Introduction: The Why, What and How of Social Systems Engineering

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The Very Idea

The expression 'social systems engineering' is not new. As far as we know, its first appearance in the literature dates from the mid-1970s. In 1975, the Proceedings of the IEEE published a special issue on social systems engineering (Chen *et al.*, 1975). Here, Chen and colleagues referred to social systems engineering as the application of systems engineering concepts to social problems. Likewise, the special issue seemed to emphasize that the potential contribution of engineering to social issues was predominantly based on the consideration of quantitative modelling as the workhorse for intervention. Although we concur with some of these points, for us the expression 'social systems engineering' has a broader connotation, not meaning that we advocate exclusively for the application of engineering methods to social issues, but rather that we stand up for the consideration of *design* perspectives as a pivotal way to generate knowledge and transform systems. The intrinsic engineering orientation to *action* and *transformation* as its ultimate goals for improving a system, for meeting needs, for addressing successfully a specific problematic situation that someone wants to improve, etc. are emphases that this book highlights. Such goals demand the recognition of specific engineering considerations and their implications for addressing *social systems*. We want to emphasize the complexity of engineering 'social' (human) systems (as opposed to engineering mechanical systems, electrical systems, etc.), since such systems are then in fact 'social' (formed by purposeful actors that display agency, with diverse, clashing interests and goals) and therefore their design, redesign and transformation, unlike in other engineering domains, cannot be completely determined or planned beforehand. These designs are formal and informal, emergent, always 'in progress', adapting and evolving out of diverse dynamics.

Social Systems Engineering: The Design of Complexity, First Edition. Edited by César García-Díaz and Camilo Olaya.

Social systems engineering has a paradoxical status. On the one hand, it is an under-researched topic whose *theoria* has rarely been explored. On the other hand, it is perhaps one of the most common endeavours in society since it concerns the *praxis* that seeks to design, create and transform human organizations. Consequently, we need to understand what engineering thinking means, and how it relates to social systems. Steven Goldman, one of the contributors to this book, stated more than 20 years ago regarding the autonomy of engineering (as distinct from other activities such as science or arts) that 'while engineering has a *theoria*, analogous to, but different from, that of the physical sciences, unlike science, engineering is quintessentially a *praxis*, a knowing inseparable from moral action' (Goldman, 1991, p. 139). The recognition of engineering as an autonomous activity, independent from science (though related in many ways), seems just a recent explicit realization that can be identified with what can be called a 'philosophy of engineering' (Bucciarelli, 2003; Goldman, 2004; Miller, 2009; Sinclair, 1977; Van de Poel and Goldberg, 2010). Perhaps the key word to understand the autonomy of engineering is *design* (Goldman, 1990; Layton, 1984, 1991; Pitt, 2011b; Schmidt, 2012; Van de Poel, 2010). Engineering, being driven by design, shows a distinct *rationality*, as Goldman shows in Chapter 1 of this book. He characterizes engineering design as 'compromised exactness', since its formal apparatus delivers approximate 'solutions' that are subject to their context of application, which means that they are always subjective, wilful and contextual. Social systems, as belonging to the realm of artificial systems, exhibit *design*, which means that they are, and can be, *engineered*, but not in the traditional sense (Remington *et al.*, 2012; Simon, 1996). Traditional engineering, design-based methods, which essentially aim at control and prediction, *cannot* be applied to social systems due to the very nature of these systems – unlike mechanical systems, social systems do not 'obey laws', as Galileo imagined (Galileo Galilei, 1623), but are driven by the agency of human beings. Yet, engineering thinking can be used in several other ways, for instance for *steering* social systems towards a given direction, for influencing action (Pennock and Rouse, 2016), for *opening new possibilities*, for *driving conversations* among its members, for *imagining* different futures, for *learning* about the complexity that social systems entail, etc.

Whenever engineering concerns social systems (i.e., firms, public and private organizations, urban systems, etc.) it implies the design of social artefacts and social constructions such as management structures, incentive schemes, routines, procedures, ways of working (formal and informal, planned and spontaneous), agreements, contracts, policies, roles and discourses, among others (Jelinek *et al.*, 2008; March and Vogus, 2010). Therefore, such types of engineering face a special type of complexity, since these artefacts depend on and are constructed through human action, meaning that not only individuals but also their emotions, language and meanings are involved.

