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Systems Thinking in Energy Efficiency Planning: Evaluation of a Framework for Energy Efficiency Action Plans

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Abbreviations

CAS	Complex Adaptive Systems
CSH	Critical Systems Heuristics
EE	Energy Efficiency
EEAP	Energy Efficiency Action Plan
“GT/GF”	Green Thoughts, Green Futures
Mtoe	Million tonne of oil equivalent
OC	Organizational Cybernetics
PLEEC	Planning for Energy Efficient Cities
RE	Renewable Energy
SD	System Dynamics
SOSM	System of Systems Methodologies
STEEP	Systems Thinking for Energy Efficiency Planning
SST	Soft Systems Thinking
ST	Systems Thinking
TSI	Total Systems Intervention
UM	Urban Metabolism
UNEP	United Nations Environmental Program

Abstract

Urban settlements demand the highest levels of resource consumption and waste management. It has been accepted that cities should be considered organisms. Through Urban Energy Metabolism the planning and management of energy that flows across cities achieves important developments towards sustainability. Energy Efficiency is one of the primary tools used to produce sustainable development. Cities worldwide are developing action plans that implement the teachings of holism and eco-friendly practices. Systems Theory is a field developed with the intention of managing systems based on interdisciplinarity and a holistic approach. Fundamental practices of systems thinking are applicable to the study of cities as sustainable organisms/complex systems. Planning for Energy Efficient Cities (PLEEC) is an European project that was executed by a group of participants from the public, private, and education sectors, with the purpose of designing energy efficiency action plans to meet the targets of 2020. This work introduces, based on a literature review, several systems theories. A critique of the characteristics of PLEEC's framework is performed to assess the level of systemic consideration into holism and sustainability. The evaluation of the process or success of the energy efficiency plans elaborated is not in the scope of the research. Using a modified version of Michael C. Jackson's Total Systems Intervention and a table that summarizes the principles of systems thinking, it is concluded that the plan lacks systemic consideration of cities as complex systems. The framework includes several concepts attributed to the field, such as interconnection of elements exchanging information and resources, but fails in defining self-organizing feedback based structures and function-driven behavior. It is of paramount importance that system thinking basics be at the core of all planning.

1 Chapter I

1.1 Introduction

"Man is not only a political animal: he is, before and above all, an individual. The real values of humanity are not those which it shares with biological entities, the function of an organism or a community of animals, but those that stem from the individual mind."

Ludwig von Bertalanffy

According to Angelo Facchini, the 21st century is the "century of the city" because the majority of the world's population already lives in urban settlements and the percentage is continually increasing (fig.1), in large part due to the progress of the less developed countries and the development of more megacities[1] (Facchini, et al., 2017). A changing mindset in humanity exemplified with the groundbreaking Paris agreement and the ever-growing community for development of sustainable cities champion a new perspective, we must apply now a paradigm shift towards the conservation of the planet. Accept the whole ecosystem and not just the tiny element of the global system that has historically been the only focus of development, ourselves. Through time humankind developed cities for comfort and safety now covering three per cent of the earth's surface area, cities are responsible for ¾ of the global final energy consumption and carbon emissions, becoming a key factor in reaching sustainability (Bai, et al., 2016). Energy management, renewable energies penetration, demand reduction and energy efficiency targets were, and continue to be set around the world, and in order to meet them, all of the areas must improve constantly based on different tools and technologies. The importance of behavior and social sciences inclusion to this endeavor proves to be critical.

Cities are complex systems and must be analyzed as such, understanding what drives the demand and how the energy consumption connects between fields and actors creates a demand for researchers to study how to improve the performance of the city as a system (Keirstead, et al., 2012). The practice of applying complex systems analysis to energy is in an early stage but the benefits of doing so is presented by Catherine Bale (Bale, et al., 2015). One the most replicated and persisting problems is that energy impact analysis is commonly done for a single end technology over its lifecycle (Labanca & Bertoldi, 2013). Improved understanding and higher awareness of benefits in the global community means great potential to use energy efficiency in the search of energy sustainability (World Energy Council, 2016). Since energy efficiency and metabolism are unique systems from city to city, the best practice is to search for a dynamic path that can adapt, this can be achieved through systems thinking (STEEP Project , 2015).

[1] Cities with a population greater than ten million (10,000,000) people.

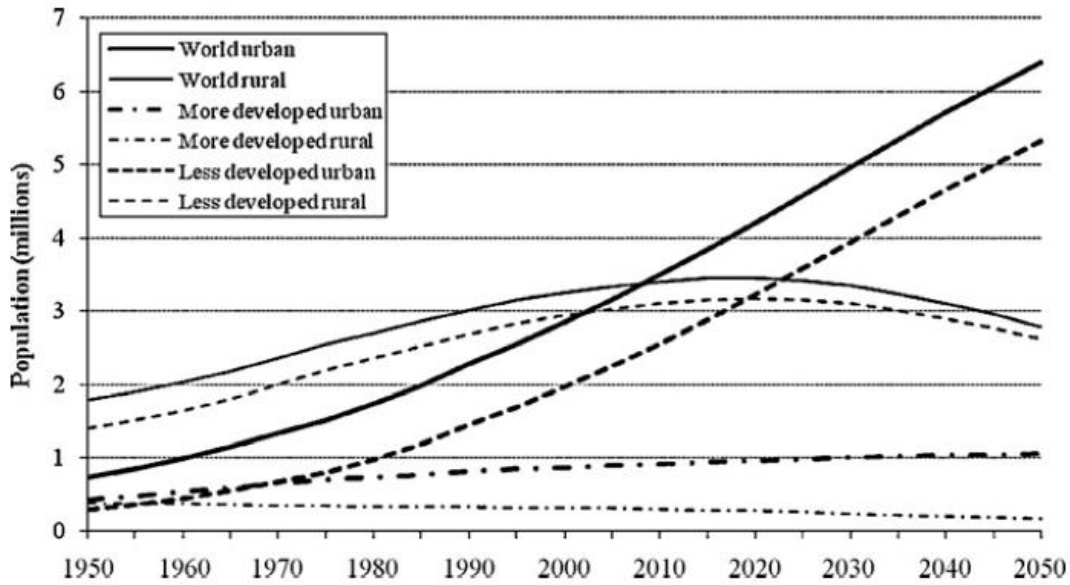

Figure 1 Population Growth in Cities per rural-urban of less and more developed countries. Source: (Madlener & Sunak, 2011)

The European Union is working towards their 2020 climate and energy targets, and one of the projects that set out to contribute based on studies in energy efficiency and sustainable cities is called PLEEC (Planning for Energy Efficient Cities). The program finished in 2016, with the core of the results being the *"PLEEC model for energy efficiency and sustainable urban planning"*. This work attempts to utilize systems thinking theory and approaches to evaluate how far the resulting framework for energy efficiency planning is holistic and sustainable.

1.2 Introduction to Urban Energy Metabolism

With the rise of economies came the downfall of the environment, blind desire for economic growth neglected environmental impact. The term urban metabolism was coined in the discourse to describe how cities, as organisms, use resources and create waste. Understanding resource consumption and waste depletion is central to achieving a sustainable urban ecosystem, if the waste cannot be reused by the system, it must be detoxified for the environment (Zhang, 2013).

In the beginning, urban metabolism studies focused on water supply problems and disposal of wastes, such as sewage, pollutants, and solid waste. It focuses on the management of flows so a sustainable development, could someday be achieved. Some of the flows are material, that can be managed by accounting methods, others are cross disciplinary, such as energy, revealing a complex series of interconnecting elements and functions. This are being tackled through investigation and policies for circular usage of materials and energy outputs, motivating for a switch to sustainable equivalents such as renewables, and improved spatial designs of cities (Roggema & Alshboul, 2014).

Urban Energy Systems studies have centered around supply and demand, intensity of use, and the structure of energy use. Recently, energy systems in cities have been linked to complex systems science to study urban metabolism and flow of energy (Facchini, et al., 2017).

1.3 Introduction to Energy Efficiency in Cities

Technological innovations in renewables and political framework lead the change to a carbon free and sustainable energy sector for the world, investments and installations of solar photovoltaic panels reached a high point, being responsible for 77% of the new power installed worldwide in 2015. The world now boasts 785 GW of renewable energies without the inclusion of hydroelectric power in the numbers, and 173 countries have policy targets for renewable energy integration (REN 21, 2016). The other major actor in sustainability for energy is efficiency. Defined as *"the ratio of benefits gained and the energy used"* by the Wuppertal Institute (Irrek, et al., 2008), energy efficiency (EE) delivers proven economic benefits that go hand in hand with efficiency measures that target environmental stress and greenhouse gases emissions. Policies that promote and enable energy efficiency are gaining importance. One advantage of confronting efficiency is that by nature it is a solution take tackles several barriers at once, with increased efficiency in the sector automatically affecting the emissions, costs, generation and demand of energy. If done correctly, it will help achieve sustainable development (World Energy Council, 2016).

Countries implement efficiency targets (fig.2), thus creating a demand for EE tools, practices, indicators and other solutions. The number of institutions, targets and policies for energy efficiency keeps growing, with 60% of the countries that are members of the World Energy Council now have an energy efficiency agency, an increase in the amount of countries who have quantitative energy efficiency targets, introduction of building energy ratings and even mandatory energy audits in some of the member states (World Energy Council, 2016).

Figure 2 Existence of Energy Efficiency policies around the world. Source: (World Energy Council, 2016)

Development causes the presence of smart appliances and growing expenditure for intelligent houses, devices, and more. This behavior steers society to a state where an increased need of cooperation between demand side technologies and energy suppliers is necessary. The use of smart devices creates a dependency on information loops, the devices search for the moments where electricity is available at lower prices (Labanca & Bertoldi, 2013). Increased efficiency has been accompanied by an elevated presence of appliances. Energy use could be lower with current technology, an example is the passive house design where energy goals are met by a reduced demand for heating, but it isn't. Following this phenomenon, energy consumption must be understood in a day to day basis to be able to work towards efficiency. A search for comfort and a deeply rooted set of personal and cultural practices reflects on the differences in consumption between people from the same social context (i.e. from student to student that live in the same city), concluding that individual behavior regarding energy consumption can trump the benefits of technology and policies (Karresand, 2013).

1.4 Introduction to Systems Thinking

Systems Thinking (ST) is a philosophy centered around interdisciplinarity that has developed from several fields that shared basic principles in the years after the second world war. Its main goal is to drive the necessary change from reductionism and specialization in the way humans think, to a holistic view that accepts and works with the relations between different aspects of the world. With its starting point being Ludwig von Bertalanffy's General Systems Theory (Strijbos, 2012). Ludwig von Bertalanffy's (Von Bertalanffy, 1969) says that fundamental contributions to the theory were developed in separate projects but hold true to the same ideas that were floating in the air around the minds of scientists. Nobert Wiener's Cybernetics, Shannon and Weaver's Information Theory, and von Neumann and Morgenstern's Game Theory came to be between 1947 and 1949. He states that general systems theory then can define and in some cases, lead to quantitative analysis of concepts troubling organized complexity.

	The 'Hard' Tradition (Simon)	The 'Soft' Tradition (Vickers)
Concept of organization	Social entities which set up and seek to achieve goals.	Social entities which seek to manage relationships.
Concept of information system	An aid to decision making in the pursuit of goals.	A part of interpreting the world, sense making with respect to it, in relation to managing relationships.
Underlying systems thinking	'Hard' systems thinking: the world assumed to be systemic	'Soft' systems thinking: the process of inquiry into the world assumed to be capable of being organized as a system.
Process of research and inquiry	Predicated upon hypothesis testing; quantitative if possible	Predicated upon gaining insight and understanding; qualitative.
Social theory	Functionalism (stemming from Durkheim)	Interpretive (stemming from Weber)
Philosophy	Positivism	Phenomenology

Figure 3 Broad summary of systems thinking. Source: Checkland and Holwell reproduced by (Costello, 2012).

Regarding this well documented complexity, systems, in their infinite possibilities of outcomes are based on stated purposes. Therefore, it must be accepted that the understanding of any human system is based on incomplete evidence. It is possible and useful due to the core that arises from systems properties that establishes order even when man cannot understand completely the relationship between systems' structures and behavior (Jokela, et al., 2008).

2 Chapter II

2.1 Role of Cities in Sustainability

Bulkeley and Betsill (Bulkeley & Michele, 2005) cite the Bruntland Report stating in 1987 that cities should be a central point in humanity's quest to sustainability, followed and strengthened by Rio de Janeiro's Conference on Sustainable Development in 1992.

In 2015 the establishment of a specific goal[2] centered around cities in the United Nations Sustainable Development Goal (SDGs) (fig. 4), and urban applications present in most of the other goals recognize the paramount importance of cities in sustainable development for the world. It is in cities were the inequalities and the faulty governance become visible, and the complex interconnections between the different goals become apparent (Bai, et al., 2016).It is clear that urban settlements are a central point to human capability of sustainability. The majority of the world's population lives in cities and urban metabolism have reflected the importance of addressing the ever-growing impact of cities on environmental impact caused by stressing of resources and accelerated loss of biodiversity (Roggema & Alshboul, 2014). To reach sustainability a shift in production and consumption patterns must be achieved. Most of human development has taken inspiration from nature, except for urbanization, city design and management. Urban settlements are not planned with ideas for adaption, the cycle of growth, transformation, and death can be applied to city's life cycles. This would habilitate change and adaptation without a necessary destruction of the whole (Roggema & Alshboul, 2014).

Figure 4 United Nations Sustainable Developments Goals. Source: (United Nations, 2015).

[2] Goal 11, Sustainable Cities and Communities.

2.2 International work on Energy Efficiency

Economic development and energy consumption are linked, for when one grows the other grows with it. Thriving economies and developing cities increase the level of consumption (fig.5), and they are in their right to do it. The opportunity to avoid the consequences of previous urbanization processes exists, we must turn the energy input into a sustainable path, and one of the most powerful tools is efficiency, reducing the demand of energy generation while coping with the needs. Several sectors and stakeholders are responsible for energy consumption, one of the most consuming being the building sector, where there are plenty opportunities for efficiency. The annual energy consumption has been on the rise, driven by individual demand for energy, people are consuming more energy, between 2001 and 2011 per capita energy consumption increased 11.18% (Allouhi, et al., 2015).

Since Rio 92, cities have been playing a role for sustainability at the international level. Some of the ideas in the UK were exemplified by Newcastle, demanding higher standards on energy efficiency on building designs and promoting energy efficiency for houses through policies (Bulkeley & Michele, 2005). This previous examples are part of the classification of policies and measures that promote energy efficiency and reduce energy consumption. These categories are (Allouhi, et al., 2015):

1. Regulatory measures that impose minimum requirements.
2. Voluntary Standards rewarded by certifications.
3. Economic incentives in a variety of forms that range from tax exemptions to subsidized loans for refurbishment.

