission and goals

The programme develops design skills and analytical abilities, proposes various research methodologies and promotes a collaborative disposition.

The main academic field is Design. Other academic fields partially covered are: Philosophy; Language Theory; Sociology of Cultural Processes; History of Art; Science and Technology of Materials; Industrial Engineering.

The achievement of the PhD qualification in Design requires a study and research activity equivalent to at least three years of full-time study. During this period, both educational and research activities are provided.

At the beginning of the programme, candidates become effective members of a research team, within which they develop an original research topic: this activity is the core of the learning process. Parallel to this, candidates are involved in training and specialist activities. Moreover, the activities of the PhD in Design include participation in conferences (as listeners or speakers) and writing of research papers and/or journal articles.

The programme offers doctoral candidates the following opportunities:

- to develop an original theme of research, becoming an effective member of a research team;
- to attend courses and seminars on design research and on research in general, developing skills concerning the discipline of design and the profession of the researcher;
- to attend courses and seminars referred to a specific field of research, developing high-level specialist skills and acquiring knowledge and tools for the development of their own research;
- to develop the ability to clearly and effectively present the contents of their own work;
- to spend a period abroad as visiting researcher in a research centre to verify the assumptions, the methodologies and the results of their doctoral work.

Qualifications

The PhD program in Design intends to educate a flexible figure: a designer who knows how to carry out research and a researcher who uses design tools. At the same time, she is also an expert in knowledge management, in constructive interaction among different actors and in the sharing of ideas and proposals.

The combination of these skills is useful in a variety of work environments. Specifically: in institutions expressly dedicated to the development of design research, such as universities and research centres; in design agencies and in design-oriented companies; in public corporate bodies and in organizations for territorial development which, increasingly, are faced with complex problems, which the designer-researcher can effectively address, analyse and contribute to resolve.

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A STUDY OF THE WATERMARKS IN LEONARDO DA VINCI'S MANUSCRIPTS AND DRAWINGS

A DESIGN-BASED INQUIRY INTO THE WATERMARKS IN THE CODEX ATLANTICUS

Claudio Cali – Supervisor: Prof. Pietro Cesare Marani

The thesis draws attention to a crucial issue that has been largely neglected in the literature: the relationship between the paper watermark and the manuscripts of Leonardo da Vinci. Since the 13th century, the paper has played the role of the leading information medium in Europe. Over the centuries, it has been possible to transmit collective memory on it, passing on notes, thoughts, dissertations and research. Since then, alongside the immediately identifiable data fixed by the ink, the oldest papers have retained the precious detail of the watermark between their fibres. The watermark was an inseparable element of ancient paper. It formed a figurative pattern on the sheet during the papermaking process. Visible in transparency, this *signum* represented the identifier mark of the original paper mill and, in this sense, was an innovative *ante litteram* design product. This “logo” was conceived and introduced in Fabriano (Italy) at the end of the 13th century and quickly became papermaker’s “signature”, the certificate of the sheet, and an indicator of the quality of the finest papers. If the paper was already widespread in the Mediterranean area during the 12th century, the watermarked paper began to settle in Europe permanently from the 14th century onwards.

The watermark, however, has not lost its usefulness even in recent times. It has always proved to be a valuable and alternative resource among the possible methods of dating a paper document, which

is why “filigranology” is considered one of the auxiliary disciplines of history. This discipline elected as its founding father the Genevan historian Charles Moise Briquet, who, in his “dictionary” of 1907, collected a total of 16,112 watermarks from between 1282 and 1600. The value of watermarks as an auxiliary tool for dating ancient documents is still too little used, with schools of thought active about its actual application, and this also depends on the amount of data available to the community. In this sense, the international institutes and museums that hold the main watermarked-paper collections have safeguarded their material heritage to put it at the service of the community as a digital



Fig. 1
Caspar Luyken, after Jan Luyken
Papiermaker, 1694
Etching on paper 80 x 141mm
Amsterdam, Rijksmuseum, inv.
RP-P-0B-44.516.
Note: Detail of the folio.

encyclopaedia. In literature, there are significant examples of the use of watermarks in art history, especially when there is a need for additional information, for a comparison between documents whose location and dating are in doubt. In this sense, notable contributions are the studies conducted on Italian maps from 1540 to 1600, Rembrandt’s prints, and drawings by Mantegna and Michelangelo.

On the other hand, studies on watermarks concerning Leonardo da Vinci’s manuscripts and drawings are still too marginal and carried out with discontinuous and heterogeneous methodologies and levels of technical investigation. Moreover, the scientific dissemination of these topics is very limited.

This “black box area” in Leonardo’s domain is somewhat surprising, despite the power of new ICT technologies and the widespread democratisation of knowledge. Therefore, the researcher worked to develop a model for the digital extraction of watermarks in standardised terms and to define a protocol for cataloguing the physical data of papers with or without watermarks. The design-based method involved designing and sampling the model with real-world applications, with tests on sheets of the *Codex Atlanticus* in Milan and drawings in the *Royal Collection* at Windsor Castle.

Four parts structure the work. Part 1 offers a historical survey of the origins of paper, its various uses, types



Fig. 2
Leonardo da Vinci,
De trasmutazioni de le superfizie [Studi geometrici, verso il margine destro profilo di testa di vecchio con barba], ca. 1517-1518, Pen and ink on paper.
Watermark (cut) on the left edge of the sheet (recto). Watermark motif: “six-point toothed water wheel, letters “IM” (?) and crown”, close to Briquet no. 13565. 265 x 185 mm
Milan, Veneranda Biblioteca Ambrosiana
Codex Atlanticus, f. 660r (ex 242r-b) © Veneranda Biblioteca Ambrosiana / Mondadori portfolio

of production, dimensions, mould data and relevance. Part 2 has two main sections. The first analyses the primary printed and digital editions of Leonardo’s drawings and manuscripts. It highlights the manifold and fragmentary ways in which

watermarks appear in secondary sources. The second section examines a wide range of existing online archives part of the *Bernstein – Memory of Paper’s Consortium*. Part 3 presents a new method for recording the physical properties of hand-made paper and, in particular, watermarks. The method is entirely digital. It consists of photographing with a high-resolution digital camera an illuminated watermark from the back (transmitted light) and the drawing of vectors for digital retracing of the watermark to scale. A sample



Fig. 3
Watermark motif: “six-point toothed water wheel, letters “IM” (?) and crown”, close to Briquet no. 13565. – Milan, Veneranda Biblioteca Ambrosiana – Codex Atlanticus, f. 660r (ex 242r-b) © Veneranda Biblioteca Ambrosiana
Note: Detail of the watermark. Image in mixed light created by the author.

of 24 sheets of the *Codex Atlanticus* (the manuscript held in Veneranda Biblioteca Ambrosiana of Milan) was newly photographed, stored and analysed using this method. Three graphs were produced: images in natural light (diffuse light); images in transmitted light; vector diagram. The method is a clear indication of the power of technology to explore and disseminate the content rather than to replace the original. A significant number of new watermarks (and fragments) were recorded and catalogued from this initial sample of sheets, and some now-separated sheets were convincingly reconstructed. Part 4 highlights collaborations, results and future developments.

The research results define theoretical and practical guidelines to set a protocol for the acquisition, cataloguing and digital enhancement of the watermarks in Leonardo da Vinci’s paper collections but in a broader sense also valid for all paper documents made on laid and watermarked paper from 1200 to 1600. The research is actively supporting the development of an Online Archive of Leonardo’s manuscripts and drawings conceived by the Museo Galileo of Florence, particularly in the definition of the contents and the cataloguing system of the section’s data dedicated to the information on the sheets. In parallel, developing a watermark taxonomy system applicable to each collection is underway.

COLOUR DESIGN TRAINING ITINERARY: A FRAMEWORK FOR THE TEACHING AND LEARNING OF COLOUR IN DESIGN DISCIPLINE

Ingrid Calvo Ivanovic – Supervisor: Prof. Silvia D. Ferraris

Colour is an essential element of design, and, at the same time, it is one of the most complex. The knowledge of colour comes from a multiplicity of disciplines: e.g. from physics, in its immaterial interplay with light and space; from chemistry, concerning the material substance of colourants and pigments; from psychology, when conceived as a symbolic language and capable of producing different effects and affects in the human being; from arts and aesthetics, when considered an aspect of beauty, harmony and visual pleasure; among many others. This field of knowledge has been called for centuries with the name of *'colour theory'*, when in fact it consists of much more than only theoretical postulates: much of what we know about colour today is due to the practical and applied work of artists, colourists, architects and designers, and corresponds in reality to fundamental empirical knowledge without which would be impossible to understand the chromatic phenomenon completely. Therefore, more and more colour researchers are becoming aware of the need to consider the study of colour as a discipline in its own right and have proposed to call it *'colour science'*, where science can be understood as *'knowledge arranged in an orderly manner, especially knowledge obtained by observation and testing of facts'*. From this perspective, the word science, far from removing colour from a creative perspective or from putting it in the opposite pole to the arts, aims to integrate all disciplines that study it: the scientific areas

related to its vision and perception; the aesthetic fields in which it is used creatively for its selection, combination and communication, the commercial aspects of the products and productive sectors in which it is applied, and the technical considerations for its reproduction as well as the regulations and tools that allow it to be managed and codified, just to name a few.

Away from the more complex aspects of colour science, the visual experience of colour is omnipresent in our daily lives. Many of our decisions every day are based on colour choices, which are often unconscious: from crossing a street guided by the traffic lights to the final step to buy a product once we have explored its features. Colour is so present in people's lives that it is often taken for granted. We notice colour only when we see something that catches our attention, that generates visual pleasure or dissonance in the natural or human-made environment surrounding us, or when an object or product becomes iconic through an original, usually intense, chromatic palette. However, despite the impossibility of conceiving a colourless world, the discussion about colour has been historically minimised within the aesthetic disciplines to only some relevant treatises. On numerous occasions, the reflection on design and design thinking, criticism, and disciplinary research has avoided naming colour as a fundamental element in planning the built world. Furthermore, there is an even greater silence in the

subject of colour teaching in design, architecture and art, despite the relevance of visual skills in the roam of these disciplines.

During the last 30 years, studies about the inclusion of colour in aesthetic and project-based education have evidenced a critical panorama: there is a lack of proper training of this subject at all educational levels –primary, secondary and higher education–. Additionally, scholars have highlighted a great need to provide colour training resources to teachers and, consequently, learning tools to students. In the context of higher education, the lack of regard for colour has been recognized as current international malpractice in design, architecture and art schools. Studies revealed that less than 40% of design schools include colour education in their programs. Within them, colour is sometimes offered as an elective or short course, the choice of which is left to the students' discretion. Other times, colour is taught even less, in a few lessons inside another course, usually basic design courses. However, technical or advanced colour knowledge is rarely meaningfully integrated. In both cases, the dedication of hours to colour training is insufficient. The issue becomes critical when we consider that those colour lessons are probably the only instances that students will have to learn colour within their degree. Evidently, the remaining 60% of schools leave colour straight out of their curricular planning.