This book seeks to offer an overview of what social systems engineering entails. The reader might hasten to think that this is a mechanistic approach to social systems. However, there is no such thing as optimal design in social systems (Devins *et al*., 2015). In contrast, the very idea of social systems engineering, although it emphasizes *action*, does not necessarily rely on prediction; it is context-dependent, iterative, builds upon different modelling perspectives and decisively aims at influencing the path of, rather than deliberatively designing, the evolving character of self-organization of human societies. This is a starkly different approach from a purely scientific viewpoint. The book encompasses three sections that follow an intuitive inquiry in this matter. The first section deals with the very idea of what social systems engineering might be and the need for addressing the topic in its own terms. The second section samples illustrative methodologies and methods. The final section illustrates examples of the challenge of designing the complexity that results from systems created through human action.

Epistemic Notions on the Engineering of Social Systems

There are diverse beliefs regarding what engineering is about. Perhaps the most popular is to believe that engineering *is* 'applied science'. However, this would mean assuming that 'scientists generate new knowledge which technologists then apply' (Layton, 1974, p. 31) and therefore would suggest that what makes an engineer an engineer, and what an engineer delivers, is (applied) scientific knowledge, instead of a different type of knowledge (Davis, 2010), which is, at best, misleading (Goldman, 2004; Hansson, 2007; Layton, 1974; McCarthy, 2010; Pitt, 2010; Van de Poel, 2010). The recognition that science and engineering stand on different epistemic grounds (Goldman, 1990; Koen, 2003; Krige, 2006; Layton, 1984, 1987, 1991; Petroski, 2010; Pitt, 2011b; Vincenti, 1990; Wise, 1985) is perhaps the first step in thinking of social systems *engineering* and requires a brief overview.

If it is not 'applied science', what are the defining characteristics of engineering? We can start by realizing that engineering and science usually pursue different goals: scientists, first and foremost, look for systematic *explanations* of phenomena; engineers, on the other hand, pursue the *transformation* of a situation through the design of artefacts that serve as vehicles to solve problems. In short, as Petroski (2010) puts it, scientists seek to explain the world while engineers try to change it. The scientist deals primarily with the question 'what *is* it?' The engineer deals with '*how must this* situation be changed?' and 'what is the *right* action to *do*?' Engineering is concerned 'not with the necessary but with the contingent, not with how things are but with how they might be' (Simon, 1996, p. xii). Such different missions lead to different values, norms, rules, apparatus for reasoning, considerations, type of knowledge, methods, success criteria, standards for evaluating results; in short, different epistemologies.

Engineering knowledge is intrinsic to engineering and different from scientific knowledge. Engineering *know-how* is a distinctive type of knowledge, different from the scientific *know-that* (Ryle, 1945). For example, 'engineering knowledge is practice-generated… it is in the form of "knowledge-how" to accomplish something, rather than "knowledge-that" the universe operates in a particular way' (Schmidt, 2012, p. 1162). Knowledge-how is not concerned with the truth or falsehood of statements, 'you cannot affirm or deny Mrs. Beeton's recipes' (Ryle, 1945, p. 12). Engineers *know how to do* things. It is a type of practical knowledge. Therefore, the resources and information to get the job done can be varied and diverse, in principle they are not rejected under any a-priori principle, 'resolving engineering problems regularly requires the use of less than scientifically acceptable information' (Mitcham, 1994). The scientific 'empirical evidence' might be useful, but it is not a necessary requirement. Such a practical approach requires also that designs must *work* in real life; the effects of friction or air resistance cannot be ignored (Hansson, 2007). Since the task of the engineer is to be effective, to accomplish, then mathematical precision and analytical solutions are not required. Unlike the scientist, the engineer does not assume ideal conditions, s/he knows what to do in imperfect situations.

Engineers address practical problems: their know-how is constructed contingently and for very specific contexts (McCarthy, 2010). Engineering deals with particulars in its particularity, they are not taken as instantiations of a universal (Goldman, 1990). This implies that engineering design faces a variety of constraints related to idiosyncratic values and factors (economic, cultural, political, reliability, viability, ethical) that co-define and specify the design problem, unlike scientific research in which such constraints are absent in the definition of a scientific question (Kroes, 2012). This singularity of each design problem explains why there is no unique solution for an engineering problem: 'an engineer who understands engineering will never claim to have found *the* solution… This is why there are so many different-looking airplanes and automobiles and why they operate differently… they are simply one engineer's solution to a problem that has no unique solution' (Petroski, 2010, p. 54). Moreover, there is usually more than one way to solve an engineering problem. Such diversity of possibilities, methods and solutions contrasts with the goal of scientific communities that typically pursue the one best theory, at any given time, for explaining a phenomenon; when a theory is shown to be erroneous, it can be replaced with a better one.

