

# Sustaining Sustainable Design Through Systemic Thinking\*

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*We believe that in order to ensure a sustainable future, the design of our built environment should be based on systemic thinking. A radical transformation is required in how we educate future designers. This paper proposes a systemic thinking framework that can be applied to assess the impact of innovative educational interventions. Results are presented from a study aimed at understanding the types of attitudes and skills that are necessary to reformulate unsustainable design practices. The authors identify a set of insights related to the evaluation of systemic thinking, its development, and its enactment in design practice.*

**Keywords:** systems thinking; sustainable thinking; interdisciplinary teams; systemic focus

## 1. INTRODUCTION

SUSTAINABLE DESIGN CAN be defined as the ideation and planning of a built environment ‘that meets the needs of the present without compromising future generations’ [1]. Implicit in this definition is the acknowledgement that, until recently, designers have been concerned with creating solutions for the short term and therefore the modifier ‘sustainable’ is now required to emphasize the long-term effects of our present material satisfiers. We believe that this transition towards a sustainable future demands a significant change in our way of thinking. Designers, who build specifications of what the future will be like, have relied on a ‘classical’ or Cartesian mode of thinking characterized by reductionism, analysis, linearity, determinism and rationality [2]. We cannot expect to generate disruptive change unless our thinking tools evolve into more holistic complex thinking guided by non-linear dynamics, indeterminacy, adaptive evolution, self-organization and emergence [3].

A radical transformation is required in how we educate future designers. Teaching paradigms in industrial and engineering design remained largely unchanged throughout the twentieth century. The environmental, social and economic challenges ahead, demand that designers learn to responsibly assess the future feasibility and consequences of their ideas [4]. This paper proposes a systemic thinking framework that can be applied to assess the impact of innovative educational interventions towards this goal. One important motivation for this ambitious task is the Reengineering of the

Teaching-Learning Process (RTLTP) [5]. RTLTP is aimed at shaping students’ learning experience. The core element of Tec de Monterrey’s RTLTP is the change of the teaching and learning roles [5]. Students become more active in their learning, whilst teachers facilitate the student-learning process. We believe that this role change is one of the keys for sustainability education. The drive for this change is the teaching faculty since they design and conduct the learning experience.

In this paper we present results aimed at understanding the types of attitudes and skills that are necessary to reformulate unsustainable design practices. The paper is organized as follows: Section 2 provides definitions about systemic thinking and our proposed framework. Section 3 describes background teaching experiences that motivate and guide this work. Section 4 presents the assessment framework and the results of its application. Finally, section 5 provides some conclusions and defines a research agenda for the future.

## 2. SUSTAINABLE THINKING

The term ‘sustainable thinking’ refers here to the type of underlying reasoning processes that seem necessary to identify and overcome decision-making models that yield unsustainable solutions and perpetuate unsustainable practices. In regards to design, sustainable thinking becomes the cornerstone of an evolutionary change required to sustain a paradigm shift from the dominant view of ‘designing things right’ (technically correct, efficient, emotionally meaningful or successful in the marketplace) to a new worldview of ‘designing

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the right things' (i.e., aligned with the needs of the present without compromising future generations). These two paradigms are not incommensurable; in fact, we envision sustainable designs as the balanced achievements that combine these two goals, i.e., 'designing the right things right'.

From this definition, a design may not be considered sustainable only because it is manufactured in recycled or biodegradable materials, or produced and distributed in a fair-trade scheme. Besides such considerations, sustainable products must address the long-term interests of future generations. This usually requires changes not only in the intrinsic characteristics of a product, but more importantly, it demands radical transformations of the expectations, values and cultures that emerge in the relation between products and humans. Such changes, therefore, lie beyond technical improvements and in fact require new ways of understanding the role of products in our models of progress, consumption, and well-being.

Sustainable thinking is hence defined here as *the type of reasoning that enables the dealing with complex systems with the appropriate scope, depth, versatility and insight to generate qualitative changes that increase the sustainability of products and systems*. This definition guides us to published research on systemic thinking. Relevant frameworks for dealing with a scale of systemic thinking styles may turn useful to characterize sustainable thinking in design and engineering. At this point in time, we focus on the definition and measurement of systemic thinking styles, using these results to discuss the implications for sustainable thinking.

Stave's framework [6] defines basic/low-level, intermediate/mid-level and advanced/high-level systems thinking styles. A similar range is described between systematic or analytical thinking in the lower end, to systemic thinking in the higher end by [7]. Stave [6] defines low-level systems thinking as 'see things, not relationships; see cause-effect relations as one-way; one cause/one effect; external events cause system reaction', while high-level systems thinking is defined as 'see relationships rather than things; sees cause-effect relations as reciprocal; multiple causes/multiple effects; system structure causes system behavior'. Examples of low-level systems thinking include 'recognizing interconnections; identifying feedback and understanding dynamic behavior'. Examples of mid-level systems thinking are 'differentiating types of variables and flows and using conceptual models'. Sample instances of high-level systems thinking are 'creating simulation models and testing policies'.

