A SYSTEMIC APPROACH TO SYSTEMS OF PRACTICES IN ENGINEERING PROJECTS

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ABSTRACT

The engineer's work is based on the conception, design, and implementation of artefact creation and improvement. These devices are nested in an economic, social, environmental, and cultural operation, on which to think what is better and worse makes sense. The difference with other professions is the direct responsibility for thinking and designing to solve problems in social systems, in most cases without contemplating the dynamics of the environment or the cultures receiving these solutions. To solve this problem, there are different theories that, from critical visions, try to reformulate the teaching and practice of engineering in social and environmental contexts of vulnerability. Then, the use of systemic models would allow us to anticipate, based on an understanding of the social system and its dynamics, solutions based on possible scenarios. Through understanding the characteristics and structures of the engineering systems of practices as human activity systems and conveying it through a systemic model, this article explores a novel approach to the problem of social justice design in engineering. The results show us that there are five possible categories of engineering practices associated with working with communities, based on intellectual work intensity and the engineer's social engagement. In addition, causal loops that reinforce or affect the application of these practices were identified and used as leverage points within the systems of practices structure.

Keywords: human activity systems; systems dynamics; engineering practices

INTRODUCTION

Social justice is not an issue from only one discipline. The study of problems related to the development of society and the implications of the relationships that we, as humans, built with our societies were relegated for a long time to areas of knowledge such as sociology or anthropology (Kuhn, 1998). This situation includes studies in economics, in which not only the visions of the Marxist economy are highlighted (McBride, 1975), but also, the advances in the study of cooperation and competition in the search for common welfare (Cárdenas, Rodríguez and Johnson, 2015). However, movements about social justice have begun to shift into other areas and become part of the backbone of disciplinary knowledge for professional practice (Acevedo *et al.*, 2009). This phenomenon reflects a need to understand how the knowledge generated from, for example, engineering practices (EP) may produce profound changes in society. Far from idealism, engineers must change the notion from going beyond duty (Nichols and Weldon, 1997) to, as a profession, connect the knowledge, people, and environment to foster and spurt the world transformation (Baillie, 2006).

If, for example, engineers “make things better” (Rodriguez Valbuena, 2012), better should include profound changes for all society's welfare and well-being. However, one of the fundamental questions that engineering (as suggested by Olaya (2019)) must ask for the construction of this society that is raised in the previous sentence is the concept of "better" or improvement (for whom?). In short, the idea of development, improvement, or sustainability (as ideas of “better”) has been widely contested, and there is no consensus at the scientific or social level about these ideas. Therefore, any EP's effort will be biased under a specific vision based on his training as an engineer (Baillie and Catalano, 2009). Thus, the difficulties for applying engineering that positively impacts society are raised as questions about the use, misuse, or even end of the engineering (Long III and Mejia, no date).

Answering the previous questions is relevant if we consider the need for engineering solutions for many communities worldwide, especially in Colombia. According to the Nobel laureate economist Joseph Stiglitz (2017) and the data of organizations as The World Bank (2018), Colombia has been and continues to be one of the world's most unequal countries. However, in recent years, the country has had higher sensitivity to inequality and the social and economic consequences of income inequality, wealth, and opportunity (Cárdenas, Rodríguez and Johnson, 2015; Pérez-Garzón, 2018). This sensibility is relevant in a country where internal conflict, violence, and drug trafficking are found across the discourse, resulting from years of these inequalities (Stiglitz, 2017).

Even further, with the end of the armed conflict and the signing of peace agreements, a mix of opportunities and challenges become evident in most of the territories of rural Colombia, and these challenges, if well managed, can help in the elimination of the systemic barriers to having wellbeing in these areas of the country. Given the opportunities for improvement opened by the peace agreement, it is necessary to continue moving towards a more just society. This agreement (which looks to reverse the effects of the conflict with FARC guerrillas) puts on the table topics such as reducing inequality and unsatisfied basic needs (Ramírez et al., 2012). Furthermore, two out of the five proposals made in the document emphasize the need for a society more equalitarian and just, the comprehensive rural reform and political participation (Gobierno Nacional, 2016). Each one of these proposals can be viewed as an opportunity for a more socially just engineering. The reconstruction of Colombia requires material and social infrastructures that engineering can help design and implement.

The previous panorama raises essential questions about the changes needed by engineering. This change takes relevance in the engineer's life when an initiative such as scientific and technological research becomes an opportunity for intervention on artifacts (Ostrom, 1980) resulting from social and environmental changes. While the conflict imposed high adverse economic costs on society as a whole, ensuring sustained peace requires that engineering should be prepared to assume and face economic and institutional challenges (Stiglitz, 2017).

