Design, systems approaches, and the engineering-economics nexus

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Abstract

Economics and engineering are discovering new opportunities for cross-fertilization. This is partly given to the advent of modern artificial intelligence methods. These opportunities have appeared in the past, resulting in marginal improvements toward integration. As explained by Mariotti (Journal of Industrial and Business Economics, 2021), over the years there has been an intertwining of the two disciplines along the progression of economics *for/and/as* engineering. Mariotti (2021) also points out that a real transdisciplinary integration (i.e., *à la Prigogine*) implies a mutual nurturing, where one discipline's conceptual apparatus is incorporated into the other. A fine-grained view of the epistemological differences of the two disciplines reveals that an integration might be more likely along some, but not all directions. I explain these differences based on different connotations of the concept of design. Particularly, when referring to design aspects of social systems, I also argue that systems approaches may serve as a bridge to integrate economics and engineering. Finally, I offer alternatives to explore how this integration might be undertaken.

Keywords Design · Systems · Complexity · Economics · Engineering

JEL Classification A12 · B50 · C63 · Q01

1 Introduction: two distinct epistemologies

Both economics and engineering develop knowledge aiming to improve the working of systems—be them physical or social—but with different epistemological frameworks. Economics is a social science, and economists have traditionally conceived themselves as scientists (Mazzoleni & Nelson, 2013) despite requests to adopt a more pragmatic approach (Mankiw, 2006; Roth, 2002). Economists essentially work

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through the discovery of regularities in social systems by formulating theoretical frameworks and their subsequent empirical testing. As Lazear (2000, p. 99) argues, “[e]conomics is not only a social science, it is a genuine science. Like the physical sciences, economics uses a methodology that produces refutable implications and tests these implications using solid statistical techniques”. In contrast, engineering fields are problem-oriented disciplines that do not develop but employ fundamental scientific principles from the physical sciences; engineers expand their knowledge through practice along the iterative nature of artifact design. The creation of artifacts that fulfill a specific objective is at the core of the engineering profession. Recalling Theodore von Kármán’s quote, “[s]cientists study the world as it is; engineers create the world that has never been.” (Chen et al., 1975, p. 340).

These epistemological differences come out when assessing the quality of produced knowledge. As Marks (2012) puts it, the derivation of necessary and sufficient conditions is very important to the mainstream economists’ equilibria formalization. Engineers’ main objective is solving problems through artifact design that comply with a “targeted functionality”. Distinct approaches toward the use of research tools may exemplify such differences. For instance, when exploring properties of designed systems, engineers may use computer simulation to assess reliability levels; theoretical economists, in contrast, rarely employ computer simulation as a primary tool for theory development. One reason is that simulation models can guarantee sufficiency, but not necessity (Marks, 2012).

Despite the above disagreements, engineering and economics have many commonalities. In the next paragraphs, I will briefly present these commonalities and differences by borrowing the framework set out by March (2014). March specifically comments on microeconomics and argues that the (sub-)field is featured by two distinct projects. The first project is intimately linked to intelligent choice and definitively amenable to extensions of the neoclassical sort; the second project acknowledges the fact that choice is embedded in rules, identities, institutions, and constantly evolving organizations. Recalling March and Olsen (1996, 1998), these two projects emphasize different logics of decision making: the “logic of consequences” (LoC) and the “logic of appropriateness” (LoA), respectively. They also serve as a ground to examine the potentials and difficulties of engineering and economics to forge alliances. There are obvious reasons for a linkage under a LoC framework, but not so along the other path.

2 Traditional design as a bridge between engineering and economics

Both engineering and economics have long been familiar with constrained optimization, probability theory and stochastic processes. These have provided a common language to tackle a wide range of interesting problems. Back in the 60s, integration of both disciplines found homes like the Stanford engineering-economics (EE) initiative, which evolved to become a problem-solving subject of study based on the instruction of fundamental mathematical techniques (Luenberger, 1985).

Perhaps one the legacies that this engineering-economics encounter has contributed is the application of computational approaches to market settings such as

algorithmic game theory for mechanism design (Roughgarden, 2010), computer-mediated transactions (Varian, 2010), Markov-perfect equilibria computation (Pakes & McGuire, 2001), and financial networks (Onural et al., 2021). During the last decades, engineering approaches have been employed by the economics profession due to the growing interest in “the design and maintenance of markets and other economic institutions” (Roth, 2002, p. 1341). In such cases, the concept of “design” is essentially seen as an approach to explore, provide, and preserve (near-)optimal solutions through sophisticated modeling techniques. This approach to design is being applied in contexts characterized by a high degree of organization, by being technologically driven, or by having salient digital features (e.g., energy markets, auctions, and blockchain operations). In this way, engineering and economics might be on the right track to build a strong and successful alliance, aligned with the LoC project of microeconomics. Economic systems design under these algorithmic approaches promises to provide impressive solutions to market inefficiencies.