In order to characterize and measure systemic thinking, in this paper we present a three-tier framework based on Stave [6] where  $S_L$  corresponds to low-level,  $S_M$  to mid-level and  $S_H$  to high-level systems thinking. Fig. 1 represents these levels and their relations. Systematic thinking refers to a mono-disciplinary, low systems thinking level ( $S_L$ ). This level of thinking is focused on analysis, simple

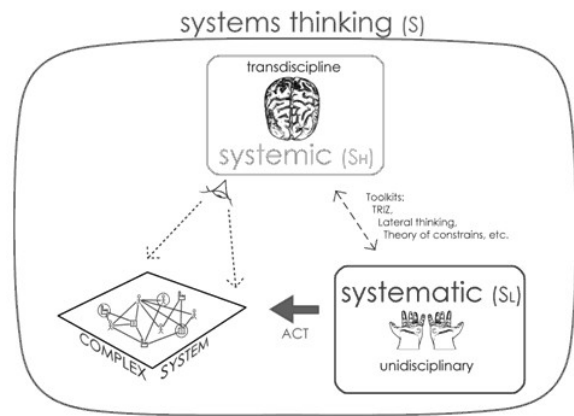


Fig. 1. Systemic thinking framework and related tools and concepts, based on [6].

causal explanations, and is aimed at system-wide solutions. Systemic thinking refers to an interdisciplinary, high systems thinking level ( $S_H$ ). This type of reasoning emerges when the problem solver adopts a wider view of the system and includes reasoning about time, context, and its own role in understanding and framing the problem. The person learns within the situation and develops new strategies targeted at key leverage points of the problem. The development between low and high-level systems thinking may be accomplished through the application of different toolkits to understand and define which, where and when the best actions should be taken.

Given the current world crisis, striving for sustainability and a consequent paradigm shift in education is unavoidable. Such a reform in higher education demands a significant effort to develop students' higher-order cognitive skills (HOCS) capability; i.e. question-asking, critical systems thinking, decision making, problem solving, systemic thinking, etc [8]. This means a paradigm shift from the prevalent algorithmic teaching to HOCS-promoting courses, curricula, teaching strategies and assessment methodologies. The consequent shift is thus from disciplinary to inter- and trans-disciplinary learning. HOCS are also known as HOTS (Higher Order Thinking Skills).

### 3. BACKGROUND EXPERIENCES

The teaching experience of the authors has been the source of identifying the need to change our thinking paradigms in design and engineering. This section presents the main teaching scenarios that have led us to the study of sustainable thinking in design.

#### 3.1 Interdisciplinary design studios

Two project-based courses from Electronic Engineering and Industrial Design have been merged into a senior-level Design Studio that is being offered in our school for the last two years.

Students enrolled in this course have a three-year background education on either engineering or design. They live a collaborative experience addressing a complex design challenge related to Social-Intelligence Design [9]. Innovative results by students of this design studio have been presented at international specialized forums [10, 11].

Two main systems thinking factors emerge in this interdisciplinary studio: tolerance to uncertainty and a holistic approach to complex problems. Engineering students tend to become anxious during the first weeks, when teams are exploring the situation and framing the specific task to work in. Meanwhile, design students are used to work in such ambiguous conditions. Another important activity developed during the course is the cycling between divergent and convergent thinking dynamics. Engineering students play here a crucial role by enabling and advancing the initial design concepts. At the end of the semester, the teachers observe that the interdisciplinary teams tend to improve their systemic skills and develop a holistic point of view beyond their conventional fields of expertise.

### 3.2 Beyond product innovation

In the fourth year of our Industrial Design program, the design studio is oriented towards design interventions in complex social, economic and environmental systems. When exposed to such scenarios, design students tend to think first in physical alternatives—particularly in consumer products. Through group debates around sustainability, ecological footprint, life-cycle assessment, consumerism, social wellbeing and biomimicry, students reinterpret their project goals in order to surpass the realm of objects. Concepts like systems and service emerge, and the proposal made by team members tend to encompass a complex network of innovative decisions about people, economics, politics, markets, function, semiotics, production processes, natural capital, etc. The orientation of this design studio has yielded results with extraordinary potential of positive impact in our society, including the project ‘Waste Recovery System’, a 2009 finalist in the prestigious Index Design Award [12].