The activity of engineering does not need epistemic justifications. The intentional creation of artefacts is done by experimental methods that are more fundamental than (and not derived from) any type of *theory* (Doridot, 2008). The origin of design is irrelevant, it does not necessarily have to be *a priori* supported by anything, including theories or data. Design can be freely generated with the help of any procedure, sourced from reason, or guided by previous expectations – 'theoretic' or not (Stein and Lipton, 1989), guided with the help of a model, or just based on imagination, or instincts. 'Empirical evidence', or any other indirect mechanism of representing the world, is just another option, but it is not a requisite. For instance, 'the inventor or engineer… can proceed to design machines in ignorance of the laws of motion… These machines will either be successful or not' (Petroski, 2010, p. 54). Engineering handles a *pragmatic* concept of 'truth' (Doridot, 2008). An artefact or an engineering solution is not false or true (or closer to), simply it works or it doesn't. If it works, engineers succeed. The popular notion of knowledge as '*justified* true belief' means nothing in a pragmatic approach in which knowledge is *unjustified*. In the words of Pitt: 'If it solves our problem, then does it matter if we fail to have a philosophical justification for using it? To adopt this attitude is to reject the primary approach to philosophical analysis of science of the major part of the twentieth century, logical positivism, and to embrace pragmatism' (2011a, p. 173).

We are interested in particular in the engineering of *social systems*. What are the implications of the recognition of such philosophy of engineering for the domain of social systems? Let us consider, for instance, that the predictive logic of scientific causal models relates to the idea that prediction is a requirement of control (Sarasvathy, 2003). A fundamental question is how much prediction, derived from causal explanations, is needed to transform a social system. Before the apparent unpredictability of the behaviour of social systems, one idea is to operate under a different logic and to drop the very idea of prediction in design, as Sarasvathy (2003) puts it. Sarasvathy (2003) claims that, in relation to endeavours of enterprise creation, a design logic highlights the fact that '*to the extent we can control the future, we do not need to predict it*' (Sarasvathy, 2003, p. 208), implying that '*a large part of the future actually is a product of human decision-making*' (Sarasvathy, 2003, p. 209). And yet, the future remains uncertain. How to deal with such uncertainty of social systems? William Bulleit offers a possible answer in this book. The unpredictable and complex nature of human action means to face a special type of uncertainty that is, as Bulleit develops in Chapter 2, much larger than that found in other engineered systems. The uncertainty that engineers usually confront resembles an explorer in a jungle with unknown dangers; this explains why engineers consider *as part of* their design considerations, elements such as 'safety factors', 'safety barriers', 'unforeseen factors', etc. (Doorn and Hansson, 2011; Hansson, 2009a,b). However, unlike probabilistic risk analysis, the design of social systems deals with true uncertainty under *unknown* probabilities. As Hansson (2009a) pictures it, such uncertainty is unlike that which a gambler faces at the roulette wheel. Social systems represent perhaps the extreme case, whose design and maintenance requires a distinct mind-set that brings together bottom-up and top-down solutions, along with the recognition of the adaptive nature of social systems, as Bulleit suggests.

How to engineer problem-solving designs in such unpredictable social systems? The recognition of adaptive and evolutionary dynamics leads us to think of the possibility of producing designs without 'knowing' beforehand the way in which the system to be designed or transformed 'works'. Perhaps the main contribution of Charles Darwin is in the realm of philosophy, indicating a way to produce a design without a 'designer' (Ayala, 2007; Dennett, 1995; Mayr, 1995, 2001). Evolution already shows how and why the selection of blind variations explains the success of any system that adapts to changing and unknown environments (Campbell, 1987; Harford, 2011; Popper, 1972). Perhaps we must resist the apparent requisite of having knowledge beforehand for doing something. Bruce Edmonds makes an analogy in Chapter 3 that compares social systems engineering with farming. Since there is no such thing as 'designing' a farm, farmers instead know that they must continuously act on their farms to achieve acceptable results. Edmonds underlines that, since we are far from even having a minimal and reliable understanding of social systems, then engineers of social systems must recur to system farming. Edmonds emphasizes that traditional design-based engineering approaches are simply not possible to be applied to social systems; a systems farming lens should rely more on experience rather than on system control, should operate iteratively rather than as a one-time effort, and should make use of partial rather than full understanding, among other considerations.

Yet, the notion of evolution challenges the very idea of whether humans can deliberately improve social systems. Is it possible to control, manage or at least direct an evolutionary process? Martin Schaffernicht deals with this question in Chapter 4. Like Edmonds, Schaffernicht questions whether deliberate social system designs can actually be made and if they can really be translated into improvement. Schaffernicht rather suggests that engineering can contribute to influence the pace of the evolutionary nature of social systems through *policy* engineering. He underlines that *collective policies* are evolving artefacts that drive behaviours – they are never definitive but in constant revision and adaptation – and become the central elements for developing an interplay between evolution and engineering that ends up shaping open-ended social systems.

