Complexity, Design and Culture: convergence for digital experiences

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Abstract. The design of digital experiences and sociotechnical solutions in the contemporary society is characterized by increasing complexity. More and more variables are present and unpredictable effects are observed. The complexity of systems calls for increased awareness and problem-solving abilities. In this survey, design in general, and design of the user experience in particular, is positioned in the scope of complexity. Moreover, the design reasoning and methods are framed by culturally determined factors and cognitive styles. This survey aims to converge complexity and complex problem solving, design of the user experience, and cultural variations, reviewing bodies of work to inspire and map interdependencies that shape future challenges in systems and experience design.

Keywords: Complexity, Complex Problem Solving, Design, User Experience, Cultural Dimensions

1 Introduction

Uncertain behavior, unexpected phenomena, unknown solutions, and unanticipated effects are common in modern social and technological scenarios. As people, organizations, and societies evolve towards a higher degree of interconnectedness and mutual dependency, the problems to be solved and the challenges to be addressed defy the established interpretation and understanding capacities, ask for smarter design of creative solutions, and show a vivid sensitivity to the contexts of individuals, groups, and communities. This survey proposes a path of convergent inquiry between the topics of complexity and complex problem solving, the design of interactive systems and user experience, and the cultural variations that shape a significant background.

Complexity science emerged from fields like physics, mathematics and life sciences, with the goal of understanding phenomena that escape the reductionist paradigm. Mitchell [110] defines "*a complex system is a system in which large networks of components with no central control and simple rules of operation give rise to complex behavior, sophisticated information processing, and adaptation via learning or evolution*". Inspired by the scientific problems of the original disciplines, complexity proved to be an inspiring perspective for the understanding of a number of systems, natural and man-made, from climate change to organizational or political phenomena.

From the psychological and cognitive perspective, complex problem solving has been studied for decades, as in Sternberg and Frensch [147] and in Frensch and Funke [48], as the ability of individuals to face novel, complex, dynamic, and *intransparent* problems. Complex problem-solving ability differs from other forms of reasoning, like logical, spatial, or mathematical, and is a facet of human intelligence. The spectrum of complex problems ranges from large-scale problems such as global warming or financial crises, to small-scale conflicts in the public and private life. Nevertheless, complexity science and complex problem-solving research share common ground.

The concept of design has evolved from a craft for creating consumer objects and products to a generalized approach to build systems and solve complex problems. In this evolution, the practices of design have developed, as Cross vividly reviews [23], and design thinking, see Brown [14], and design research, reviewed in Laurel [90], are nowadays first order methodological and even epistemological frameworks.

The conceptualization of design thinking led to a wider attention to the Peirce's concept of abduction [125]. Abduction, as a type of logical argument, formalizes an extension of the reasoning possibilities beyond the two classical types of induction and deduction. Abductive reasoning became a conceptual foundation for design and for addressing complex problem solving in domains ranging from law to clinical practice.

Design elements have a strong homology with complex problem solving and a recurring tendency to challenge the deterministic reasoning types suggested by reductionism: divide a problem top-down in smaller parts, organized hierarchically, and then design bottom up. Even in engineering artifacts, traditionally seen as solid and built systematically, uncertainty or error are essential, as Petroski [126] illuminates.

Design and its methodological foundations have developed hand in hand with the evolution of digital and pervasive interactive technologies. A foundational program, leading to one of the most defining demonstrations of the digital world, by Engelbart [41], set the stage for a vision of interactive spaces in the H-LAM/T framework (*Human Using Language, Artifacts, Methodology, in which he is Trained*). This systemic goal of integrating humans and technology (*augmenting the human intellect*) is a fundamental principle in the design of systems and artifacts. From then on, the user interface was a core component of digital systems and Human Computer Interaction (HCI) grew a strong personality in computing ([33], 1st ed 1997), evolving to incorporate more and more human and social dimensions. The scope of HCI widened towards Interaction Design (Sharp et al [144], Moggridge [111]) and the space for the interaction opportunities expanded with pervasive and ubiquitous computing [42].

The evolution of the interaction design concepts and methods shaped the idea of user experience (UX for short). Digital technology expanded the space of interactive experiences for individuals, groups, and societies, in communicating, learning, or creation. Design became a key enabling process for the new experiences - design for the experience as claimed by Giovanella [53][54]. The UX goes well beyond the pragmatics of human machine communication and includes contextual, cultural, and emotional dimensions. As we will review, UX design should be situated in the scope of complexity and complex problem solving.

A final viewpoint is suggested by the consideration that the development of information technology in the last century has happened mostly in the western world. Cultural differences and variations became a first-order variable in digital technology design only in the last decades. Nowadays, cultural aspects affect the way problems are expressed and solved, the way design is performed, and the way experiences are invented and lived. One of the most referenced works on culture differentiation is *Cultures and Organizations* [73] (discussion in section 5). There, Hofstede sets up a framework for culture differentiation in organizations based on five indices of cultural values: power distance, individualism vs. collectivism, uncertainty avoidance, masculinity vs. femininity, and long-term vs. short-term orientation (a sixth came later, indulgence vs. restraint).

The cognitive differentiation adds another perspective. Nisbett [116] work has established distinctions in cognitive reasoning styles of East Asian (mainly Japanese) and Western (mainly American) individuals that define a spectrum from holistic to analytical types. These distinctions are observed at basic cognitive levels, like perception of simple visual scenes, and may be pre-conditions for the understanding of complex problems and user experience, adding up to different strategies for information exploration that individuals may show (independently of cultural traits) as reported in Giovanella and Canale [57]. At a more fundamental level, Lloyd [97] discusses cognitive variations among cultures in cognitive domains such as color perceptions, spatial cognition, emotions, and perceptions of health or well-being.

Cultural differences also impact on the experience design processes and goals. Since early work on ergonomics, user interface design or usability, cross-cultural aspects were identified, as is Clemmensen [21]. The globalization of the space of UX design generates opportunities for incorporating of cultural objects, references or metaphors that were until now hidden behind the cultural standards of western technology.

1.1 Motivation

This survey is motivated by the consideration that digital technologies, as they evolved from focused scopes (individuals users, specific tasks) to a pervasive background in modern societies (interconnected, data-intensive, social), have become critical instruments to deal with more and more complex problems. As such, looking at the design of digital experiences and solutions under the perspective of complexity and complex problem solving is a necessary consequence. Moreover, digital artifacts are also designed globally with culturally heterogeneous perspectives on problems, on design methods, and on experiences and solutions. Cultural context and variables should therefore to be integrated into the reasoning and design framework.

As this paper is being finished, the world is dealing with a global pandemic, COVID-19, that will be the subject of many papers in many scientific domains, as well as history books. This global and complex problem, and the techologies that are being used and designed to solve it, either bio- or digital, exposes, very emphatically, the dimensions that underly this survey: (i) the challenge of understanding the problem (and the myriad of sub-problems), (ii) the challenge of designing solutions (many of them digitally based – not only personal apps, but also data management, communication and coordination tools) and (iii) the challenge of bringing together culturally diverse perspectives on problem understanding, problem solving and effective experience designs that have been developed across the globe.

The primary audience for this survey are designers of digital experiences for global communities and the suggested question is "***how do designers tackle the complex problem of creating digital experiences in culturally diverse communities?***" This question is approached by looking at perspectives in the several research domains. The conclusion, or discussion, aims to inspire a deeper and pragmatic reflection on their convergence.

1.2 Structure

This survey starts, in section 2, with a perspective on complexity and complexity science and a review of research in the complex problem-solving domain. There is no assumption of equivalence between the two domains. Given the evident commonality in the departure point, however, there are grounds to relate perspectives and questions raised in the two domains.