Engineering and Social Justice

The analysis of the concept of justice is the starting point for many areas of knowledge to find its meaning within their practices. First, the concept of justice developed by Rawls (1999) shows us a philosophical view of justice as a virtue of social institutions, making a distinction between justice and equity in terms of the potential and the real. Rawls believes that people would rationally adopt two fundamental principles of justice for our society: (1) equality in the assignment of basic rights and duties or potential justice, and (2) holds that social and economic inequalities are just only if they result in compensating benefits for everyone or real justice. From studies in economics, we emphasize the debate on creating institutions to obtain greater efficiency and the location of common goods to ensure the income, wealth, and power of society (Buettner-Schmidt and Lobo, 2012). Finally, from the theory of development, Martha Nussbaum and Amartya Sen (Sen, 2000; Kaufman, 2005) put social justice in terms of freedom and human development capabilities.

In the studies of engineering and social justice (ESJ), three scholars are relevant to understand this concept contextually. First is Donna Riley's work (Riley, 2008), vital for developing the ESJ concept. In her book about ESJ, Donna Riley studies how the structures and engineering mentality generate social injustice in class, gender, militarist culture, globalization, and racism. This analysis of the engineering mentality leads her to conclude that it would be wrong to construct a general definition of ESJ since social, temporal, economic, cultural, and ecological conditions make it change, mutate, and adjust. Therefore, Riley invites engineers to decide what ESJ means for each one.

On the other hand, the work of Leydens and Lucena (Leydens and Lucena, 2014) focuses on connecting the studies and vision of Capeheart & Milanovich (2007) with the work of Nussbaum (2005). For them, there are three relevant aspects to study social justice in engineering. First, we see that it focuses on a study of engineering practices. Second, they talk about human capabilities in terms of opportunities and resources. Third, they expose social justice in Ursula Franklin (Who benefits and who pays?). This second definition is accompanied by recommendations about the operationalization of this definition.

Finally, we see the work of Baillie (Kabo and Baillie, 2009), which combines three essential traditions, namely, education in engineering, the practice of socially just engineering, and the STS. Together with Catalano (2009), they highlighted the traditional vision of engineering within society, the development of ethics, and the multiple lenses in which it can be studied, such as understanding social justice by the students. However, there is not an explicit relationship between these topics and system thinking, a very special gap to be explored.

Engineering Practices and Systemic Theory

The relationship between engineering and society has focused on applying its knowledge by constructing artifacts and technologies that serve as an engine for developing projects of various kinds. Therefore, through history, engineering projects have been the engine of progress that has given solutions to society's problems (Arias et al., 2016). However, what has been seen throughout history is that engineering is also responsible for multiple issues and injustice situations around the world (Eizenberg & Jabareen, 2017; D. Riley, 2008), showing the necessity to expand our vision of engineering. Within this framework, and with the arrival of several critical perspectives about the engineering practices in the world, the nature of the application and implications of the engineering knowledge need to be adjusted.

Now, the question that remains is, why and how should we think about the practice of engineering and its deconstruction in terms of social justice? We have already discussed some interesting aspects inside engineering and the need for changes in its practice. Nonetheless, it is worth elaborating about community and social transformation for social justice. The engineer's work is based on the conception, design, and implementation of artifact improvements. All these artifacts come from an economic, social, environmental, and cultural operation, on which to think that there is better and worse makes sense. In a general sense, the difference is engineers' direct responsibility for thinking, unlike other social systems. From the origin of operations research and work design, cradle and father of industrial engineering, the theory has focused on studying and designing social systems, systems in which people play the critical role (Ackoff, 1988). Although engineering applications have been diversified in the last 20 years (Mendoza-Chacón *et al.*, 2016; Johnson, Midgley and Chichirau, 2018), what remained constant is the notion of improvement in systems where people matter, systems of human activity.

The human activity systems are notional system which expresses some purposeful human activity (Checkland, 1981). These systems are notional because intellectual constructs are included and not explanations of actual real-world doings (Banathy, 1988). There are several examples of human activity sets related to each other to form a whole (system) (Larsson, 2001). Even though human activity systems form a whole emphasized by other systems' existence, this kind of system is often designed (Larsson and Malmsjö, 1998). Therefore, the design of human activity systems, being an activity typical of engineering, can be considered in terms of the distribution of benefits, power structures, and, in general terms, engineering for social justice.

Based on the need to design socially just human systems, studying the existing methodologies for designing human activity systems from a social justice perspective will be valid for this article. Looking at human activity systems and social systems in engineering can identify several trends and epistemologies, but two major social justice trends are of interest.

First, studies in soft systems, born from Peter Checkland (1981), were mainstream during the 1990s. This type of systems research has sought to connect systems thinking with the practice of social systems engineering. This vision derives tools such as the Soft System Methodology and goes along with organizational cybernetics tools such as the Viable System Model (Espejo, 2003). These models use the human activity systems as a constructivist tool for designing and diagnosing social organizations (Ackoff and Gharajedaghi, 1996). This is also complemented by a study of the observer and his conception of social systems (Nelson, 2003; Reynolds, 2005), in which participation is essential in constructing a social identity.