However, the invisibility of colour within the design academy is not always reflected in the professional practice of the discipline, nor even within the research community. In recent years, there has been a growing tendency to consider practices related to the application of colour in design, encompassed under *'colour design'*, as an emerging subfield of the discipline. Following industry requirements, some designers have begun to specialise in this field of work and have started to call themselves *'colour designers'*. This figure is still incipient, and its field of action within the discipline of design is not yet widely recognised, and as a consequence, it has not yet been sufficiently institutionalised within schools or training institutions, resulting in a lack of educational instances to train *colour designers*.

With all of the above, the main purpose of this research was to evaluate the key elements that should be considered in a colour literacy for current design education needs within higher institutions, and to propose an educational framework that may support the teaching and learning of colour in the design discipline. In the search of a guiding thread for the instructional design of the educational project, the research relies in the didactic approach called constructive alignment developed by J. Biggs, which represents a convergence between a constructivist understanding of the nature of learning and an aligned planning of teaching activities. Constructive alignment provides pedagogical basis

for a student-centred innovation in design education, able to easily dialogue with design-based learning (DBL) for different design education needs.

The main contribution of the research will be then the *Colour Design Training Itinerary* (CDTI), a complete educational framework that defines different levels of action for the improvement of the teaching and learning of colour in the design discipline. Moreover, the CDTI provides the basis for curriculum structuration of colour design as a subfield of design discipline. The CDTI was developed from the alignment of the different elements that shape the educational itinerary: (i) the definition of specific training paths for different design education needs; (ii) the proposal of guidelines for defining intended learning outcomes; (iii) the modulation of relevant colour contents for design discipline; (iv) the description of teaching and learning activities concerning colour from a DBL perspective with examples; (v) guidelines for the creation of assessment strategies to evaluate students' learning, and (vi) bibliographic and complementary materials for design teachers and curriculum planners. The CDTI was built through consultation, involvement and collaboration with colour teachers from different countries and backgrounds. Also, the CDTI is intended to be useful for different pedagogical contexts, considering resources for in presence teaching, blended-learning and

online-autonomous learning. To support the CDTI implementation and dissemination for broad contexts and needs, two research artefacts were developed, an *Open Educational Resources Repository* (OER) in the shape of a website, and an *Archive of Teaching and Learning Activities*.

DESIGN CAPABILITIES AND ENTREPRENEURIAL ECOSYSTEMS. INVESTIGATING DESIGN UNDER AN ADAPTIVE LOGIC OF COMPETITION FOR DEVELOPING NEW PRODUCTS IN MANUFACTURING.

Caterina Dastoli – Supervisor: Prof. Barbara Del Curto – Co-supervisor Prof. Cabirio Cautela

This thesis started from the premise that the employment of design capabilities for developing new products through system-level entrepreneurial knowledge engagement is limited in manufacturing companies. Despite the recent emphasis on adopting the entrepreneurial ecosystems (EEs) approach for new product development (NPD), manufacturing companies primarily invest in design capabilities as a strategic resource to inform vertical product-oriented strategies at the firm level. Described as able to access and synthesize dispersed knowledge and to reframe it into final competitive solutions, design capabilities currently lack a proper definition of their impacts when the company requires to enter a complex network of entrepreneurial relationships by engaging with system-level entrepreneurial knowledge under an organizational perspective.

In the pursuit of bridging this gap, the research develops a comprehensive matrix that reports and compares different design capabilities impacts when design capabilities are employed over the EEs' necessary phases of NPD, namely sensing, seizing, and reconfiguring, by engaging with a multi-actor entrepreneurial interface. The matrix derived from empirical investigations and was intended to support manufacturing companies to (1) making decisions about the kind of design capabilities to invest in when NPD projects aim to follow a

system-oriented approach, (2) being aware of the organizational phases of NPD in which design capabilities can provide an impact when system-level entrepreneurial knowledge is engaged, (3) being aware of design capabilities impacts for accessing and strengthening system-level entrepreneurial knowledge for NPD.

This research intends to contribute to new knowledge in the field under a theoretical lens by:

- Defining design capabilities and their impacts when a different meaning of co-creation drives NPD

When co-creation is intended as “the enactment of creation through interaction” rather than “any act of collective creativity”, design capabilities intervene under open innovation forms of co-creation. In the context of EEs, this means that knowledge access and strength goals rather than the acknowledged goals defining co-design processes drive design activities for NPD. This shift in the meaning of co-creation led to the identification of design capabilities that ontologically simplify complexity (capabilities that rely on engaging entrepreneurial knowledge through codification and synthesis) as the ones that showed a wider and general pattern intervention in satisfying entrepreneurial capabilities finalities for NPD.

- Expanding the discussion on design capabilities for NPD in manufacturing when the organizational level

of entrepreneurial knowledge engagement is considered. Manufacturing companies traditionally adopt a vertical approach of technical and market knowledge engagement that informs firm-level strategies and practices for superior product development. Consequently, design capabilities are highly specialized in satisfying companies' consumer-centered approaches by engaging with knowledge in the systems for informing companies' new product directions. However, as several challenges in developing superior products that satisfy consumers' needs in the Twenty-first century are highlighted in the literature, manufacturing companies often lack organizational knowledge about the entrepreneurial process of NPD. Nevertheless, the literature review did not report classifications of design capabilities for NPD in manufacturing that emphasize the strategic role of design capabilities under an organizational perspective of entrepreneurial knowledge engagement. Specifically, when the design literature links design to open innovation, design capabilities cover a role in task partitioning once a central authority defines a priori the technical and market knowledge needed for NPD. This research adopts the definition of EEs as complex adaptive systems. Consequently, the property of self-organization requires design capabilities to intervene in a complex and not predetermined network of relationships for NPD. The conducted

investigations showed how design capabilities might be classified and employed in adaptive contexts for NPD.

- Providing an empirical work that defines design capabilities impacts under the sensing, seizing, and reconfiguring dimensions for NPD in manufacturing

Although several authors in the design literature recently reported design capabilities impacts in sensing, seizing, and reconfiguring, they do not refer to empirical findings in situated contexts but focus on their theoretical conceptualization. This research has been built within the situated context of packaging manufacturing for the food industry ecosystem, and provides a contribution to the topic by showing how design capabilities due to their ontologies nurture the finalities of entrepreneurial capabilities for NPD. Moreover, this research is unique in the way it expands the topic under the EEs perspective, thus opening a new investigation space for studying design capabilities as dynamic when a multi-actor interface of entrepreneurial knowledge drives NPD.

Two practical contributions mainly supported the theoretical contributions:

- An engagement-driven taxonomy of design capabilities informed by open innovation theory

The research developed a design capabilities taxonomy that could enable the investigation of the

relationship between design capabilities and EEs. Although design capabilities traditionally deal with heterogeneous knowledge participation when employed for NPD, the finalities by which they are classified reflect a product-centered rather than a system-centered orientation of engagement. Consequently, a new taxonomy that classified design capabilities under ontological engagement dimensions was developed by integrating design and open innovation knowledge about the classes of action that enable system-level engagement, namely simplifying complexity and *driving action*. Specifically, *simplifying complexity* capabilities relied on engaging knowledge through codification and synthesis, while *driving action* capabilities relied on engaging knowledge through experiential learning. This allowed for investigating which design capabilities could serve the entrepreneurial capabilities aims and goals for NPD in EEs.

- A framework that creates an analytical and interpretative space by visually displaying capabilities belonging to two different domains: design and EEs

The research developed a framework that visually supported analytical and interpretative activities of the investigations results. Specifically, the logic behind the framework structure is to display an open and visual space of analysis that derives

from the clustering of design and entrepreneurial capabilities and related dimensions over a vertical and a horizontal axes. Each design capability ontology can potentially intersect with all the entrepreneurial capabilities finalities, and intersections nodes indicate this possibility within the investigation space. Although the investigation of the relationship between design capabilities and EEs reported informative findings that can potentially support further research, the study's main limitation is the unintentionality of developing the examined projects under an EEs perspective. Although the projects reported characteristics that enabled the investigations, their selection was made based on opportunities presented to the researcher over the doctoral path. Collaborating in research with researchers that currently investigate NPD projects intended to serve an adaptive logic of competition might have led to the interpretation of a more informed set of data. Nevertheless, this research represents a novel touchpoint between the design and the EEs communities when investigating the relationship between design capabilities and EEs for NPD in manufacturing.

RESEARCH THROUGH VISUALIZATION IN LITERARY CRITICISM ADAPTATIONS OF VISUALIZATION TO SCHOLARS' INTERPRETIVE WORK

Tommaso Elli – Supervisor: Prof. Paolo Ciuccarelli

This thesis describes the results of a multi-year experience conducted in contact with data visualization and literary criticism. The work has been carried out in the area of inquiry that is commonly defined as Digital Humanities, in which disciplines of the humanities meet digital technologies. Encounters of this kind are often characterized by the experimentation of new capabilities of technologies and employ humanities as a testing ground. In this case, however, the goal was different.