Section 3 addresses foundational elements of design, the use of abduction as a pervasive reasoning modality and the perspective of design as complex problem solving. The concept of UX is introduced as the focus of conceptual and practical work on the design of digital experiences and the complex nature of UX design is highlighted.

Section 4 introduces cultural dimensions that are considered to be relevant in the understanding of complex systems and problems, and in the design of systems and experiences. Each one of the three sections (on complexity and complex problems, on design, and on culture) identifies a set of open questions that emerge from the reviewed literature. The conclusion highlights convergences between these bodies of knowledge, that are meant to be inspirational and should develop into hypotheses to be refined and tested in future explorations and experiments.

1.3 Review approach and process

A review based on bibliography search, as a bottom up approach, suggests that relations between the domains of complexity, complex problem solving, design (UX) and culture need to be harvested in a stepwise way. For example, keyword search for each of the topics in Scopus (www.scopus.com queries on "Article title, abstract, and keywords") resulted in 1537 hits for "complexity science", 973 for "complex problem solving", 3566 for "design thinking", 72286 for "cultural factors" and 28570 for "user experience". Pairwise combinations of these terms result however in highly sparse document sets, such as 1 for "Complexity science + complex problem solving", 4 for "complexity science + design thinking", 1 for "design thinking + cultural factors", and 36 for "cultural factors + user experience", 3 for "complex problem solving + cultural factors". These results led to the conclusion that the search for relations requires a more conceptual approach.

This review is based on: (i) a number of background, theoretical, and reference works, (ii) contributions from a core group of authors (and clusters of collaborators), and (iii) complementary examples and reflections included and commented in the context of the relations between the areas. The core authors are mapped below.

Table 1. Core authors and clusters of bibliographic sources

Complexity science	Complex problem solving	Design thinking	User Experience Design	Culture
Mitchell, M. (18)	Funke, J, (20)	Dorst, K. (15)	Hassenzahl, M. (29)	Nisbett, R. (64)
West, G. (47)	Wüstenberg, S. (13)	Cross, N. (18)	Thuering, M. (9)	Kitayama, S. (48)
Bettencourt, L. (34)			Clemmensen, T. (13)	
Johnson, J. (12)			Reinecke, K. (15)	
			Norman, D. (37)	

The number of core authors in this survey is fifteen (15). This small set of authors is believed to be representative of the individual domains and provides a solid background to search for relations between the addressed topics. The impact of the contributions may be confirmed in the www.scopus.com database, through the respective *h-index* (superscripts in the table above). H-indexes are generally isomorphic between databases like Web of Science, Scopus or even Google Scholar, insofar the impact of a group of authors, in spite of their variation in absolute value, correlates strongly across those bibliography databases.

2 Complexity and Complex Problems

Complexity is a concept of multiple natures. The interdisciplinary interaction of established sciences has created and nurtured the concept of complexity science, where mathematical and computational approaches converge in the understanding and explanation of problems. From the perspective of the human perception and intelligence the challenges created by problem complexity have been intensively studied by psychologists and cognitive scientists. This is the background for the review of the convergent perspectives on complexity and complex problems.

2.1 Complex Systems

A complex system, quoting Mitchell [101], is "*a system in which large networks of components with no central control and simple rules of operation give rise to complex behavior, sophisticated information processing and adaptation via learning or evolution*". Complementary concepts are defined by West [158]: "*complex collective behavior, the result of collective actions of vast numbers of components, each one following relatively simple rules with no central control or leader*".

Some characteristics of complex systems are: (1) the strong networked nature, composed by a high number of mutually connected, or interacting, elements – nodes, (2) the emergence of behaviors that cannot be inferred from the characteristics and behavior of individual components, (3) a dependency from initial conditions that leads to variable and hard to predict stable states, if any, (4) the relevance of "frustration", defined as "*non-coincidence of intentions and goals of the elements of a system*" by Giovanella [54], or "*the result of competing interactions in multidimensional levels (within and beyond the domain of biology)*" as in Wolf [161].

Mitchell and West, among others, resort to phenomena that are observed in physics, climate, living systems, economies and organizations to illustrate the above characteristics. When mentioning these system spaces, there is a quest for unification, if not of the models, at least of the epistemological perspective. In the background of much of the complexity reasoning are references like Systems Thinking [141], Cybernetics [159] or General Systems Theory [156]. These are often associated, as Gates [52] discusses in the scope of program evaluation in social interventions.

Complexity science is a conceptual and reasoning framework that attempts to harness the perplexity generated by system behaviors that escape reductionist explanations. The reductionist approach [75] decomposes a system top-down, in parts and subparts, with well-defined interfaces and communication mechanisms. In opposition, complexity science starts from elementary behaviors and observes the joint and cumulative evolutions in a connected space over a temporal line. These observations may be mediated by computational models or illustrated by computer supported thought experiments as in Axelrod [7] (Mitchell [110] pp 115-126 and pp 209).

Whatever the experiments and system domain, the goal is to understand emergent collective behaviors. The work presented by the Santa Fe Institute (*www.santafe.edu*) continues to be paradigmatic as a unifying view of complexity across heterogeneous domains. Introductory definitions and general context are given by Heinrich [68] and Chen [17]. A general survey on methods and techniques for quantitative understanding and modeling of complex systems is given by Newman [113] and a more recent example is presented by Johnson [82]. The future perspectives of complexity science development and its application in socio-economic domains are reviewed by San Miguel et al [138] and Johnson et al (eds) [83].

The exploration of complexity is often based on computer-based simulations developed from scratch in generic programming platforms or in environments that facilitate the simulation of real-world systems (for useful and recent reviews of Agent Based Modelling and Simulation tools see Abar [1] or Kravari [86]).

One of the top example domains, financial markets, is known for unexpected evolutions (financial unpredictability has a long history, see "*Extraordinary Popular Delusions*" [99]). Complexity science helps to explain some of the financial market behaviors. In [70] Hemakon et al present a computational and algorithmic approach to analyze, and eventually predict, financial stress: "*we examined the financial market from the point of view of complexity science […] This work has conclusively demonstrated the utility of posterior complexity science approaches in the assessment of financial stress*".

The adoption of the complexity science perspective also grew in contexts where human and social dimensions are critical. Although the direct mapping of complexity concepts onto these domains should be critically evaluated, McMurtry [103] outlines a sensible perspective on the linkages between complexity and activity theory (which underpins discourses in social sciences, for example), their similarities and differences.

Ramalingan [132] addresses the domain of development and humanitarian work, and Furtado [51] the domain of public policies. Ramalingan maps complexity onto the space of aid: "*the important implication of complexity science – that it provides ways for practitioners, policy makers, leaders, managers, researchers, to stop and collectively reflect on how we are thinking about trying to solve aid problems […] Similarly, responses to humanitarian crises are local, complex and adaptive – in the Asian tsunami, 97% of lives that were there to be saved were saved before international agencies arrived*".

Complexity science is also applied to the analysis of healthcare systems. Leykum et al [94] address interdependencies within the system "*[…] We identified system-level uncertainty as a defining characteristic of complex systems through which we interpreted our results. We identified characteristics of healthcare tasks and diseases that impact the ways uncertainty is manifest across diverse care delivery activities*". A note by Yuan [165] is relevant here as a sign of the tension between reductionist and holistic views in medicine (Western vs. Chinese), a topic we will revisit below.

A final example relates with cities and urbanism, linking to modern work on smart cities, as illustrated by Bettencourt et al in [9], [13], [10] or [139]. Bettencourt et al [10] "*address this challenge by discussing the character of cities […] as complex systems. […] taking a perspective of cities as integrated social networks embedded in space and time and requiring general properties for their open-ended land use and infrastructure development, provides us with a new unified model of urbanization*".