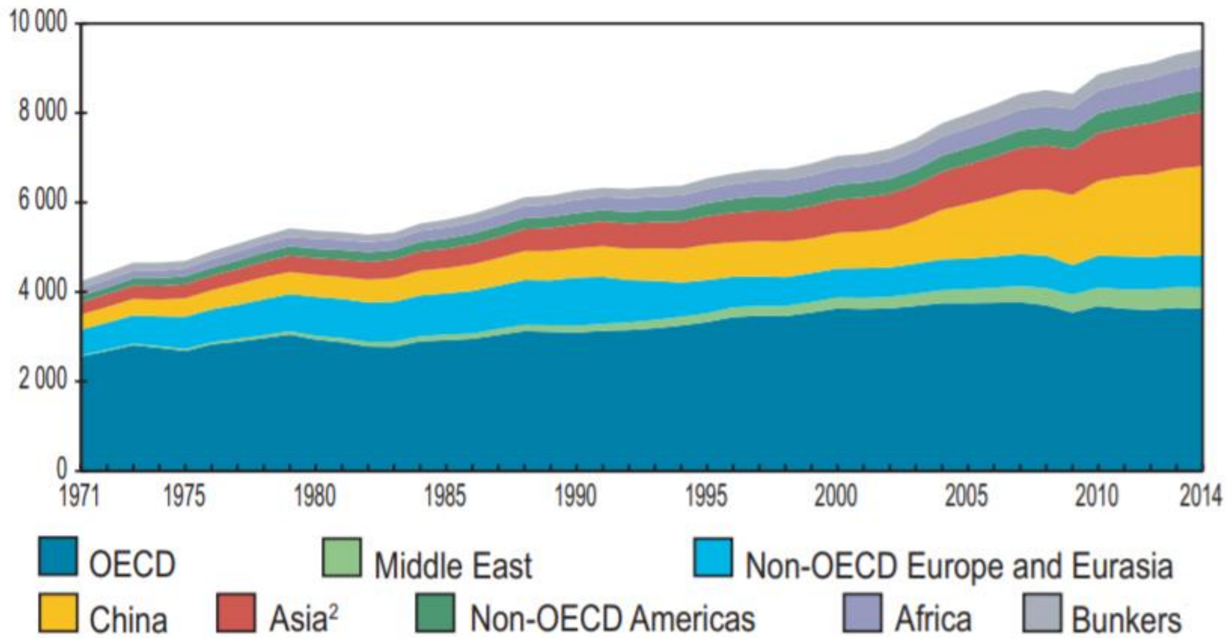

Figure 5 World's Energy Final Consumption (Mtoe). Source: (IEA, 2016).

Europe is the forefront of energy efficiency with its "Energy Efficiency Directive" that challenged its cities to achieve an increase of 20% in energy efficiency. The technology to do so exists across Europe, the challenge is to create a policy mix capable of ensuring this goal. Cities are gaining power in policy making towards energy efficiency, and a correct mix of policies can guide technology and actors through complex multilevel decision making to achieve their goals. The importance of this mixes is clear, but research is still lacking in studying how policies complement or trade-off between them in different countries (Rosenow, et al., 2016).

Energy Efficiency has been improving at a global level, an increase of 0.9 % between 2000 and 2014 reflects the adoption of combined cycle gas turbines. Penetration of Renewable Energies (RE) also increase the overall level of efficiency, RE are considered to generate electricity at 100% efficiency. Since 2000, this improvement in energy productivity prevented the release of 7 $GtCO_2$ to the environment (World Energy Council, 2016). These results can be appointed to cities, they have been driving energy efficiency and carbon reduction around the globe. In 2013 a research led by the UNEP exemplified that planning and exploiting of district energy systems in cities is considered a best practice for energy efficiency. Results are seen in Denmark's 20% reduction of CO_2 emissions based on district heating, Combined Heat and Power plants (CHP) utilize up to 93% of their primary energy source energy content. The 45 leading cities around the world have installed a combined capacity of 36 GW of heating capacity, 6 GW of cooling capacity, and 12,000 km of district energy networks. The central position of cities and their local government in energy efficiency is unquestionable as it is considered a key factor to overcome energy efficiency barriers (UNEP, 2015). Embracing this responsibility are several organizations, one of the best examples being C40, a network of cities working at different levels through cooperation of mayors and experts to share knowledge and resources in the quest towards sustainable urban development (C40 Cities, 2017).

2.3 Cities as Systems

The nature of the resource intensive activities humankind engages in lead to environmental problems, especially in rapidly developing cities. In an attempt to learn how to manage these pressures, two questions are asked, can cities emulate natural ecosystems to mitigate the problems? And, when possible, how can cities imitate the natural systems (Zhang, 2013)?

The key elements in energy systems include households, business, energy conversion and suppliers, economic regulators, environmental managers, local governments, infrastructure, technology and the environment itself. All of them are interconnected, leading to emergent properties that change dynamically over time due to non-linear influences (Bale, et al., 2015). All these are characteristics of complex adaptive systems (CAS). They deal with certain behaviors such as self-organization, emergence, co-evolution, etc. These characteristics are common in a varied amount of systems, one of them being human settlements (Labanca & Bertoldi, 2013). Settling a widely accepted analogy between cities and ecosystems used in urban metabolism discourse is the statement from da Silva that based in his personal experience says that spatial analysis is not enough to evaluate a city because it is in *"constant flux as a result of many dynamic factors, reorganizing and adapting to feedback across multiple scales temporally and spatially"* (da Silva, et al., 2012).

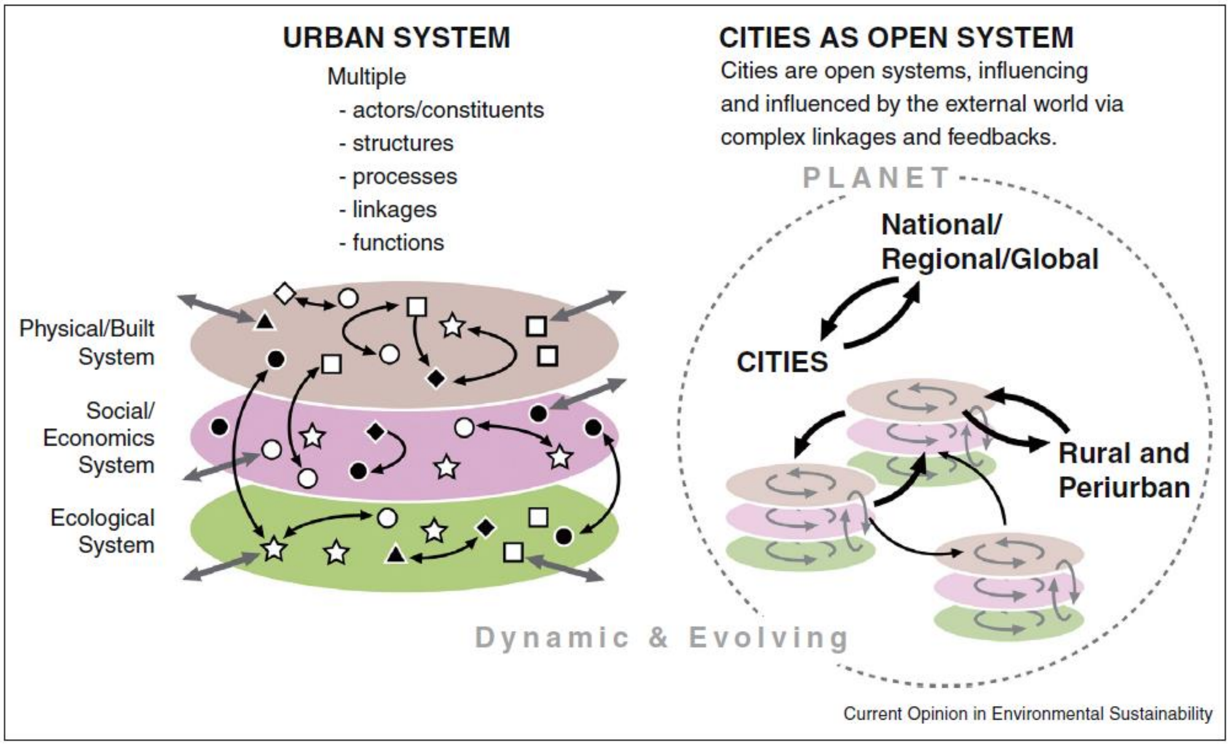

Figure 6 Cities as complex systems. Source: (Bai, et al., 2016).

3 Chapter III

3.1 Research Gap

Current National Energy Efficiency Action Plans developed by the European countries are not capable of meeting the targets agreed upon the Energy Efficiency Directive (Rosenow, et al., 2016). Couple this to the complexity in cities, and an enormous challenge that provides opportunities for research and practices based on systems approaches arise. Cities' governments are fragmented and with a low degree of cooperation among branches that ends in a translation of problems to unforeseen sectors (Bai, et al., 2016).

Costello (Costello, 2012) performed a literature review of the application of soft systems modelling application to project management on which it is reflected that there is a clear lack of debate and application. The application in project management of hard systems thinking decreased and the one of soft systems thinking increased, but it was recorded that they need to be complementing each other. At the same time systems theory has experimented a theoretical evolution, but it still isn't applied to the extents its exponents hoped. It has been accepted, and it added new ethical and holistic normative considerations, to the planning table, but it still faces the major challenge of linking itself to other fields; *"such as development studies"* (Strijbos, 2012).

The current age is the age of systems, interpretation of reality must adapt to this conclusion, so an understanding of systemic ramifications of actions is necessary. Energy performance must be studied as imbedded in a larger system. Due to the characteristics of cities as evolving systems it is problematic to assess how energy efficiency improvements affect the system in the long term and bigger scale. Primary due to systems being open (flux of intake and output of energy is not in equilibrium and co-evolves with the environment), they operate on multiple scales of space and time, and evolution due to autocatalytic interconnections (Labanca & Bertoldi, 2013).

Energy Efficiency planning and acting must then be ruled by the logic and principles of systems thinking. Working alongside the evolution of systems instead of trying to impose a path, that will end in unpredictable results over different time and boundary scales. Technology is a source of change but it on itself is not capable of creating efficiency. It must be connected to social and cultural structures (Karresand, 2013).

3.2 Research Questions

What tools can provide a holistic and sustainable base for planning?

Do existing energy efficiency action plans are designed in a systemic thinking way?

How is systems thinking applicable to sustainable city planning?

Is energy efficiency a leverage point for sustainable energy use in cities?

3.3 Objectives

Link through literature Systems Theory to Sustainability.

Study a finished energy efficiency action plan framework on its inclusion of systems thinking to conclude if systems theory is present and to what degree.

Through the modification of a systems meta-methodology, to define and apply a method to evaluate the presence of systems theory in a framework or model.

Contribute in the familiarization of systems thinking, embracing the complexity of issues and exemplifying that different backgrounds can converge to learn and employ ST.

3.4 Methodology

Jackson and Flood's Total Systems Intervention (Flood & Jackson, 1991) uses the System of System Methodologies (SOSM) to ensure adequate pairing of systems approaches based on the specific systems conditions and assumptions. When analyzing a finished framework that tackles a complex problem, in a complex adaptive system such as a city, there is a need to somehow judge the level of systems thinking of the plan, due to the time and resource heavy nature of city level action plans it is important to define a plan that accounts for the most scenarios possible and includes the most stakeholders and works according to the parameters of sustainability.

This methodology is an attempt to apply the TSI procedure in a different order, with small alterations of logic order (table 1), allowing us to diagnose the level of systems thinking of a finished plan or model. Beginning with the initial step in a different fashion, the creativity step becomes the "existing" step. The purpose is to proceed to identify selected elements in an existing stakeholder, principles, targets, mediums list. This is when we exchange the order of TSI and before going to the SOSM (fig.7) to the phase known as "choice", we list known system approaches characteristics based on the SOSM matrix (table 2), and proceed to compare this characteristics to the list of the "existing" concepts, or "matching". Based on what and how many characteristics of the diverse systems approaches are recognized, we plot into the matrix of SOSM points in the corresponding sectors of the approaches. This results in a visual overview of the framework's concerns represented as systems principles in the matrix, mapping how it spreads over the complexity vs participants graph. The areas covered then reflect the level of systemic integration into said framework. This last step represents going in the third phase from "Implementation" to a "Surfacing" of systems approaches.

3.4.1 Tools

3.4.1.1 TSI

Defined as a meta-methodology, it was designed to assess problems that cannot be understood from a single world view. Encouraging to see these problems from different viewpoints and register them creatively using metaphors to describe them. When there is a consensus among the hurdles to tackle, the methodology, or set of methodologies, must be chosen by accounting for each systems approach strengths and weaknesses. The tool to perform the selection is the SOSM (Jackson, 2003). Imbedded in the core principles of TSI is pluralism, important to keep it in mind because it justifies the existence of different approaches in one single framework.

Phases of TSI analysis (Flood & Jackson, 1991):

1. Creativity, define suiting metaphors that facilitates noticing the main interest and concerns.
2. Choice, choose appropriate systems approaches using the SOSM, based on the knowledge gained from the previous step.
3. Implementation, application of the approaches identified to tackle the dominant concerns, while continuing to hold true to the pluralist principle and manage the other concerns with their appropriate system approach.

Table 1 TSI methodology. Modified.

Three Phase TSI Methodology		Modified TSI to evaluate existence of Systems Thinking Approaches	
Creativity		Existing	
Task	Highlight problems and concerns	Task	Analyze the problems and concerns tackled by the implementation of the specific changes desired by the framework
Tools	Metaphors	Tools	Framework under revision.
Outcomes	Dominant and Dependent metaphors that are linked to the principal problems	Outcomes	List of concerns wished to be tackled by the Framework
Choice		Matching	
Task	Selection of appropriate system approach or set of system approaches	Task	Identify which system approaches perform the desired change on the problems identified.
Tools	SOSM	Tools	Table of principles and properties of System Approaches
Outcomes	Dominant and Dependent Methodologies	Outcomes	List of System Thinking principles reflected
Implementation		Surfacing	
Task	To arrive and employ specific changes	Task	Plotting in the complexity vs participants graph the position of the reflected systems principles.
Tools	Systems Methodologies selected according to the logic of TSI	Tools	SOSM
Outcomes	Highly Relevant Intervention	Outcomes	Graphic representation of the "Coverage" of systems thinking in a pluralist setting by the framework.

Source: Source: (Flood & Jackson, 1991).

3.4.1.2 Systems Thinking Principles

Based on the research and the literature review of systems theory (detailed in a section 4.3 of this work), a selection of principles is condensed into table 2. The content refers to a wide arrange of works encompassing various approaches and theories: (Ackhoff, 2001), (Bale, et al., 2015), (Checkland & Poulter, 2010), (Chettiparamb, 2014), (Churchman, et al., 1957), (Cleveland, 1994), (Costello, 2012), (Espejo & Gill, 1989), (Flood, 2000), (Flood & Jackson, 1991), (Forrester, 2009), (Jackson, 2003), (Meadows, 2009), (Mehregan, et al., 2011), (Molineux & Haslett, 2005), (Montuori, 1998), (Perez Rios, 2010), (STEEP Project , 2015), (Sanakaran, et al., 2010), (Schwaninger, 2006), (Senge, 1990), (Ulrich, 2005), (Ulrich, 1996), (Vester, 2012), (Watson & Watson, 2011), (White & Taket, 1997).

Table 2 Systems Approaches concepts table.