This work is inspired by critical and ethical viewpoints on technology that are concerned with the suspension of common habits and the reversion of power relationships. Similar stances are located at the intersection between information design, HCI, feminism, and activism. In relation to humanities, critical stances about technologies question authoritative roles and investigate the influence that humanities tenets may have, in turn, on digital tools. Instead of focusing on how much the humanities could benefit from digital solutions, as more and more often it happens, this research wonders about how we can differently design approaches to algorithms, computation, and interfaces to benefit research communities of different disciplines. Along the journey of this research, data and visualization were observed from two perspectives. On the one hand there is the mechanistic and positivistic stance, inherited from natural sciences, that prioritizes the functioning of technologies and that inherits an approach to knowledge

that is objective and observant independent. On the other hand, there is the constructivist approach of hermeneutics, that acknowledges all knowledge as situated, partial and observant dependent. With visualization spreading across so many different fields, this dichotomy becomes more observable and the pursuit for a balance between the two philosophies vigorously emerges. The design work underneath this research developed new methodologies to help scholars in the formulation of critical thinking and, while doing it, it understood the external discipline and identified principles useful to design for it. Research communities are still in an active phase of experimentation and a design reflection may be capable of providing interesting angles on the matter, because characterized by a fluency in technologies that coexists with a non-scientific nature. Design is capable of embracing, balancing, and valorizing ambiguities and contradictory standpoints. It does it through the iterative advancement of prototypes, specifically realized to inquire and reflect over problematic situations, the so-called wicked problems; the setting of this research is therefore fundamentally practice-led. In addition, it is also cooperative. It developed within the context of a research project named "Atlante Calvino: literature and visualization" that brought together communication designers and literary scholars. The goal of the project is to contribute to the current need of renovation of literary studies by creating

opportunities to experiment with non-textual representations, data collections and visual analysis. The research experience was so broad that it is possible to discuss it from many different angles: literary criticism, web technologies, project management and more. The project was taken as an opportunity to immerse in an intense and prolonged participatory observation in which to become familiar with a specific humanistic discipline, the contemporary literary criticism of Italian literature, and identify meaningful aspects to be inquired and disclosed. In particular, the research observes how visualization behaves when employed in a terrain that is different from the positivist ground in which it supposedly evolved. In chapter *Visualization and Literature*, I present a review of the literature that takes into consideration the modern evolution of humanistic disciplines and the critical reflections that emerge from computational manipulation performed to extract data that get eventually visualized. I start by prospecting the transformations of the workflow of scholars, describing the cultural clash between supporters of traditional methods and DH enthusiast, the loss of exclusivity of the textual medium, and the necessary adoption of a project-based collaborative work modality. Subsequently I review theories about empiricism applied to literature that comes under the guise of *distant reading*, the most influential approach with which my research confronted. In parallel I report critical stances referred to it, that comment

on the pros and cons of the approach and on the incompatibility between literature and data. The second-last section encompasses criticism about the use of data and visualization, making the review of theories related to modelling, manipulative inquiries, and constructivist approaches to knowledge. In conclusion I reflect on the role of evaluation of visualization as a form of research in digital humanities, and its intertwining with the design process. In chapter *Synergies between Design and Humanities*, I state my research goals and the methods used to address them. Goals are oriented towards an increased understanding about how visualization could be conceived to better comply with humanistic tenets. Firstly, I describe the aspects that render the discipline of design a good co-operator in tackling the problem. As I will explain, these aspects entail the embracement of tenets (situatedness, ambiguity and singularity) that are important to all hermeneutical disciplines. Then, I expose the specific research questions, related to the achievement of an actionable knowledge about the discipline of literary criticism and of guiding principles useful to design for it. The knowledge contribution is achieved with the application of action design research to the field of visualization. The dissertation then describes *Atlante Calvino*, a digital humanities project aimed at bringing together data visualization and literary studies on the exemplary case of Italo Calvino, one of the most well-known Italian

writers. The research is bound to the project but at the same time it fought to separate from it, striving to identify a clearly separate knowledge contribution. In *Criticism of Contemporary Literature*, I report the insights gained on literary criticism that emerged from the long and energy consuming project, formalized by using a structured interview. The chapter depicts, from the viewpoint of a designer, the interests, and workflows of scholars along with several considerations about their research culture. Interview also encompassed the relevance of Italo Calvino and scholars' opinions about the use of visualization in their work. After it, I prospect the reflections on the outcomes of action design research, formulated into four principles for designing visualization for literary criticism. Such principles take into consideration the importance of creating situated viewpoints into visualizations, the handling of elusive concepts that characterize Criticism, the use of visual overview as a companion that values traditional scholars' methodologies, and the significance of visual manipulation. Lastly, I reflected on the methodological imprinting of the work, and I proposed the framework of Research through Visualization, as a declination of Research through Design; RtV is centered on visualization and can be a means to inquire the epistemology of disciplines with whom design is collaborating.

THE DESIGN OF DATA SONIFICATION. DESIGN PROCESSES, PROTOCOLS AND TOOLS GROUNDED IN ANOMALY DETECTION

Sara Lenzi – Supervisor: Prof. Paolo Ciuccarelli – Co-Supervisor: Prof. Michele Mauri, Prof. Juan Sádaba

Data sonification is the use of sound to represent and communicate data. It is a field that emerged almost three decades ago, and today, in an increasingly data-intense society, it is gaining momentum as an alternative or complement to the visualization of data. Nonetheless, a series of unresolved issues are still preventing sonification's full transition from a niche practice for the analysis of scientific data to a widely adopted medium that could impact the way we make sense of complex phenomena (Vickers and Barrass 2011; Barrass 2012; Nees 2019). The lack of widely adopted design tools, experimental protocols and shared processes for the design of sonifications, are among the most cited obstacles. As a structured discipline that is used to tackle complex, real-world problems, can design provide the necessary means for data sonification to expand its reach and emerge as a valid alternative for building and shaping our relationship with data?

In this work, I attempt to answer this overarching question in two ways. Through a theoretical investigation, I will first inquire into other sound design practices and their contribution in terms of processes, tools and evaluation protocols; by looking at recent cases, I will later explore the role of intentionality as a pre-requisite for a designerly approach to data sonification. To contextualize intentionality – i.e., deliberate decisions taken to address specific needs, with a purpose and in a given context – I will also engage authors of recent sonifications in a conversation where

their approach to sonification will emerge through their projects. From these conversations, I will chart a data sonification space map which is condensed into decisional blocks to form the basis for a data sonification canvas. The canvas, which I intend as a tool to support communication designers in the use of data sonification, will be validated through two series of workshops to provide the first tangible results from this work.

Two design actions form the basis of the practical part and ground the theoretical investigation in data sonification applied to real-world cases: the detection of anomalies caused by cyber-attacks on digital and digital-physical networks. The two actions involved the design of a series of prototypes through a purposely defined experimental protocol in which expert users were engaged in quantitative and qualitative research in a real-world setting. The definition of a structured design process and the experimental protocol which emerged from these design actions represent the two main results of this work. Lastly, this work contributes to the corpus of experimental evidence on the potentialities of data sonification as a valid solution for the real-time monitoring of anomalies. In particular, the prototype designed for the second design action is now a fully functioning anomaly-detection tool for which development is ongoing.

This work proposes a designerly approach to data sonification which aims to increase the role of sound as a sensory modality for making

sense of an increasingly complex world through: a proposal for a structured design process and an experimental protocol – both of which are grounded in sonification for anomaly detection; the definition of a sonification design canvas as a tool to guide designers in the integration of sound as a data representation modality; the development of specific experimentally validated tools that use sonification to support experts in monitoring anomalies in real-world contexts.

INSTAGRAM AS AN EDUCATIONAL TOOL TO SUPPORT DESIGN EDUCATION. VISUAL DIGITAL PLATFORMS AS ACTIVATORS OF EDUCATIONAL ACTIONS, METHODS AND TOOLS TO SUPPORT FASHION DESIGN EDUCATION.

Vittorio Linfante – Supervisor: Prof. Valeria M. Iannilli

The research explores the topic of didactic innovation and the relationship between social media and education within the design studios, focusing mainly on those related to fashion education. The research began based on some considerations arising from personal teaching experience – which is a pandemic period that has seen a necessary acceleration from the point of view of the use of technologies and digital – from personal work experience developed within fashion industries and, finally, from the observation of the increasing “mediatisation” of fashion, which has defined not only new forms of communication but also, and above all, new ways of creative sharing, implementing the “visual” approach to design. New communication models are emerging, changing the culture, the way companies and consumers relate to each other, and their tools. The mediatisation of fashion, thanks to the ever-increasing pervasiveness of digital communication, has made possible not only greater sharing of images, products and events but has generated a spontaneous sharing of the various creative and design phases, which potentially become a teaching resource of considerable value. If, on the one hand, Instagram allows targeted and user-governed searches, on the other, it also defines a form of digital ‘serendipity’ through the constant reception of stimuli and feeds generated by algorithms. In a context of continuous technological, social and cultural changes, the designer’s training

becomes an exciting field of experimentation to implement the use of technologies, but above all to work on a renewal of the contents provided in educational pathways, as well as the approaches, tools and channels used to provide training and education to the new generations that are demanding greater flexibility in the places, methods and times of learning. Communicating to teach and to learn is an activity inherent to human beings, to the way we “are” in the world; communication is the anthropological mark of teaching and, therefore, teaching interaction is always, whatever the contingent specificities and the technical equipment, a relationship mediated by communication. Communication becomes both the means of teaching and the end of learning. The specifics of didactic communication revolve mainly around the message and, specifically, the language codes: the pedagogical gap. Therefore, the different level of linguistic competence that separates the teacher from the learner and the specificity of didactics lies in the ability to propose, encourage and manage this asymmetric interaction. Educational communication represents a particular case of human communication, characterised by two processes, teaching and learning, and generally asymmetrical and intentional. This process can be considered an open system in which each subject is an interacting member and in which the quality of the interaction conditions the results.

Since didactics deals with teaching in its connections with learning, one of its primary tasks should be to identify the conditions that can favour effective communication to help build the most suitable conditions for minimising the difference between the meaning attributed to the message by the teacher and that perceived by the student. To achieve correct and effective communication, it becomes fundamental to consider the “multi-dimensional” character of communication; it’s a complex process that implies numerous other factors alongside linguistic factors. If teachers can propose contents that find significant links in the students’ cognitive structures and if the methodology adopted determines an active involvement of the students, it is possible to shape an effective didactic and pedagogical action. Communicating and connecting with peers and teachers through technologies became a crucial aspect to consider supporting the educational process, creating knowledge, and acquiring skills. Students use technology to collaborate; thus, they are more prone to participate and feel more comfortable in a technology-driven environment. Current students are immersed in a rich, technology-enhanced life and learning environment and select appropriate technologies for their personal and learning needs. When used appropriately, enable new ways of teaching and learning rather than allow teachers and students to do what they have done

before in a better way. The digital acceleration has stimulated the need to experiment with new educational methods. The evaluation of the role of social media as activators of virtuous and transmedia processes leads to the development of new forms of innovative didactics capable of fostering cooperation, exchange and integration processes. The project, therefore, deals with the relationship between design studio teaching and visual social media and involves experimenting with the use of Instagram as a channel to create a “social” form of the augmented classroom. Instagram is here being considered from different points of view, according to the potential offered by the different features – both as a platform for interaction and information sharing between teachers and students and between the students themselves, and as a channel to support the different design phases and last but not least as a creative stimulus. Although the origins of design education can be traced back to the creation of material objects, these requirements have evolved, not only as a result of the introduction of new materials, innovative tools, and production processes but also as a result of the ever-increasing interaction between diverse design scales and disciplines, between heterogeneous tools, physical artefacts, and digital technology. As Meyer and Norman state, the time has come for the design education community to emulate the revolutionary spirit of the early Bauhaus by adapting design pedagogy to the diverse approaches and objectives of twenty-first-century design. Digital technology enables an