On the other hand, we see the school of C. West Churchman (Wilby, 1997) as the birth of Critical System Thinking. As in the tradition of soft systems, this line of thinking of human activity systems focuses on critical theory for people's emancipation from power structures (Tsivacou, 1992). Because of this work, the Critical Systems Heuristics (Ulrich, 1987) is derived. This heuristic is a tool for designing social systems that emphasize on Boundary Criticism. As a result, the designer's assumptions about the human activity system become evident and the implications regulations of the design itself. To date, this is the only systemic tool in which explicit use of critical thinking is made (Maru and Woodford, 2001).

However, the application of the systemic in complex human systems to create equality has its most remarkable example in Stafford Beer and Raul Espejo's work with the president of Chile, Salvador Allende (Thomas, 2006). Before the coup d'état of Augusto Pinochet, these two organizational cybernetics, together with government officials, designed a viable system model for Chile's social, economic system, which in turn sought political freedom and democracy (Thomas, 2006).

Systemic Representation of Engineering Practices for Social Justice

Finally, the last aspect that must be considered is how to represent engineering practices for social justice. Within systemic thinking, in addition to the methodological tools and heuristics presented in the previous point of the article, some models and representations help us understand and capture the systems in which we find ourselves immersed.

The use of models and modeling of complex systems has been developed for several years. First, the models traditionally used within systemic thinking are based on understanding the dynamics of systems behavior, their structure, and the feedback that exists within them (Ackoff and Gharajedaghi, 1996). Second, the models used are usually tools associated with engineering processes (Olaya, 2012, 2019), and the knowledge of science and mathematics is connected to the art of graphic representation. Finally, the type of models that work in systemic thinking is based on the participation of the various stakeholders that are part of the system, which gives the models richness and depth (Damart, 2010). Voinov et al. (2018) have compiled these models, including levels and flow models, agent models, and causal loop diagrams.

Applying systemic thinking to social systems requires appropriate tools to observe and understand the behavior of these systems. A model simplifies a more complex object that allows for further study and analysis. The field of system theory corresponds to a reduction and order of the complexity of a system. Models are then epistemological instruments produced due to observing systems that express the structure and dynamics by compressing their characteristics (Moe and Kaivo-oja, 2018). These models cover qualitative tools, semi-quantitative tools, and detailed quantitative modeling methods (Voinov *et al.*, 2018). Thus, systemic thinking provides tools that allow proper modeling of systems and their subsequent analysis.

One of the most frequently used modeling tools is system dynamics. A system dynamics model represents the behavior structure of our world (Groff, 2013). Moreover, system dynamics tools are means to recognize the knowledge that underlies our mental models as representations of a system's complexity. However, Forrester (1989) reminds us that these models are applicable only if judged from their structure and clarity to communicate our thinking. Data and mental models are necessary for a correct representation of a system. Given the above, the use of system dynamics allows the understanding of causal relationships between its different elements, which generate specific dynamics from emerging structures (Allender *et al.*, 2015).

Inside the tools of system dynamics, causal loop diagrams stand out (CLDs). Haraldsson et al. (2006) define these diagrams as a systematic tool for identifying, analyzing, and communicating the structure of a system through cause-and-effect relationships between variables. These diagrams have been used to study different types of systems such as health (Baugh Littlejohns *et al.*, 2018), education (Groff, 2013), and even pandemics (Sahin *et al.*, 2020). Moreover, Olaya points out (2019) that system dynamics tools are based on engineering, opening the door to CLD as artifacts for decision-making, policy, and system design, showing the significant uncertainties of a problem or challenging mental models towards paradigm shifts. Given the above features, CLDs are valuable tools for studying social systems and, in particular, the pursuit of their well-being.

Some of the aspects that stand out of causal loop diagrams are that it allows the study of complex systems and problems, facilitates stakeholder participation, generates collaborative learning, and requires few resources (Voinov *et al.*, 2018). First, given the nature of the issues to be studied, causal loop diagrams can handle uncertainty, making their construction more effortless, without specific expert knowledge of the modelers. Hence, these models can be made from qualitative and quantitative information. Second, CLDs enable people with different knowledge or expertise to contribute to the development of the model, facilitating its subsequent discussion and validation. Third, these models allow an in-depth understanding of participants' mental practices and models, enabling improved proposals and joint action. Finally, the implementation requires low costs and time.

