Extending System Design Tools to Facilitate Systemic Innovation in Prospective Ergonomics

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Abstract. Through an extensive literature review**,** this article aims to promote systemic innovation, which is presently too much influenced by context and too limited by rationality. As such, the article argues for the use of systems design methods and tools for anticipating future needs in the development of innovative products and services. Building upon theoretical concepts, such as *"Bounded Rationality"*, *"Situated Design"* and *"Practice Theory"*, systems design methods and tools, such as the Function-Task Interaction Matrix Method and Dependence Structure Matrix, should be made more comprehensive by extending technical and user elements with contextual elements. These matrices help to identify problem fields as well as opportunities by juxtaposing and force-fitting technical, user, and contextual elements.
Conclusively, the application of extended system design tools, such as EDSM define and FTCIM define, represents and incorporates design information. It also demonstrates how scenario-based methods can be effective in identifying innovative products, services and contexts.

Keywords: Systems Design, Systemic View, Methods and Tools.

1 Introduction

Traditional ergonomics focuses on physical and cognitive human-machine interactions in context [1]. However, its perspective of treating context as "something to comply with" limits ergonomics in adopting a prospective view towards innovation, where stakeholders, artifacts and contexts are to be considered variables. Furthermore, as technology continues to converge and service expectations continue to rise, it becomes increasingly more important in consumer's daily lives, [2]. This trend instigated a shift from production to utilization, from product to process, and from transaction to relationship, demanding a forward-looking way of dealing with products and services in ergonomics [3].

As such, there is a need to promote systems thinking in ergonomics by structuring interactions among humans and other system elements to manage complex environments [4]. This implies that physical objects, activities, and how these activities are organized and controlled in ever- changing social environments, should be considered as an initiative to enlarge the design space and develop a design discourse 'beyond the object'.

Capitalizing upon a realistic representation of the real world, this conceptual article aims to extend systems thinking by emphasizing on its softer and contextual aspects. Such extension should be angled towards increased affordances and multiple stakeholder involvement in predetermined contexts. In other words, how can systems thinking, and its tools be extended to flexibly accommodate inconsistencies, encourage emergent decision making, as well as manage context dependent and systemic environments?

The first part of this article, which has been discussed in section 2, explains how Prospective Ergonomics (PE) developed from traditional ergonomics, In the second part, section 3 discusses several interrelated theoretical frameworks to argue that a more holistic perspective on systems thinking should be built upon the concepts of (1) bounded rationality, (2) situated knowledge development, learning and designing and (3) practice theory. The third part as described in sections 4 and 5 argue for systemic underpinnings to extend the systems design approach with multiple non-technological dimensions. As exemplified by the Function-Task Interaction Matrix (FTIM) [34]. and Dependence Structure Matrix (DSM) [35], contextual dimensions will be added to extend these tools to become more systemic in nature.

2 Systems Thinking and Prospective Ergonomics

To form an "integrated whole" a system can be considered as a set of interacting and interdependent components [5]. In its broadest sense, systems thinking encompass a large and body of methods, tools and principles, all oriented towards the interrelatedness of forces, seeing them as a part of a common process [6].

Complex systems, for example organizations, teams and types of technology, are composed of interrelated components, the properties of which are adaptable. A systems approach emphasizes two specific aspects of social and organizational behavior: (1) their systems character, so that movement in one part leads in a predictable fashion to movement in other parts; and, (2) their openness to environmental inputs, so that they are continually in a state of flux [7, p3].

System Design Engineering (SDE) initially focused *on developing a full life cycle of the system* "cradle-to-grave" structures. Later on, SDE adopted an increased interest in designing the 'user experience' [8]. From a human-centered perspective, it was first applied to the micro-ergonomic range of hardware design/engineering, software development, ergonomics, and seller/purchaser economics, but later extended to macro-ergonomic endeavors, when it was appropriate to effect organizational change [9].

As such, system can then be described as a scientific discipline within ergonomics, concerned with the understanding of the interactions among humans and other elements within a complex environment, comprising of physical objects, activities and how these activities are organized and controlled in a social environment [3].

Moreover, A comparable shift also became apparent in human factors through the introduction of Prospective Ergonomics (PE). This PE intervention towards innovation was based on the anticipation of "hidden" user needs [10]. as well as a re- interpretation of the concept of '*product'*, underlining that the client does not really require the products or services, but what these products and services help the user to achieve [11]. The reinterpretation of "system" within PE introduces new types of stakeholder relationships and/or partnerships, new constructions of mutual economic interests, and optimization of resources [12]. Within the above context, the designer is required to synthesize solutions emerging from the comparison of different viewpoints, needs and socio-cultural models, iterating from the traditional design domain to the domain of design management, and vice-versa [13].