These brief ideas indicate the immense challenge in 'engineering' (designing and redesigning, that is) social systems, or as put by Vincent Ostrom, it means a problem of 'substantial proportions… In Hobbes's words, human beings are both the "matter" and the "artificers" of organizations. Human beings both design and create organizations as artifacts and themselves form the primary ingredient of organizations. Organizations are, thus, artifacts that contain their own artisans' (Ostrom, 1980, p. 310). Human beings co-design the social systems that they form, this is why those designs might be intentional up to some point but they are also emergent, dynamic, incomplete, unpredictable, self-organizing, evolutionary and always 'in the making' (Bauer and Herder, 2009; Garud *et al.*, 2006, 2008; Kroes, 2012; Krohs, 2008; Ostrom, 1980). The ultimate challenge is to address the complexity posed by the relations between human beings. Joseph Pitt illustrates this concern with a concrete example: what does it mean to be a friend of someone? This question will lead us to challenge the very possibility of designing a social system. In Chapter 5, Pitt suggests that we can only design an environment in which a social system emerges and evolves, a suggestion that is in line with the first part of this book that calls for the need to recognize the experimental, evolving and open-ended nature of social systems. This is the first requisite for anyone aspiring to transform a social system.

Using Engineering Methods

How to engineer social systems? The second part of this book introduces different methods for engineering social systems. Engineers proceed in a distinctive way. Billy Vaughn Koen in his book *The Discussion of the Method* (2003) defines engineering by its method. For him, the engineering method is any 'strategy for causing the best change in a poorly understood situation with the available resources' (p. 7). Engineers call such strategies 'heuristics'. 'A heuristic is anything that provides a plausible aid or direction in the solution of a problem but is in the final analysis unjustified, incapable of justification, and potentially fallible' (Koen, 2010, p. 314). Koen highlights the distinctive nature of heuristics as opposed to other ways of facing the world; in particular, he considers the differences from scientific theories. A heuristic does not guarantee a solution, it may contradict other heuristics (Koen 2009); it does not need justification, its relevance depends on the particular situation that the heuristic deals with and its outcome is a matter of neither 'truth' nor generalizability. The engineering method – as opposed to the scientific method – is a heuristic; that is, unjustified, fallible, uncertain, context-defined and problem-oriented. Hence, the second part of this book can be seen as a small sample of heuristics that in particular share a common preferred strategy of engineers: modelling.

Engineering design requires the capacity to 'see' and imagine possible (both successful and unsuccessful) futures. Zhongyuan Yu and her colleagues show in Chapter 6 how policy flight simulators may help to address 'what if…' questions through model-based interactive visualizations that enable policy-makers to make decisions and anticipate their consequences. Policy flight simulators drive the exploration of management policies according to possible factors that contribute to an existing or potential state of a system. Through two detailed cases, the chapter shows how such simulators can be developed and how groups of people (rather than individuals) interact with them. These interactions are the central piece of the method, since the involved stakeholders and policy-makers bring conflicting priorities and diverse preferences for courses of action. The chapter illustrates with practical cases the mentioned idea of Schaffernicht: the centrality of the evolution of 'collective policies' for transforming social systems and the way in which such evolution can be enhanced through learning. Yu and her colleagues underline that the key value of their models and visualizations lies in the insights that they provide to those intending to engineer their own social systems.

Models are powerful tools for supporting design activities (Dillon, 2012; Dodgson *et al.*, 2007; Elms and Brown, 2012; Will, 1991). Unlike scientific models that are usually built for analysis of observations and generating 'true' explanations (Norström, 2013), engineering models are judged against their usefulness for specific, diverse (Epstein, 2008) purposes. For engineers, they serve as focal points ‘for a story or conversation about how a system behaves and how that behaviour can be changed. It is by mediating in this process – acting to focus language by stressing some features of the real system while ignoring others – that models contribute to new shared understandings in a community of engineering practice’ (Bissell and Dillon, 2012, p. vi). Chapter 7 by Peer-Olaf Siebers and colleagues introduces a structured framework for guiding such conversation processes through model development, from conceptual design to implementation. In particular, this framework organizes both the process of building and using agent-based models and the way in which the resulting simulation models can be used as decision-support tools for exploring the application of policies. Being a heuristic, they adapt what they consider appropriate for developing their framework; in particular, they borrow ideas from software engineering for tackling problem analysis and model design. The chapter uses international peacebuilding activities in South Sudan as an example to illustrate the practical possibilities of their proposal.