### 3.3 Innovation and sustainability seminar

This fourth-year seminar has been useful to witness a significant change in perceptions and attitudes of design students towards innovation and sustainability. The seminar initiates with the diagnosis of students’ previous knowledge and experiences, which tend to denote a technology-driven view of innovation and an environmental-focused view of sustainability. Throughout the seminar, students are introduced to principles such as value creation-convergence-destruction, paradigm shifts, innovative business models, systemic creativity, resistance to change, imitation and dissent, wellbeing and happiness. As a result,

students develop their own systemic interpretation of sustainable innovation that enables them to understand the dynamic interactions, multi-level processes, hidden components, and uncertainty that characterize these systems.

These three experiences have allowed us to recognize the need to develop assessment tools to assist students’ reasoning strategies when approaching design problems from a systemic viewpoint.

## 4. ASSESSMENT OF SYSTEMIC THINKING

This section presents results from an assessment exercise of systemic thinking in our students. This evaluation is carried by designing and applying a questionnaire that requires both open and closed responses. We analyze students’ attitudes and explanations based on the framework presented above in Section 2.

### 4.1 Systemic thinking assessment

We developed an assessment tool in order to evaluate the thinking levels of our students. This tool is based on a combination of Stave’s systems thinking framework [6] and a HOCS questionnaire [13]. The three levels of Stave’s taxonomy were adapted to the HOCS questionnaire. The questions were elaborated taking into account expected answers for different levels of systems thinking. Respondents were students from our Electronic Engineering (EE) and Industrial Design (ID) undergraduate programs. The questionnaire was designed to be answered online, in less than ten minutes. Voluntary participation was scheduled as a class activity. After the description of a global challenge (non-renewable energy), students were requested to answer two sections: Section A consisted of multiple choice answers that helped us classify the thinking level of our students. Three alternative actions to address the problem were available: #1 corresponds to mid-level systems thinking, #2 to high-level thinking and #3 to low-level thinking [13]. Section B was an open question to elaborate on their choice in Section A. The questionnaire is shown in Fig. 2.

### 4.2 Statistical results

From a total of 49 responses, 22 were electronic engineering (EE) and 27 industrial designers (ID). Participants were 26 female and 23 male: most EE students were male (82%), while most ID students were female (81%).

Responses to Section A of the questionnaire are useful to characterize the way in which students first approach a complex problem. 53% of respondents chose option #3 in section A ( $S_L$ ); 10% chose option #1 ( $S_M$ ); and 37% chose option #2 ( $S_H$ ). No major differences were registered in the distribution of responses in these three categories between EE and ID students. This also implies that no signifi-

'The pattern of consumption of oil as a main source of energy is unsustainable in the long-term (Mexico's oil reserves are expected to be depleted in ten years). There are alternative sources of energy such as solar, wind, sea currents, nuclear, fuel cells, etc.; nevertheless each of them presents disadvantages. We may even consider energy sources not yet developed. A sustainable decision consists on selecting a path to substitute finite energy sources with renewable sources'. Please, answer the following questions. All may be considered correct, we ask you to choose the one that you consider most appropriate.

- A. Choose only one of the following actions to address this global problem:
1. I propose to analyze and combine energy sources according to the goal in each case as well as strategies for their diffusion and correct use.
  2. I would first identify the pros and cons of each alternative, study their implications and relevance of each factor in our context, as well as their implementation effects.
  3. I would analyze all the variables that determine the advantages and disadvantages of each energy source.
- B. Please, explain in a paragraph your choice and the contribution of your academic specialization to a multidisciplinary team that works on this area.
- C. Personal data: Academic program you are enrolled and sex.

Fig. 2. Questionnaire.

cant differences were registered between female and male students. Namely, across disciplinary and sex categories, our questionnaire consistently showed that more than half of our students consider that the solution to a complex problem would require primarily to focus on action #3, i.e., exhaustive analysis of the variables at hand.

An inconclusive trend worth exploring in the future is the importance ascribed by male respondents (most of them EE students) to action #1, i.e., the role of context, diffusion and use. 17% of all male students chose this option, compared to only 4% of all female subjects. Option #2 received a similar rate between disciplines (EE = 36%, ID = 37%) and between sex categories (38% of all female and 35% of all male subjects). We can preliminarily conclude that roughly one-third of our students opt for exploring alternatives and their effects in different contexts when addressing a complex problem. This, however, requires validation through the responses provided to explain their choices, as shown in the following section.