Systems Thinking Principles

Approaches	Metaphors	Characteristics	
Hard Systems Thinking	Machine	Strictly defined boundaries. Strict definitions of goals. Not holisitc. Mathematically driven.	Interdisciplinary. Simple-unitary nature. One "optimized" solution. Interconnected.
System Dynamics	Flux and Transformations	Feedback loops. Time delays. Resource stock and flows. Whole is more important than the parts.	Systems with similar structure will have similar behaviors. Hierarchy and self-organization. Non-linearity. Computer simulations can reveal behavior of systems.
Organizational Cybernetics	Organism and Brain	Self-regulation leading to evolution. Recursive character of viable systems. Variety to destroy variety. Function must be independent from quantitative growth.	Systems must operate on a funtion oriented manner. Negative Feedback must be dominant.
Complexity Theory	Flux and Transformations	The Butterfly Effect. Order arises from chaos. No strucuture, infinite possibilities, evolving behavior. Autopoiesis.	Edge of Chaos. Strange Attractors.
Soft System Approaches	Cultures and Political Systems	Dialectics ensure inclusiveness. Different perspectives of the world generate different interpretations to situations. Not functionalist, encourages learning. Participation of all possible parties, world views, levels, system elements, etc. Holistic.	Problem structuring is more important than problem solving. Possibility of achieving a synthesis.
Emancipatory Systems Thinking	Instruments of Domination and Physic Prisons	Focus on social fairness. Follows a critical path to set targets. Doubt every answer. Allocation of responsibility.	
Postmodern Systems Thinking	Carnivals	Order is defined from interaction, reality is the product of chance. We shape reality as reality shape us. Pluralism. Mix and matching of methods to specific conditions.	

3.4.1.3 The System of System Methodologies (SOSM)

Is a framework that classifies systems approaches and methodologies, it accomplishes this by graphing level of complexity versus number and nature of the participants (fig.7). Unitary have the same beliefs and goals, pluralists consider more than one world view and generate a debate but finalize in a synthesis of ideas, and coercive are the ones with little to nothing in common and no will or have ill temper to discuss concerns ending in a stalemate of ideas that doesn't allow for common ground (Jackson, 2003).

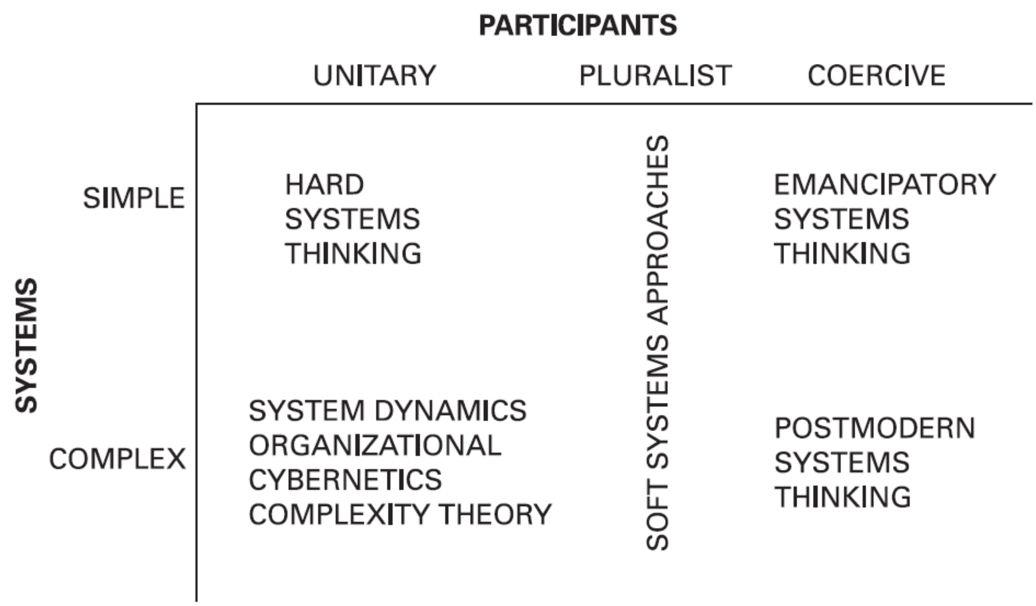

Figure 7 SOSM matrix. Source: (Jackson, 2003)

4 Chapter IV

4.1 Urban Energy Metabolism

Urban metabolism (UM) is defined as *"the total sum of technical and socioeconomic processes that occur within cities that lead to the growth, production of energy and waste disposal"* (Kennedy, et al. cited in (Barragan & Terrados, 2017). It has helped to manage material and energy flows in cities and incited a change from linear to circular metabolism. It establishes cities not as individual organisms but as ecosystems that need interaction with the outside environment to develop. The artificial quality of cities as ecosystems cause an inefficient metabolism of the input resources, join this to the fast growth of cities to birth a problem that extends far out of the capabilities of managers. This has motivated the research and innovation of theory and methodologies to cope with this interdisciplinary challenge. The complexity has also led to a single flow study, energy is an example, to understand it better (Zhang, 2013). UM in general can be divided into two general methodologies: input and output of materials or a representation of flows as energy broken into emergy and exergy, or usable energy and waste energy (Barragan & Terrados, 2017).

The historic development of urban metabolism assessment started with Abel Wolman in 1965 with the accounting of a hypothetical city's resources. He defined a per capita input and output values based on the national utilization and production. Food, water, and fuel were the selected input resources and waste water, solid waste and air pollutants the output categories. This early and simple analysis was followed by Ayres and Kneese who performed a national level analysis of material flows in economy for the United States of America. They stated that economic activities should account for the priceless environmental resources they affect (i.e. air and water bodies). Their approach proved successful in the fight for the inclusion of externalities, successful in the sense that it proved cost relationship between residues discharge and external costs, and that research in the field received a boost. Studies using the material flow accounting dominated until 1997, when Helmut Haberl introduced energy flow analysis (Zhang, 2013).

The advantages of using urban metabolism are presented by Princetl and Bunje, referenced in (Facchini, et al., 2017):

1. It performs an explicit definition of system boundaries.
2. Encompasses input and output.
3. It allows a hierarchical path of analysis.
4. Specific elements can be decomposed for targeted study.
5. Requires the analysis of outcomes under the sustainability lens.
6. Is an adaptive approach. It evolves according to solutions and consequences.
7. Interdisciplinary. Social science plays a role next to technology and natural science.

Models, the most common tool for UM, have been developed in order to visualize, quantify, and manage functions of the city. The most widely accepted is the "Extended Metabolism Model of a City" (fig.8) which defines sustainability in cities as a minimal use of resources and waste production so it respects the ecosystems around it, that is accompanied by an elevation in the quality of living of the residents. Comprehensive city metabolism must be characterized by flexibility in its modelling, the use of renewable energy is not the only path that must be followed when spearheading a movement toward sustainable energy behavior in society. The way energy is generated is important, as much as the way it is metabolized. It is during the metabolism of the flow of energy where we face an interdisciplinary and multi participatory problem. The study of energy input and output is specific to the time it's done, even though it is accepted that metabolism of energy in cities is subject to external influences that may change the process in a different time frame (Roggema & Alshboul, 2014).

Angelo Facchini and a group of researchers performed a comparison of the energy metabolism of 27 cities around the world (Facchini, et al., 2017). Among their findings, they determine that cities with an equal share of GDP do not follow the same path of resource metabolism. When they compare energy consumption per capita to urban population density, it reveals that it follows a power law. As density increases, energy consumption per capita decreases. This is most noticeable in densities under 10,000 inhabitants per km^2, with higher densities than this the impact is slim.

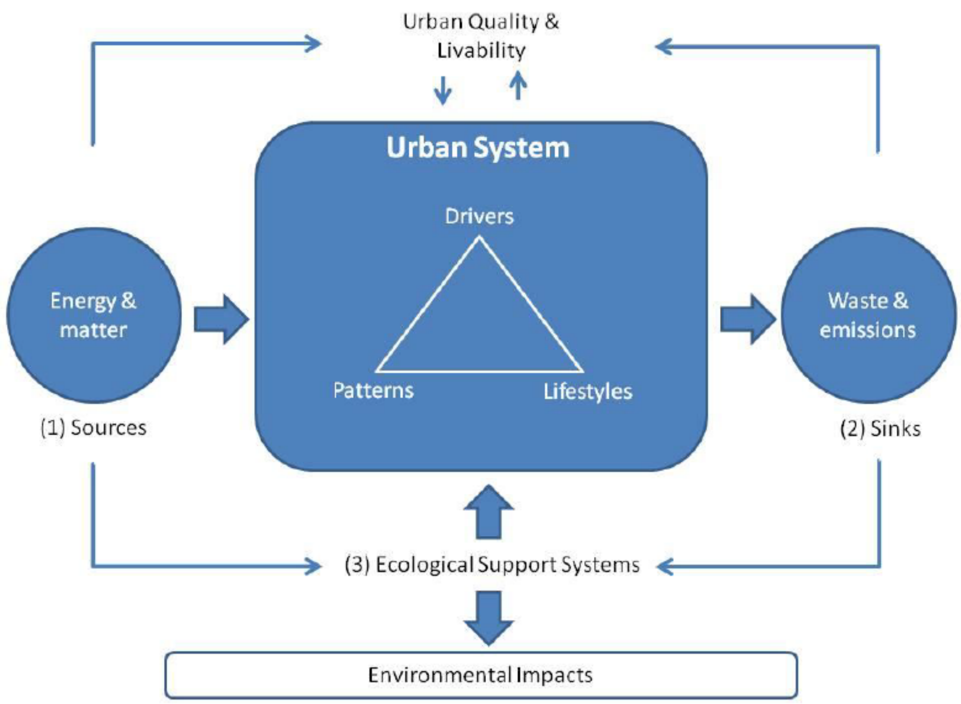

Figure 8 Extended Urban Metabolism Model. Source: (Minx, et al., 2010).

Electricity Consumption has experienced an accelerated growth in the cities located in developing countries, small increases in the developed countries, and the special case of London where it decreased. It is important to separate the energy use between stationary and mobile; the former refers to every form of energy that doesn't involve mobility while the latter covers public and private transport energy use. This with the purpose of relevant policy making due to the electricity base of stationary energy and the heavy fossil fuel dependent mobile energy. A field of study that has developed to the point where it is impossible to deny the variety of factors influencing simultaneously the way it behaves. Energy urban metabolism is a complex system. (Facchini, et al., 2017).

Even though it has developed vastly, urban metabolism has some short comings. It needs to be more aggressive against carbon related metabolic processes. It must optimize the metabolic networks. Internalization of impacts of social nature. There is still not a defined solution to the existing externalities (Zhang, 2013). Some of these critics can be undertaken by the inclusion of systems thinking.

4.2 PLEEC

4.2.1 What is PLEEC?

"Planning for Energy Efficient Cities" is a project funded by the EU Seventh Framework Program that finalized in 2016. Meant to be a tool in the daunting task of the 20-20-20 targets defined in the European directive. Consisting of 18 partners from 13 countries (fig.9) that breakdown as 6 medium cities, 9 universities, and 3 industry partners. They defined five principal fields of development in cities that must be addressed with their plan, Green Buildings and Land-Use, Mobility and Transport, Production and Consumption, Technical Infrastructure, and Energy Supply. All this to be achieved through clear targets and a holistic approach delivered as Energy Efficiency Action Plans (EEAP) (PLEEC, 2016a).

Figure 9 Locations of the diverse participants of the PLEEC project. Source (PLEEC, 2016a).

4.2.2 Objectives

As stated by the project's factsheet (PLEEC, 2016b):

- Assessment of energy saving solutions and potentials for inclusive city planning.
- Demonstration of the superiority of integrative planning compared to isolated measures.
- Creation of EEAPs that shall be presented to decision makers.
- The development of a synergized model for energy efficiency and sustainable city planning.
- Recognition of future research in the field of energy smart cities.

4.2.3 Framework

The core of the project is an online model that follows a defined framework (PLEEC, 2016c). It consists of 5 buttons with underlying chapters (fig.10) that guide you through various steps, recommendations and tools in a step by step construction of a EEAP. The following is a rough depiction of the process, in the factsheet (PLEEC, 2016b), all the documents and websites that are available for the guidance and implementation of the PLEEC tool and its complementary methodologies and work packages are available to the public.

The first step, "Becoming energy efficient" welcomes the user, it defines the purpose and use of the framework. The 6 cities that serve as an example have a brief introduction and description.

The second, "How do we get started?" consists of three chapters: Get the decision, Set up Project, and Engage Stakeholders. The goal of this step is to search, convince, and initiate the cooperation between public and private actors interested in an EEAP. These actors should be completely invested, in agreement of scope and goals, and capable of implementing it.

"Where are we?" starts the quantitative part of the framework. Collecting data, the suggested method is the Smart City Profiles (fig.11) that resulted from the Vienna's University of Technology "European Smart Cities" approach from 2007. Following this methodology, the cities define their strengths and weaknesses, and can be compared between them, based on the linked indicators to each of the 6 smart city profiles. The PLEEC cities developed a list of 49 indicators, that stand separate from a database of 81 indicators for benchmarking in the Smart City database. To include social learning perspectives a questionnaire for stakeholders must be elaborated that reflects attitudes and priorities among the key areas defined and the level to embrace innovation. PLEEC also provides 5 key fields for urban energy efficiency that they separate into domains encompassed inside each key field. The domains guide the baseline of energy efficiency targets setting, the existing indicators must be listed, and the domains questioned if they are missing on possible indicators. The core concept of profiling cities is that methodologies and best practices can be interchanged among cities with similar smart profiles.

In the "Where do we want to go?" the 5 key fields determined by PLEEC are broken down into technology, structure, and behavior. Inside each of these 3 categories guides to energy efficient solutions and options are presented with the goal of establishing clear and achievable goals.

Finally, in "How do we implement?" the practices for the writing of the EEAP are presented. What a scope should include, presentation of a timeline, strong and clear justification of the choices made, how the project will be monitored and evaluated, resource and funding plans, and the definition of the responsible party for the EEAP after it is accepted.

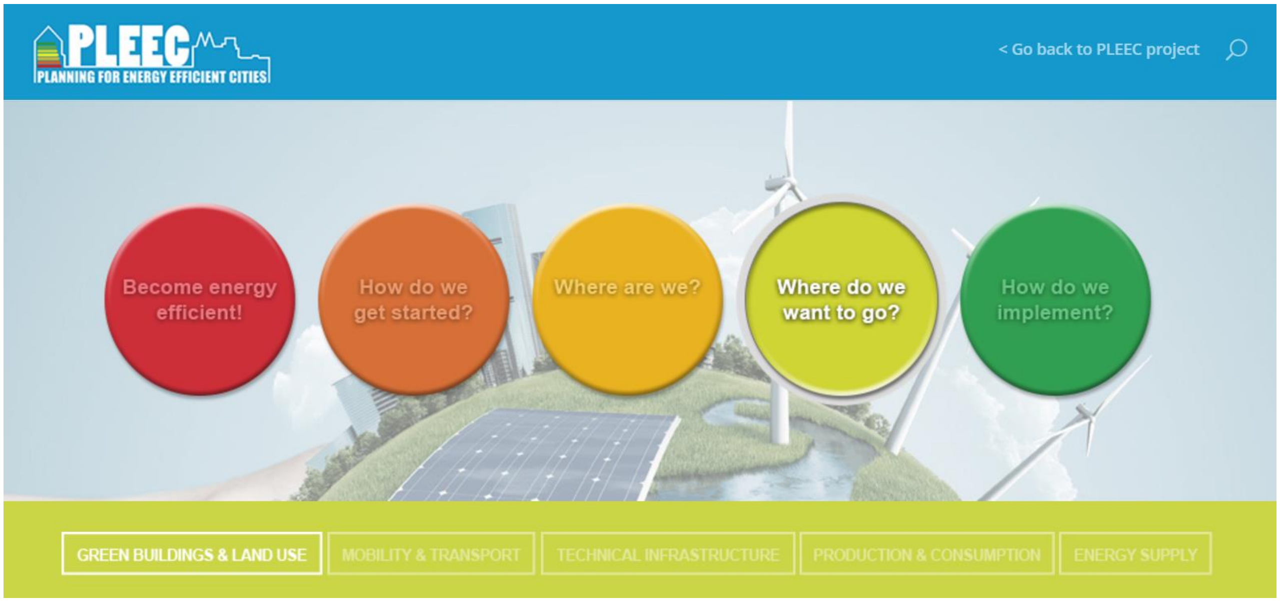

Figure 10 PLEEC's model guiding buttons. Source: (PLEEC, 2016c).