Concurrent with the focus of incorporating systemic thinking into the concept of social justice is a call to implement these concepts within engineering (Burnham, 2009). As shown in this document, considerable research has identified engineering practices from social approaches as a viable alternative to build this bridge (Trevelyan, 2010). Leydens and Lucena (2016) mentioned that engineering ideologies had prioritized technical approaches, excluding the social dimensions of their practice. On the one hand, movements such as engineering for social justice or humanitarian engineering argue that it is possible to transform engineering from the understanding of the fundamentals of its practice (El-Zein and Hedemann, 2016). On the other hand, studies in engineering education have explored approaches focused on practice-oriented to social problems (Monteiro, Leite and Rocha, 2019). However, there are not studies that have conceptualized engineering practice systems through systemic tools. To contribute to this discussion, this article aims to examine the engineering practices system involved in projects that seek the well-being of society and understand how these systems help or hinder practices to solve social and environmental challenges.

Therefore, from systemic models, we can represent the practices that engineers carry out to implement projects that seek social justice. Through understanding each of these projects as a system of human activity and conveying it through a systemic model, this research pursuits for a novel approach to the problem of social justice in engineering. Although any possible model is just a simplification of reality, these organizational dynamics and engineering projects are unique and broaden our understanding of social justice.

In short, little attention has been paid to the analysis of engineering projects for social justice through a systemic perspective, and little priority is given to the exploration of their social and cultural dimensions typical of the contexts in which these projects are developed. In particular, the impact of engineers and communities' practices on decision-making and social project management systems remains underexposed.

METHODOLOGY

The biggest challenge of this research is designing a research methodology that combines several epistemologies harmoniously to study engineering practices. Then, a general framework was selected to guide this thesis project, using three research methods. First, before presenting the methodology, some basic principles about systems thinking need to be described for clarity.

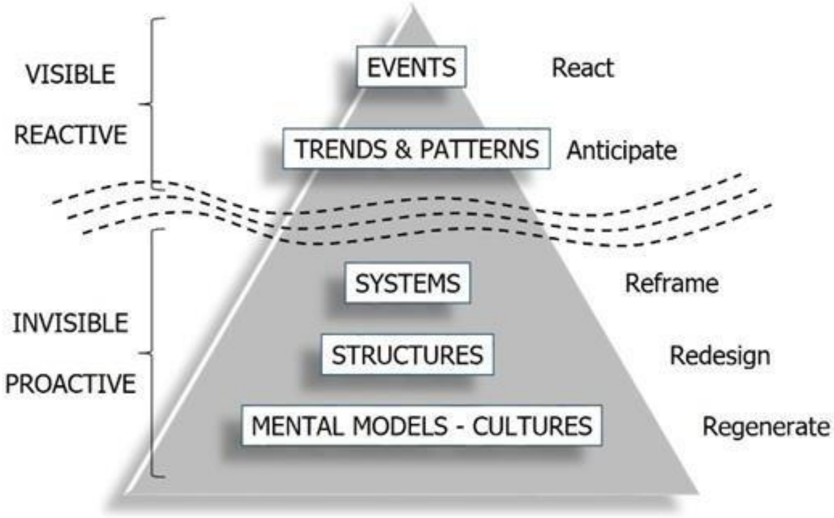

Figure 1. Systems Thinking Iceberg Model

It is vital to recognize the very structure of systemic thinking and its role within this project. As can be seen in Figure 1, the way of representing systemic thinking resembles an iceberg. In this model, there are different levels on which the systems and their behaviors can be analyzed. As research goes deeply into this model, the systemic understanding of a phenomenon is greater. Thus, the methods that accompany this research should aim to reach the deepest levels.

Given that this research's objective tries to elucidate attributes of engineering practices, it is necessary to determine the level of analysis that is appropriate. First, when we talk about events or patterns, the central point is the behavior of certain variables that help us identify the vision using the actors in the system. Second, by using an approach from systemic structures, it is possible to understand how the system's dominant behaviors and patterns are produced and how work is done to make changes in mental models operational. Finally, at the level of mental models are the values, beliefs, and assumptions that allow the system to function specifically and guide systemic structures. Therefore, this research will follow a bottom-up model, in which mental models will be analyzed, their structures to achieve specific patterns that allow social justice to be included in engineering practices. Furthermore, understanding these mental models should allow us to understand systemic structures. For this, a methodology based on the systemic thinking loop will be used, shown in Figure 2.