The quest for understanding the dynamic behavior of different systems guided the study of complexity. The question of how individuals tackle complex problems has been concurrently addressed. A scenario presented to (complex) problem solvers is described by Doerner [34]. The scenario highlights the multiple non-trivial problems that emerge when trying to improve the life of the *Moros* tribe in Africa. It is evident that this scenario resonates many of the complexity science tenets.

2.2 Complex Problem Solving

There are two foundational references in the study of complex problem solving from a cognitive psychology perspective: Sternberg and Frensch [147], and Frensch and Funke [48]. A critique of the two approaches is found in Quesada [131]. We focus on the European perspective, updated in Doerner and Funke [34], and review the associated body of work that crosses conceptual, experimental, and applied levels.

The concept of complex problem solving, as defined by the above authors, is: "*Complex problem solving is a collection of self-regulated psychological processes and activities necessary in dynamic environments to achieve ill-defined goals that cannot be reached by routine actions. Creative combinations of knowledge and a broad set of strategies are needed. Solutions are often more bricolage than perfect or optimal"*.

According to Funke [49]: "*the typical attributes of complex problems are (a) complexity of the problem situation which is usually represented by the sheer number of involved variables; (b) connectivity and mutual dependencies between involved variables; (c) dynamics of the situation, reflecting the role of time and developments within a system; (d) intransparency (in part or full) about the involved variables and their current values; and (e) polytely (Greek term for many goals), representing goal conflicts on different levels of analysis*".

The body of research on complex problem solving (CPS) is anchored in the use of artificial (computer-based) experimental environments (microworlds) where minimal complex systems (small systems with a small number of variables), based on MicroDYN [58] [59], play a central role to assess CPS ability under multiple experimental conditions[1]. The issue of CPS ability assessment and the validity of the different instruments have been persistently discussed throughout this research. The reflection on the limitations of the studies insists, for example, on the effect of analyzing CPS ability *in vitro* (i.e. in the lab) versus *in vivo* (in real world conditions), and on the effects of learning generated by a small systems-based assessment. The debate

[1] MicroDYN and other scenarios are built with a computer platform for complex problem-solving assessment, called CBA (Computer Based Assessment). Item Builder is available from the German Institute for International Educational Research (DIPF) (https://www.dipf.de/en/research/research-infrastructure/software-for-computer-based-assessment).

concerning the CPS ability assessment illustrates the difficulty of the goal, as evident in Wüstenberg [162] and Funke [49].

Whatever the methods and the validity of the procedures, the goal of designing assessment instruments for CPS is justified and the characteristics of complex problems are an important baseline. In this line of reasoning, the identification of complexity characteristics for a given problem is an important step to distinguish complex problems from merely large or "complicated" problems. This identification is illustrated by Amelung [3] when analyzing climate engineering a scenario for CPS.

The study of complex problem-solving strategies assumes a stepwise and iterative structure: as in Fischer et al [43], "*the process of CPS usually consists of different phases: (1) knowledge acquisition and (2) goal-oriented knowledge application. Usually, a problem solver switches between these phases in a complex way [...]*".

Together with the definition of CPS, its testing, and assessment, other dimensions were highlighted. A first one is the role of emotions in CPS, and the second is the cross-cultural/cross national study of CPS. We will return to these two dimensions below.

A third dimension is the view of CPS ability as "*one of the key competencies humans need in a world full of change, uncertainty and surprise*" [24]. The goal of testing and assessing CPS ability is now an element of the educational strategic thinking at a global level, and is now part of the OECD PISA procedures, where the dynamic problem-solving perspective was introduced (since PISA 2012) [24].

The complex problem-solving and the complexity science perspectives are not equivalent but are certainly convergent. Table 1 below illustrates the linkages between complexity and CPS concepts. In this convergence, we position Irwin [77] and her proposal of transition design as an emerging approach to deal with "wicked" problems, i.e. problems recognized as complex by both views.

Table 2 . Complexity and Complex Problems (links do not reflect strict equivalence)

Complexity from [110][158][54][161]	Complex Problems from [2][34][48]
networks on (many) elements	*number of interdependent variables*
emergent behavior	*dynamics of the situation reflecting the role of time*
dependence on initial conditions	*intransparency about the variables*
frustration	*politely = goal conflicts and different levels of analysis*

3 Design and User Experience

Design theory and methods set the stage for the idealization and creation of digital experiences. This section opens with the notion of abductive reasoning as an important conceptual principle to deal with the design complexity. Next, the specific domain of UX design is presented, with an emphasis on new dimensions of UX design. This reflection must be taken as partial, insofar it does not address processes, methodologies, or the encompassing concept of design literacy (as in Giovanella [55]).

3.1 Abduction and Design

Abduction is a form of reasoning. Suggested, admitted, or intuited by Aristotle [129] as a third form of reasoning, alternative to deductive reasoning (present in logic, mathematics or geometry) and to inductive reasoning (the method of natural sciences like physics, biology or geology), it was Peirce [125] who brought the concept to the light of modern epistemology and made it a fundamental reference in modern times. According to Peirce's original definition, that distinguishes this form of inference from induction or deduction, abduction can be logically represented as:

"The surprising fact, C, is observed,
But if A were true, C would be a matter of course,
Hence, there is reason to suspect that A is true"

Peirce also defines abduction as *the operation of adopting explanatory hypotheses*. Explanatory hypotheses can translate to possible designs, to a correct clinical diagnosis, or to an organizational innovation.

A broad perspective of abduction motivated by the relation with the Chomsky linguistic theories and with the concept of sub-cognition suggested by Douglas Hofstadter [72] (an inspiration for complexity science pioneers) is presented by Melrose in [104]. We retain his final conclusion: "*[...] what remains seductive in abduction - apart from the fact that it may be a 'natural hypothesis' - is that it permits us to glimpse an alternative to the cognition model, to reductionist linguistics. For it opens up the possibility of a linguistics that attends to spreading feelings, arbitrary spontaneity, sub-cognition, symbols with halos, the wavelike aspect of language, process, and the 'choreography' of the spoken mode*". Another analysis of abduction is presented in [46], mapping this reasoning mode to management research.

Design has recently become a reasoning and methodological framework, beyond the sum of crafts and practices adopted by builders of systems and creators of artifacts. The term "*design thinking*" also became a reasoning style that propagated to eclectic domains such as engineering, management or social sciences [31] [71]. Boy [12] discusses the design of complex systems with a focus in human experience.

The analysis of abductive reasoning in design is systematically discussed by Dorst [36]. In this work, "*the core of design thinking and its application - a model from formal logic is used to describe key reasoning patterns in design and as a basis for understanding how design deals with open, complex problems*". Abduction is introduced as the basic reasoning pattern in productive thinking - where value creation is the objective. Two types of abduction are identified: Abduction-1 associated with conventional problem solving, and Abduction-2 associated with open and complex problems where only the end value is known to the problem solver (the designer or design team). Abductive reasoning presented by Johansson-Skoldberg [81] or Meyer [105] as a core component of design thinking. The first authors review design thinking discourses and position abduction "*in the idea generation phase of design thinking as a way to approach indeterminate organizational problems*". Likewise, the second author establishes that "[...] *in design thinking, abductive reasoning is used to generate ideas and form solutions to ill-defined problems*" (citing Cross [22]).