To summarise this section, the emphasis on user experience as a motivator for developing successful services argues for the implementation of systems thinking in Design. Complementary, it cultivates interest in designing "experiences" to enlarge the design space, as well as a development of design discourse 'beyond the object', and a response to the shortcomings of existing models of how usage and users are considered in the design process [14].

3 Theoretical Frameworks

Bounded Rationality [15], Practice Theory [16, 17], and Situated Design [18, 19]. have been selected as core theoretical concepts to explain that systems thinking helps to structure systemic innovation within the context of Prospective Ergonomics. Firstly, it emphasizes that bounded rationality and structured problem solving are not opposites, but complement one another in developing systemic strategies for innovation. Secondly, it discusses the importance of "Situated Design". And thirdly, it provides an argument for using practice theory to influence the transition from bounded rationality to situated design, and structured problem solving to systemic strategizing.

3.1 From bounded rationality and structured problems solving to systemic strategizing

It is difficult to acknowledge the existence of the "fully rational man", because complete rationality requires unlimited cognitive capabilities [20, p.3]. Human beings have limited cognitive capabilities, and for this reason alone, their decision-making behavior cannot conform to the ideals of full rationality.

This is contrary to Simon's design process, where designing is seen as problem solving within an engineering educational context, free from human judgment and experience, operating within a closed and abstract system [21, p.35]. According to Simon, whereby "design theory is aimed at broadening the capabilities of computers to aid design, drawing upon the tools of artificial intelligence and operations research." [15, p.114]

However, "en route" to understanding and developing systems, one should not adopt stands, that of bounded rationality versus the structured and problem-solving approaches. According to literature from organizational studies and innovation strategies, practitioners and scholars should acknowledge that in the real world, planning, structuring and using prescriptive models, processes and methods may only lead to satisfactory results, because they consider systemic constraints as well as human limitations, capabilities and interests. The need for being deliberate and targeted in planning, while acknowledging that humans are bounded by rationality, is a typical trait of the systemic approach [22]. This systemic view is not only applicable for business strategizing, but also for PE in the anticipation and development of innovative products and services.

3.2 The Concept of "Situated Design"

Within the field of ergonomics and design, processes and methods should not be described as though they are universal and can be applied in the same way across contexts [23]. (Simonsen et al, 2014). This is based on the concept of "Situated Design", where particular activities cannot be detached from society, because the rules and resources it furnishes are essential to their action [19].

In other words, design is situated to highlight the interactions and interdependencies between designers, designs, design methods, and the use situation with its actors, activities, structures, particulars, and broader context. This means that situated design deals with all the "thinging" that goes into the making of things. Bjögvinsson, Ehn, and Hillgren emphasized a fundamental challenge for designers and the design community, which is the transition from designing objects to designing socio-material assemblies [24, p.102]. This perception of design is in line with the concept of mode 2 knowledge developed, which defines practice-oriented scientific knowledge [25]. It stresses that analysis and design should be carried out in continuous dialogue with the field and in collaboration with participants. Complementary to "Situated Design", Suchman [19] introduced *situated knowledges* by arguing that knowledge is situated and partial. As knowledge production takes place under specific historical, political, and situational circumstances, it is embedded in context [18].

From an overarching perspective, "situated design" emphasizes the complex relationships between the context and the design situation at ground level, involving different actors and stakeholders, as well as societal structures dictated by institutions, regulation, market mechanisms, and so forth. The challenge is to interpret, work within, and simultaneously reconstruct the context to arrive at a situated design that fits as well as stretches the context.

3.3 Bridging "Bounded Rationality" and "Situated Design" through Practice

In this section, practice theory is being discussed to bridge "Bounded Rationality and "Situated Design", and as a precursor to the systemic perspective. As a dialectic between social structure and human beings working back and forth in a dynamic relationship with diverse motives and intentions, make and transform the world in which these social beings live [26].

Practices refer to shared routines of behavior, including traditions, norms and procedures for thinking, acting and using 'things' [22]. Practice theory tends to emphasize the tacit and informal, reflecting its origins in the sociology of everyday life [27]. Such emphasis on the "everyday life" and the growing engagement with activity instigated a wider 'practice turn' in systems design and design methodology. Seminal theorists promoting the "practice turn" include Pierre Bourdieu, Michel de Certeau, Michel Foucault and Anthony Giddens. Aiming to overcome the dualism between individualism and societism [17], these practice theorists aim to respect both the efforts of individual actors and the workings of the social. To the individualists, they insist there is such a thing as society; to the societists, they affirm the significance of individual activity [22, p.614].