interactive culture with knowledge, creativity, and information flows in this context. It can be viewed as a catalyst for developing new teaching and training options inside design schools. The arising digital flows introduce new modes of engagement and sharing, transforming students and teachers into both consumers and creators of content, thereby promoting a discipline, design, that is “blurred at the edges” and stimulating reflection on the possibilities (and criticalities) offered by the subject’s increasing complexity. While still useful and necessary, conventional design education must be “upgraded” by introducing and experimenting with new teaching techniques that instil in students an open-minded attitude to even the most complicated challenges. In this setting of societal changes and the inescapable omnipresence of social media and digital in general (greatly affected by the pandemic), the study project is conceived as a reflection on the untapped potential of several instruments currently in common usages, such as social media. Digital and social media platforms, particularly Instagram, are becoming a laboratory for ad hoc didactics to identify methods and processes capable of establishing a self-transcendent form of knowledge. Within this framework, Instagram seems to offer an opportunity not to be missed for implementing innovative hybrid and interdisciplinary learning models. A learning system related to different educational models, mediated by digital and aimed at managing those undefined solutions and problems that contemporary life throws up new challenges. A paradigmatic change

not only in the context of scientific research but also, above all, in the typicality of the individual experiential dimensions where the study of new pedagogical approaches and the renewal of the contents provided become essential actions. A new direction towards a flexible and open structure is also connected to bottom-up communication. Thanks to the web spread in extensive networks, social media and social networks highlight social and collaborative character. It is a dimension that recognises how educational, artistic, linguistic, and IT experiences are now metaphors and places for disseminating content and complex concepts. It is also a place that erases the space of the here and now by extending the places, methods, tools and times of learning. The research aims to identify and share a set of tools, principles and procedures to integrate social channels as didactic interfaces that enable design and creative processes to be included in the training programmes implemented in the design studio. The project presents some results of ongoing experimentation within fashion ad communication design courses on using a social platform, Instagram, as a channel to support teaching activities. Instagram, used as a highly visual medium, stimulated student learning and facilitated teaching through dialogue, engagement, and interaction. The project reflects on hybrid learning contexts as a possible future context for expanding experimentation in design education. Physical space, digital space, and time become components of a fluid creation of knowledge.

LEARNING AND TEACHING GLOBAL COOPERATION SKILLS IN CULTURALLY PLURAL DESIGN TEAMS: COLLABORATIVE LEARNING PRACTICES AND EXPERIENCES IN PLURAL CLASSES

Francesca Mattioli – Supervisor: Prof. Silvia D. Ferraris – Co-Supervisor: Prof. Stefano Crabu

As contemporary societies are increasingly culturally plural, global competence is widely acknowledged as one of the most relevant key competences for life-long learning. Globally competent individuals can examine local, global and intercultural issues, understand and appreciate different perspectives and worldviews, interact successfully and respectfully with others, take responsible action toward sustainability and collective well-being. Under many names that span from intercultural to democratic competence, this competence is gaining momentum since contemporary societies increasingly require individuals to interact effectively and collaborate in culturally plural groups. Formal education is identified as a crucial context to foster the development of this competence which can be enhanced through constructivist learning models such as problem-based and collaborative learning. In this scenario, higher design education traditionally relies on project-based learning in the situated collaborative context of the design studio. The combination of these two archetypical approaches is defined as design-based learning: an approach in which learners construct knowledge, skills, and abilities as they self-direct the process of creating futable solutions to real, open-ended and ill-defined design problems in a situated context that aims to recreate a dynamic of real-world interactions. Design-based learning provides an ideal social context for students to become aware

of cultures and skilful in collaborating with plural others. The subset of global competence called global cooperation skills, which correspond to knowledge and skills required to participate successfully with others on shared activities, tasks and ventures, is increasingly recognised as crucial for designers. Given this opportunity, there is a lack of comprehensive research that studied if and how students develop global cooperation skills throughout their path in design education. A knowledge gap exists about how design-based learning modules' instructional design could improve the learners' development of global cooperation skills. The doctoral research focused on design-based learning in plural design education to discover how these formative experiences foster global cooperation skills development. The research aims to help understand how teaching strategies could integrate these competences within the instructional design. The researcher explored students' collaborative experiences in plural design-based learning settings, identifying the elements that foster their global cooperation skills acquisition and an understanding of their perceptions of design education. The qualitative research has been undertaken through two parallel investigations that provide a deeper understanding of the phenomenon. The first investigation was based on the learning trajectories approach, which proposes to ground the design of instructions on qualitative understanding of students'

developmental progression toward competence. This investigation was conducted with students of the Master of European Design programme (MEDes), and the learning trajectories within this highly plural curriculum have been studied in-depth for a whole semester through questionnaires, diaries, and interviews. Data interpretation led to a descriptive global cooperation skills developmental model and three key assumptions to explain how collaborative projects in plural classes can support students' progression. The second investigation was based on the constructive alignment approach, which proposes to ground the design of instructions on the coherence between learning outcomes, activities and assessment. This investigation was conducted through critical participatory action research in which the researcher designed an instructional module to foster global cooperation skills in the context of the Design & Engineering Master (D&E) at Politecnico di Milano. The module was delivered throughout students' entire path in the master and concluded with data collection through two final focus groups, disclosing insights on authentic and contextualised instructional design implementation. These insights enrich the models developed, providing hands-on guidelines for design teachers to implement instructions in design-based learning. The research contributes to the discussion around global competence in the specific context of higher design education,

providing a descriptive model of competence development and prescriptive guidelines for teachers to coherently approach the design of instructions in design-based learning to guide students in developing global cooperation skills. Specifically, the MEDes investigation provided an extensive dataset of multi situated learning experiences to ground the descriptive developmental progression model. The D&E investigation confirmed that students live similar experiences in a plural situated context. It also emerged from both investigations that institutional culture has a significant role in shaping the learning experience in design-based learning. If, from one side, multi situated learning experiences support a more spontaneous development of global cooperation skills, on the other, situated learning experiences in design education benefit from institutional recognition and sensibility toward plural collaborations to foster effective progression toward competence. The research also allowed to identify the prescriptions about elements of design-based learning instructions that support students learning of global cooperation skills. MEDes investigation provided an extensive dataset of multi situated learning experiences from which three elements emerged as particularly relevant to develop global cooperation skills: the crucial role of engaging in collaborations with plural others, the centrality of conflicts in the learning process and the role of teachers in supporting students awareness

on global cooperation skills. The D&E investigation confirmed that collaborating with plural peers is a significant challenge for design students because of frequent conflicts and misunderstandings and that educators play a role in addressing the challenges and opportunities of plural collaborations. Finally, the research identified possible strategies for educators to approach the instructional design of design-based learning courses to support the development of global cooperation skills. The D&E investigation showed that design educators could employ critical participatory action research to assess the untoward consequences of their practices in the case of global cooperation skills and rethink them through the constructive alignment approach. The MEDes investigation showed that design educators could employ the learning trajectories approach to develop understanding and models to guide the instructional design. The research reveals that global cooperation skills are often taken for granted: students collaborate in design-based learning, but a well-thought-out training programme rarely accompanies this experience. On the other hand, design educators recognise the importance of global cooperation skills but might be more robustly supported with knowledge, tools and strategies to foster their development through the design of instructions in design-based learning courses. Lastly, design educators (design professionals or academics)

collaborate in plural contexts, an experience that can be vital to rethinking instructional practices with design ways of doing and thinking.

ENGINEERING COLLISIONS. LEVERAGING THE USE OF PHYSICAL AND DIGITAL LAYERS OF THE SPACE TO ENHANCE NEW FORMS OF INTERACTION BETWEEN THE MICROCOSM OF UNIVERSITY AND INNOVATION CAMPUSES AND THEIR OCCUPANTS.

Martina Mazzarello – Supervisor: Prof. Luisa Collina

The ability to design spaces that foster social relationships and encounters, as well as the disintegration of social segregation between individuals, has received increasing interest from academic researchers, urban planners, architects, designers, and sociologists. This doctoral thesis focuses on the particular context of University and Innovation Campuses, defined as Knowledge & Innovation Spaces (K&I spaces). These milieux are destined to aggregate and concentrate functions, people and spaces to foster new ideas, creativity, knowledge and innovation because they belong to the same ecosystem.

Furthermore, it is a typology of space aiming to be a dynamic and complex landscape environment that can encourage participation, increase social interaction and attract students, faculty, staff and external visitors in a variety of ways.

The purpose of this thesis is to deploy and develop a design framework to encode and decode the relational entities and mutual interactions between spaces, artifacts, and people in K&I spaces, by being able to comprehend environment-influencing factors.

The theory to date has neglected to account for the role of the intersection of space and physical-digital behaviours. This is considered worth exploring as a shortcoming this thesis addresses by investigating the dialogue between different layers of space: physical, digital, and human

interactions.

The main questions of the research to tackle these challenges address several aspects: to identify, characterize and systematize the elements

that influence these mutual interactions; to find some features of the environment and turn them into measurable goals and conditions to be created through a purposeful spatial design and finally, to find a strategy to achieve the predefined goals.

The thesis's title is connected to the rationale for the approach to the problems studied, which considers a vibrant system to be an essential feature for K&I spatial success.

Engineering collisions is in the sense of planning and designing an architectural strategy to foster

collisions, as events in which two or more bodies exert forces on each other between people, spaces and artifacts in a relatively short time. Collisions between people are present in many forms, such as weak ties, serendipitous encounters, and other types of collaboration or cohesion aimed at productivity in various possible forms.

The thesis started from the hypothesis that there is both a physical and a digital dimension that generate relational entities, which are important factors in the knowledge and innovation creation process. Sixty-three international best practices on the topic are investigated to learn their lessons in terms of the intersection of physical, digital, and human behaviour.



Fig. 1
The Strategic Handbook Cover and Index

Research through design (fieldwork at the State University of Milan (Unimi)) and quantitative analysis (conducted at MIT Senseable City Lab in Boston) began part of the process and set the stage for exploring the physical and digital layers in K&I spaces with another lens and experimenting with strategies to engage human diversity with the design process.

The experiment at the MIT Senseable City Lab, in particular validated an assumption of how a blending and merging of the digital and physical should be the focus of contemporary spatial design and re-design. This path led to some key results of validated assumptions. Together with the organization of some contents, it also led to a new theoretical framework for K&I spaces, a vocabulary and model of interaction setting with its own values, parameters, elements, characteristics and objectives, in which the correlation between physical proximity and collaboration is confirmed as essential in fostering collisions. The framework identified through the main findings was reported and translated into three useful tools for the designer as bricoleur, researcher and facilitator: The Strategic Handbook of Collisions, The Periodic Table, The Collisions Card Deck Tool.

These tools are a framework for the process, not a guideline; design tools that in the same format create a new framework proposal for a model of a collision-friendly environment in

the context of K&I spaces, providing a taxonomy of elements and strategies, and a set of participatory activities to use in order to customize the framework and build new scenarios according to different needs.