Abduction is present in diverse domains where unique or specific systems and solutions have to be designed. Clinical reasoning (in nursing) is discussed by Mirza et al [109] where tools like storytelling emerge as key elements in the design process and in solving complex problems. In this context, the authors conclude that "*the abductive reasoning strategy [...] provides a pragmatic approach to exploring and explaining a care situation. As a scaffolding technique, the proposed strategy within Problem-Based Learning could enable the broader detection of salient points and the creation of hypotheses*". A similar context, clinical reasoning in psychology, is presented by Vertue [155], where "*ATOM (abductive theory of method) provides valuable insights and suggestions for enhancing the work of clinical psychologists [...] The complex, systemic nature of human functioning means that any case conceptualization will necessarily rest on simplifying assumptions and idealizations. [...]* ". In management sciences, abductive reasoning is studied by Dunne in [37], where the authors present "*an empirical analysis of how people actually use abductive reasoning in complex product innovation*".

Recalling Doerner's definition of a complex problem, complex problem solving recurs to abductive reasoning styles. Moreover, complex problem-solving ability may be viewed as homologous to abductive reasoning ability (and its assessment).

As a related concern, relevant to educators, some studies address the role of abductive reasoning training in higher education and its relevance for the design ability of students and future professionals. At the educational level, the abductive reasoning ability should be related with the ability to handle complexity or CPS ability. O'Reilly [122] notes that: "*the level of encouragement for abductive reasoning found in the degree project intended learning objectives assessed (in Swedish KTH engineering programs) was low to medium with no explicit or strongly implicit encouragement to be abductive*". Self [140] compares (design) problem solving strategies of design and non-design students to conclude (cautiously) that "*design students appeared to more readily engage abductive reasoning when engaging a typically ill-defined design problem"*.

3.2 User Experience

Human machine interaction has its roots well before interactive computing. Many principles and guidelines have been laid out with the industrial revolution. One example of this path is the German school of *psychotechnik*. Johanssen [80] and Hellige(ed) [69] give historical and broad perspectives coming out of the German industrial traditions.

The development of personal computing stimulated the design of new user interfaces. The Engelbart demo [41], coined as "the mother of all demos", brought to the public a significant number of functionalities that are taken for granted nowadays, 50 years later (bitmapped screen, pointing devices, hypertext features, conferencing and distributed computing). This demo and the contribution of Xerox Parc with the Alto and Star machines inspired the current dominant creators of digital environments to develop the framework for the computing literacy of the 20th and 21st century.

Contemporary digital environments reflect the convergence of work on human computer interaction, from early graphical user interfaces (aka GUI's) to multimodal interfaces (graphical plus touch, gesture, voice and pattern recognition, like fingerprints or faces). Usability research and engineering was a core element of this progress. With their development, the toolbox of methods and tools for the lifecycle of interaction design was developed and refined, including (multidisciplinary) models and theories, user and task analysis [62], prototyping and testing techniques [87], [33] and [144].

As usability research and engineering matured, together with some dialectical perspectives - see Don Norman in [119] [120], a new focus for interaction design emerged in the last decade, based on conceptual, technical and industrial needs: the focus on user experience (UX) design. Two driving forces should be considered here.

The first trend was the evolution of the technological landscape due to the invention and development of a multiplicity of devices types. The seminal paper by Mark Weiser [157] and the work of Xerox PARC set a starting point for the digital transformation of our environment, from the desktop computer to the portable devices, now generalized in mobile phones and social networks, to the present and coming IoT (Internet of Things). The presence, often seamless as described by Streitz [148], of digital devices in our physical and living spaces, from the workspace to the home, the car, the built environment or the city, has implications for design and for the explosion of the complexity of the user experience. For example, a discussion on mapping interaction concepts onto elements of the urban space (*media façades*) is made in Diniz et al [31].

The second trend was the consideration of emotion as a first order dimension of the scientific and technological vision of the world. The importance of emotions in human cognition and reasoning has been definitely established by neuroscientists like Damásio [26] and the emotional dimensions in the design of digital experiences have been conceptualized as in Picard [127], Norman [118] or Fogg [45].

The definition of UX. The concept of user experience (UX) is an outcome of the above trends, even if “user” should give place to “human” in the digital environment. The characterization of UX has been extensively debated in the last years. A consistent observation is the fuzzy and multidimensional nature of any UX definition. This has led to the search for implicit, bottom-up, and survey-based definitions.

One example is given by Law [91] followed by Lallemand [89]. Law et al conclude, based on a survey of 275 researchers and practitioners, that “*respondents tend to agree on a concept of UX as dynamic, context-dependent and subjective, which stems from a broad range of potential benefits users may derive from a product*”. Lallemand et al survey 758 researchers and practitioners on top of the previous survey and look for consensus on the UX concept. They report a higher resolution perspective of UX, identifying consensus on “*the importance of both user-related factors and contextual factors as important variables shaping UX as well as on the temporal dynamics of UX*”.

The empirical characterizations coexist with theoretical reflections, like Pucillo’s discussion [130] on the generalization of the affordance concept and its psychological foundations and also with the standardized ISO definition of User Experience as in [79] “*a person’s perceptions and responses that result from the use and/or anticipated use of a product, system or service*”.

The vision and conceptual model of the UX presented by Hassenzahl [66] suggests three levels for the design of the interaction with an object: the What, the How and the Why: “*the What addresses the things people can do through an interactive product, such as making a telephone call, buying a book, or listening to a song and is reflected* *by a products' functionality […] the How addresses acting through an object on an operational, sensory-motor level: Buttons pressed, knobs turned, menus navigated, touch screens stroked, or remotes waggled […]. The How is the typical realm of the interaction designer: to make given functionality accessible in an aesthetically pleasing way*". Finally, "*the Why* [...] *encompasses peoples' actual motivation to use a product. For the couple being separated, the SMS was not primarily an SMS, it was a love message, a way to fulfill their need for relatedness. This is the Why of product use [...] and relates this level with the foundations of the design process: Experience Design is a remedy to this. It starts from the Why, tries to clarify the needs and emotions involved in an activity, the meaning, the experience*". This perspective of the UX design matches the seminal Winograd and Flores view [160] whereby the end goal of interaction design is to create structural coupling in the system composed by the human user and the artifacts. The above *Why* may be associated with the goal of invoking, through design, the Heideggerian concept of thrownness or being-in-the-world that was adopted by these authors as a conceptual reference.

Bargas-Avila et al [8] review "*how empirical research on UX is conducted, based on systematically selected sample of 51 publications from 2005-2009, reporting a total of 66 empirical studies"*. In general, and with the purpose of identifying UX dimensions, the authors synthesize that*: "UX takes a holistic view of users' interaction with interactive products, [...] UX focuses on positive aspects of the interaction, UX emphasizes the situational and dynamic aspects of interaction [...] and the importance of context [...], UX views and models the quality of interactive products as multidimensional [...] including the value of a product to accomplish tasks and also its symbolic and aesthetic value, and UX entails a need for new methods and approaches for designing and evaluating experience*".

As a critique of the current understanding of UX, two observations from this review are especially relevant here: (i) "*a heavy emphasis on art and consumer products [...] Further the turn to art and consumer products may preclude conclusions about experience with other types of products*" (this observation is in line with the above note on the pervasiveness of digital devices and calls for a reflection on the opening of the UX design and validation methods to a broader scope of environments) and (ii) concerns are elicited on the methodological dimension: "*First, the proposals for new methods are rarely validated. In usability evaluation, many papers have highlighted the difficulty of comparing methods [...]. In UX methods, these difficulties receive scant attention [...]. Second, what we call constructive methods (e.g., sketches, probes) are not only rarely validated and raise many issues about the process and validity of interpreting their results [...]. Third, some authors argue the need to rely on first-person methods for understanding experience. In contrast, much work on user centered design and usability research emphasize that we need to look at behavior, what people do, rather than merely listen to what they say and what they say they do*".