Here, three core themes can be distinguished for practice theory. The first theme addresses society. In their different ways, practice theorists are concerned with how social 'fields' [16]. or 'systems' [28] are able to guide and enable human activity by defining practices based upon shared understandings, cultural rules, languages and procedures. This is emphasized in Foucault's attention to how society's disciplinary practices subtly shape expectations and behavior [29], as well as in Bourdieu's notion of 'habitus'[16], where ordinary human conduct is typically determined by unconscious incorporation of social traditions and norms. Both of these accounts show that actors are not atomistic individuals, but essential elements of the "social world".

In the second theme, practice theorists continue to pursue individuality by asserting people's actual activity 'in practice'. In his study about daily urban living in apartments, workplaces and shops, De Certeau [30, p.70] was not only interested on *what* was done, but also of *how* it is done, which requires close anthropological attention of tacit and explicit micro-activities.

Similarly, for Bourdieu [16], social practices are followed in rough and ready ways, according to the requirements of the situation. Hereby, the challenge is to capture the 'practical sense' by which life is actually lived in the moment. This can neither be deduced from prescribed processes and activities nor macroscopic accounts of society's structures and functions.

The third core theme addresses the distinction between practices and what really happens 'in practice', namely "Praxis" [22]. The distinction between praxis and practices follows Reckwitz's interpretation of the dual sense of practice in social theory, both as something that guides activity and as activity itself [31, p.249-252], whereby the domain of praxis is wider, embracing the routine and the non- routine, the formal and the informal [32].

4 Introducing Systems Design in a Systemic Landscape

Reference to the previous theoretical section of this article, *Practice Theory, Situated Design, Bounded Rationality,* and *Structured Problem-solving*, will be elaborated to underline and re-construct the concept of Systems Design from a "systemic" perspective. Instead of making choices, it is about "doing things in context" by integrating: (1) micro-detail and larger social forces, (2) deliberate and emergent activities, as well as (3) by balancing different objectives.

Having characteristics of both classical and processual approaches, systemic strategies are developed in complex networks and are culturally defined [22]. Many situations show a discrepancy between indented strategies and practices on one hand and what really has been practiced and achieved on the other hand. In other words, some cases in design and ergonomic practice have revealed that intended aims were compromised, as suddenly emerging inspirations and ideas were incorporated, leading to realized, but revised aims.

This means that in systems thinking and design, systemic perspectives may intervene planned and intended objectives, because user needs and people´s behavior are emergent and contextually embedded in a network of social relations, involving their families, state, their educational and professional backgrounds, religion and ethnicity [33]. However, the mismatch between the “intended” and the “realized”, because of emergent and unforeseen circumstances, should not refrain designers and ergonomists from using structured design methods to anticipate, construct and represent future systems. A typical example of a prescriptive design method, based upon relationships between users’ activity and available technology, is the Function-Task Interaction Matrix Method (FTIM) [34], which is an extension of the Dependence Structure Matrix (DSM) [35]. However, as the focus has shifted from general user needs to addressing multiple stakeholder´s interests in localized context-heavy environments, these methods should be extended a second time to incorporate social, economic, environmental and political dimensions.

5 Methods for addressing the softer aspects of systems design

From a systemic perspective, context is an important factor to be considered in acquiring design information for human-centered design practice [36]. As such, the increased focus on context as a variable for addressing design complexity should be incorporated in systems thinking and design, while considering end-user needs.

Presently, and from a sustainable system innovation perspective, several models focus on societal and economical changes involving different stakeholders interacting in context. These models are mainly descriptive models aimed at understanding socio-technical or societal developments, mostly from studying developments afterwards (‘ex post’) instead of influencing them in a certain direction ahead of time (‘ex ante’) [37].

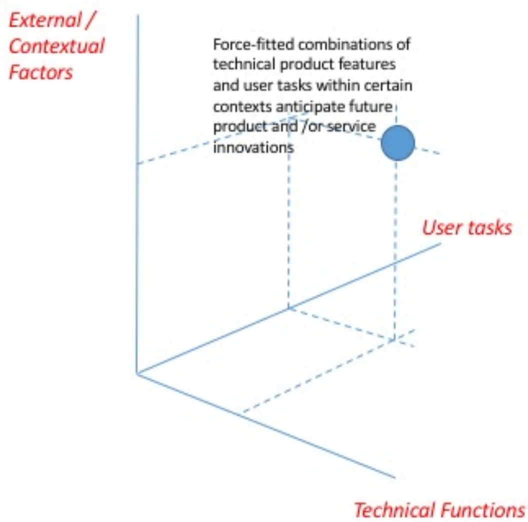

Fig.1. 3-Dimensional Function-Task-Context Interaction Matrix (FTCIM) (adapted from Galvao & Sato, 2005)