The practical implications of this thesis are connected to the supporting role for teams of architects, planners, designers and researchers to better communicate and collaborate by providing an in-depth understanding of the multiple contributions they can integrate to create the conditions for new Knowledge & Innovation spaces. The main contributions of the research from design cognition are twofold: an extended role for designers that assumes a key function in building the structure of a K&I design process and a new tool for



Fig. 2
The Periodic Table

designers. The design framework and process are a support tool for designers and the development team to consciously address the creation of a K&I institution, taking all the crucial factors into account and posing a mixed physical and digital environment as a base.

The tool is directed at every member of the development team but implies specific design skills: it requires competences that are typical of design such as scenario building and the ability to interpret imaginatively given constraints, and an ability to follow a process that is essentially a design process (especially in the use of the cards).

It must be remarked that the design framework proposed here is a tool that speaks the language of designers and aims at sensitizing developers about the crucial aspects of a K&I project.

On this basis, the process is still ongoing and does not aim to create unrealistic visions for hypothetical future challenges, but rather points to new development directions to positively influence the development of future growth of K&I spaces by stimulating debates and new research initiatives.

DESIGN THINKING FOR BOOSTING CREATIVE CONFIDENCE IN INDIVIDUAL EMPLOYEES. HOW PRIVATE ORGANIZATIONS ADOPT DESIGN TO NURTURE ORGANIZATIONAL CULTURE THROUGH EMPLOYEE ENGAGEMENT.

Michele Melazzini - Supervisor: Prof. Francesco Zurlo

Private organizations from various sectors are increasingly adopting methods and approaches to innovation from the Design discipline, in processes that are conventionally named "Design Thinking". The roots of this debated term are in the soul of the design discipline itself. In the last decade in the business community, it has been spread as a relevant innovation practice that can also contribute to the development of the organizational culture. In this scope, design researchers and practitioners are interpreting Design Thinking (DT) as a means to merge design culture into the organizational one.

The relationship between Design Thinking and organizational culture has been attentively investigated but mostly oriented to emphasize the impacts on the company's productivity and performances. It emerges a gap in investigating DT and Corporate culture towards the means that intertwined them: the individuals, the organizations' single human beings. Thus, the starting point of this research consists of observing Design Thinking impacts on organizational culture, particularly on **employee engagement**. In this research, the relationship between organizational culture and Design Thinking is observed from a perspective that is underestimated in previous studies: **the organization's micro-level**, the single employee dynamics and behaviours. Which are the beneficial effects that a single person might have from adopting *creative confidence*? How can this model of Design Thinking

adoption produce values to be transformed into corporate culture? A qualitative analysis has been run to address these questions: the research implements a mixed methodology combining Case Study research with Participatory Action Research to accomplish the research objectives. The specific phenomenon of interest is studied within and with the HR department of the *Corporate Investment Banking Division in Intesa Sanpaolo*; this organization is adopting Design Thinking through the HR department to empower the employees' potential. This study has defined a **model of interpretation of how Design Thinking impacts individual-specific behavioural constructs** (motivations, attitudes/mindsets, capabilities and behaviours). The objective is to recognize specific relationships among these behavioural constructs and the specific DT adoption processes (named **DT integrator**) characterized by various design principles. Individual motivations, individual aptitudes and individual creative capabilities are the constructs to identify the **individual employee sphere** in the research. The specific research question defined by the conceptual framework is: How design thinking implementation affects employee's following individual constructs -

- A. Motivations - aptitudes?
- B. Capabilities?
- C. Behaviours?

To explore and describe how this complex phenomenon occurs, the researcher develops a conceptual

framework with a specific structural logic: a specific DT action (INPUT) impacts a specific combination of individual motivations, individual aptitudes, and capabilities (CATALYSTS). This combination makes employees react by activating specific creative behaviours in a specific context (OUTPUT). This model and the related constructs were derived by the literature and their validity has been assessed within the study with the support of design practitioners and academic experts. Observing a specific phenomenon of interest within a big private organization, the research aims to capture the impacts on individual employees during and after the adoption of Design Thinking actions. Furthermore, the case analyzed allows the conceptual framework's refinement and the related definition of the most significant **behavioural patterns**. These patterns act as a reference for the setup and development of the final and empirical research phase experiments, with a Participatory Action Research (PAR) set of activities. A solid partnership is established with the company selected for the case to study. **It emerges a fertile context to co-create and co-disseminate knowledge with the partner organization**. The researcher develops an experimental Design Thinking action (named *Train the Trainer*) to test in practice the conceptual framework and embed knowledge in a real context. **Simply put, the empirical experiments of this phase**

permit a detailed observation of the effects generated by a specific DT integrator on specific individuals within an organization. The data evaluation process verifies whether the Pilot Project confirms this study's assumptions and recognizes which findings can be considered effectively replicable in similar contexts.

The main findings confirm the **mutual influence between the individual employee sphere and the DT integrators**: in particular, DT integrators activate a series of creative behaviours that affect the people's working life positively. **DT in organization can represent a trigger to professional progress but moreover personal engagement**. The study explained this phenomenon, presenting a conceptual pattern named **creative inner loop**, emphasizing DT's experiential nature as a crucial variable in producing an effective change in individual working life and organizational culture; this model shows that specific attributes in the *individual employee sphere* boost the adoption of DT generating creative behaviours; these creative behaviours as well influence the inner working life of people making them personally and professionally progress. **The creative inner loop implicitly generates and boosts employee life engagement**, confirming this study's central assumption. After the analysis of the results, it was possible to delineate a selection of most recurring behavioural patterns revealing the **creative behaviours**

that emerge the most in employees working life after the process of DT adoption: *to act proactively, handle uncertainty, confidence in speaking, mediate and negotiate*. Each creative behaviour influences the process of change in corporate culture. The key driver in activating these change processes lies in the **experiential nature of creative behaviours**: enabling a mutual exchange between thinking and making people effectively absorb new practices to be transformed into corporate culture evidence. Furthermore, the process of change activated by DT integrators on an individual level corresponds to a process of contamination of the corporate culture. The dissertation illustrates this bond between micro and macro levels within organizational behaviours.

In order to replicate the empirical model developed in this study, it is essential to consider the **key aspects to make a DT integrator effective** and adapt to the organization in question. The attributes to remark are related to the context and DT adoption situation, which should create the proper conditions to make an individual grow. The other aspect to consider is the **gradualness** that should drive each DT adoption process to overcome initial resistance; the project-focused avenue for cultural change could be an effective means, as demonstrated by this study. This aspect led to the critical underpinning of the research: DT must not be intended as the purpose of the adoption, instead

as a means to achieve innovative purposes (in non-design intensive organizations). The contribution to the field of research is expressed by the exploration and tentative explanation of how Design Thinking impacts non-financial performances in organizations. This research aspires to be meaningful for private organizations that would adopt Design Thinking to culturally evolve and desire to be guided in this process of adoption. The outputs obtained imply the proper consideration of limitations in design thinking's adoption process, depending on the context and the actual organizational culture.

DESIGN FICTION 4 CRITICAL THINKING: DESIGNING CONSCIOUSLY TECHNOLOGICAL ARTEFACTS TO TACKLE AWARE BEHAVIOURS

Mila Stepanovic - Supervisor: Prof. Venere Ferraro

Critical design theories and practices, such as Speculative Design and Design Fiction, offer principles able to trigger critical thinking and use the future as a space for critical inquiry regarding the opportunities, limitations, constraints, and application of technologies, with a purpose to design more consciously technological artefacts. In this research, the author focuses on technological artefacts to tackle aware behaviours, for instance, influence the users to adopt and maintain more sustainable habits, make more sustainable choices (i.e., air pollution, energy consumption, health and wellbeing, others).

To design more consciously imply the adoption of critical thinking in design research and practice. Critical thinking is intended here as a capability to reason about the technology and the society (considering both human and non-human actors) as an interconnected system, exploiting its ethical and societal implications and crosscutting factors involved in change processes.

Nowadays, design researchers and practitioners are required to deal with the complexities of the changing world and its uncertainty where dealing with human behaviour have become difficult task. Designing for enabling aware human behaviour needs more critical approaches that can help design researchers and practitioners to deal with these complexities and design more consciously both for the users and for the planet.

This research aims at exploring and defining new and more critical approaches for the design of technological artefacts for aware

behaviours, founded on Design Fiction principles and speculative design proposals, considered able to trigger critical thinking. Design Fiction enables us to use the future as a space for critical inquiry through the speculation about what could be, and accordingly approach critically to reality as a field of possible actions.

Through design fiction principles, such as anticipatory scenarios and diegetic prototypes, we can investigate the potential future applications and implications of technological artefacts, explore new physical forms, experiences, and interaction rituals. Anticipatory scenarios are alternative constructions of the worlds (in a

social, cultural, political, historical sense) within which the designer anticipates, creates, and contextualises the diegetic prototype and builds mediations between humans - technology - environment. Established upon the Research Through Design (RTD) methodology, this research commits to answer how design fiction can help design practitioners and researchers design more consciously the technological artefacts to tackle aware behaviours, through the pluriversal perspective considering the societal and ethical implications and exploration and anticipation of mediations generated through the interaction

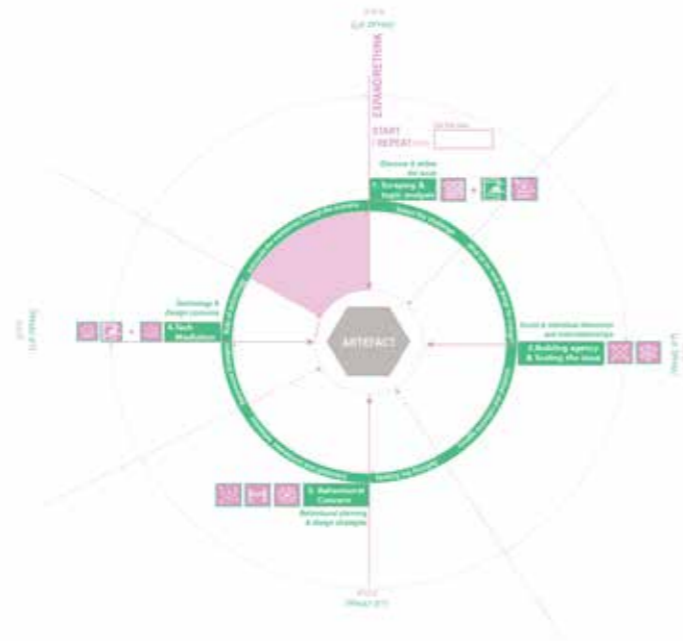


Fig. 1

rituals, experiences, new forms and applications of technologies. In regard, this research proposes a new and more critical approach, and it operationalises this approach into the Protocol ready to use by design researchers and practitioners. Protocol is intended here as a set of rules and procedures to follow to design more consciously technological artefacts. The Protocol (Fig.1) is founded on four stages and combines several theoretical concepts, methods and tools. It is applicable for design research and practice concerned with sustainable development, human behaviour and technolog, and it is suitable for different design areas, from product to interaction design, and service design, but it does not limits to it. The Protocol with tools found its purpose also in design education activities concerned with design with Artificial Intelligence, Interaction Design. The Protocol with tools can be used both in short and long-term design research activities - from brainstorming to conducting the research using the stages of

the Protocol. The kind of the output that can be produced throughout the Protocol are Anticipatory Scenarios and Diegetic Prototypes (materialisations of scenarios). These outputs can be used to conduct the critical reflection, open the debates about the possible futures with wider public (citizens), generate new knowledge (about the human behaviour, interaction rituals, analyse possible ethical implications of technologies, etc.). In parallel with the Protocol author creates an Envisioning Tool (Fig.2) exploring and exploiting the diegetic prototypes from Sci-Fi cinematography as tools to stimulate a critical discussion among the researchers and practitioners about the possible ethical and societal concerns regarding the technologies and environmental questions. The Envisioning Tool is a support tool for the protocol but it can be also applied independently in design and research, or educational activities for brainstorming, discussing, creating narratives, etc.