Figure 11 Components of a Smart City Profile urban development fields. Source: (PLEEC, 2016c).

4.2.4 Results

PLEE deliverables are open access and free to the public, they consist of (PLEEC, 2016b):

- The model for energy planning and sustainable urban planning (PLEEC, 2016c).
- Energy Efficiency Action Plans for each of the 6 participant cities.
- Green Thoughts, Green Futures report (PLEEC, 2016a).
- Work Packages that cover the procedures required to carry the steps presented in the model. Smart City Profiles, Technology driven efficiency, Structure Driven energy efficiency, Behavior driven energy efficiency.

4.3 Systems Theory

"There are no experts in the systems approach"

C. West Churchman

Donella Meadows describes systems thinking as the process of analyzing a system, which *"is an interconnected set of elements that is coherently organized in a way that achieves something"*, and the things of which it consists of: *"elements, interconnections and a purpose"*. She said systems are resilient, self-organizing, and work through hierarchy (Meadows, 2009). It is to be understood that systems thinking is the process of applying the concepts and tools of systems theory to study a system's behavior and structure to understand better how an applied change by the implementations of policies or other means will really affect the defined system. Systems Thinking (ST) leads to a better representation and a holistic consideration of results caused by policies, technologies or any other form of interaction between the stakeholders and the system. Inside of the systems thinking paradigm exists a diversity of views on what a system should be and on how it is studied, represented, defined and which purpose it fulfills. The variety of systems cannot even be imagined since by the definition a boundary is by choice and different views of one system of any type can be observed by the interested party.

Systems Thinking is continually developing without consensus of which is a predetermined way of defining a system, the only given and accepted part of it being that the process of learning how a system behaves is more important than the goals a system must achieve. The idea that the world problems, at any given scale, topic or place, should be studied through a broader lens than the traditional reductionist approach started to brew in the years surrounding World War II, when different scientist and researchers began to tackle complexity. Inspired in the operational research, system analysis and other management and investigation practices and theories that were developed and applied during this period, scholars set out to establish a way to deal with the complexity of the real world, leaving behind a problem based mentality. Michael C. Jackson (Jackson, 2003) describes and introduces systems thinking birth, growth and its different branches. Introducing the philosophical ideas of Hegel and Kant as precursors to this mindset, Jackson develops the discourse that Kant communicated that man must be seen as a whole that is a product of the interrelation of its parts. Hegel installed the logic of process, by stating that the truth can be studied by utilizing a systemic approach based on the looping of thesis versus antithesis to achieve a synthesis, and with this result, repeat the cycle including the new information.

Some of the shared and basic characteristics of systems thinking is that the study should focus in the behavior of the system not on the performance of the parts, understanding the interaction is more important that defining an isolated mistake. A system consists of numerous separated parts that are linked in a certain manner to realize something. The boundary of a system is fictional, systems are open because they interact with the environment they are in and depending on the scope and desires of the examiner, the boundary is set for the sake of studying it. The result of a system study depends on the type of systemic approach applied but in all the cases the learning process and methodology applied are the biggest lessons. Systems respect hierarchies that are created by the system itself through self-organization, that is continuous throughout its life span. Systems thinking approaches (that are explained briefly in the coming sections) assign their own properties according to the way their specific thinking include this set of ideas that run through systemic logic.

The use of metaphors is a powerful tool when discussing systems, since they are represented by a mental model. Everybody uses mental models every day without realizing it, all the decision making in which we incur is done through the modeling of a system, be it simple or complex. Man connects different bundles of information or parts with empiric knowledge and instinct in an attempt to forecast behavior and/or results (Forrester, 2009). This leads to the way system thinkers present their concepts to the general audience, with the example of "the eight images of organizations" (Morgan, 1997), which are the following:

1. *Machine*
2. *Organisms*
3. *Brain*
4. *Cultures*
5. *Political Systems*
6. *Psychic Prisons*
7. *Flux and Transformation*
8. *Instruments of Domination*

Examination of problems through these metaphors are not limited to organizational problems, the different viewpoints are used by Jackson to categorize the several branches of systems thinking. The following pairing of each branch to one of the metaphors provides him a way to facilitate the understanding by presenting a more familiar construct to explain an abstract notion (Jackson, 2003).

1. Hard Systems Thinking (Machine)
2. System Dynamics (Flux and Transformations)
3. Organizational Cybernetics (Organism and Brain)
4. Complexity Theory (Flux and Transformations)
5. Soft System Modeling (Cultures and Political Systems)
6. Emancipatory Systems Thinking (Instruments of Domination and Physic Prisons)

7. Postmodern System Thinking (Carnivals[3])

This representation of systems as something else urges the mind to wonder on why this specific description is given to that specific dimension, that moment is when the interested make conjectures about the characteristics of the presented metaphor, leading to an easier understanding of the systemic concepts that they reflect.

4.3.1 Categorization of the Systems Thinking Approach

Operational Research sparked the curiosity of researchers in complexity, which in turn led to systems thinking. In an attempt to transfer the problem-solving ability demonstrated in the different systemic sciences developed, to problems in the real world, scientist met with the complex nature of actual systems. Different philosophies caused systems thinking to evolve in distinct directions, each one with its own idea on how to represent a system as well on what drives its behavior. The most common systems thinking approaches are described briefly, due to time constraints, their extensive nature and the complexity of systems thinking.

4.3.2 Hard Systems Thinking

The first step towards the development of a systems view of the world as some authors refer to systems thinking, was the General Systems Theory that von Bertalanffy presented in 1937, this turned the attention of the academic and applied research to the existence of systems and complexity everywhere. Keeping in mind that traditional deterministic and linear studies rule the world of science it was natural that the first approximation to systems kept some of the representative features of a deterministic and reductionist approach. A system methodology is when the concepts of systems are used to develop a problem structuring or solving process to be applied in the real world. According to Peter Checkland, Hard Systems are those whose boundary is strictly defined, a system whose parts interact towards a defined goal, a system that is built to fulfill a specific purpose. They are rigid in their behavior, and are mathematically driven, making them useful physical tools. Operations Research, Systems Engineering and System Analysis are the initial hard systems and their application in engineering was and is successful, but it lacked a holistic approach, by definition these methodologies tackled a fixed problem with quantitative data that is processed with one precise end, leaving various levels of complexity and possible actors or system parts that influence, out. The most influential field of Hard Systems Thinking was introduced by C. West Churchman, Russel Ackoff and E.L. Arnoff with the publication of "Introduction to Operations Research". This book popularized the idea that when confronting obstacles in the real world, the systemic methods and tools had to consider an interdisciplinary perspective to the problems (Strijbos, 2012).

The six steps for operational research (listed below) presented in their book establish a systemic approach for reviewing complex problems (Churchman, et al., 1957). It exemplifies the rigid structure and its goal driven agenda, there is no mention of system behavior or system learning, they just set out for a solution to a problem.

1. *Formulating the problem.*
2. *Constructing a mathematical model to represent the system.*
3. *Deriving a solution from the model.*
4. *Testing the model and the solution.*

[3] Ninth metaphor added by Jackson to the eight previous from Alvesson, M. and Deetz, S. (Jackson, 2003).

5. *Establishing controls over the solution.*
6. *Implementation.*

Checkland also establishes the following assumptions that every systems person follows when tackling real world problems applying hard system thinking (Jackson, 2003).

- There is a desired S_1.
- S_0 exists and it is known.
- Going from S_0 to S_1 can be achieved through varying means.
- The system thinker must define the most efficient mean to accomplish it.

The metaphor is clear, with a very rigid boundary and a behavior defined by the pursuit of a goal (fig.12), we can see how a machine represents hard systems thinking. Think of the engine of a car and the deep understanding of physics and other disciplines that are necessary to design and produce one. It is a set of interconnected parts with a behavior that accomplishes a goal, this will fulfill some definitions of a system. It achieves the desired purpose and will always perform in the same way, therefore the interested in complexity questioned to what extent it represented a real-world system, thus leading to other approaches that embraced more of the challenge of complexity.

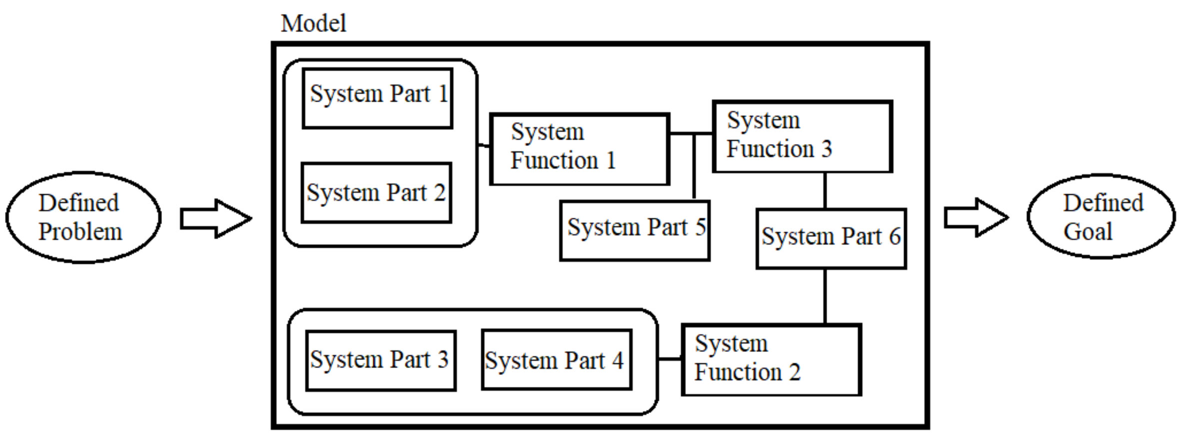

Figure 12 Hard Systems representation, simplified. Source: (Author's Own)

4.3.3 System Dynamics

Initiated by Jay W. Forrester at the Sloan Management School of the Massachusetts Institute of Technology, system dynamics is the most popular approach from, and often mistaken by the general public as, systems thinking. Not satisfied with the approaches of hard systems thinking, Forrester expressed that problems have no beginning or end in the real world, they are a loop that create change through continuous interaction between the current state, the actions taken and how this actions now change the aforementioned state, that in its new form due to the changes, demands new actions to be taken. This concept is applied to systems as the feedback loop, in all systems change is possible because of nested feedback loops (Forrester, 2009).

Peter Senge and Doanella Meadows, both followed Forrester's philosophy that complex systems could be mathematically modeled through a series of positive and negative feedback loops that dominated in a system's stocks and flows. This is the core of System Dynamics (SD), the modelling of feedback process that reflect how resource levels varies while simultaneously accounting for the availability and rates of consumption. Time delays that exists between conversion of resources and the subsequent consequences are included in the model, so real world complexity is represented more accurately. This allows the model to consider a systems' behavior to be dynamic, resulting in better prediction of the effects of the diverse strategies considered to reach a goal (Flood, 2000).

As stated earlier in this work, systems thinking is often considered to be system dynamics, this is due to the popularity of this specific approach, Forrester published his *"World Dynamics"* in 1971 followed by Doanella Meadows *"Limits to Growth"* in 1972. These books presented the power of system simulation, but it was until Peter Senge publish *"The Fifth Discipline"* in 1990 that the world embraced system dynamics. Senge translated the computational and mathematical implementation of his predecessors to a managerial application, opening the doors of systems thinking, not only system dynamics, to a broader audience.

There are principal concepts that are applied throughout systems thinking that were expressed in a straightforward way by the different authors of system dynamics. Forrester, Meadows, Senge and Vester, who uses concepts from dynamics and cybernetics, describe the characteristics of systems with their own personal mindset (Forrester, 2009) (Meadows, 2009) (Senge, 1990) (Vester, 2012). The following are characteristics of systems according to them and system dynamics.

- Systems consist of elements or parts, interconnection or links and have a purpose.
- When analyzing a system, the whole is more important than the parts.
- Systems are in reality open, boundaries must be established by the observer to examine a particular scope of a system.
- System structure[4] is the root of the systems behavior, therefore systems with similar structures will have similar behaviors.
- A system that performs well complies with three characteristics: It is hierarchical, self-organizing and resilient.
- Account for the unknown.
- Embrace soft data, intangibles, social values.
- Behavior based study, do not fall for the short-term event understanding.
- Exchange linear relationships for non-linearity.
- Diversity is better, "Do not put all your eggs in one basket."
- System purpose arises from the system's behavior.
- Stocks, measurable elements of systems.
- Flows, modify stocks, they can be Inflows or Outflows.
- Feedback loops as information channels of the system.
- Positive or Reinforcing Feedback loops, act as enhancers of the current direction.
- Negative or Balancing Feedback loops, act as regulators.
- Time Delays that affect the dynamics of the stocks and flows.

[4] System Structure refers to the organization and interconnection of the parts.

- Feedback loops can be dominant over others, when no feedback loop is stronger, the systems is in dynamic equilibrium (the balancing loops and the reinforcing loops are equal in strength), a shift in their dominance can occur as well, when this happens the system's behavior changes.
- Changes performed to the system will only be noticeable in the future, no change can cause instant systemic change. This is reflected by Oscillations, when a delay is not correctly interpreted and a change is introduced to the system, it may cause the line of dynamic equilibrium to oscillate, from high stocks to low stocks, because the delay in the flow caused the decision maker to strengthen one of the feedback loops. One of the examples of the complex behavior of systems.
- System Dynamics focus on learning about the system, models of different scenarios, "what-if" questions, the power of it comes from the ability to assess the systems behavior and based on this explore the effect of decisions.
- Leverage points arise from the simulations, this are the points that affect the system's behavior the most.
- Computer simulation of systems models based on these concepts are necessary. Only by simulating the structure will the behavior be revealed, and with this, things that may seem odd can arise and baffle the researcher or manager. Strange consequences that were not imagined by the human mind are then represented by the application of system dynamics.

The representation of the stock and flows, feedback loops and their interconnection is done by causal loop and stock and flows diagrams (fig.13), from this mental model then a computational model must be developed that can test the proposed structure. Since similar structures generates similar behavior, general structures of systems can be found, as well as common misconceptions when handling leverage, called archetypes.