However, no attempts were made to propose prescriptive models or methods that provide insight into the development of one new product or service in relation to developments that occur on the socio-technical and societal level. The absence of such prescriptive models or methods urges the development of softer approaches towards systems design, where elements, products and users are perceived as small building blocks of the whole. Such a softer approach is exemplified by extending two system design tools: (1) The Function-Task Interaction Matrix (FTIM) [34] and (2) The Dependency Structure Matrix [35] (see figures 1and 2). The purpose of these models is to construct creative scenarios and solutions by cross-linking and force-fitting technical-functional, user, and contextual dimensions. Similarly, to a morphological chart, these tools are more than just a general framework for representing and incorporating design information.

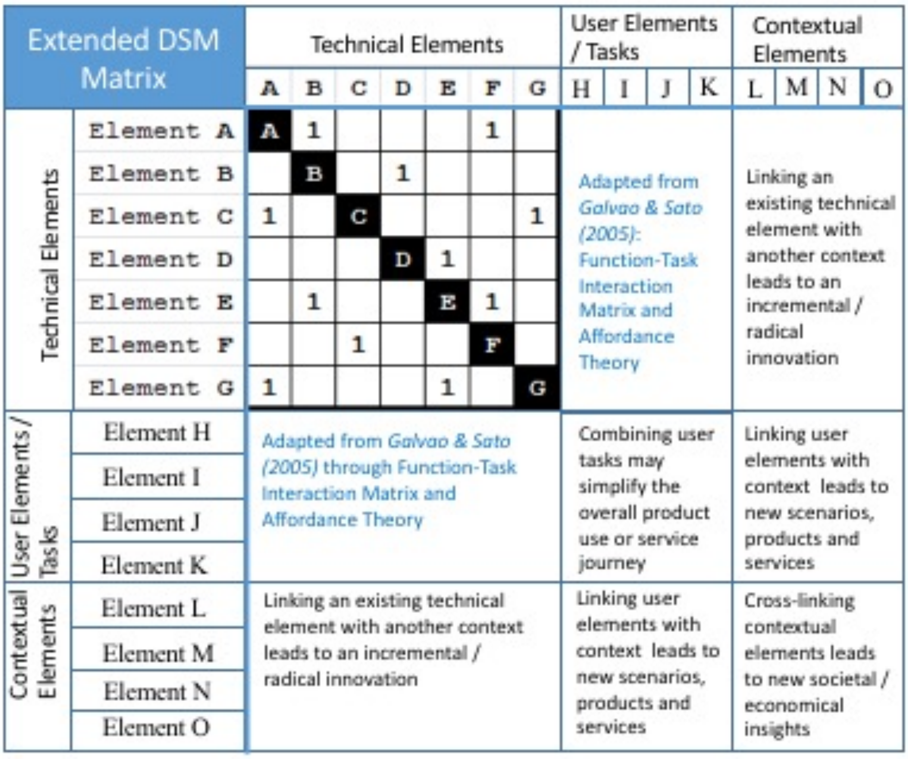

Fig.2. Extended Dependence Structure Matrix, incorporating user and contextual elements (adapted from Steward, 1981)

6 Discussion

This article aims to develop a framework for a designers, end-users and other stakeholders to apply and understand the value of systems design methods and tools when searching for innovative solutions in the systemic realm. As a precursor to the systemic perspective, it builds upon the concepts of "Practice Theory", "Bounded Rationality and "Situated Design".

Based upon prospective ergonomic and systemic strategy views, as well as systems design methods, the Design Structure Matrix (DSM) have been extended by incorporating user and contextual elements. On one hand, such an extended DSM helps to structure and manage inconsistencies and emergent developments. On the other hand, it makes systems design approaches more adaptable to specific contexts, as well as more flexible in absorbing the inefficiencies of human behavior. For example, as shown in figure 2, juxtaposing different user-tasks may simplify new product uses or service journeys, whereas combining user tasks with contextual elements may lead to innovative scenarios, products and services. Cross-linking contextual elements may provide new societal and economic insights.

In conclusion, to match the realities of how different stakeholders and artefacts interact with one another in a systemic environment, systems design methods and tools, such as the FTCIM and DSM, should be extended to encompass a wider spread of dimensions: technical-functional, user, and contextual (figures 1 and 2). This implies that a Prospective Ergonomic approach should be embraced when considering systemic and contextual elements.

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