#### 4.3 Qualitative results

Section B of the questionnaire enables a more accurate interpretation of students' responses to the open question as to why they chose their strategy to approach the problem of alternative energy. In order to classify these responses, we conducted a semantic analysis identifying a hier-

archy of thinking styles as shown in Table 1. This classification matches our framework as explained in Section 2 above. First, low-level systemic thinking or  $S_L$  responses are those focused on analysis as the main explanatory reason provided. We also include here responses related to optimization, improvement and efficiency because they denote a straightforward approach linked to analytical thinking [2, 3]. Next, mid-level systemic thinking or  $S_M$  responses suggest that the student adopts a more relativistic stance where solutions require adaptation to context conditions, and where hidden consequences are expected. At this level, students also incorporate socio-technical interactions such as modifying the prevailing energy-use culture and values held by stakeholders. Lastly, high-level systemic thinking or  $S_H$  responses include those that take into account time-based criteria, cyclic stages, and contingency planning. Of special interest,  $S_H$  responses also include meta-cognitive processes such as a student realizing that engineering schools need to incorporate these issues in interdisciplinary courses, due to the relevance and complexity of this type of problems.

#### 4.4 Overall implications of the assessment exercise

This exercise shows that there are more instances of low-level ( $S_L$ ) than mid-level ( $S_M$ ) and high-level systemic thinking ( $S_H$ ) across our students. An approximate ratio of 2:1 is observed across each

Table 1. Students open responses categorized in low-level ( $S_L$ ), mid-level ( $S_M$ ) and high-level ( $S_H$ ) systemic thinking categories, based on our framework

$S_L$	$S_M$	$S_H$
Analyze all advantages and disadvantages in order to make a decision	Combine or adequate depending on context, needs, priorities, applicability. Find appropriate solutions for every case.	Consider time: choose the best moment to act; understand the stages of the energy cycle from generation to use and disposal.
Compare, implement, optimize, integrate, improve, increase efficiency; as soon as possible.	Consider the effects, particularly those that may turn into bigger problems in the future.	Design new strategies; focus on new knowledge and evidence; simulate future scenarios; consider 'plan-B'
Analyze all the variables or features of the alternatives, and design the best solution for all.	Build and reinforce a culture of saving, help people realize how they consume and waste energy.	The curriculum of Engineering schools should integrate these issues as interdisciplinary courses.

hierarchy. Nonetheless, this type of assessment tools need not yield a discrete categorization of systems thinking in a population. Namely, each response may match more than one hierarchy. This is insightful as it shows that subjects may include several types of thinking as they formulate their responses even in a short period of time. The role of the time available to respond the questionnaire, as well as its scope, in shaping these results remains an open question. Only the iteration of this exercise in different populations and in a variety of rephrasing scenarios would provide conclusive evidence.

## 5. CONCLUSIONS

The authors identify three directions for discussion derived from the aims of this research, the framework proposed, and the assessment exercise described above.

### 5.1 Insights related to the evaluation of systemic thinking

This work demonstrates the applicability of a framework for the evaluation of systemic thinking. As in every exercise subject to interpretation, keywords by themselves are not enough; they must be considered within a context. For instance, the authors were looking for distinctively characterized answers, but the assessment demonstrated evidence of diverse types of thinking within a single response. It would be important to consider that a person could develop systemic thinking while elaborating their ideas, that is to say that systemic thinking can be achieved gradually within the same process of answering a question. A more adequate assessment tool may capture and support this kind of constructive process of ideas.

As this is a framework under development, we acknowledge the need for validation by repeating the process to students from other programs and exploring alternative phrasing of the problem and the courses of action available.

### 5.2 Insights related to the development of systemic thinking

Beyond strategies for assessment, it seems necessary to study the role of existing creativity and design methodologies in the development of systemic thinking. The framework and tool presented in this paper would be of great value in the process of preliminary evaluation—tool application—post evaluation. A future research agenda is to evaluate the effectiveness of existing or modified methodologies when promoting a shift from lower to higher levels of systems thinking among our students. As a result, we would be able to characterize methods and techniques according to their type and degree of application.

Arguably, the end goal may be that design teams need to exhibit systemic thinking in order to sustain sustainable design, but it may turn out nearly impossible to develop high-level systemic abilities on every team member—even possibly undesirable. Instead, one possible strategy would be to incorporate an assessment exercise like ours during team formation in design projects in order to maximize team diversity [14]. This could help guarantee that in every team there was a range of low to high-level systemic thinking that would guarantee cycles of idea divergence and convergence [14].

### 5.3 Insights related to the enactment of systemic thinking in design practice

In order to understand the effects of systemic thinking in design projects, further research is needed in the connection between thinking styles and their outcomes in design projects. Future work along these lines is required in order to assess high-level thinking interventions in students as well as in instructors of design and engineering. Of key importance is the evaluation of the hypothesis that systemic thinking enables designers to transcend short-term, narrow and limited decisions that have lead to an unsustainable built environment.

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