Overall, the exploitation of and the reflection on the concept of UX converges to a multi-dimensional reasoning framework that takes into account: (a) the user-centered pragmatics and rhetoric of the interaction, (b) the context where the experience occurs, (c) the process-related diversity of the experience styles, a refinement of the "What" mentioned above, and (d) the dynamics of the experiences. A comprehensive framework for the representation of the UX (3D+1) is proposed by Giovanella [54]. Some recent results on context measurement are reported by Lallemand in [88].

The focus of this survey is not to discover the ultimate definition of UX but to highlight some of the new intertwined experiential dimensions of digital artifacts that increase the complexity of the design and intensify the impact of cultural features. The new dimensions are complementary to the functional and pragmatic ones that were dominant in the early principles and guidelines of usability.

Aesthetics and Emotion in the UX. A distinctive and researched attribute of user experience falls into a point of convergence between concepts like beauty, aesthetics, and hedonic features. The first is a social and historical creation (on beauty and ugliness, see Eco [38], [39]). The later are inventions of the Greek philosophers that crossed centuries in philosophical reflections.

Aesthetics, while defined by conventions that evolve over time in cultural contexts, has reflections on the emotional element of the experience. On the primitive relation between aesthetic pleasure (beauty) and perception, Reber et al [133] assert *"[...] aesthetic pleasure is a function of the perceiver's processing dynamics: The more fluently the perceiver can process an object, the more positive is his or her aesthetic response*". The conclusion is inspiring for the further review of work on UX design: "*we have seen that beauty does not rest in the objective features of an object but derives instead from the processing experiences of the perceiver. Is beauty therefore in the eye of the beholder? [...] beauty appears to be in the interaction between the stimulus and the beholder's cognitive and affective processes*".

In the scope of the UX frameworks, the hedonic features of interaction are systematically addressed in Diefenbach [30], Hassenzahl [66], and Lenz [92],[93].

Dieffenbach et al summarize the hedonic dimension of the interaction as: "*the concept of hedonic quality provides a more concrete idea of product attributes related to positive experience. It created a bridge between the general "experiential" claim on the one side and product design and especially evaluation on the other side*".

Hassenzahl et al [65] collected over a thousand technology-mediated positive experiences with media and obtained measures describing aspects of the experience itself (affect, psychological need fulfillment) and of the product (i.e., content and technology) integral to the experience (pragmatic and hedonic qualities). They report "*a strong relation between intensity of need fulfillment and positive affect. [...] Pragmatic quality was not linked to experiential measures. [...] the study further emphasizes the qualitative difference between hedonic and pragmatic quality perceptions. All in all, pragmatic quality was not related to the experiential variables studied. [...]* ".

Another stream of work identifies emotional and other cognitive features in the UX and focuses on their evaluation and assessment. Mahlke et al [100] devise the measurement the different components of the interaction's emotional experience as a "*combination of self-assessment ratings, physiological indicators and cognitive appraisal questionnaires*". Thuering et al [151] bring together emotions and perceptions of instrumental and non-instrumental qualities in the CUE model (Components of User Experience) and support the assessment and evaluation of the UX (meCUE - modular evaluation of key CUE) on questionnaires ([107], [108]). Still in the scope of identifying characteristics of the UX, Gross and Thuering [60] present an analysis of the effect of surprise on UX, concluding for the negative effect of unexpected events and leaving open the evidence of positive effects of surprise. They show that there are non-instrumental factors beyond aesthetics to be considered in the UX design, leaving it open for further research.

The above research examples pave the way for this survey. UX, even though it encompasses the previous usability concept (together with its requirements, principles, assessment and validity), goes beyond its pragmatic goals. The number of variables in the design and evaluation of the UX is therefore much larger than the number of factors considered for usability evaluation and one of the dimensions to be considered is the intertwining of the aesthetical attributes of the artifact and their emotional reflection on the user. This focus on the emotional dimension of the UX does not rule out other UX dimensions that motivate the actions of individuals, like safety - Antonelli [4], comfort versus fatigue, or augmentation as defended by Engelbart [41].

Related to our convergence goals, and in the context of CPS, studies like Spering [146] question "*whether positive and negative emotions differentially influence performance in complex problem-solving in the same way […] showing that the overall scenario performance is not affected, but positive and negative emotions elicit distinguishable problem-solving strategies: participants with negative emotions are more focused on the seeking and use of information*".

3.3 UX Design as a Complex Problem

Given the above discussion, we argue that the design of the UX is a complex problem. To support this argument, we relate to the reasoning path of Amelung et al [3] that apply the complex problem solving (CPS) perspective to the domain of climate engineering. By analogy, we show how UX design can be seen as a complex problem.

Quoting again [3], and reusing the definition presented above, a complex problem has the following characteristics: *"(a) the number of elements relevant to the solution process is large (complexity) as well as highly interconnected (connectivity), (b) the system is dynamically changing over time (dynamics), (c) neither the decision structure nor its dynamics are fully disclosed to the actor (intransparency), and (d) goals are not easily set: in dealing with a complex problem, a decision maker is confronted with a number of different goal facets that have to be weighted and coordinated (polytelic situation)*". UX design may be analyzed under this perspective.

Complexity. The number of variables to be considered in UX design is large. First, the number of user types (human heterogeneity) is large, either in systems or artifacts targeted for specialized user groups (corporate and professional environments) or in systems of artifacts designed for the general public or consumer market where, for example, the cultural variations discussed below are more and more relevant. Second, the number of functional and usability requirements, as well as the acceptance, adoption and emotional involvement criteria are multiple. Finally, the technological options and constraints are usually diverse, from the core computing and network infrastructures to the surface interaction modalities.

Connectivity. The variables involved in UX design are mutually connected. Users are connected to other experiences, share context and relations with other users in groups or communities; usability principles and guidelines are connected with frameworks of analysis and evaluation and with external references like standards. The technological platforms are, by definition, networked and interdependent.

Intransparency. Both user and designer have to cope with hidden features of the digital artifacts as there are always tradeoffs between the simplicity of use and the knowledge of the internal mechanisms of the artifact or system. Not all the technical and usability factors are open for manipulation or observation (just look at our cars, computers or washing machines).

Dynamics (and **emergence**). The UX is far from static. At the individual level, people evolve with factors like learning, adaptation or age. Often, the uses of an artifact are unanticipated by designers and emerge from usage (SMS is a paradigmatic case). At the group and social level, simple functionalities lead to the emergence of social phenomena as we have been witnessing with knowledge creation and sharing or privacy challenges in social networks. The dynamics of the individual experience in a social setting feeds back into the initially designed experience.

Polytely. The design of digital artifacts, for individual or collective use frequently addresses conflicting goals as, for example, user's pleasure, satisfaction or health, often opposed to work efficiency, employee satisfaction, corporate productivity or social responsibility at an individual, group or community level. Many of the UX goals derive from social and political regulations and norms.

The analysis presented above is not a reflection of the discursive complexity associated with UX design. The process and the results are complex phenomena themselves, evoking the attributes that are inherent to complexity, such as emergence, *gestalt* effects or dependencies from initial conditions.

4 Cultural Dimensions

The impact of the cultural context in the design of digital artifacts is expected to become widespread. For decades, digital technology has been designed in the context of the western culture, based on western inventions and engineering innovations, which embed a whole background of cultural references and metaphors, as well as reasoning pre-conceptions (the digital computer, the mouse, the desktop metaphor). In this second decade of the 21st century, we are witnessing radical transformations in the geography of technology design and development. Some examples are the Chinese social networks (*WeChat* or *Weibo*), used by hundreds of millions of users and developed out of the traditional centers of technology, the Indian mobile networking services, expanding at unprecedented rates, or mobile payment services like MPESA, that brought together millions of users in Kenya, prior to similar systems anywhere in the world.