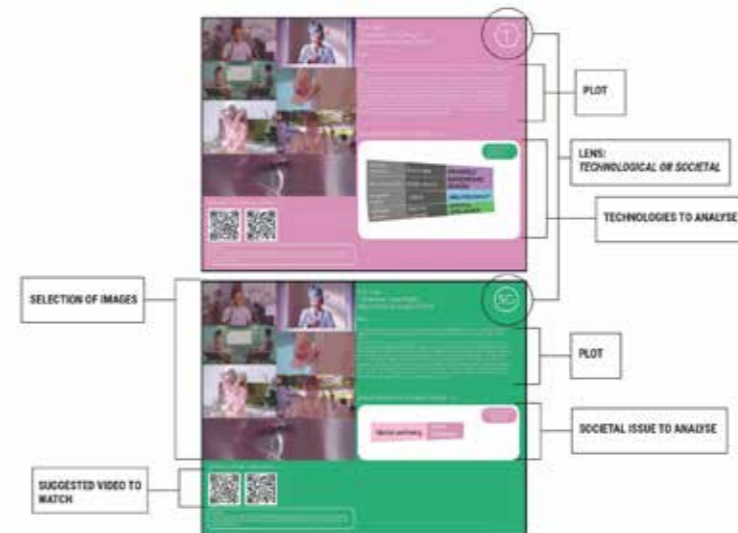


Fig. 2

During the three-year period, the author applied the Protocol and Envisioning tool in several short-term and long-term design research and educational activities, at Politecnico di Milano (Design Department and School of Design) and in collaboration with ITU Copenhagen (IxD Lab). Besides, the author engaged also the experts coming from other international universities and companies, such as Amsterdam University of Applied Science (NL), Università Bicocca (IT), digital agency Specifici (DK), Istituto Europeo di Design (IT). During these collaboration were produced anticipatory scenarios and diegetic prototypes

The outputs of this research aim at supporting the processes toward sustainable development and it supports the objectives of building more thriving, resilient, and sustainable societies and conditions, exploring both micro (local) and macro (global) levels. It is founded on the values of the EU such as Human Dignity, Democracy, Human Rights, and goals oriented toward promoting the well-being of the citizens, sustainable development, social progress, promoting scientific and technological growth, and others, and it raises the questions on how the design discipline and design knowledge can contribute and support these processes.

The Protocol with support tool (Envisioning Tool) has achieved the Trademark at Technology Transfer Office (TTO) of Politecnico di Milano for the protocol. In this way, the knowledge produced within the PhD executed at Politecnico di Milano will remain preserved as such.

GOVERNING ETHICALLY THE SUSTAINABLE TRANSITION, AN INSTITUTIONAL DESIGN FRAMEWORK

Alessandro Piazza – Supervisor: Prof. Paolo Gaetano Volonté

Climate change is one of the biggest moral problems that humanity faces today. Furthermore, there is now overwhelming evidence from the scientific community on the fact that this environmental catastrophe is in fact human driven. Therefore, societies need to rapidly shift from a carbon-based economy to a new model of sustainable development. As a result, in the last decade a new literature on sustainable transitions has flourished.

In this regard, a sustainable transition has often been defined as a radical transformation of a socio-technical system towards a sustainable development. Nonetheless, governing sustainable transitions is one of the most complex challenges which decision-makers face today, as they involve the management of a complex network of social actors, public and private institutions, physical and digital infrastructures, technological innovations, and natural ecosystems. Accordingly, sustainable transitions cannot be governed in a technocratic way, solely by setting new bodies of rules or by incentivizing the penetration of sustainable technologies within national markets. There is a growing awareness on the fact that designing policies in abstraction from their interconnections with social actors can lead to delays and failures in the implementation of new rules, plans, and projects. Socio-technical transitions are, then, deeply complex transformations of our societies that can lead to contestations, frictions, and stalemates when new policies are not responsive to the society in which they

are formulated. Therefore, governing a sustainable transition requires the development of an analytic understanding of the interconnections between new transition policies and the social, technical, and ecological variables to which they apply. The thesis is then framed within the field of transition studies, and it focuses on better understanding the socio-technical dynamics of sustainable transitions. More specifically, the research concentrates on the challenges presented by the energy transition, the radical shift from a model of development based on fossil fuels to one based on renewable energy sources. As it will be argued throughout the text, such a structural transformation of the socio-technical organization of a society raises the challenge of complexity. Governing sustainable transitions requires the management of both social, technical, and ecological variables in their

structural interconnectedness. As a result, decision-makers are faced with the difficult problem of governing complex adaptive systems, where the transformation of the physical infrastructure of an energy system cannot be managed in isolation from the adaptive responses of its social and ecological components. Therefore, the thesis will highlight how the radical transformation of energy systems cannot be considered separately from the social issues that it brings about. The aim of the thesis will then be to articulate the role of morality within the governance of the energy transition. In this respect, it will argue that achieving a responsible and responsive governance is a key precondition for the moral acceptability and social acceptance of sustainable transitions. Accordingly, the development of the work has been organized around two main research questions:



Fig. 1

Q1: How can responsibility be achieved in the cooperative governance of energy transitions?

Q2: How can we design energy institutions which are responsive to all societal stakeholders?

Raising these two questions responds to one main objective of the research: the development of an articulated understanding of the moral implications of designing new institutions in a sustainable transition. In this regard, these research questions are aimed at filling an important knowledge gap within the academic debate on sustainable transitions, namely the articulation of a comprehensive framework connecting the design of new institutions with the moral perceptions of stakeholders.

To achieve these objectives the thesis is structured around a mixed methodology, combining the theoretical elaboration of a new framework with the empirical test of its main insights, through the ethnographic investigation of an energy community. For what concerns the theoretical apparatus, the thesis mainly combines the contributions coming from applied ethics, science and technology studies, and political economy to develop an original pragmatist theory of cooperative governance within the energy transition. Here, the work establishes a close dialogue with the Institutional Analysis and Development Framework, developed by the political economist Elinor Ostrom, and proposes that such a framework can be fruitfully extended to account for the moral implications of designing

new institutions in the energy transition. To test the insights provided by the Extended IAD Framework, the research benefits from the analysis of the energy community of Schoonschip, in the city of Amsterdam. Here, in a one-year long observation of the internal dynamics of a nascent energy community in the Netherlands, the work will assess the fitness of the elaborated framework to the real-world dynamics surrounding the ethical issues raised by sustainable transitions. This mixed methodology allows the research to ground its theoretical proposals in the concrete analysis of the socio-technical dynamics of transitions, thereby articulating a framework which stands the test of its theoretical implications. To conclude the research is aimed at filling a gap in the present literature on sustainable transitions as most theories of governance have so far disregarded the role of morality in the development of new energy institutions. The dissertation provides then an original work, articulating an analytical understanding of the interconnections between socio-technical variables in the development of new projects, policies, and institutions in sustainable transitions, by showing the importance of meanings, values, and norms in the achievement of a responsible and responsive model of cooperative governance

MATERIALS DESIGN FOR SUSTAINABLE BEHAVIOUR, THE CASE OF COMPOSTABLE MATERIALS FOR PACKAGING AND SUPS.

Romina Santi – Supervisor: Prof. Barbara Del Curto

Designing the material side of a product can fulfil functions and performance, characterise the product experience and express a specific emotional and aesthetic intention. Thanks to advances in technologies and processes, there is almost total freedom to design through materials: the same material can have infinite aesthetic properties, and different materials can wear the same identity. However, designing the aesthetic-sensorial dimension of materials becomes a complex task because their perception does not solely determine a hedonistic taste but move the consumer's choices, actions, and behaviour.

This research explores materials behavioural dimension, starting from aesthetics, perception, experience, and meaning of materials. While the definition of the “performative” level of materials related to the actions users perform by materials (i.e., tweak, smell, pat) is widely acknowledged within the materials and design literature, the consequences that materials aspects have on human behaviours are underinvestigated. It was, therefore, searched how the main research object was immerse in the background literature, starting with four main pillars: Sustainability, Behavioural sciences with a focus on behavioural change for sustainability theories, Product design in the fields of interaction design, product experience, semantics, and Materials sciences with a focus on materials senso-aesthetic dimension and engineering of aesthetic appearance. Since behaviours constitute the human response to interaction,

“behavioural materials” have been defined as materials that can guide/stimulate/steer cognitive or instinctive users' behaviour through aesthetic-sensorial attributes applied in products. Behavioural materials have been analysed on a broad spectrum: they can lead to safe, learning, spatial-oriented actions. However, this PhD thesis is focused on the consequences of materials aesthetic-sensorial dimension on users' behaviour when sustainability is the primary field of inquiry. Once investigated the background of the Materials Design for Sustainable Behaviour (MDfSB) field, the research examines preliminary cases in the literature and inspiring works in which materials guide sustainable behaviours due to their aesthetically designed attributes. They settled in the emotional durability and gracefully ageing, accepting imperfection and in the interactive consumer relation



Fig. 1
Picture taken during “Their own identity” test

with objects by materials. Clustering and mapping early cases of MDfSB gave the input for defining the sustainable behaviours that different emotional-sensorial triggers can guide by materials' aesthetic-sensorial attributes.