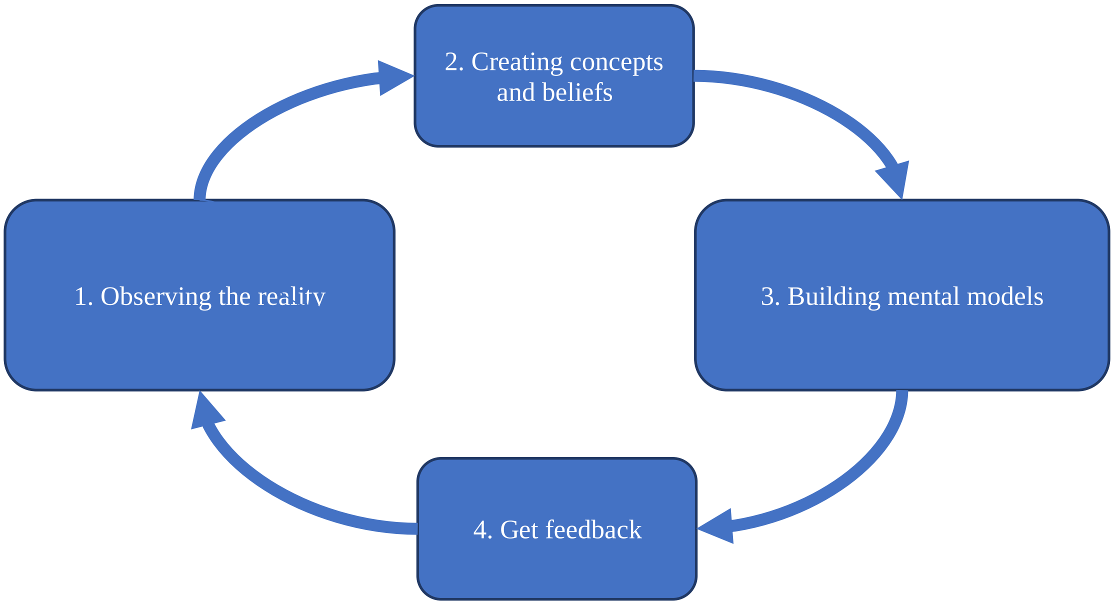

Figure 2. System Thinking Loop (Cabrera and Cabrera, 2019)

In the first phase of the study (observing the reality), data collection methods gather information about the past and present of each one of the cases presented in the problem statement. Semi-structured interviews were conducted with the participants of these case studies. The selection criteria were engineers who participated in the projects, non-engineer members of the projects, and community members who benefits or were affected by the projects. Data saturation was reached when sampling more data will not lead to more research questions.

This project analyzed three Colombian organizations involved in community engagement or supported engineering participation in social justice activities. The first organization, Engineers without borders Colombia, recommended working with the project "La Liga del Agua," in which engineers work with high school students in rural areas for water-saving through information technologies and prototypes. The second organization was the Center of Humanitarian Engineering of Universidad Sergio Arboleda, who suggested working on the Artisanal and Small Mining Project, where engineers and economists work with informal gold miners in Antioquia (Colombia) to substitute mercury during extraction. Finally, the Scientific Park of Social Innovation of Corporación Minuto de Dios invited us to meet the Empreverde project, in which engineers and other professionals supported small rural businesses' transformation into green companies, including the commercialization of the products.

The first part of the data analysis was a systemic phenomenographic study, associated with the second phase (creating beliefs and concepts). Considering that this article looks for descriptions of human activity systems, phenomenographic research highlighted the central aspects of the vision of community engagement and engineering practice. All interviews were transcribed, and the transcripts were subjected to iterative phenomenographic analysis. The transcripts related to a specific question were read, and a set of description categories were devised. This process was iterative until no more themes could be formalized in a system of developed conceptions, and no more categories are found in the transcripts. Furthermore, Terra and Passador's (2015) considerations about the systemic side of phenomenographic studies will be included to create the description categories.

After defining the categories of engineering practices for social justice, it is necessary to understand systemically how these practices can be fostered based on the mental models of the participants (third phase of the loop). To accomplish this task, these practices were represented through Causal Loop Diagrams (CLD). The process suggested by Jhon Sterman (2000) was adapted to carry out the analysis of the results

RESULTS

The phenomenographic analysis identified five qualitatively different conceptions of how people within engineering projects with social impact in Colombia view community-engaged practices (Table 4.2). Due to the phenomenon complexity, interviewees express different aspects of the conceptions. In addition, it is crucial to highlight that the top categories are better than the first ones. On the contrary, each category subsumes the previous categories, making the top categories more complete in terms of engagement. Additionally, each category of description is supported by illustrative quotations representing critical aspects of each category. Finally, since not all excerpts can be presented here, only a few selected samples are presented.