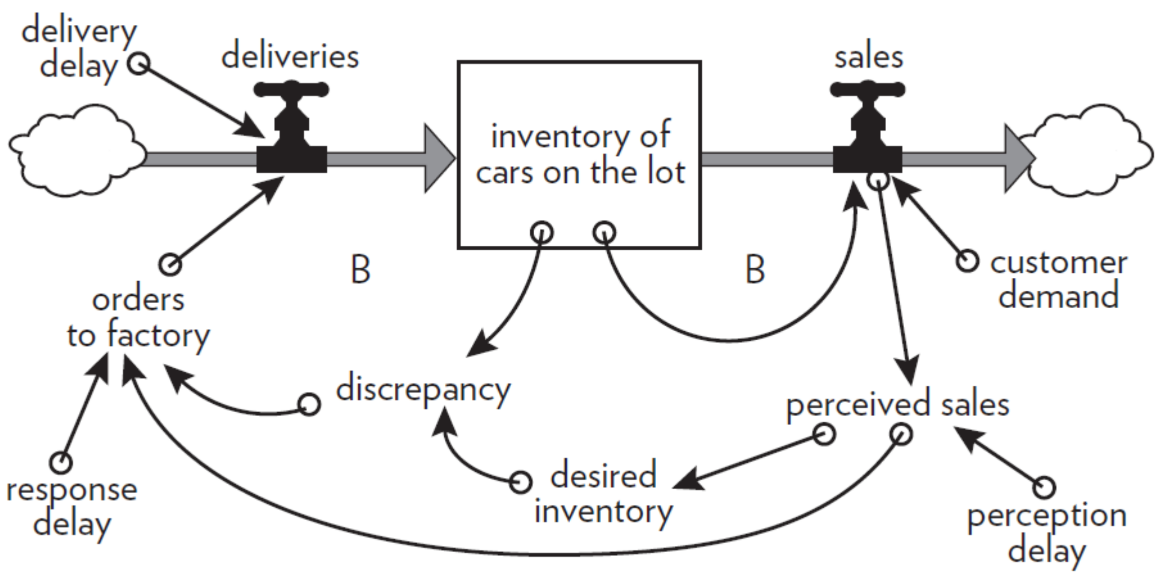

Figure 13 Stocks and Flows with feedback loops of a car dealership represented in a diagram. Source: (Meadows, 2009).

4.3.3.1 The 11 Laws of the Fifth Discipline (system dynamics archetypes)

As Peter Senge presented them (Senge, 1990):

1. *Today's problems come from yesterday "solutions"*. This refers to the nature of systems to not change immediately, so a quick fix for a short-term problem is determined, but the underlying problem is not solved, the fix could solve one problem but caused another or just shift the problem to another part of the system.
2. *The harder you push, the harder the system pushes back.* When the solutions and tactics applied to a system have a rebound effect, and instead of improving the conditions of the system lead to consequences that where not foreseen, working harder to correct the unforeseen effects by doing more of the same that made the system worse.
3. *Behavior grows better before it grows worse.* A policy or any other form of intervention on a system based on a specific current problem that does not consider the future environment or the structural behavior of the system will probably improve the conditions for a short-term period before the problem manifest again due to the time delays that exist on systems.
4. *The easy way out usually leads back in.* Not contemplating change or creativity that arises from complexity when looking for answers means that managers or the people tasked with manufacturing solutions will stay in their comfort zones of thinking, because its easier, and rely on the same old techniques, that may not be adequate any longer.
5. *The cure can be worse than the disease.* Solutions that are considered effective based on their short-term success can become the root of problems. Senge and Meadows use the example of "addiction", an initial relief caused by something creates an obsession, the system becomes dependent on it and behaves counterproductively to get more of it.
6. *Faster is slower*. A popular saying, fast fixes are not always the right ones, actual change needs time.
7. *Cause and effect are not closely related in time and space.* Senge discloses that mankind has always assumed that cause and effect are completely linked in time and space, that an intervention will have its effect right there and then, when these are decoupled. The effect of a cause can occur on a completely different part of the system and it can be noticeable after a time span that allowed the system to integrate said intervention (the cause) to its behavior.
8. *Small changes can produce big results-but areas of highest leverage are often the least obvious.* Leverage points are one of the principal concepts of system thinking, they are the "magic" points of a system that influence its behavior the most. Implementing a sensible action to a system leverage points will trigger the most amount of change in a system. These points are difficult to find, hidden to human traditional logic. Separated in time and space and most of the time against intuition, that is why systems thinking encourages to consider behavior, processes and the long-term instead of short-term events.
9. *You can have your cake and eat it to-but not at once*. When seeking a goal, the consideration of the factor time is crucial. When in a rush to an objective traditional management decides sacrifices to be made, what must be compromised to achieve the target. This "law" takes from number 6, with the incorporation of time into the processes, compromises can be avoided and a goal can be complete if it is allowed to develop, achieving in better results than a goal that is designed to be accomplished immediately.

10. *Dividing an elephant in half does not produce two small elephants.* The idea of studying systems as wholes is the concept under scrutiny, classical scientific approach is reductionist and isolates that which is being studied, needless to point the outrageous success and development of sciences, system thinking considers that a better way to understand complex systems is through boundaries. Since systems are self-organizing and hierarchical, it is possible to say that the world is a system and whichever other system analyzed is just a part of the bigger one. Boundaries come into play here, allowing system thinkers to define a system based on a boundary that includes the important interactions for the corresponding issue. The biggest challenge is obvious, how do we know what are the important interactions? Meadows states that the boundary is set by the questions we want to ask the system, always remember that it is artificial and created just for the sake of being able to study.
11. *There is no blame.* The reasons for the systems conditions are not created by someone else, when man has a problem, he himself is a part of the system where this unwanted behavior is happening.

System Dynamics is the systems thinking approach applied in most of the cases, from commercial and industrial management to global leaders, policy development, economic growth, environmental studies and more. The availability of user friendly modeling tools and penetration of the concepts to the public made it possible. People are afraid of complexity, but this is already a step in the right direction. The quantitative analysis through the computer model is essential and programs that turn casual-loop and stock and flows diagrams to mathematical models are available, the most popular being: DYNAMO, STELLA, ithink, DYSMAP, VENSIM and POWERSIM (Jackson, 2003).

4.3.4 Organizational Cybernetics

Frederic Vester (Vester, 2012) defines cybernetics as*: "the perception, control and self-regulation of interconnected process with the minimal expenditure of energy"* and then proceeds to call it bio because of its occurrence in nature. The brain and organisms are the metaphors for this systems approach, when analyzing them with Vester's definition of bio cybernetics their relevance is highlighted. Which is the most powerful analysis, controlling and regulating tool in the natural world? The brain. He expresses how complex is not necessarily complicated and that to understand complex systems we must study its *"evolutionary intelligence"* or the interaction of the parts and how they self-regulate, like living organisms. Separated from system dynamics by fundamental concepts of how systems come to be, the two of them share basic systemic concepts and the goal driven functionalist identity.

Stafford Beer is considered to be the father of organizational cybernetics, he was a pupil to Norbet Wiener, who identified the existence of feedback, loops, and intercommunication in natural and artificial systems. Ross Ashby, responsible for the first law of cybernetics, that establishes that a systems capacity to withstand change depends on how malleable the system is itself, and Warren McCulloch, responsible for neural-network modelling (Schwaninger, 2006).

Concepts that are particular to cybernetics include (Perez Rios, 2010):

1. *Viability,* system's readiness to survive and adapt to a dynamic environment, to do so it must comply with general concepts of systems for instance, self-regulation, capacity to learn, resilience and evolution.
2. *Variety*, it is a depiction of the variability of a system, the possible behaviors, conditions and diversity of actors that can exist in it.
3. *Ashby's Law of Requisite Variety: "Only variety can destroy variety",* according to Ashby's statement, to understand and work with complex systems, the analyst must consider and include every possible behavior, actors, parts, interconnection and influences that form part of it. In essence, manage the biggest diversity of knowledge from the specific system to reduce complexity.
4. *Conant-Ashby Theorem,* management and regulation of a complex system can only be achieved through a model of it, the relevance and impact of the decisions depend on the model and its comprehension of the system.
5. *Viable Systems Model,* the product of Stafford Beer's work (fig.14), a model that states the characteristics models should include if they are to be viable.
6. *Recursive character of viable systems,* Boundaries are defined according to the purpose of the study, the recursive character reflects on the nature of systems being embedded in other systems, having subsystems and themselves being a subsystem of a larger system.
7. *Organizational pathologies,* common problems that appear when there is a malfunction in the model's communication channels, incorrect implementation and/or design, missing parts or any other mistake when using Beer's Viable Systems Model.

The Viable Systems Model is often considered the model of choice for organizational cybernetics, Stafford Beer's holistic approach to organizations is the principal reason of the success in its application when managing change. Incorporation of systems dynamics into the viable systems model where applicable, help study the behavior and responses of organizations to different strategies, making the tool even more robust (Espejo & Gill, 1989). Frederic Vester, presents another toolbox for cybernetics, he embraces systems dynamics more and introduces computational modelling to cybernetic concept based management.

Through his study of bio cybernetics, Vester addresses why people are afraid of complexity and the errors committed when confronting it. Hearing the term complexity induces a sense of strangeness, like it is something outside the human natural existence, when in reality it is everywhere. This is why systems theory and the study of complexity becomes important and in studying it, scientists translate it to tools available to the general public. The eight basic rules of bio cybernetics and the methodology for the application of the "Paper Computer" and the Sensitivity Model are Vester's translations of systems thinking.

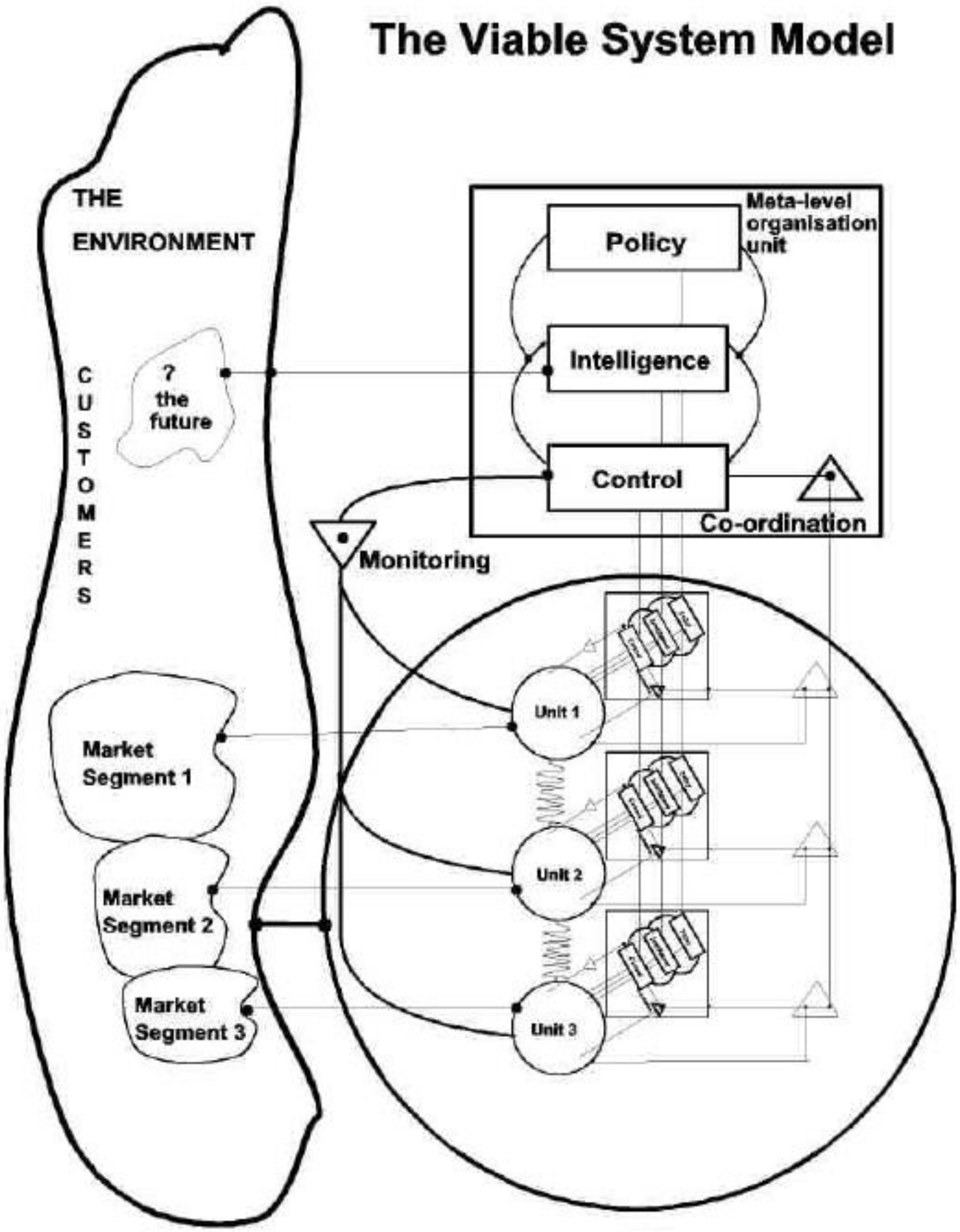

Figure 14 Diagram of Stafford Beer's Viable Systems Model. Source: (Espejo & Gill, 1989)

4.3.4.1 The eight rules of bio cybernetics

Frederic Vester states (Vester, 2012):

1. *Negative feedback must dominate positive feedback,* negative feedback is also known as balancing feedback, due to the unsustainability of perpetual growth or depletion that can come from an uncontrolled positive feedback, the balancing feedback must dominant to ensure system or dynamic balance.
2. *The function of the system must be independent of quantitative growth,* like Meadow's limits to growth, Vester declares unlimited growth as a cause of systemic failure, complex systems can grow, until they need to evolve and restructure, respecting their quality of self-organization. When a system grows without control it will inevitably reach a point where it ceases to be viable.
3. *The system must operate in function oriented, not a product oriented manner,* Behavior is the principal cause of goal achievement, structure will fulfill its target and adapt. The desired goal will not define the function of a system.
4. *Exploiting existing forces in accordance with the ju-jitsu principle rather than fighting against them with the boxing method,* Interventions and/or solutions should not go against the system's behavior and structure, the efficient way of interacting with systems is understanding how they work and use their own regulation and leverage points to attain the objectives.
5. *Multiple use of products, functions, and organizational structures,* his take on Ashby's law of cybernetics. The greater the flexibility inside a system, the bigger its ability to, and chances, of success.
6. *Recycling,* Vester invokes the notion that nature doesn't know waste, only humans. Everything in nature is used again, by the same or a different system. This principle must be replicated by humans in our understanding of systems, and not narrow the possibilities of circular use and recycling to a couple of fields but widen the scope and look for interdisciplinary recycling.
7. *Symbiosis*, following the second metaphor of organizational cybernetics, organisms, systems should work together and thrive through cooperation. The design of interventions in systems that base their function in the exploit of sources and sinks will only lead to long term failure.
8. *Biological design of products, processes, and forms of organization through feedback planning,* not refraining to it being a metaphor of the brain or living organisms. Vester incites systems thinkers, managers, scientist, and people in general, to replicate the known structures of viable ecological systems.

The "paper computer" or "matrix of influence", and the "Sensitivity Model" apply the eight principles of bio cybernetics and allows non-system thinkers to enter this world view and apply it. He presents in the art of Interconnected Thinking (Vester, 2012), the Sensitivity Model and the "Instrumentarium", a set of tools for the application of organizational cybernetics. Where the computer modelling, simulating, and stock and flow accountability that is essential to system dynamics is expanded to include behavioral tracking and structure representation that permits to observe and modify the self-regulation of the system by appropriate cybernetic influences.