The globalization of artifacts encompasses a globalization of design and brings cultural variables to the forefront of design. The relation between culture and technology and the tension between social uniformity and difference in the scope of the technology adoption is presented in Nye [121] and deepened in Pineda [128]. In short, digital designs, pervasive, immaterial and borderless as they are, may be understood as *glocal* artifacts, as global designs to be adapted for the local experiences.

Taken technological globalization as a fact, cultural diversity plays a first-order role in technology design, use and literacy, especially considering that it also leads to cognitive diversity, with deep impacts on the UX. In [25], D'Andrade forecasted this diversity: "*I have tried to present the view that culture, as the source of most of the shared representations and procedures with which we do our thinking, is part of the basic material to be studied within the framework of cognitive science*". Miller [106] spots cultural heterogeneity in styles of reasoning, *"[...] it is demonstrated that at older ages, Americans make greater reference to general dispositions and less reference to contextual factors in explanation than do Hindus. References to general dispositions also undergo a much greater developmental increase among Americans than among Hindus, whereas references to contextual factors show the opposite pattern of developmental change*".

In this section, concepts and research on cultural differences that are believed to have implications for dealing with complexity and design challenges are surveyed, starting with general cultural differentiations established by reference research, followed by studies of cross-cultural implications in UX design, and finishing with a reference to the use of cultural-specific artifacts and metaphors in the design itself.

4.1 Cultural values, cognitive styles and cultural dispositions

A widespread reference for cultural differentiation is Hofstede [73], in the early 1970's, and the known IBM study. Hofstede defined five (then six) dimensions of cultural values (1) Power distance (PDI), (2) Individualism vs Collectivism (IDV) (3) Uncertainty avoidance (UAI) (5) Long-term vs short term orientation (LTO) and (6) Indulgence vs restraint (IND). The questionnaires, applied to 100,000+ employees of IBM in 40-50 countries, generated a map of cultural values differences. The Hofstede framework has been vastly applied in organizational and management studies, like communication and marketing, but also in usability studies and in UX design analysis.

Nisbett and colleagues [114] [115] [102] [116] and Kitayama et al [85] studied variations of cognitive styles. The distinction between the analytical and holistic reasoning styles of westerners (mainly American) vs. east Asians (mainly Japanese) respectively, was observed and measured. The core finding, in the opening of Culture and Systems of Thought [115], is *"[...] East Asians are holistic, attending to the entire field and assigning causality to it, making relatively little use of categories and formal logic, and relying on dialectical reasoning, whereas Westerners are more analytic, paying attention primarily to the object and the categories to which it belongs and using rules, including formal logic, to understand its behavior [...]*".

The causes of the cognitive style differentiation, discussed by Varnum et al [154], are possibly related with social orientation, in particular through the in- or inter-dependence variable (not excluding hypotheses like language or genetics). This causality may be important when we consider the dynamics of cultural styles in individuals or group involved in design and use of digital artifacts.

More recent works refined the holistic/analytical differentiation: (i) different geographies were explored by De Oliveira [28], [29], (ii) the effects of priming as a mechanism to influence culturally determined cognitive styles by Tominaga et al [152] and (iii) other specific effects of culturally determined cognitive differences like Senzaki et al [142], Ueda et al [153] and Cheek and Norem [16] were studied.

Deeper cultural variations, or dispositions, are studied by Lloyd in [97] from an anthropological perspective. Lloyd addresses cognitive variations in color perception, spatial cognition, visions of the natural world, emotions, perceptions of health and well-being, and notions of self, agency and causation. The epistemological frameworks of different (ancient) cultures are the subject of a recent book [98]. These views have an impact on the reflection about the implications of culture in design.

Cultural background and Programming Paradigms. Programming models like object-programming (OOP) are an example of cultural influence. In 1988, Stroustrup, the main designer of the C++ programming language, summarized OOP as "*programming using inheritance beyond data abstraction*" [149]. In the currently pervasive Java (docs.oracle.com/javase/tutorial/java/concepts), the definition of object is "*models of the real-world objects that you find in everyday life*", the definition of class is "*models of the state and behavior of a real-world object"* and the definition of an interface is *"a contract between a class and the outside world*". These views are clearly related with the Aristotelian Categories [5] and the concepts are projections of the western philosophy roots. In the same line of reflection, the differences in perception and adoption of fuzzy logic between the East and the West, described in [166], deserve further study.

4.2 Complexity and Culture

Correspondences between complexity science concepts and cultural theory and frameworks are a contribution for the refinement of the convergence we have been shaping. An important link is created by the reasoning strategies that may be induced by cultural background in the presence of complexity and complex problems.

Complexity overlaps wicked problems [67][15] and challenges design thinking processes. These are impacted by social and individual characteristics with close relation to culture, as Thompson illustrates [150]. The reasoning on wicked and on complex problems is impacted by the attitude towards uncertainty, a related studied like ambiguity tolerance (AT) [50], and also by the abovementioned notions of analytical vs. holistic cognitive styles. These cultural traits ought to be considered in the design processes facing the contemporary problems as discussed by Diwekar et al [32].

In the scope of the CPS studies Guess [61] and Wüstenberg [163] report cross national studies of CPS. The nationality of individuals impacts problem-solving ability and strategies. This study, actually presented as cross-national and not cross-cultural – "*examined cross-national gender differences in [...] CPS and their determinants. A CPS test relying on the MicroDYN approach was applied to [...] Hungarian and German high school students [...]. Results showed that measurement invariance of CPS was found across gender and nationality. Analyses of latent mean differences revealed that males outperformed females and German students outperformed Hungarian students*".

As a lateral, and maybe inspiring level, Shaw [145] proposes to model *culture* as an emergent collective behavior resulting from the interaction of individual mental representations. The conclusion of the work is that "*a model (an empirically grounded model of individual sense-making + Agent Based Modelling (ABM)) was able to speak to the spontaneous emergence and patterns of shared representation, cultural path-*

dependency and 'lock-in', endogenous sources of cultural change, and the manifestation of these collective processes in individuals' experiences of culture" [2].

4.3 Culture and User Experience Design

In this survey, we look at three dimensions of cultural factors in UX design. The first one is the adaptation of usability principles and guidelines to encompass cultural contexts. The second one relates with the impact of cultural attitudes and perceptions in the design methods. Finally, we consider the presence of cultural elements in digital artifacts themselves.

Culture and Usability. The expression "cultural user interfaces (CUI)" has been presented back in 1996 by Yeo [164], who defined the concept as "*a user interface that is intuitive to a particular culture. The CUI takes advantage of the shared or common knowledge of a culture which could be defined by country boundaries, language, cultural conventions, race, shared activities or workplace*".

Reference works on the interplay between culture and usability are [18][19][20] and [21] by Clemmensen et al. In [19] these authors (with Nisbett in the background) *"[...] discuss the impact of cultural differences on usability evaluation that are based on the thinking-aloud method (TA). The term 'cultural differences' helps distinguish differences in the perception and thinking of Westerners (people from Western Europe and US citizens with European origins) and Easterners (people from China and the countries heavily influenced by its culture)*". Frandsen-Thorlacius [47] analyses differentiation of user's perceptions from different cultures towards focused usability attributes, like visual appearance, fun, effectiveness or efficiency. In [18], Clemmensen proposes a *"[...] theoretical background, related work and a definition of culture that should be useful for studies of cultural fit in multiple-country usability testing*".