Table 1. Categories of description

Categories of description	Summary	Key aspects
Category 1: Engineers theorizing social issues	Community-engaged practices are based on the contribution from theory to solve social problems	Engineers as problem solvers Theoretical solutions

Category 2: Engineering practices as interdisciplinary work	Community-engaged practices are based on their contribution to other professions in their projects	Knowledge contribution Collaboration Conceptual capital
Category 3: Engineers as consultants in projects with communities	Community-engaged practices are based on the recognition of the community as a problem source	Consultee models Life improvement Communication skills
Category 4: Co-design as a professional practice for engineers	Community-engaged practices are based on the joint development of artifacts to solve social issues	Community knowledge Knowledge transfer Shared responsibility
Category 5: Engineering practices that eliminate systemic barriers for communities	Community-engaged practices are based on the system recognition and social mobilization	Systemic thinking Life transformation Social fabric

The first conceptualization identified in the study reflects on theorizing about social issues within engineering practices. In this concept, community engagement is low because these social problems come from data or their perceptions. The following conceptualization includes working with other professions in professional practices, showing community engagement depending on the relationship between the "other" outside the study area, and nurturing engineering work. These first two concepts have low involvement with communities since the engineer remains in his position without recognizing their privileges. Then, we see a more personal relationship with the community in the following conception. In this category, the practices focused on creating a fundamental connection with the community to develop an engineering solution where the community is also part of the engineering process, but only as an information source. Then, we find that the following conception includes a collaborative process on engineering projects. This process, which we call co-design, allows engineers and communities to be part of identifying, designing, and implementing the solution. Finally, we see the top conception, the more complete of this phenomenography. In this category, engineering can remove the barriers that systems have placed on communities as we see a deep understanding of community engagement, which allows not only to include people but also to transform the inequalities that exist in the context. The last three conceptions show a closer relationship between engineering practices and community engagement, with an even more active involvement as higher the category is.

From the previously presented outcome space, selecting the variables that should be included within the model was made. These variables were selected based on the dominant topics included in each one of the interviews. The dominant themes were 4: Activities related to the economy, related to the environment, associated with the social system, and technological development. Because of the simplification process, 14 variables were obtained, presented in table 2, and 29 relationships, of which 22 have positive and seven negative polarities (Table 2). The final causal loop diagram is illustrated in Figure 3.

Table 2 Key Variables Regarding Factors that influence Engineering Practices

Number	**Variable name**	**First time quoted**	**Other quotes**
1	Environmental concerns	C001	C002, I001, I002, I003, I004, I006, I007, I008, I009, NI003, NI004, NI005, NI006.
2	Social concerns	C001	C002, I001, I003, I005, I006, I007, I010, I013, NI001, NI002, NI003, NI005, NI007.
3	Economic concerns	C001	C002, I001, I002, I007, NI001.
4	Technological development	C001	I001, I002, I004, NI001, NI002.
5	Engineering Practices	C001	All interviews.
6	Learning	C002	I007, NI007.
7	Political operation	I001	I003, NI003.
8	Ethics	I001	I002, I005, I006, I007, I009, I013, NI001.
9	Soft Skills	I003	I006, I009, I010, NI001, NI003, NI004, NI005, NI006.
10	Institutional Support	I003	C002, I001, I005, I006, I007, I010, I012, I013, NI001, NI002, NI003, NI004.
11	Community engagement	I003	I004. I007, I008, I010, NI001, NI004, NI005.
12	Interdisciplinary work	I004	C001, I001, I002, I003, I005, I006, NI001, NI003, NI004, NI006.
13	Systemic Thinking	I007	I010, NI005.
14	Design Thinking	I007	I009.
Note: C: Community member; I: Engineer; NI: Other professional			

The next step was to identify the loops of the model to investigate what combination of the variables presented offers possibilities to encourage engineering practices for social justice. Based on the model shown in figure 5.1, a total of 9 loops were identified, of which six are balancing loops, and 3 are reinforcement loops. Each loop was noted with colored dotted lines and included its number and polarity.