Both approaches, Beer's and Vester's rely on the internalization of existing viable systems, brain and organisms, into management tools. Systemic approaches to reality based on natural complexity.

4.3.5 Complexity Theory

A common idea repeated though literature of complexity theory is that “complexity” means something different to each individual, leading to a confusion among people that is not familiar with systems thinking and its vocabulary. This confusion had persisted due to the lack of establishment of systems thinking and complexity theory in a certain sector of science (Chettiparamb, 2014). The name is used in physics, math, and social sciences, with similar basic concepts applicable in a superficial sense, but its position in social sciences is in the realm of the systems mindset.

Based on the identification that small changes in the initial state of systems generates big changes in the long run, the now commonly known “Butterfly effect”, Edward Lorenz started studying complexity to identify the order that exists under chaos. Following this idea scientist started studying complexity under the umbrella that simple arrangements, orders, laws or rules create unpredictability. Complexity theory differentiates itself from chaos theory because it covers the social elements of systems as well as the natural ones (Jackson, 2003).

Properties of systems according to complexity theory are non-linearity, they are not proportional in the sense that small changes lead to big effects, self-organization, order and chaos are always both present, and the capacity to withstand shocks from its environment. Most of the concepts are present in the other approaches of systems thinking as well, so complexity theory is a renovation of the existing aspects of system sciences. It includes new considerations, the biggest change being that systems do not have a determined structure, they can undergo structural change, this produces indeterminate and unforecastable results. The identity of a system relies in its distinction from its environment, if it changes its organization or evolves, but the distinction is the same as before, it is still the same system (Chettiparamb, 2014).

The other system world views defined that the structure of a system give rise to its behavior. Complexity theory uses all the same founding concepts but then denies that a system will have a deterministic behavior. The constant of feedbacks and self-organization habilitates a system to have endless possibilities in outcomes.

Complexity theory deals with complex adaptive systems (capable of learning and storing information that allows them to evolve). Key characteristics from these systems are that they are complex, self-organizing, adaptive, dynamic and co-evolving. In depth, it means that they consist of several parts interconnected between them, they create themselves (autopoietic[5]), they can learn and change behavior to achieve resilience, they stand at the “edge of chaos”, and change together with their environment and the systems interrelated to them (Cleveland, 1994). It is important to add two more characteristics. The first is self-similarity, this means systems have the same structures at different hierarchies, the concept of fractals[6]. The second being the influence of “strange attractors” (fig.15), or the notion that even though they are unpredictable, systems will behave in similar ways due to a reference situation or event (Jackson, 2003).

The “edge of chaos” mentioned before is the desired state of a complex system. It is a description of systems behavior; they can be ordered, in the edge of chaos, or chaotic. Systems in any of the other conditions will reach failure sooner or later. Systems on the edge of chaos are thriving. This is because at this point systems are exposed to enough disorder that

[5] Self-creation

[6] Fractals are systems or shapes that create complexity through iteration of simple rules.

information exchange occurs, chaos prompts the system to fight, to learn, but there is also enough order for the system to absorb and internalize the lessons (Cleveland, 1994).

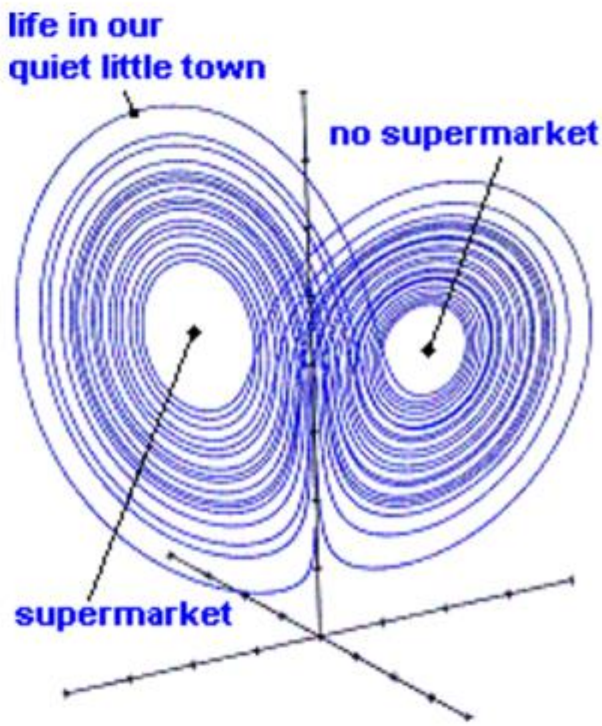

Figure 15 Example of the path of a system subject to "strange attractors". Source: (Abarim Publications , n.d.).

4.3.6 Soft Systems Thinking

Separating itself from the previous approaches to systems thinking, soft systems thinking is a branch that focuses on the mental representability of models that represent real world problems. There is not a functionalist definition of the models, they are not goal oriented. It bases its philosophy on the fact that humans create their own version of reality based on their personal experiences and environment. The systems concepts that existed are employed to create a systemic representation of the different world views. Personal emotions that shape the models must be included in the study of systems, thus one observation or interpretation is not enough to reach a truthful representation. This process of inclusion of human intention brings social elements in systems to a higher level of influence and depiction of reality. It includes more participants into the study of complex systems, drifting apart from the goal driven system dynamics and cybernetics. Shifting from models that are reflections of the real world, to models that become lenses from which to see the real world. The biggest examples of soft systems thinking are, Checkland's Soft System Modelling, Ackhoff's Interactive Planning, and Mason and Mitroff's Strategic Assumption Surfacing and Testing (Flood, 2000).

4.3.6.1 Interactive Planning

Russel L. Ackhoff designed Interactive Planning and inspired with his works "social system science" and "community operational research". Tackling complex issues or messes requires an expanded thinking and management that accounted for learning. Ackhoff, around 1974 delivered on this need with his Interactive Planning method. Motivated on his desire of working with applied philosophy, he left traditional systems thinking and operational research, that were stuck on deterministic and functionalism, and started social system sciences (Jackson, 2003).

It is important to establish the difference between planning techniques; reactive, preactive, and interactive. Reactive Planning deals with identified problems once they already occurred and tries to fix them. Preactive planning relies on prediction for what can happen, forecasting possible problems and conditions and preparing for them. Interactive planning includes the system ideology that how the systems behaves now will shape the future, instead of looking for or predicting problems, it concentrates on establishing a good present. Reaching an ideal design for the system through stakeholder engagement and continuous application (Ackhoff, 2001).

The methodology for Interactive Planning consist of six steps (Ackhoff, 2001):

1. *Formulating the mess*[7].
2. *Ends planning.*
3. *Means planning.*
4. *Resource planning.*
5. *Design of implementation.*
6. *Design of controls.*

4.3.6.2 Strategic Assumption Surfacing and Testing

Developed by Richard Mason, Ian Mitroff, and Jim Emshoff, the main goal of the methodology is to work with the assumptions of the stakeholders involved. It helps them create and navigate through their ideas and test them, in a five-step procedure, with the purpose of conciliating a group of parameters on which the stakeholders agree. The assumptions of each one is subjected to different pressures; the approach establishes that this trial should include four different principles that are permanently applied through the five steps of discussion (University of Cambridge, 2016).

Principles (Jackson, 2003):

1. Participative, there must be an inclusion of stakeholders, as much relevant participants as possible, the discussion gains strength and validity in diversity. Knowledge and opinions from more sources will lead to a better synthesis of ideas than just two or three from a similar background.
2. Adversarial, the diversity needed comes in hand with opposing world views, accounting for differed opinions and assumptions conflicting with the personal ones creates better solutions.
3. Integrative, it is crucial that the assumptions generated considering the varied parties are synthesized into an accepted and applicable plan.

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[7] Ackhoff defines mess as *"a system of interacting threats and opportunities, a system of problems"*.

4. Managerial mind supporting, subjecting the involved to this process widens the mindset and views on the problems at hand, habilitating a learning mechanism about complexity, pushing forward on holistic and inclusive solutions.

Phases or steps (University of Cambridge, 2016):

1. Group Formation, the goal is to form groups with big differences in their problem perspective that consist of individuals that share the view of the group they belong to.
2. Assumption surfacing and rating, each individual group develops a list of assumptions about the problem at hand, including stakeholders involved.
3. Within group dialectic debate, the assumptions are revised through two criteria: a) Importance and b) certainty. The group decides the rank of the assumptions after the inside debate and plot it in an "importance/certainty matrix" (fig.16). This shows which assumptions are key and should be confirmed and investigated, as well as showing which ones could be eliminated.
4. Between groups dialectic debate, groups present the matrix and clarify the assumptions, after all the assumptions from each group has been explained a debate is engaged where agreed assumptions are noted and disagreed or assumptions that generate conflict and tension are further discuss until reaching a point of modification or acceptance.
5. Final Synthesis, the groups now work together with the resulting list of assumptions, organize following steps to tackle the approved ones. Development of a planning book that includes a ranked list of the critical aspects resulting from the SAST. Knowledge level on these issues and the plans on how to close a knowledge and technology gap where needed.

4.3.6.3 Soft Systems Methodology (SST)

The inspiration for the previous soft system thinking approaches is Peter Checkland's Soft System Methodology (fig.17). The preferred instrument to transcend the functionalist and deterministic approach of the systems thinking perspectives that existed, but didn't represent social realities. Systems Thinking created goal-defined representations of the world. It was then that it was distinguished from ST, the latter portrays a personal world view that is constructed from individual experiences. Systemic Thinking is used in soft system thinking to subscribe the models to focus on construction and definition of actions, instead of the objective centered systems thinking. Contrary to systems thinking's boundary definition for problems management and/or solving, soft systems modelling allows system thinkers to embrace the human morality and existing dilemmas. With soft systems modelling, reality is represented by individual mental models that reflect personal views, constructed through systems concepts (Flood, 2000).

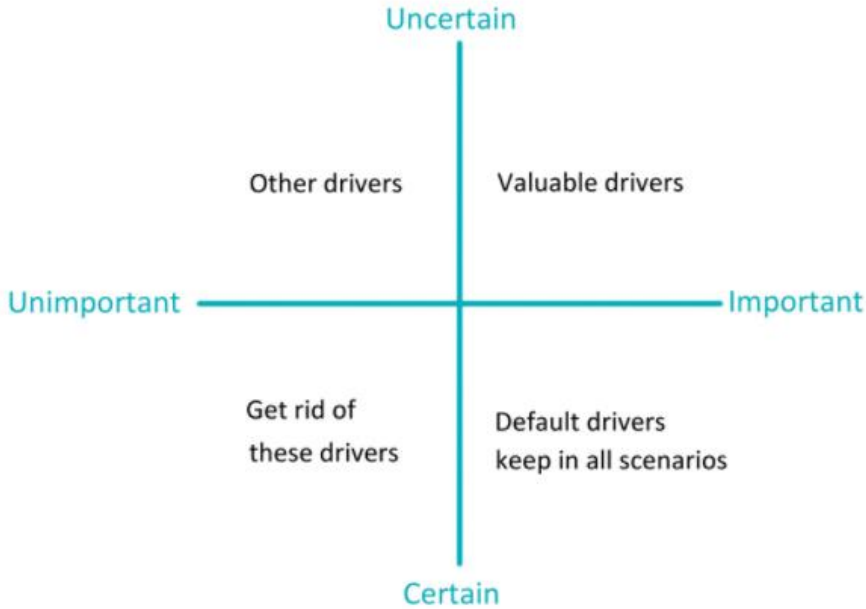

Figure 16 Importance/Certainty Matrix. Source: (Kailas, 2010).

Peter Checkland describes his methodology with the help of John Poulter, a managing consultant that has experience applying his procedure. They invite men to stop thinking the world is full of problems. Why? Humanity is more complex than action-reaction and fix here and now situations. Solutions are not possible because conditions are constantly changing. It is better pictured as a non-stopping flux of information and events that contain *"problematic situations"* that can be managed and improved (Checkland & Poulter, 2010).

Holon is a term used by Checkland to represent the systems and to facilitate the study of processes. A Holon is a whole by itself, that is also a part of a bigger system and is formed by smaller holons. Structured in hierarchical organization and interconnections, Holons, achieve the purpose established in the "human activity system" they represent (Yearworth & Burger, 2015). These systems are a set of interconnected activities defined by a person based on their own world view of reality (Wastell, 2012).

The biggest differences between soft systems methodology and other approaches starts from the moment the unconformity is tackled. Rich pictures of the situation are a better starting point than a pure systems model. This are literal drawings depicting the participant's way of seeing the problematic situation. It leads to creativity. Since the representation of the system is tied to world views, a variety of inclusive relevant human activity systems, will surface. These models are called root definitions, and they are the holons Checkland uses when graphically representing the system. Using the resulting root definitions, decision makers observe and analyze several world views that open their eyes to the systemically appropriate changes (Jackson, 2003). Root definitions are expressed as dense and pragmatic statements of purpose. They are developed through a CATWOE analysis (Clients, Actors, Transformations, Weltanschauung[8], Owners, Environment). Verb models are used to write the human activity

[8] German word used by Peter Checkland. Translates to "world-view".

system. A system to do P by means of Q in order for R, this includes the CATWOE. (Yearworth & Burger, 2015) (Sanakaran, et al., 2010).

A continued development for 25 years has led Soft Systems Methodology to base itself in a philosophy that determines all real-world problems are steered by people with personal agendas, who create human activity systems. The principle of one model for each "world-view", to record and exploit the variability of models created by different stakeholders, keeps Checkland's methodology as representative of human diversity as possible (Wastell, 2012). The human activity systems are not models that will be simulated for quantitative information, they present activities, that considering several world-views, spark a learning cycle towards a holistic achievement of goals.

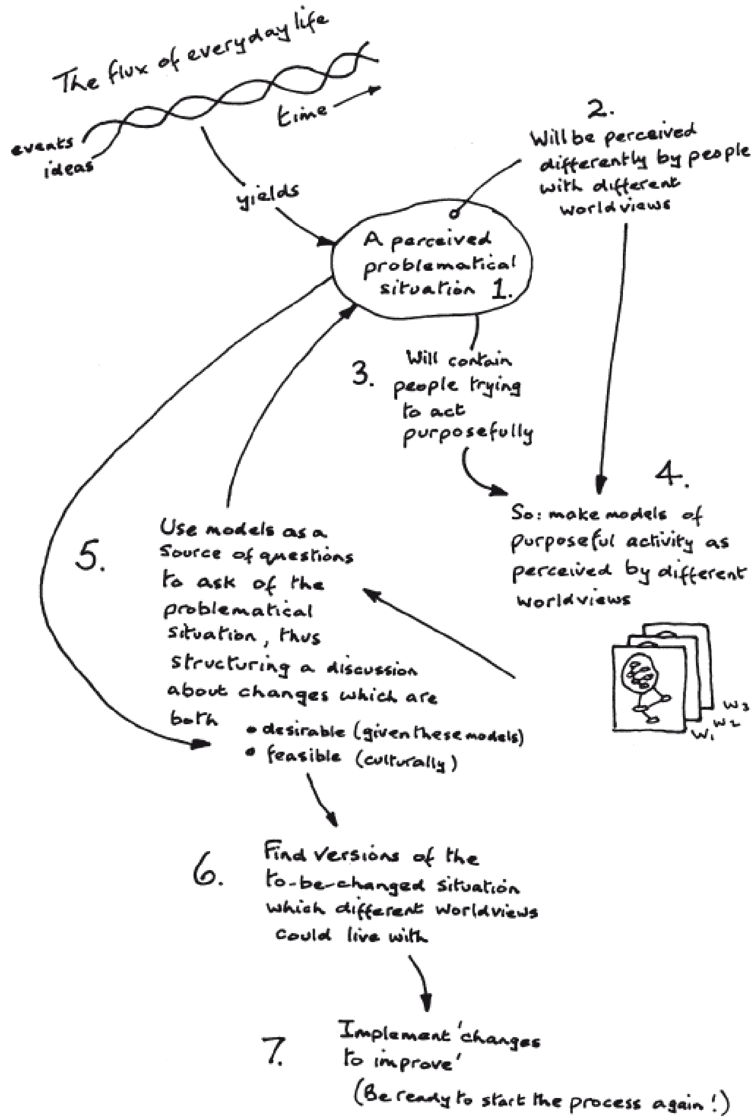

Figure 17 The seven stages of the Soft Systems Modelling learning cycle. Source: (Checkland & Poulter, 2010).