Nonetheless, this potential alliance has its perils. Reaccounting what Mariotti (2021) suggests, a value-free algorithmic economy may leave out contextual, historical, cultural, and political features of our societies. In a similar vein of some ideas of behavioral economics that started apart but have been gradually embedded into the neoclassical framework, the algorithmic “*machina economicus*” might perfectly become an extension of the mainstream ideas, leading the field to reflect the status of a pure science and to resist the advocated pluralism claimed by many economists. Of course, many problems within the scope of the “*machina economica*” may be amenable to the mechanistic design of traditional engineering. Typical ideas of design in economics somehow resemble that of mechanical artifacts, given that they approach markets (their “artifacts”) as external objects. However, many other problems connected to, for instance, paths toward sustainability, development, and societal transitions, among others, need a different flavor of design. Design in the context of human organizations is another kind. Particularly, we may say that organizations should not be regarded as external objects before the eyes of designers. “Organizations are, thus, artifacts that contain their own artisans.” (Ostrom, 1980, p. 310). This takes us to wider considerations of design in the realm of social systems.

3 Design as a co-participation

An alternative viewpoint of design contemplates the construction of solutions through human co-participation. This becomes even more pertinent when dealing with current societal challenges; as noted by Banathy (1996, p. 34): “[d]uring the early eighties it was recognized that the capability to deal with increasing systemic complexities, rapid societal changes, and design decisions that affect our society cannot be left to the so-called design experts. This recognition led to the idea of a broad-based participation of the users of design in the design of their systems. It was proposed that to complement the expert culture of professional designers, we should build design cultures that include the general public.”

Banathy (1996, p. 14) recalls Peter Checkland’s notion of social systems as human activity systems (Checkland, 1981), which is in contrast with traditionally

engineered systems. Human activity systems portray diverse appreciations of problems, varied meanings, as well as pluralistic solution possibilities. Likewise, aspects such as identity, ambiguity and conflict come afloat and become important features for consideration when speaking of change. To James March, these aspects are of crucial relevance to understand human behavior (March, 2014); these aspects are also borne in mind by those engineers that deal with the management of people: industrial and systems engineers.

Two major associations that group professionals of the above-mentioned disciplines are INCOSE (the International Council on Systems Engineering) and the IISE (Institute of Industrial and Systems Engineers). INCOSE considers systems engineering as being interdisciplinary and based on systems approaches that integrate science, technology, and management (INCOSE, 2021). The IISE keeps a management systems society with a prominent interest in the application of engineering concepts to enterprise transformation, sustainability, and organizational development (see <https://www.iise.org/sems/>). Both the INCOSE and the IISE associations grant design a central role by highlighting the involvement of stakeholders, the use of systems thinking methods, and the role of co-participation in the creation of effective solutions. When dealing with systems with multiple stakeholders, I suspect that many industrial and systems engineers might be more sympathetic with the LoA project of microeconomics. Hereinafter I will refer to this category of engineers simply as systems engineers.

Evidently, systems engineers are interested in designing systems within a perspective that is far from the mainstream economics mindset. As pointed out by Pennock and Rouse (2016), traditional engineering approaches do not work in social systems, so design should strive “to influence change” rather than “to predict and control”. Pennock and Rouse highlight that, in the presence of inescapable uncertainties of complex social systems, the design of context-driven adaptive strategies is key. These strategies are moving schemes that consider multilevel occurrences, evolving behavior and path dependence of the system of interest. Likewise, computational models that capture essential dynamics are an important part of the design process, but not everything. As opposed to the machine-type design, this design perspective is amenable to the integration of quantitative and non-quantitative aspects. In fact, Pennock and Rouse (2016, p. 38) pose an important challenge to be resolved: “how do we use noncomputational models of an enterprise to influence computational models of enterprises and vice-versa?” In that respect, design is a multi-method endeavor. Then, how can engineering and economics join forces within the co-participatory framework of design?