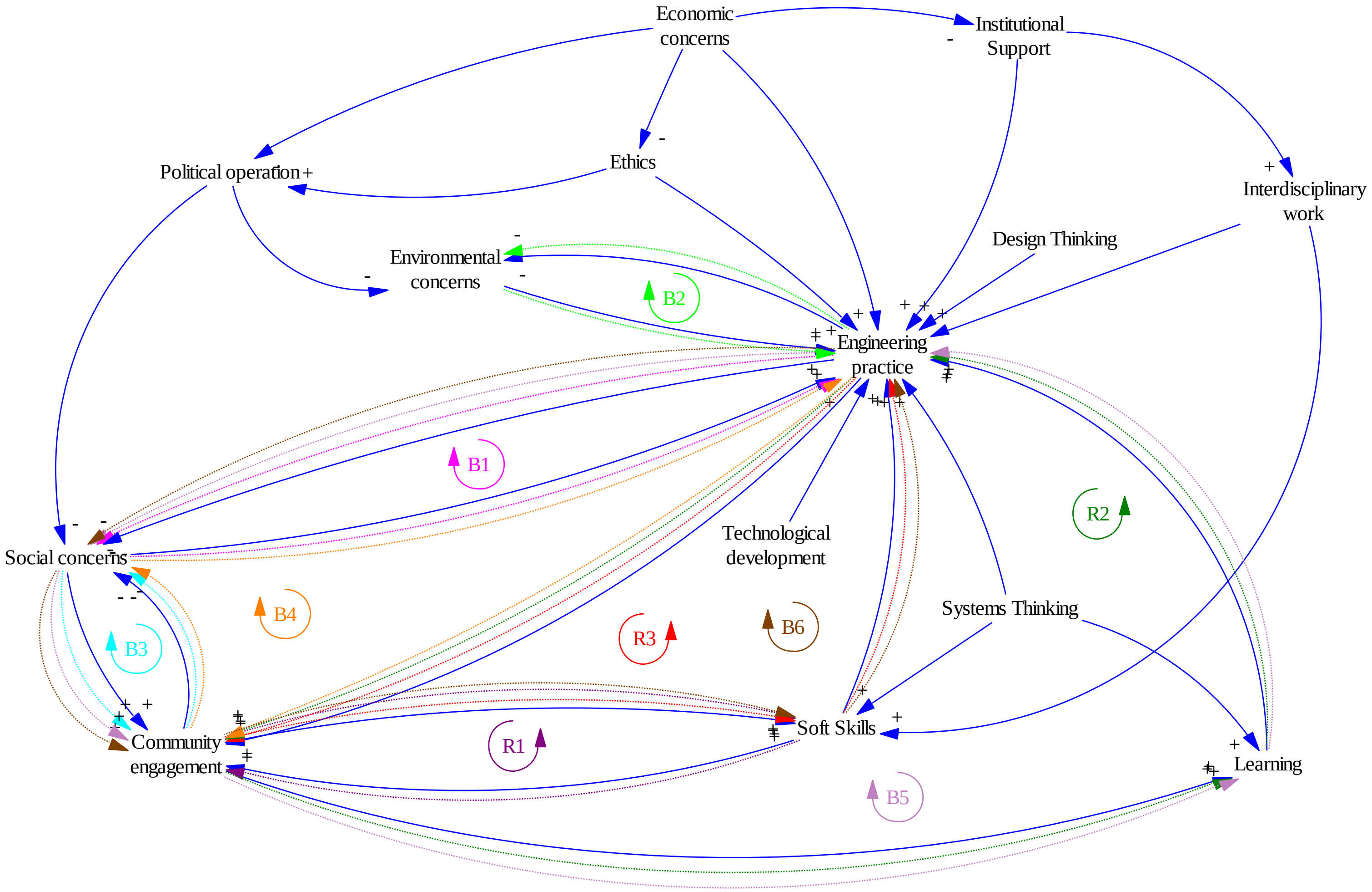

Figure 3. Causal Loop Diagram of the Engineering Practices System.

The causal loop diagram presented in the previous page can identify the complex interplay of factors that affect engineering practices and explain why the studied projects can be implemented effectively. This diagram represents a complex picture with numerous interactions and feedback mechanisms. The approach used in this study improves our understanding of the patterns in this shared practice system to identify potential opportunities to foster these kinds of practices inside engineering.

According to Donella Meadows (2016), some points within a complex system (such as the one presented in this study) where a slight change in any element can produce significant changes in the entire system. She called them Leverage Points, twelve points organized based on the effectiveness they have to make a change and are subsequently studied to understand the structure, rules, and paradigms of a social system. These points are likely to be used in systems dynamics models, as the model of the engineering practices systems presented in this chapter. The strategies and recommendations presented in this section are based on the leverage points proposed in the literature.

Balance feedback loops are intended to slow down a process and bring the variables to a stability level, a goal, with a monitoring system and a response system adjusting the behavior. Furthermore, the strength of a balancing loop depends on the combination of its parameters and relationships, which makes it valuable as a leverage point. Within the loops presented, some of the strategies that could be developed are:

- For the B1 loop, it is necessary to determine when the stability goal is reached (the attractor of the variable behavior or when this behavior becomes regular and stable). In the case of engineering practices variable, social concerns make engineers want to act more and become involved in solving these problems. However, these concerns are reduced after some time for these actions, taking the loop to a stabilization point where practices are not fully developed. A reflection on personal practices associated with social problems will reduce the negative effect of the loop. This recommendation is tied to the conclusions reached by McIntyre (2002) on the role of critical thinking in the development of praxis and its relationship with individual responsibility in social and environmental problems.
- For the B2 loop, as in the last numeral, it is necessary to determine the level of stabilization of the loop. The exact mechanism of the B1 loop applies in this case, but environmental problems influence it. Thus, reflecting on personal practices associated with environmental issues will help reduce the negative effect of this loop.
- In the B4 loop, we see a similar effect to the B1 loop, in which engineering practices stabilize from their relationship with social problems. However, the B4 loop includes community participation as a fundamental part of solving these problems. In this case, this loop evaluates an additional variable, the level of

participation achieved in the projects. As indicated by Arias et al. (2016), active community participation in all phases of a social engineering project generates better results and, therefore, improves engineering practices. Thus, to eliminate the balancing effect of this loop, engineering practices must encourage community participation (Damart, 2010).