4.3.7 Critical Systems Heuristics (Emancipatory ST)

Werner Ulrich shocked the systems thinking world by introducing social fairness into systems studies. Everyone affected by a decision must be a part of the decision-making process. This establishes the branch of emancipatory systems thinking. Ulrich developed Critical Systems Heuristics as a methodology that ensures the transparency of interests in a planning or system design and implementation (Jackson, 2003).

Motivated by his perception of planning being a problem, Ulrich states that the solutions from the traditional planning methods created a divide between *"the experts and those who can afford to pay them"* from ordinary people. The aim of Critical Heuristics is to deliver a tool that gives a qualified outlet of opinions to the public, and by doing so, include them in the planning process. He redefines planning as *"the art of promoting improvement"*. A choice between different people's ideas of how, and what must be improved, leads to conflict. Since there is no justification for choosing one set of needs over another, Critical System Heuristics develops a *"critical path"*. Through systems concepts and practical philosophy, this methodology manages to introduce to the management of situations information streams coming from the people (Ulrich, 1996).

To understand and work with this tool, it is important to establish the concepts and principles it follows. Ulrich uses "critical" to express that any analysis must be reflective, there must always be doubt over the answers, a discussion of the variety of assumptions. "Heuristics" is the process of discovery, it evokes exploration of the knowns in a particular problematic situation. "Systems" is the dependency of the methodology on boundaries and feedback. The human mind can't deal with complex systems of a certain size and bigger. Definition of a boundary for the system under study, to contextualize and to work with it, is necessary and it is done by setting "boundary judgements". This are the boundaries that will separate between what is pertinent to the system and what can be left out based on the context of the debate. "Claims" are statements and opinions of the people involved, that are deemed to fulfill the "merit" requirement. Merit refers to the worth of the claim when criticized by the ideologies of Critical Systems Heuristics. A claim that is worthy to be included is inside of the boundary judgements and its relevant for all of those who can be affected when a procedure is concluded (Ulrich, 2005).

The process to define the boundary judgments is a questionnaire consisting of 4 target groups (client, decision-taker, designer, and witnesses) of 3 questions, concerning the roles of the involved, the specific matters of each role, and the problems regarding that specific actor boundary judgements. The set of 12 must be answered two times, from two different perspectives. The "ought", or the desired case, and the "is", the reality of the case (Jackson, 2003).

Ulrich's 12 questions for boundary judgement (fig.18), called "boundary critique". Each question must be answered for both operators (Ulrich, 2005):

1. *Who [ought to be/ is] the plan's client?* Who are benefited by the study of this system.
2. *What [ought to be/ is] the plan's purpose?* Which are the desired effects of the system, what objectives should be/ will be met.
3. *What [ought to be/ is] the underlying measure of improvement?* Description of mechanism to evaluate the success improving the system.

4. *Who [ought to be/ is] the decision maker?* Who has the authority to modify the mechanism that will track the plan's performance.
5. *What resources and other conditions of success [ought to be/ are] controlled by the decision maker?* The extent of the decision maker's power to modify and or decide systems interventions.
6. *What [ought to belong/belongs] to the plan's environment?* The components that re outside of the decision maker jurisdiction, elements that must remain natural to the system.
7. *Who [ought to be/ is] involved as a planner?* Who are the people that is qualified to work in the system's design?
8. *What expertise (special knowledge or experience) [ought to be/is] brought in?* What is the knowledge and skill set desired/available? What will be/is their job? What knowledge must be/is considered relevant for the plan.
9. *Where [should/do] the people involved see the guarantee that the plan will be implemented and will work?* What (or who) is responsible for the proof that the design of the systems intervention will be/is being implemented and proving to be successful in the eyes of the plan's mechanism to measure improvement.
10. *Who [ought to be/is] witness to the interest of those affected but not involved?* Who will be/is responsible to include the voice of the stakeholders that have no representation in the decision making.
11. *To what extent and in what way [ought/are] those affected be given the chance of emancipation from the premises and promises of those involved?* How are the affected that have no power on the planning given a choice, are they capable of deciding if the plan is good for them?
12. *On what world views [ought to be/ is] the plan based?* What are the different notions of improvement that shape system? Both planners and affected views must be depicted and explained. What is the procedure to close the gap between views?

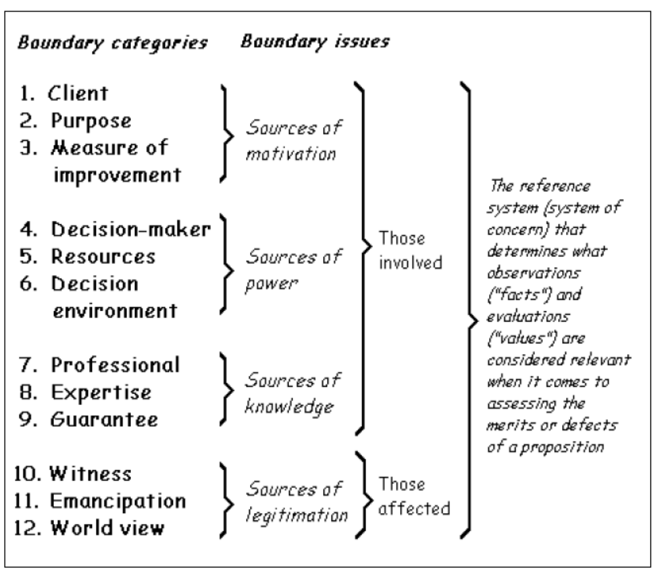

Figure 18 Explanation of the 12 questions' role in driving critical examination of judgement boundaries. Source: (Ulrich, 1996).

These questions allow 4 applications. Ideal mapping, the ought to be answers guide the regulations used for the acceptance of a claim. Evaluation, after the "is" answers are presented, they are compared to the ought be answers, thus exposing the claims to an objective scrutiny of its merits. Reframing, when the claims are evaluated with a different set of "ought to be" answers it expands the possibility of holistic solutions, because this changes the boundaries and the role of the systems parts and interconnections. Finally, the last application is challenge, the questions try to ensure an inclusive planning boundary, if a stakeholder does not answer for whatever reason, it may represent a hidden agenda (Ulrich, 1996).

Critical Systems Heuristics is a methodology that defends the involvement of all the participants in a defined system. How the boundary is set and why is the plan elaborated the way it is, is the central evaluation point, making this method useful for social fairness, but in necessity of a systems methodology for actual planning. It is a complementary tool the boundary critique performed by the application of the 12 questions in the "ought to be" and "is" perspective judges the plan elaborated by another methodology.

4.3.8 Postmodern Systems Thinking

The principal philosophical core of postmodern system thinking is that reality is relative for everyone, scientific development and history is not human discovery of progress, it is the unfolding of the path taken by that person in that moment. There is no final answer to an event. Knowledge depends on context, changing the established paradigm that science explains reality. Order falls from its pedestal and gives way to disorder. There can be no rigid structure of knowing. Order originates from interaction, not from a defined scientific truth. Postmodern thinking then is just a critique, expressing that systems theory is totalizing by defining systems that represent and predict reality. Systems theory advanced and introduced the social unaccountability into its concepts and systems started to not be considered as existing, rather than mental representations of the personal world view. Since man is part of reality, we shape it as it shapes us, therefore the relation is active, the relative knowledge is then relevant (Montuori, 1998).

4.3.8.1 Participatory Appraisal of Needs and the Development of Action (PANDA)

Since it is postmodern based tackle on knowledge management, Leroy White and Ann Taket (White & Taket, 1997), do not consider this approach a methodology, but a framework that links several methods that help people understand and plan.

It is important that the framework in table 3 respects the pluralism of postmodern thinking. This is done by maintaining a critical mind that is open to many view-points. Understanding that compromises might be needed to achieve participant consent and not forget that the truths developed are only for its specific context. Mixing, matching and adapting methodologies to specific needs, not stopping with one for each but trying several methods for a situation. Encourage freedom of speech and being. Trying to maintain fairness throughout the whole process and conclusions (Jackson, 2003).

Table 3 PANDA phases and Tasks, adapted.

Phase	Tasks	Goals	Methods
Deliberation I	1. Selecting Participant 2. Defining Objectives 3. Exploring the Situation	• Provide a platform for a debate. • Definition of stakeholders involved. • Ensuring variety and diversity. • Enabling the involvement of the participants.	• Secondary Sources. • Semi-structured interviewing • Transects • Trend Analysis • Venn Diagrams • Wealth Ranking • Analysis of Differences • SWOT • Analysis in Interconnected Decision areas • Team Syntegrity • Comparative Advantage • Strategic Assumption and Surface Testing • Mapping and Influence Diagrams • Commitment Packages • Action Methods
Debate	4. Identifying Options 5. Researching Options 6. Comparing Options	• Achieve control of the subjects at hand, ensure deep understanding. • Structure the available options. • Addition and filtration of options. • Strive for maximum participation.	
Decision	7. Deciding Action 8. Recording decisions	• Discussion of methods to apply for decision making. • Decision over the options to implement.	
Deliberation II	9. Evaluating and monitoring.	• Observation and supervision of the selected actions implemented.	

Source: (White & Taket, 1997), (Jackson, 2003).

4.3.9 Critical Systems Thinking

Resulting from a junction between critical theory and systems theory, Critical systems theory is the answer to the need of a more socially inclusive practice of systems thinking. Soft systems thinking and the other socially aware philosophies in systems thinking are most of the time applied at ideological level and ignore the conflict between stakeholders' motivations. The result are practical, applicable methodologies that critically assesses qualitative characteristics of systems. Systems thinking without critique are subject to unjustifiable boundaries and non-inclusive goal definitions and behaviors, on the other hand, critical theory that does not follow systems thinking is unable of exercising analysis over situations that are interconnected systems. Following its philosophy, not one systems methodology is adequate for a type of problem or context. Strength and emancipation results from the ability of recognizing and mixing procedures relevant to particular purposes in specific conditions (Watson & Watson, 2011).

Robert Flood (Flood, 2000) explains that Critical Systems Theory doesn't have a define set of concepts or principles that encases it. A set of core commitments defined by Jackson establish what is essential when using a critical systems thinking approach. Apply the systems idea, have critical and social awareness, focus on human emancipation and always apply approaches that are theoretically and methodologically complementary.

4.3.9.1 Total Systems Intervention (TSI)

Michael C. Jackson and Robert L. Flood (Flood & Jackson, 1991) developed the first Critical Systems Thinking methodology in their book *Creative Problem Solving: Total Systems Intervention*. The different systems theory approaches boast strengths and weaknesses, the need to leave behind a mere functionalist paradigm, and the proven compatibility of system approaches when considering them complementary are fundamental elements of Total Systems Intervention (TSI) (Jackson, 2003). Acknowledgement from systems thinkers that there is no "super methodology" and that the way to handle the diversity of complex situations is with increased variety of methods is reflected by TSI by its permanent questioning of which methodology? When do we apply it? Why this one? This reflect the critical and social awareness demanded by critical systems thinking (Flood, 2000).

The meta-methodology enables creative problem solving through the elaboration of systems metaphors that represent the issues at hand. The defined framework links this issues to the system intervention or set of systems interventions that are most suitable (Molineux & Haslett, 2005).

TSI is based on three phases (Flood & Jackson, 1991):

1. Creativity, using metaphors as mental images for the organization or situation under scrutiny, it is desired that stakeholders think creatively to better appreciate the relevant aspects of their system. TSI proposes the metaphors of machine (closed system), organism (open system), brain (learning system), culture (driven by norms and values), team (unitary political system), coalition (pluralist political system), and prison (coercive political system).
2. Choice, based on the system of systems methodologies, a coupling between systems methodologies and metaphors based on the underlying traits can be achieved (fig.19).

3. Implementation, once the organization or situation was represented with a metaphor, and consequently evaluated with the SOSM, follows the implementation of the approaches that result appropriate.

Systems methodology (examples)	Assumptions about Problem Contexts	Underlying metaphors
System dynamics	Simple-Unitary	Machine/Team
Viable systems diagnosis	Complex-Unitary	Organism/Brain/Team
Strategic Assumption Surfacing and Testing	Simple-Pluralistic	Machine/Coalition/Culture
Interactive planning	Complex-Pluralistic	Brain/Coalition/Culture
Soft systems methodology	Complex-Pluralistic	Organism/Coalition/Culture
Critical systems heuristics	Simple-Coercive	Machine/Organism/Prison

Figure 19 Example of metaphor-methodology coupling using Jackson's systems of systems methodologies. Source: (Mehregan, et al., 2011).

4.4 Systems Theory as energy management tool

Energy Consumption is based on daily behavior, this behavior tempers with different technologies and resources, it follows a variety of social norms, ands depend on individual skills and mindsets. Considering the interdisciplinarity and number of variables, energy behavior is a high complexity problem that branches out to the organizational level (Karresand, 2013).

Energy Efficiency is a wicked problem, and as established earlier in this document, cities are an example of complex adaptive systems. The application of system approaches as a tool for energy management at city level are justified by a list of principles that reflect how the discourses that mold research and practice must be applied to a context if it is to lead to action. Costello uses "discourse" to express a discussion that encompasses diversified approaches linked to many fields, they are fundamentally interdisciplinary. The principles on which she bases these ideas originate from Werner Ulrich, the creator of Critical Systems Heuristics. The principles manifest that any discourse is connected to changes created by different discourses at different levels. Each level will have interacting discourses of a specific object or system, and a variety of statements are likely to arise from just one problematic situation. What happens at a level may be caused by conditions at another. Even with the existing limitations of discourse communication, the important thing is through interconnected study there will exists a diversity of ways to plan and to structure concerns. Systems theory is moving forward the learning process of project management (Costello, 2012).

There was a need through all the fields, science, technology and management, to be tackled in an interdisciplinary manner based on the complexity identified. Management is the way science, and the developed technology is applied to the real world. Systems thinking has influenced management sciences, reaching topics that expand from human development to industrial ecology, or summarized, fields working toward sustainability (Strijbos, 2012).