4 Systems approaches as integrators: can engineering and economics be allies?

Many of the systems principles that are shared by systems engineers (Pennock & Rouse, 2016) are also shared by complexity and evolutionary economists (e.g., Arthur, 2014). Arguably, complexity science and systems thinking are under the same roof of systems approaches as they share compatible ontological principles

(Scrieciu et al., 2021). Both movements highlight features such as nonlinearities, feedback dynamics, evolution, adaptation, interconnectedness, and path dependence, among others. Yet, these two systems approaches have rather evolved in separate ways. Both use computational modeling as a means to operationalize system behavior (i.e., by using agent-based and system dynamics modeling), but only the systems thinking standpoint gives credit to the subjectivity dimension of individuals. This latter appreciation is particularly relevant since, as emphasized above, co-creation, adaptation, and participation should be important aspects in the design of social systems. Since the ultimate aim of design is not to articulate better scientific theories but to create and implement solutions (Banathy, 1996; García-Díaz & Olaya, 2018), interpretive elements of stakeholders are taken as a source that contributes to envision future worlds (Sarasvathy, 2003).

To give an example, when referring to decarbonization policies, Scrieciu et al. (2021, p. 711) argue that “[k]ey interpretive themes, such as the relevance of social attitudes with respect to energy technology adoption, risk perception linked to energy retrofitting of buildings, subjective conceptualisations of household energy technologies, or the multidimensional aspects of trust and confidence when seeking to manage the expectations of those targeted by energy decarbonisation programmes would rather invoke modes of inquiry along non-quantifiable or non-generalisable lines. These may include narrative analysis, rich historical accounts, case studies and descriptive analysis of surveys and interviews, stakeholder engagement, scenario visioning and participatory approaches, critical and reflexive analysis, explorative storylines and stories, or modelling of interpretation, amongst others.”

Scrieciu et al. (2021) contend that the blend of formal methods and interpretive approaches might enlarge the economist’s research toolbox; I would add that such pluralistic combination of methods of inquiry should be complemented with the systems engineering approach to intervention, forging a closer link between pluralistic economic theories and practice, and moving from the machine-type imagery toward a more holistic consideration of design and intervention.

Of course, this is not to say that it is unnecessary for design to interact with scientific theories. Very much the opposite, design and science are both sources of knowledge generation through the mutual interaction of analysis and synthesis. Particularly, design (i.e., engineering) approaches to social systems need and are needed for the development of solid social research foundations, but these foundations should require pluralistic (or systemic, if I may say so) modes of inquiry. For systems engineers, having a thorough understanding of pluralistic economic perspectives would provide them with better scientific principles to guide organizational interventions. This is very much required in a discipline that even though is guided by systems ideas, is too heavily based on heuristics (Rousseau, 2018, p. 2). As Rousseau and Calvo-Amodio (2019, p. 13) explain, “[t]his absence of a theoretical basis presents a critical risk to systems engineering as we enter the fourth industrial revolution. Theoretical foundations provide clarity and rigor to engineering disciplines, making the subject more comfortable to discuss and understand, and serves as a source of scientific insight that can be used to test, improve or delimit methods, tools or processes”. Along these matters, I argue, the integration of economics and engineering *à la Prigogine* (Mariotti, 2021) might materialize.

This is not an easy task, but if accomplished I am convinced it will provide huge benefits to society. Systems approaches have had a closer relationship with systems engineering than with economics, and that is why I believe complexity economics may in part serve as a bridge nowadays. Historically, with a few exceptions (e.g., the writings of Kenneth Boulding; e.g., Boulding, 1956), it is hard to find economists interested in the systems approaches. A diverse set of pressing societal challenges are right now necessitating a transdisciplinary focus, and thus are serving as meeting spaces for engineers and economists. These challenges relate to issues in ecological and environmental economics; post-carbon and post-growth futures; systemic risks; circular economies; urban sustainability; social protection and the Covid-19 pandemic effects on labor transformation; and many others.

Increasingly, I have seen economists interested in using engineering tools such as qualitative systems mapping, hybrid computer simulation approaches, and deep uncertainty methods (e.g., Hynes et al., 2020), but I guess that mainstream economists will yet resist to consider them as members of the same community. Other social science disciplines have been keener to explore implications of the dynamics of human behavior through computational modeling (e.g., Jager, 2021). Even if these suggested perspectives remain outside the mainstream (as they will probably do), they will still contribute to foster a more pluralistic thinking in the field of economics (Mazzoleni & Nelson, 2013). Especially in European circles, the heterodoxy has gained a little more value, and policy discussions are willing to embrace pluralism (Hynes et al., 2020). Along these lines, I also hope that economics and engineering forge stronger alliances beyond the pure technical apparatus and exchange fundamental aspects of how both fields address change and transformation.

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