The use of the Hofstede's framework of cultural dimensions to analyze and guide web-based developments (sites or information) has been presented initially by Marcus and Gould [101] and reused more recently, as in [40] or [2]. Marcus and Gould [101] propose to "*contribute to the study of this issue [the impact of culture on the understanding and use of Web-based communication, content, and tools] by analyzing some of the needs, wants, preferences, and expectations of different cultures through reference to a cross-cultural theory developed by Hofstede*".

Heimgärtner [67] extends the strict usability perspective into a more comprehensive model for the incorporation of cultural factors in HCI, a model that can also provide operational indications like distance or effort to meet cultural diversity. The author states that "*the HCI style of different cultural groups can be compared using the HCI style score, which is computed from the values of cultural dimensions […] Using these values, the HCI designer can prognosticate the localization effort and expenditures*".

Reinecke [134] [136] proposes the concept of culturally adaptive interfaces integrating cultural factors in the behavior of interactive systems and opens a research stream on the topic. As argued, "*one of the largest impediments for the efficient use of software in different cultural context is a gap between the software designs – typically following western cultural cues – and the users, who handle it within their cultural*

[2] In NetLogo 4.1 (ccl.northwestern.edu/netlogo/) to implement the agent learning algorithm and model design

frame [...] this thesis introduces a new approach called cultural adaptivity".

The vision and methods proposed above are further developed by Nordhoff et al [117] to website design in a reference study with a significant corpus of websites: "*we contribute the first large-scale analysis of 80,901 website designs across 44 countries, made available via an interactive web-based design catalog. Using computational image metrics to compare the 2,000 most visited websites per country, we found significant differences between several design aspects, such as a website's colorfulness, visual complexity, the number of text areas and the average saturation of colors*". Nordhoff et al [117] also make an additional contribution, "*Juxtapose*[3]*, an interactive design tool [...] which main functionality is the comparison of website designs between two countries […]*".

Reinecke et al [135] contextualize the cultural adaptivity concept in the methodological framework of design science: "*In a design science approach, we have developed a number of artifacts that support cultural adaptivity, including a prototype web application. We evaluate the efficacy of the prototype's automatically generated interfaces by comparing them with the preferred interfaces of 105 Rwandan, Swiss, Thai, and multicultural users. [...] The research presented here follows a design science research approach"* ([71] and [124]).

Cultural influences in the UX design process. The cultural background influences not only the prescriptive guidelines for usability and user experience design but also the design process and its creative and reasoning steps. Recalling some of the elements of the interactive design lifecycle, like prototyping alternatives (high fidelity vs low fidelity) or testing techniques (like questionnaires, thinking aloud, cognitive walkthroughs) we can anticipate, based on the discussion on cultural variations, that diverse design or user groups will show diverse perceptions, attitudes and judgments.

Hakken and Maté [63] address culture in participatory design (PD) discussing "*the extent to which PD practices are culturally dependent, what kinds of changes in PD practices are needed in each new cultural context, whether the changed practices can be legitimately still be called PD,* how *can PD practitioners deal with culture?"*

Clemmensen et al [18] discuss cultural factors in the scope of design thinking. They aim "*to understand how cultural knowledge shapes design thinking*". The authors approach the problem by "*integrating two frameworks, one on reasoning patterns in design thinking, the other on the dynamic constructivist theory of culture, and proposing a situation specific framework for the empirical analysis of design thinking in cross-cultural teams, which is then applied to 16 episodes of design*". They conclude that "*this is the first empirical study of induction, deduction, and abduction in a cross-cultural context of a design thinking process. We believe that the integration of Dorst equations with the triple A in our framework is as a starting point for further empirical research that explores and analyze cultural aspects of core design thinking processes*".

Cultural elements in the UX. Since the early models of HCI, metaphors have played a central role in the design of the interface, especially when graphical user interfaces became universal in desktop computers [33], [144]. Icons in the desktop and their manipulation, are the vivid example of the association between the interaction language

[3] http://www.juxtapose.labinthewild.org

and real-world objects and behaviors. The metaphor is a catalyzer for cultural elements and references. The earlier trashcan or mailbox icons are simple examples of reuse of references from the North American culture.

Real world objects and metaphors meet together in tangible user interfaces (TUI) as defined by Ishii [78], "*user interfaces that augment the real physical world by coupling digital information to everyday physical objects and environments*". Fishkin [44] reinforces the role and pertinence of metaphors in TUI - "*We believe that metaphor is particularly appropriate for TUIs, as opposed to other interfaces, due precisely to their physical tangibility. Once parts of an interface are made physically tangible, a whole realm of physically afforded metaphors becomes available*" - and goes on to propose a taxonomy for analysis of this class of interaction style.

The TUI concept shows how cultural elements may become references for UX and interaction design. The concept of cultural forms is presented by Horn [76] with the following purpose: "*designers can evoke cultural forms as a means to tap into users' existing cognitive, physical, and emotional resources. The emphasis is less on improving the usability of an interface and more on improving the overall experience around an interactive artifact by cueing productive patterns of social activity*". As a *quid pro quo*, this evocation may limit the universality of a design.

A rich example of the design of UX based on a culturally significant object is illustrated by Lin et al in [96]. This work is an example of "*cultural ergonomics, an approach that considers interaction- and experience-based variations among cultures. Designers need to develop a better understanding of cultural ergonomics not just to participate in cultural contexts but also to develop interactive experiences for users*". Specifically, "*the study aims to combine cultural ergonomics and interactive design to explore humane culture interaction in user experiences. The linnak is a typical Taiwanese aboriginal cultural object*". In this example, the traditional object called *linnak* (a kind of multiuser cup for ceremonies in the aboriginal culture) is repurposed into modern times artifacts. As the authors state, "*Cultural product design is a process of rethinking or reviewing cultural features and then redefining them to design a new product that satisfies modern consumers by way of cultural and aesthetic feature*".

5 Conclusion

This conclusion and discussion is an open synthesis of the convergence of complexity, design and culture, with a particular focus on the design of digital experiences. Questions that emerge from this convergent perspective are raised and working hypotheses are laid out with the aim of inspiring future inquiries.

5.1 Discover and harness the complexity

The early stages of design methods are data gathering, inquiry, problem mapping and interpretation, often condensed as the empathize stage. The digital experience is often the reflection of a productive endeavor that aims to solve complex or wicked problems. In the scope of this review, problems should then be addressed under a complexity science perspective and/or as a complex problem-solving step, an initial element of sensemaking in the design activity.

At a descriptive level, natural systems (physical or biological systems) or simple social/cooperative systems like the prisoner's dilemma representation of Axelrod or the flock of birds' example [11], may be modeled by mathematical and computational techniques or agent-based approaches. The application of complexity science to social problems (e.g. urbanism, healthcare, management or political science) seeks to: (i) characterize the problem space as complex (adaptive, interconnected, with emergent properties and dependent from initial conditions) and reach a descriptive analysis of that problem space, (ii) reduce the problem to a network of interacting individuals with (individually) simple behavior, (iii) proceed with modeling and find prescriptive or predictive results that anticipate emergent behaviors and will ideally guide design.

The identification of complexity is essentially a search for emergence, deviations from expected states, explanations resulting from the sum of individual parts. The recognition of the complexity in a system is a first step in problem solving, its knowledge acquisition phase (the observe and notice moment of design thinking).