Achieving a sustainable behaviour change by materials applied in product design is a virtuous goal, both by selecting the most traditional to the most innovative materials. Indeed, the impact of materials for sustainability can strongly depend on the consumers use phase, whose responsible behaviour becomes a necessary condition towards the systemic circularity that makes materials and related products effectively sustainable. The case representing the core of the research was compostable materials for packaging and Single-Use Products (SUPs). Indeed, they have a potential behavioural-related weakness: a hybrid aesthetic that has not yet settled in the consumers, which risks compromising materials circularity. Acting sustainably with compostable materials means pre-choosing them from conventional alternatives, persist their use and consumption and, appropriately conferring them during their end-of-life. It has been tested if and how their aesthetic-sensorial aspects represent a significant trigger for sustainable behaviours. Activities have been supported by Innovhub s.r.l (partner of the research), aiming to design an action line for the materials-behaviour relation in the context of materials recyclability. The experimental approach applied has been focused on un/sustainable

consumers' behaviours in response to the variation of aesthetic-sensory stimuli by compostable materials. Through a user-centred approach, compostable materials current perception and related behaviours have been investigated to look for a possible aesthetic linked to compostable materials intentionality. The materials sensorial-behavioural analysis tests with users were mainly three, with increasing levels of complexity: the first: “Sensory hybrid materials”, aimed at exploring the aesthetic-sensory properties, naturalness, sustainability, and perceived recyclability of samples of different materials shown to the participants in closed boxes, allowing for surface exploration. The second: “How do you throw it?” was carried out to search for correlations between the aesthetic-sensorial attributes of the materials and the waste sorting behaviour since this behaviour represents a critical action to ensure circularity through the use phase. In this case, have been selected packaging and SUPs on the market in different materials, including compostable products. They were given into the participants' hands one at a time in a random order, asking them to sort products as they do at home. The third test was the final and most deepened one, aimed at identifying correlations between designable compostable materials attributes and the identity of materials, the perception of naturalness and aesthetic quality and the end-of-life sorting behaviour. For this, a set of compostable materials samples was designed and produced

in the laboratory (“Before” lab, referent Prof. Silvia Farè, Department of Chemistry, Materials and Chemical Engineering “G. Natta”, Politecnico di Milano) with the controlled variation of colour parameters, fibrous inclusions, textures, and transparencies. They were designed so that only one variable changed at a time to build statistical significance. The results proposed a precise answer to the case study examined by developing aesthetic-sensory guidelines for compostable materials for packaging and SUPs, accompanied by a tool to support compostable materials selection and CMF (Colour Material Finish) design for sustainable behaviour. The discussion was subsequently abstracted from the specific case, hybridising the MDfSB approach. MDfSB approach is applicable by designers and practitioners who want to solve consequential problems arising from materials interaction, a behavioural-related selection of materials, or CMF design in a circular system strongly contaminated by the use phase. The thesis explored the relevance of materials aesthetic-sensorial design as a medium for achieving a sustainable behaviour change. The MDfSB approach demonstrated robustness and reliability, verified through workshops in the academic and industrial fields and ready to expand its horizons to new cases and experimentations.

DESIGN PERFORMATIVE CULTURAL SERVICE FOR LOCAL MUSEUMS: PERFORMATIVE STRATEGY AND SOCIAL COHESION IN CULTURAL SERVICE EXPERIENCE

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Keywords: Cultural service design, Performativity, Performative cultural service, Local museums, Social cohesion.

This transdisciplinary research investigates the possibility of applying the knowledge in performance studies to service design by exploring performativity as a language of service encounters whilst addressing the issue of social cohesion in the context of local museums.

The local museum in the future will not only be a space to display the local culture and history, but also strive to serve as a shared place that connects diverse communities and their memories, as well as a local media for social dialogue and social negotiation. As a promising channel for enhancing social cohesion, cultural service in the museum could create value by triggering social dialogue and open participation, encouraging visitors' reinterpretation and reproduction, and fostering relationship-building. To create a performative experience where visitors are both audiences and active participants, performance theory was introduced in this research to propose the concept of "Performative Cultural Service." As an interactive and intuitive language, performativity could systematically coordinate all the elements, from the physical environment to the human senses, from the narrative to emotional resonance, to achieve an optimized and impactful experience. The research focuses on connecting service design with performativity

to create an impactful service experience. If regard cultural service design as a sense-making activity, performativity is trying to magnify the sensitivity for visitors to understand through interactive narratives, make users witness the process of change, or be one part of the story. Meanwhile, it investigates the possibility of a local museum as a space for sharing memories and implementing social dialogue, with the aim of exploring the new potential of performativity for social cohesion within the context of the local museum.

There are three research questions. In order to address the research questions, a combined methodology of qualitative and applied research was applied with three main strategies

that lie in inductive reasoning, case studies, and participatory action research. Research Question 1: Can performance theory be applied to service design to improve the ability of cultural service design in sense-making? In which way? Research Question 2: How does Performative Cultural Service be designed for local museums? Research Question 3: How could Performative Cultural Service catalyze social cohesion? In which aspects?

The first question is asked to bridge service design discipline and performance studies and propose a new concept of "Performative Cultural Service". After conducting a literature review and a comparative analysis of

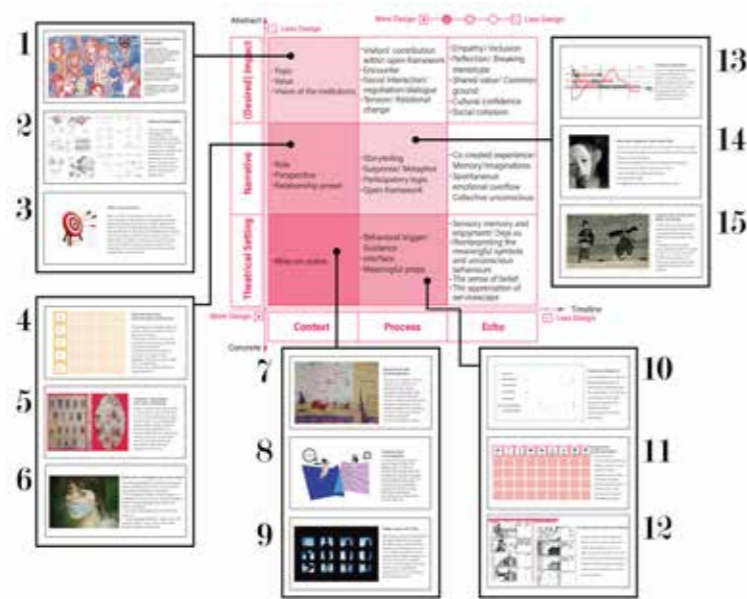


Fig. 1 Meta-design framework with toolkit

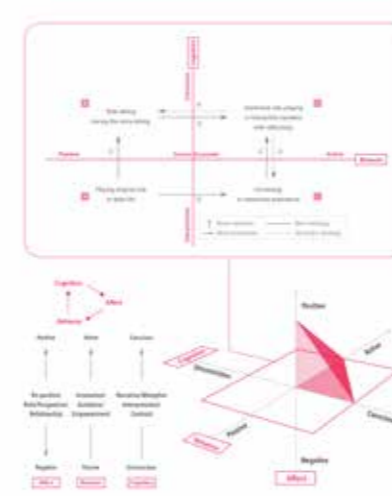


Fig. 2 Different dimensions of performativity.

the two experience modes-- service and performance, the concept "Performative Cultural Service" was proposed (Result 1). Then, the analogy was used to frame the main structure of Performative Cultural Service, consisting of three layers from the designer's perspective: Theatrical setting, Narrative and desired impact, and three stages from users' perspectives: Context, Process, and Echo. As a performative experience is co-created by designers and users, a matrix dominated by three layers and three stages is generated and identified as anchors, allowing the data from 21 relevant case studies to be gathered and synthesised into the framework. After that, a meta-design framework (Result 2) was proposed, indicating possible design parameters and performative strategies(Result 3) to facilitate relevant design practices

in different stages. Meanwhile, though comparing and analyzing the results of case studies, three dimensions of performativity(Result 4) are proposed to design a performative experience, including: the behavioral dimension generated from the tension between theatrical settings and active explorations, the cognitive dimension with the tension between narrative and active imaginations, and the affective dimension from the relationship between visitor's' original role and role taken in experience.

The second question focuses on the design process of the Performative Cultural Service in the context of local museums. In this part, participatory action research was conducted to assess the framework based on empirical work during a co-creation session(Result 5) for the Wuxi Museum held at Jiangnan University. A toolkit (Result 6) based on performative strategies was designed and introduced to participants without a constrained sequence. After the co-creation session, a half-hour interview was conducted respectively with five teams to assess the research results and to identify their general design processes within the framework. After analyzing these design processes, three orientations for the design process(Result 7) of Performative Cultural Services were summarized: relationship-oriented design process, storytelling-oriented design process, and space-oriented design process.

The third question focuses on the effectiveness of Performative Cultural

Service in promoting social cohesion, as social cohesion was chosen as the theme for the co-creation session. Social cohesion could be viewed from a relational level, while performativity is promising language in dealing with relationships, as it could intensify or release tensions or adjust between positive and negative affections through repositioning the role and perspective. Therefore, based on the magnitude of psychological distance between users and the role created in a Performative Cultural Service, a pedigree with three design paradigms (Result 8) was established to promote social cohesion in performative cultural services, including Immersion, Realistic Happening, and Defamiliarization.

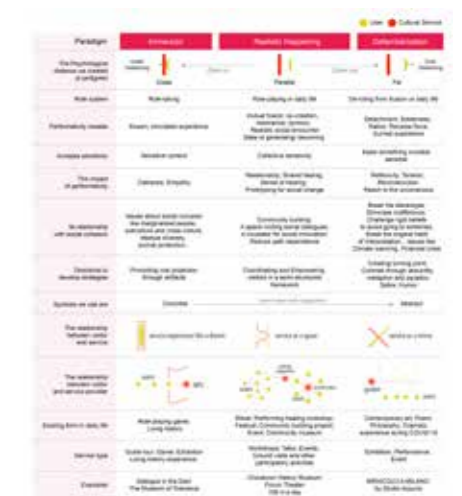


Fig. 3 Three design paradigms for catalyzing social cohesion

METAPHORICAL INVITATION: CATALYSE SUSTAINABLE BEHAVIOUR THROUGH THE POWER OF METAPHORS IN DESIGN

Siyuan Huang – Supervisor: Prof. Monica Bordegoni

Since the beginning of 2020, the coronavirus outbreak has pressed a pause button of global development and imposed an unprecedented shift in everyone's life. Simultaneously, it has raised an alarm bell to the whole world, emphasising the ponderance of sustainability of the ecosystem and civil society. In fact, responding to today's imminent sustainability-related challenges require not only radical socio-technical transitions but also substantial changes in people's consumption patterns and lifestyles. In this regard, design is becoming one of the most innovative and powerful means of encouraging and guiding people towards greener practices. By developing products and service systems for people to use in everyday scenarios, designers have significantly shaped people's attitudes, decision-making, and even behaviours to a large extent. At the same time, the results of human activities will inevitably affect the state of natural resources and thus the ecosystem. Therefore, incorporating the dimension of human behaviour into the considerations of Design for Sustainability (DfS), Design for Sustainable Behaviour (DfSB) has emerged as a focal topic within academia and practices. Specifically, DfSB is an interdisciplinary research topic situated at the intersection of environmental psychology, sustainable design, and design for behavioural change. It aims at using products and services as effective intermediaries to support pro-environmental attitudes and lifestyles to promote sustainable development.