- In B5 and B6 loops, the structure is similar to that of the B4 loop, including learning and soft skills. Inside the literature, Gómez Puente et al. (2014) talks about the importance of experiential learning in developing professional skills in engineers, while Vanasupa et al. (2009) show us the relationship between the social domain, the cognitive domain, and engineering. These authors agree that the engineering practices development is associated with improved technical and professional skills, fundamental points of these loops. Moreover, the authors recommend putting these skills into practice in real situations, giving rise to spaces for collaboration and learning with communities. Thus, the recommendation to reduce the effect of these loops on engineering practices is to encourage constant reflection on the learning generated from these experiences of working with communities.

A reinforcement feedback loop generates exponential growths on the variables involved. In contrast to balancing feedback loops, these loops do not have a limit, so they are sources of growth, explosion, erosion, and even collapse of a system. Thus, the more a loop works, the wilder and unpredictable its behavior may be. The function of the R2 and R3 loops within the model presented is to encourage the engineering practices development due to technical and professional learning. On the one hand, these loops reduce the negative effect of loops B5 and B6, promoting engineering practices. On the other hand, it is necessary to control its growth to avoid the system's collapse. Consequently, the recommendation is to ensure that engineering practices are based on real social problems, allowing B5 and B6 loops to act.

Finally, a paradigm is a system of thought that underlies complex structures and gives rise to the behaviors and loops of the system. Paradigms are the sources of systems, so they are the most challenging aspects to change since it implies a complete reconstruction of the previous paradigm (Allender et al., 2015). To produce these expected paradigm shifts, it is needed to share the new paradigm with other people within the system and insert the new paradigm in visibility and power. Therefore, the model presented is a challenge to the established paradigm on the teaching and practice of engineering (Halbe et al., 2015; Iacovos Nicolaou et al., 2017), so the strategy is based on opening engineers' mentality. As a result, this systemic representation of the engineering practice system is a mechanism to spread the new paradigm of engineering practices for social justice (Vandersteen et al., 2009). The strategy here is to create means to show the results of this study and create space to discuss this new engineering paradigm with students and professional engineers. The greater goal of this thesis is, then, to contribute to this leverage point through this systemic diagram.

CONCLUSIONS

The results of these studies recognizes the dynamic nature of engineering work with communities as a foundation for the strategies proposed here. Although the three projects studied operated with a similar basic working model and seemed to successfully generate solutions that include critical thinking and joint work, the particular constellation of activities and visions of the participants facilitated the engineers in transforming their practices. In the first study, it was shown how engineers conceptualize their practices, giving a possible range of activities, visions, and involvement in five categories. In the next study, once it is understood that this concept is not static, the use of CLDs showed that six causal loops balance or reinforce these engineers' behaviors over time. In summary, this research showed that practices are not static and change over time according to specific characteristics.

This study has demonstrated that people working within projects with social impact understand the community-engaged practices in qualitatively different ways using a phenomenographic analysis, with conceptions ranged from the notion that engineers only provide knowledge to engineering practice for social transformation. This study also shows that phenomenography, a methodology predominantly used in education research, could effectively analyze complex social phenomena. Understanding different conceptions of engineering practices in community-engaged projects could facilitate making informed decisions and developing teaching and education strategies to yield better outcomes for students and professionals. As Marton (1986) describes, 'a careful account of the different ways people think about phenomena may help uncover conditions that facilitate the transition (Jonassen, 2015; Reddy et al., 2018; Skokan & Gosink, 2005) from one way of thinking to a qualitatively "better" perception of reality" (p.33).

However, the main contribution of this paper is the application of systemic analysis to an understanding of engineering practice drivers. The systemic nature of this approach allows the practices that engineers have inside engineering with positive social and environmental impact to be considered in terms of their inner complexity and a model to be built based on participants' perceptions. Another critical point of the systems of practices analysis is the diversity among these participants. The systemic analysis approach considers a more significant number of stakeholders in three projects, contrary to the current approaches that only consider one case study. It also confirms previous works by showing that CLD can be drawn across multiple projects, with each person speaking about his/her system of practices (Vanwindekens et al., 2013). Consequently, the approach could be applied in further work in engineering studies to characterize people's perceptions.

The combination of the results obtained in these studies demonstrated that engineering practices "are greater than the sum of their parts.” The sophistication of systems thinking, the relevance of alternative engineering practices and the importance of social justice make this research a more robust and helpful tool for solving the problems that exist within our society. As mentioned earlier, each contribution adds to create a systemic methodology for running projects improving the communities' life quality, reducing risks, and eliminating barriers within the system. Thus, the most outstanding contribution of this research to the scientific world is the development of a methodological approach based on practice for the implementation of engineering projects in contexts of social and environmental vulnerability.

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