Discover complexities. For discovery and sensemaking purposes, how can complex problems, namely those that involve individual or social behaviors, be identified and tracked? The complex nature of problems can be harvested and deconstructed through quantitative methods [167] or qualitative approaches [123] or [64]. We hypothesize that an effective way to discover and expose the complexity in complex or wicked problems is to aim at complementary and congruent methods integrating intensive, and possibly mined, data sources (from sensors to social networks or digital media) together with human centered methods like ethnographic methods.

Representation of complexity. After discovery, representations of problems are required. These should: (i) reflect key observed properties of the system and individual behaviors and (ii) be open to the evolution of new individual/group characteristics that may generate new emergent behaviors. A useful representation of a problem should highlight the complex behavior and allow for the application of goal-oriented knowledge, the goal being the design of solutions and/or artifacts. What is a good representation of a complex problem, how does it induce and support the exploration of system behaviors? How does a representation favor the analogies between problems and how is it dealt with by analytical and holistic thinkers? These are open questions that need further work. The microworld approaches described above, or a scalable equivalent design, may inspire prototypical environments to represent complex problems (from Doerner and Funke [34] "*in the early years of research, microworlds started with systems containing about 20 variables in Tailorshop, soon reached 60 variables in Moro and culminated in systems with about 6000 variables in Lohhausen [...]*"). An alternative representation may be provided by causal loop diagrams as recently presented in Sahin et al [137] or agent-based models as mentioned before.

Complex problems need effective representations supporting models of reasoning and discovery that differ from top-down or composition-decomposition. A framework for complex systems representation needs different styles (microworlds, interactive simulations, games or maps), shaping a discipline of "complexity visualization".

5.2 Envisioning and prototyping with complexity

Pervasive abduction. Abductive reasoning is a key element in design. The envisioning or ideation stage of any design endeavor links the perception of complexity mentioned above and with the ability to populate the solution space.

How should the system representation induce abductive hypothesis building? Given the perspective that experience design is a complex problem and that the UX should encompass the overall relation of users and communities with technology, ideation support must be open, participatory and incorporate diversity by design. Moreover, we hypothesize that the future of engineering, design, architecture and many social sciences curricula needs to integrate abductive reasoning as a personal and group capability and as a methodological framework immersed in a space of complex problems.

Prototyping for complexity. The state of the art in UX analysis and critique emphasizes consumer artifacts and technologies for individual users (as noted by Bargas-Avila [8]). The technological evolution is expanding the scope of the UX into new spaces, from cars to cities. The new environments increase the complexity of the design problem (number of variables, contexts, dependencies, etc.). The focus on aesthetic or hedonistic qualities of the artifacts explodes in ubiquitous augmented environments. New directions of analysis are therefore opened: empathy with the environment, sense of place and feeling of augmentation. For example, cities have perceived qualities, like cosmopolitanism [143]. Which other qualities should the experience of a smart city have? As Giovanella proposes in [56], "smartness" can be considered as an emergent property of a dynamic system like a city. Culture may also have a significant role in the glocalization policies of smart cities as described by Dameri et al in [27]. In the scope of UX analysis, dimensions like privacy, pride, social recognition, social control, safety and other social norms are evident design variables.

The prototyping, testing and evaluation methods have an historical bias to the narrow scope of the individual. The widespread use of digital artifacts has shown the impact and relevance of emergent behaviors (see success or failure of contact tracing apps in pandemic times). The prototyping of digital experiences needs to model the conditions for these emergent phenomena. In this context, real-life testing and deployment cycles are critical for solutions to complex problems, just as innovation labs are doing it nowadays in entrepreneurship initiatives. The hypothesis to be tested here is that the required wicked-problem labs are equivalent to innovation labs.

5.3 Design with and for diversity

Culture has an impact on the user's view of the world, perceptions at different levels, group behavior and styles of participation. These facts have implications on how design is carried out and how designs are perceived and experienced.

It is fair to conclude from the previous discussion that the design frameworks are not neutral vis a vis the understanding of complexity, CPS ability and abductive reasoning. For example, power distance or collectivism creates limitations to the effectiveness of participatory design processes. Problem identification and solution search may also be affected by *groupthink* phenomena. Is the understanding of complexity favored by holistic reasoning? Does analytical reasoning facilitate hypothesis generation? The consideration for cultural characteristics in the design processes, taking into account the surveyed background, deserves further attention in multiple directions.

National cultures and fine cultures. The core studies on cultural variations can be said to have low resolution with respect to two geo-related characteristics. The first one is a (probably overestimated) strong correlation between culture and nationality. The IBM study of Hofstede eliminated (or weakened) social and professional factors, thereby attempting to isolate the cultural differences between nations. The Nisbett studies also map cultural differences in the geographical space. It is however likely that multiple sub-cultures coexist is the same country in social, professional, regional segments. The role of education, profession, social mobility and globalization has impacts in sub-culture development that should be explored (building on the social orientation explanation of Varnum et al [154]). For example, highly stratified societies like India may host a variety of cognitive styles that seems to be unexplored. The work of Light [95] shows that, for some design variables, the nationally related cultural attitudes are not evident or relevant, raising a justified criticism about the straight adoption of Hofstede diversity classifications. Holliday [74] breaks the univocal relation between culture and nationality.

Another characteristic of these works is a polarization between Westerners (north American culture) and East Asians (Chinese or Japanese) who show the strongest differentiation in Nisbett poles (holistic vs analytical). The studies that concern other cultures or nations smoothen the oppositions and position these other cultures half-way between the two extremes in several of the analysis axes, raising the question of what happens between East and West as studied by De Oliveira in [28]. Moreover, there is a gap in the study of some geographies like for example the Indian space, about one fifth of the world population in 2050, or the African space, a similar percentage[4].

The complexity discovery, complexity representation and complexity prototyping tools and methods are culturally sensitive. This sensitivity is probably present in sub-cultures in a national space. These assumptions need testing in live environments and in heterogeneous nationalities and communities in the context of the adaptation of the design processes.

Tuning design for culture. Considering the surveyed results, the likely conclusion is that no unique combination of cultural values, cognitive styles or predispositions is better or worse for the design ability of digital artifacts. However, we may hypothesize that some steps, phases or elements of the design processes may be positively or negatively affected by the cultural background, either at the level of the individual reasoning or at the level of the group dynamics. Moreover, an interesting research question is whether the design frameworks can be practically equipped with priming elements as in Tominaga et al [152] Senzaki et al [142] Ueda et al [153] Cheek and Norem [16] that can perform as cultural facilitators, for example, fostering holistic reasoning in the "observation" or "framing/reframing" phases, or suggesting analytical styles in the "imagine/design" and "make/experiment" phases. A consequent research

4 United Nations: World Population Prospects, 2017 Rev., Key Findings and Advance Tables.

topic is the relevance of culturally-adapted, or culturally-aware, design processes to achieve richer, better, or different design outcomes.

The discussion of deeper foundations for cultural differences is out of the scope of this review and is hypothesized in Nisbett [114], Varnum et al [154] or Lloyd [97]. The question of whether digital technology is a natural Aristotelian consequence or whether modern and global thinking about design should consider the background of the Four Great Inventions of China (compass, gunpowder, paper and print) [112] or Hindu mathematical creations (like zero "0" or the chess game) [84], [6] can be approached through an epistemological perspective but also as an inquiry on the foundations of the reasoning behind design and on the harmony of the diverse cultural elements.

This survey searched for relations and bridges between complexity, design and culture. The rationale for this review was the observation that problems tackled by different research communities share a great deal of conceptual and practical challenges. This conclusion is more an intermediate reflection then a grand finale. It is intended to act as an inspiration for further convergent research that will provide answers to the core question: *How do designers tackle the complex problem of creating digital experiences in culturally diverse communities?*

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