Over the years, scholars have

extensively studied the mechanisms underlying human decision-making and behaviours and shaped them into design-led interventions. Notably, most efforts have centred on leveraging strategies and approaches to support positive behaviour change, lessen problematic habits, or cultivate new rituals. However, aspects such as generating new insights into a design situation, assimilating behavioural strategies into design conceptualisation and expression, and the approach to constructing an entire design thinking process, remain unscrutinised.

Prompted by this room for improvements, introducing the concept of metaphor into DfSB can be a promising research direction. Inherently, human beings make sense of the world and get acquainted with abstract things through the means of analogies and metaphors. More importantly, metaphor is more than a rhetorical device in language

that stands for cognitive processes and communication. It is also firmly linked to human decision-making and behaviours. In other words, the value of metaphor is not restricted to facilitating conceptual understanding but is also profoundly reflected in human reasoning, judgement, and actions. The main reason is that metaphor understanding relies heavily on the activation of the mind-body system, involving the construction of embodied experience.

In view of the research proposition, the main goal of this research is to understand: in the context of DfSB, how can metaphor (including metaphorical thinking and conceptual metaphor) benefit both the process of designing and within the product itself? In other words, how can metaphor favour the creation and realisation of behavioural intentions in design? Specifically, research questions include: how does metaphorical thinking help designers

reframe design possibilities in terms of behaviour change goals, and how does it facilitate the integration of behaviour change strategies into the design process, leading to design proposals? What are the behavioural influences of product metaphors? How do they help smooth the process of behaviour change by triggering intuitive interactions?

Due to the interdisciplinary nature of this research, the overall research action follows a Research-through-Design (RtD) approach. In general, the thesis consists of three parts: Understanding, Exploring and Developing, Reframing and Testing (see Figure 1). The first stage is mainly about literature research. The second and third stages of work combine the literature review and case analysis results to generate theoretical knowledge and conduct empirical research through specific research methods (e.g., field observation, physical and virtual prototyping, online surveys, interviews, virtual reality-based experiments, and user tests). Overall, the theoretical knowledge and empirical findings generated throughout this research can be conducive for both design researchers and practitioners. First, a set of case cards was produced to illustrate the broad use of metaphors in everyday products to convey behavioural and experiential cues. Besides, it also serves as a classification of the behavioural influences of product metaphors. Second, a conceptual model that emphasises the dimension of behavioural persuasion of product metaphors was proposed. Third, a classification of three pathways to

generating metaphors in DfSB was analysed and clarified. The primary purpose of this classification is to help designers alleviate status quo biases, liberate the faced limitations, and further unearth design possibilities. Lastly, a Metaphor-Driven Design Method (MDDM) was developed to facilitate the design process of DfSB. It guides designers to formulate a design statement and conceptualise behavioural strategies into design proposals through metaphorical thinking. Also, it helps designers envision and shape the interactive part of the design through metaphorical mapping.

Moreover, since the meaning transfer power of metaphor can be cognitively indicative for both designers and users, the role of metaphors in DfSB can be two-folded. Metaphorical thinking and mapping can facilitate the advance of the design process, especially in design conceptualisation and the construction of the product interaction part. Product metaphors embedded in the design itself can help design expressions and invite intended behaviours. Specifically, the employment of metaphor in the design process can help designers reframe target issues, link behavioural change strategies with design conceptualisations, and organise product expressions. Second, users can better grasp the meaning embedded in product expressions through product metaphors and be prompted to act in desired ways. In conclusion, the roles of metaphor in DfSB can be understood as a design research tool, a design ideation tool, and a communication tool.

Finally, this thesis ends with a general discussion, highlighting the main research findings, social and ethical considerations, and future development prospects to expand the current research scope and agenda.

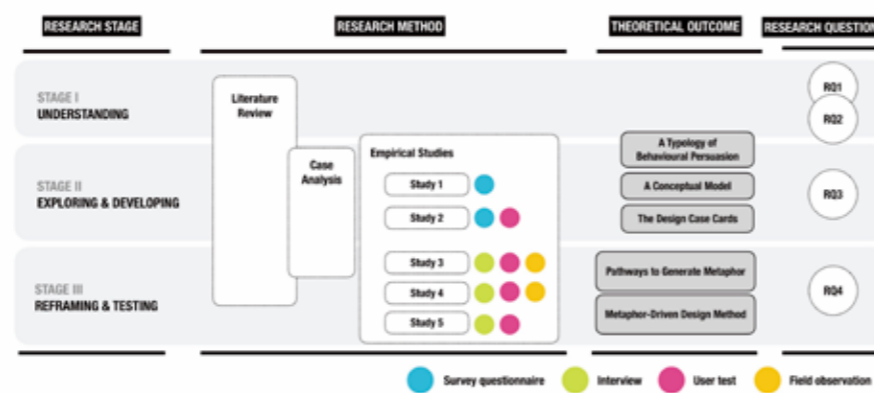


Fig. 1
Research approach and stage activities.

MEANING-DRIVEN MATERIAL EDUCATION IN DESIGN

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Keywords: Material education, Materials experience, Material in design, Design education, Material designers.

This dissertation presents a doctoral research on material education in design, which is based on understanding the tremendous undergoing changes in the material world thanks to the technology evolution and designers' continuous exploration and reinterpretation of materials. It noticed that the exploration of new materials and their characteristics have caught more attention of designers and design educators, and design and material education is developing its own approaches. It answered the research question of 'what are the new effective changes and phenomena of material education in design, and what are its potentials and values' by a mixed research methodology.

The research holds a mixed research methodology and a pragmatic worldview. It got insights from a comprehensive understanding of the past and nowadays situation to generate foresight. It started with the literature review with two main parts: material education's evolution, and the emerging issues of material in design today. Studying these two parts provided a general reflection on the academic world's development about the material in design education and material in design. With the emerging and development of new materials for a better and more sustainable future, design education is also constantly responding to the current complex changes to meet the environmental

responsibilities that designers should have. In design education, the material has multiple roles, and no theory can fully cover the complexity of the role of materials in design education. Many discussions on different aspects are valuable in understanding the importance of materials in design and design education, such as circular material selection, new material experience, Do-It-Yourself materials, design with additive manufacturing, Interactive, Smart and Connected materials, and Speculative materials. New technology, new ways of living, and our planet's future are all relevant concerns interwoven to shape a design and material culture. Today, designers understand and dialogue with materials differently, and it catalyzed the new interests and educational explorations emerging in design schools. After the literature review, the research positioned itself in the scientific committee and defined its objectives. The research objective is to investigate the new contents of material education in design today and define their features, potentials, and future values. By highlighting, understanding, and analyzing these new contents, it defined the meaning-driven material education, as an emerging phenomenon in design schools.

By browsing the top 50 Art and Design schools from the QS ranking 2021 and collecting 181 material courses, and processing qualitative information such as course descriptions and quantitative numbers such as the courses numbers, this investigation described a panorama of today's material education in design. This

investigation summarised today's material education characteristics by generating a taxonomy of design courses and mapping them. The results showed that material education involves more multidisciplinary content today, and usually with a sustainable concern, but not always. Besides learning engineering knowledge and material parameters, in design education, there are many ways to approach materials in a humanized way, by understanding and exploring materials' characters and personalities with first-hand experiences, or their sustainable values, or the ways of living it may bring. As some literature mentioned years ago, the material is multi-dimensional with its aesthetic, emotional, and environmental values that addressed to a more humanized design approach; today there is more evidence that material's multi-dimensional values and their meanings are involved in design education, and students are encouraged to design with materials more humanized. By this broad study on the current material education in design schools and mapping the courses, the researcher discovered that material education in design has some emerging characteristics and trends. Among them, many activities focusing on explore material's meanings are drawing more attention. It is one of the results of designers using design approaches to understand, transform and develop current new transdisciplinary knowledge and industrial principles. Reflected in teaching, this emerging phenomenon in material education is focused on and driven by exploring

material's multiple meanings (environmental and sustainable, social and cultural, technological and sensorial). The main design practice in the class tends to place the material at the start of the design process to consider it active and designable.

In this stage, the research defined eleven types of material courses in design education. Among them, there are some emerging courses with themes that tend to understand and explore materials more meaningful and impactful. Also, some courses that follow the heritage of Bauhaus with original hands-on approach in learning design have involved more new meaning-driven contents and discussions. And there are material courses focus on new strategy and scenario for sustainability, circular design, and green design focusing on material's environmental meanings and values. These new content and phenomenon of material education needed to be further researched, which is the material educational approach having a primary focus on understanding and exploring materials' meanings and experiences; and considering the material as designable to cultivate a multilayer of competencies to understand, questioning, select, create, and design with materials. In the next step, the research aimed to define the added values of this emerging phenomenon. Therefore, to understand more details, three courses were selected as descriptive case studies with different themes and methods to understand all the related thinking and activities more. The research specified the design competences enhanced

through these educational activities by studying their pedagogy with course input, design process, and output. These teaching and learning activities emphasized the interpretative values of materials in design, and it defined these emerging material education activities as a meaning-driven, investigation and hands-on based material study and exploration putting material as the start of the design process, so-called Meaning-driven Material Education (MdME).

Through understanding the features of meaning-driven material education, the research defined that the competences dialoguing with material is highly connected with critical thinking and hands-on activities. MdME emphasizes the significance of the humanistic and environmental value attributes of materials in design, and uses materials-centric design methods to trigger students' active learning by questioning, experimentation, and investigation. It can help improve design intuition and comprehensive competencies by building a material way of design thinking, and increase social and environmental responsibility of designers. As an educational approach derived from design, it facilitates our design culture to a more ecological and sustainable scenario, and might promote the career of future material designers. The research addressed the MdME framework with underlined theoretical input, project development approaches, and learning outcomes.

Even though there could be many design activities involved in a material design course, the MdME emphasizes

two design processes, mainly starting from material investigation and material experimentation, respectively. Material investigation and material experimentation are highly connected but lead to two different ways of thinking and exploration. To further verify the potential value of MdME, the research generated three hypotheses on the potential of meaning-driven material education in design, and they were verified by teaching activities. The results verified that design educators can enhance design education and expand design territories through MdME from different aspects. The end phrases discussed that the MdME framework can be applied to current design education in five methods: triggering material tinkering; cultivating a 'designerly way' to understand and use materials; enhancing speculative research on material futures; engaging global scale investigation; and re-awaking our consideration of the preciousness of objects.

The research outcomes are a body of knowledge around the meaning-driven material education, formalized in a methodological framework to material education in design. It contributes to informing and updating the current theoretical and methodological knowledge for materials design. In the discussion part, the thesis discussed the future of material education in design for cultivating future material designers and enhancing design education's responsibility nowadays.