There are diverse ways of building models. Sandra Méndez-Fajardo and colleagues show, in Chapter 8, how social systems engineering can employ (social) science through a methodological framework that uses actor-network theory as a heuristic for designing and building agent-based models. They use an applied case in waste of electrical and electronic equipment management as an illustrative example. Their proposal presents a way to overcome the distinction between human and non-human actors, and underlines the centrality of ‘actor-networks’ (rather than just actors) in social systems. Although these theoretic contributions stand on their own as valuable results, they unmistakably underline the engineering character of their proposal, which concerns the pragmatic usefulness of modelling rather than its theoretical validity. They frame the application of actor-network theory as a heuristic for intervening social systems through the use of simulation models to enact policy changes.

Engineering may use scientific theories but may also contribute to science. Computational modelling can complement diverse theoretic approaches, for instance it is useful for supporting theory building in social science (e.g., Schwaninger and Grösser, 2008). To complete the second part of the book, in Chapter 9 Russell Thomas and John Gero use social theory to explore the process of institutional innovation and how to influence innovation trajectories in pre-paradigmatic settings (which the authors call ‘contested territories’), where there are rival worldviews regarding the nature of problems and innovations. The authors illustrate their methodological approach with the case of cyber security and the problem of quantifying security and risk under two rival worldviews: the ‘quants’ (for whom cyber security and risk can and should be quantified) and the ‘non-quants’ (who believe that cyber security and risk either cannot be quantified or its quantification does not bring enough benefits). The chapter frames the process of institutional innovation in Boisot’s theory of the social learning cycle and the role of knowledge artefacts during the cycle. A computational model helps to explore how knowledge artefacts of different characteristics affect innovation rate and learning. The chapter makes provocative suggestions regarding not only how social science can contribute to social systems engineering but also the other way around: how this latter approach can contribute to deal with scientific questions, such as the assessment of the scientific merit of each school of thought (in terms of explanatory coherence) and the possibility of addressing further theoretic issues of social dynamics such as legitimization, power struggles and structuration, among others.

Into Real-World Applications

Since social systems engineering is praxis, then real-world applications become perhaps the true way to depict this type of engineering. The last part of the book places the emphasis on practical applications that illustrate the richness and possibilities that the first two parts suggest.

Chapter 10 by Adam Douglas Henry and Heike Brugger deals with developing strategic scenarios for the adoption of environmentally friendly technologies. Through agent-based computational modelling, they inspect non-trivial policy answers to two simultaneously desirable outcomes regarding sustainable technologies: the speed of their adoption and the guarantee of equal access to them. Chapter 11 by Clifford-Holmes and colleagues combines ethnographic data collection with participatory system dynamics modelling in the design of potential strategies in water resource management in South Africa. Clifford-Holmes and colleagues emphasize the 'muddled middle' between policy and implementation, and propose new directions in participatory modelling. In Chapter 12 Markus Schwaninger and Johann Klocker provide an account of the 30-year evolution of the oncological care system in Klagenfurt, Austria, exposing the threat of organizational over-specialization in patient treatment and highlighting the importance of holistic approaches to healthcare system design by using causal loop diagrams and organizational cybernetic concepts. Last but not least, in Chapter 13 Jenny O'Connor and colleagues explore four case studies of smart city projects in the United Kingdom and highlight the importance of understanding the unpredictability of individual and societal behaviour when confronted with new sustainable-related policies derived from technical aspects only. O'Connor and colleagues explicitly call for the inclusion of the social dimension in the engineering of social systems.

In summary, social systems engineering goes beyond the application of engineering methods to social problems. In different instances there has been a tendency to equate engineering a social system with a traditional, mechanistic, one-shot undertaking that attempts to reach optimality according to some well-pre-established objective (Devins *et al.*, 2015). That is not what social systems engineering is about. In contrast, we aim to highlight the importance of trial and error, failure, iteration, adaptability and evolution as salient features of any design-oriented process. Stimulating self-organization (as opposed to direct intervention) as a way to foster growth of desirable properties (e.g., adaptability and resilience) is also intrinsic to any design-oriented endeavour. Engineering a social system implies 'steering' a system towards a desirable state (Penn *et al.*, 2013), even if such a state is not completely understood and is subject to different interpretations (e.g., a sustainable community), and even if the journey towards it is filled with unexpected occurrences. We hope that this book will provide a broader, multidisciplinary, conceptual approach to social systems design, and stimulate the growth of ideas towards solution-oriented perspectives (Watts, 2017) in dealing with social systems issues.

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