One of the system approaches, the Complexity Theory, and its exponent, the Complex Adaptive Systems (CAS) are regulated through energy and time availability. When the limiting factor is energy supply in a well-defined boundary, efficient systems will thrive and lead to restructuration of that systems and the level of complexity inside it will increase. This will reduce the options of the system to perform a named function resulting in a decreased ability for adaptation if the boundary is modified. At the same time, the efficiency achieved by the complexity leap will reduce the stress applied by the system on the environment, liberating resources that may lead to the development of other system structures that could provide the necessary tools for re-organization when the system suffers energy scarcity again or if needed to respond to boundary changes that occur as time flows. When a system is subject to the other possibility, energy abundance but time scarcity, the system energy intake is increased to speed up the system, different systems structures will be able to take energy and process it for the systems goal and growth, leading to better adaptability in short term boundary modifications, but will forget about efficiency and increment the stress on the corresponding environment. This influence between efficiency and output is linked to systemic instability, the common idea of rebound effect, for efficiency to be defined and achieved a specific period in time must be set and systems must be in process of reorganization in order to phase out the structures that are inefficient for the current systems behavior (Labanca & Bertoldi, 2013).

5 Chapter V

5.1 Discussion: PLEEC and Systems Thinking

It is important to express that the methodology used, based on systems thinking and using tools of a systems approach cannot be considered systemic. In essence, it is a linear review of the presence of defined characteristics. Plausible and relevant due to it being an evaluation of a third-party framework that based on the review of literature and the principles exposed in the opening chapters of this work should include these elements to perform under the umbrella of sustainability and systemic consideration of urban metabolism. The position of this study is one from outside of the model and the framework, without the intention of analyzing the existing plans for the cities or the success of the model in creating EEAPs. Critique and overview is on the general framework presented for the model, in depth reviews of the techniques used in each work package that finalizes the framework's recommendations is not considered due to time and resources constraints.

The extent of system theory utilized is limited, literature on the theory and philosophy is available, but as it can be appreciated from the concepts depicted here, complex to digest. The concepts and principles used are those understood from the theories presented. Staying true to the statement found recursively through the material covered, complex must not be confused with complicated. Application of the theory is varied, with most of the examples focusing on system dynamics and organizational management.

Based on the previous clarifications and the deliverables of the PLEEC project, the most logical breakdown process is by "button" or steps. This means that the presence of systems thinking is evaluated separately for each category, leading to four plots on the complexity vs participants graph based on the framework. A fifth one based on how the project is described, presented to the public, the results harmonized, and overall concluded in the report "Green Thoughts, Green Futures" (PLEEC, 2016a) accompanies the plots based on the framework. The "Becoming energy efficient" button is consciously ignored, as it is considered to be an introduction and its evaluation is irrelevant.

Step 1 or "How do we get started?"

The first recommendations are to find support based on defined goals, established an interdisciplinary team from the start, argument why the available resources should be directed towards the EEAP, and to remain open to make the action plan part of another strategy with the idea that energy is part of many branches. Examples are transportation and the building sector. To learn from previous executed projects while respecting the differences between cities. The goals should be defined on a consensus of all the different working actors. It invites the user to consider the conflict that can arise from conflicting ideas between stakeholders, but doesn't address it. It invites to remember the 'decision-makers" so you can involve them from the beginning to the end, signaling a certain discrimination toward other stakeholders. It acknowledges the different power of stakeholders but only issues a warning and doesn't include a strategy to level the say. The stakeholders to be approached are defined by the boundary of the EEAP. Incites diversity when selecting the stakeholders. Responsibility must be assigned. It must be a long-term commitment and the parties involved should know their benefits, thus it is not function oriented but goal oriented.

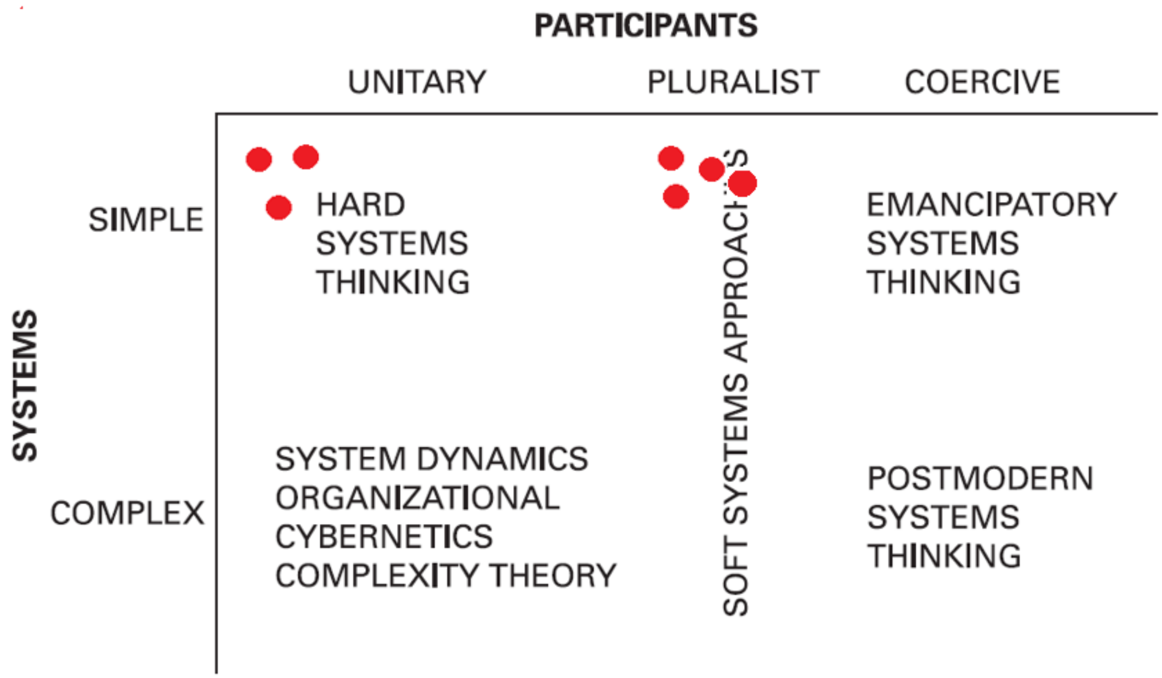

Figure 20 Plotted Jackson's SOSM (Jackson, 2003) for Step 1 of PLEEC.

It is depicted visually (fig.20) how the discussed ideas and recommendations on step 1, reflect systems thinking philosophies. Leaning towards Hard Systems Thinking and SST approaches. Goal defined, interdisciplinary, dialectic, participative, aims for diverse stakeholders, and relies on a synthesis between parties. Even though it mentions the possible problems of a coercive participation it ignores any ST principle or general process to confront it.

Step 2 or “Where are we?”

Collection of data by diverse means, primarily the set of indicators developed for six key field that conform a smart city profile. The main purpose of the profiles is to generate discussion, they warn the user to not consider them as standing-results. It also requires a questionnaire with the goal of internalizing social elements. Different to the smart city profiles key fields, PLEEC established 5 key fields of energy efficiency for urban development. Each field contains different domains that constitute the baseline for definition of indicators. The smart city profiles include concepts such as awareness, individuality, and self-decisive behavior. They represent the ideas that cities need all stakeholders to be “well aware of the city’s position”. All fields must be considered when dealing with urban development, to achieve this the profiling process demands complete transparency for the evaluation. Using the defined profiles allows cities to be compared and to share best practices among cities with similar profiles.

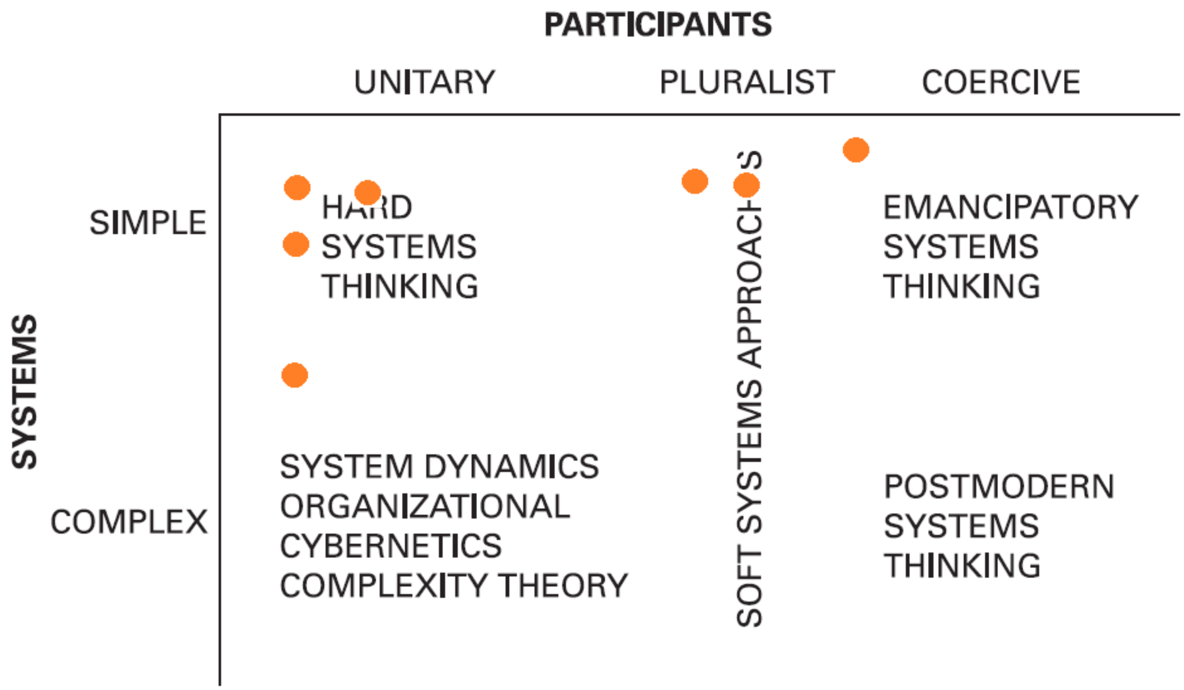

Figure 21 Plotted Jackson's SOSM (Jackson, 2003) for Step 2 of PLEEC.

Exhibiting the common traits of hard systems, boundary definition, interdisciplinarity, interconnections, and goal definition this step moves a little bit further the complexity axis due to the concept of clusters of cities with similar smart profiles (fig.21). This reflect the principle of systems dynamics and organizational cybernetics that similar structures lend to similar behavior, thus allowing and validating the exchange of best practices through system logic. The further right dot illustrates the expressed desire of having all the stakeholders well informed of the city's position and that it demands full transparency on the information used. Still it is not enough to enter to the coercive realm, but it edges close.

Step 3 or "Where do we want to go?"

The framework established five key fields to be improved by working on three aspects to ensure a holistic approach. The potential for energy efficiency is unlocked by defining goals in technological, structural, and behavioral capacities. The work packages present solutions that link land use to energy efficiency improvements. Technical solutions for renovations, new buildings, and space and land use. The mobility key field displays the energy intensive impacts of the choices of private and public transport, consequences and benefits of managing the energy mix and the spatial management of cities. State of the Art infrastructure plays a major role when applying available technologies paired with adequate behavior in their use. Production and consumption manages through dialectic means synthesis between stakeholders for energy and environmental friendly practices and competition. The trade-offs and consequences are not planned for, due to "local complexity". Energy Supply guides through the planning and inclusion of renewable energy options, stating that to overcome shortcomings of supply, variety of options must work together. Structurally, the project defines the municipal government as an actor to enable action or itself as a generator. Technology based solutions aim in reduction of quantified energy consumption and CO_2 emissions. The structure element is based on planning and urban design. How to improve transportation sector while impacting energy. Inclusion of the industrial use and the role urban form plays in energy consumption. Urban energy generation schemes. Behavior is the social and most delicate part to implement and monitor. The deliverables of the project provide a comprehensive list of methods and behaviors that promote sustainable and energy efficient styles of life. The use of peer to peer, social pressure, and social media campaigns generates interest and promotes the planner's desired behavior. The results must be quantified.

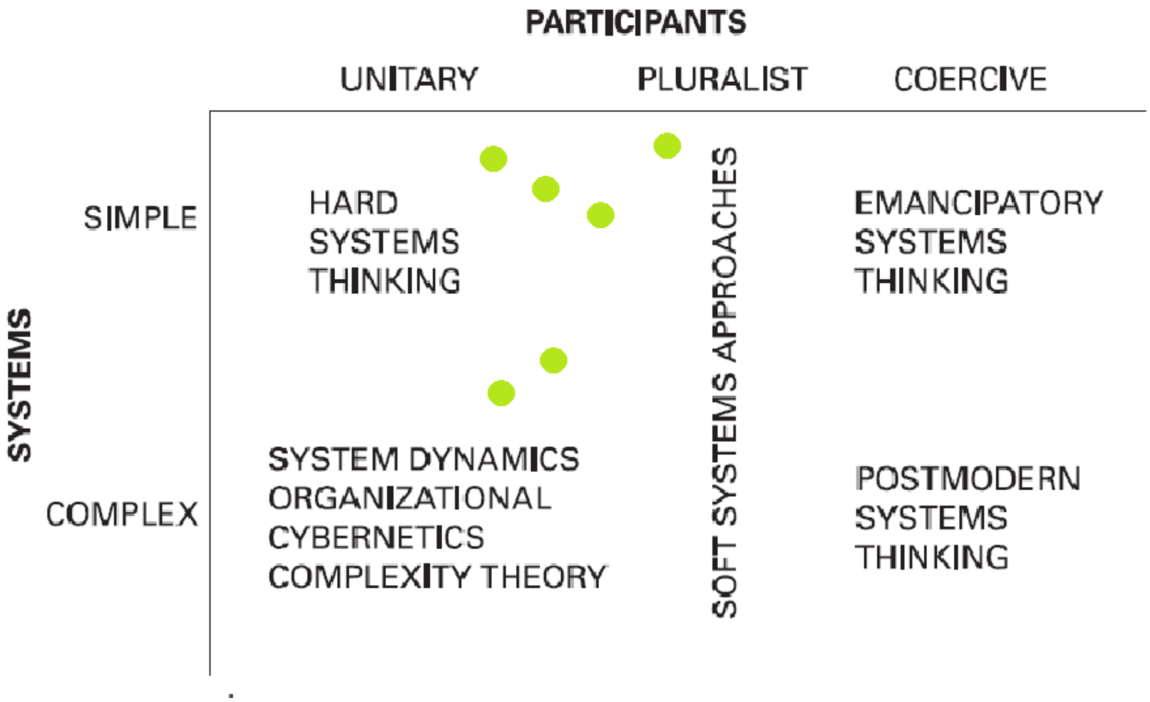

Figure 22 Plotted Jackson's SOSM (Jackson, 2003) for Step 3 of PLEEC.

Notions of being inclusive in the pursuit of being holistic, clear defense of interdisciplinarity and interconnected elements, that respond to feedback between them. Stakeholders from all levels are include, but with clear distinction of roles. The primary focus of the proposed mechanisms for planning are goal driven, not interested in structuring a functioning behavior but one that reaches the efficiency targets, positive side effects are welcomed, negative side effects are recognized but there is no comment on management. It states the power of multiple renewable energy sources as solutions to supply and demand reflecting the premise that variety is key in dealing with degrees of complexity.

Step 4 or "How do we Implement?"

All left according to the steps is to write and implement the EEAP, it must include a clearly stated goal and scope of the project. It suggests that every stakeholder consider must be named and link the plan to existing programs in the city. The bigger the scope, the greater number of stakeholders to consider. Action plans recommend for 5-10 years executions, but reminds that the goal can be long term. Transparency on the choice of action is mandatory. Responsibility for monitoring and implementation must be documented.

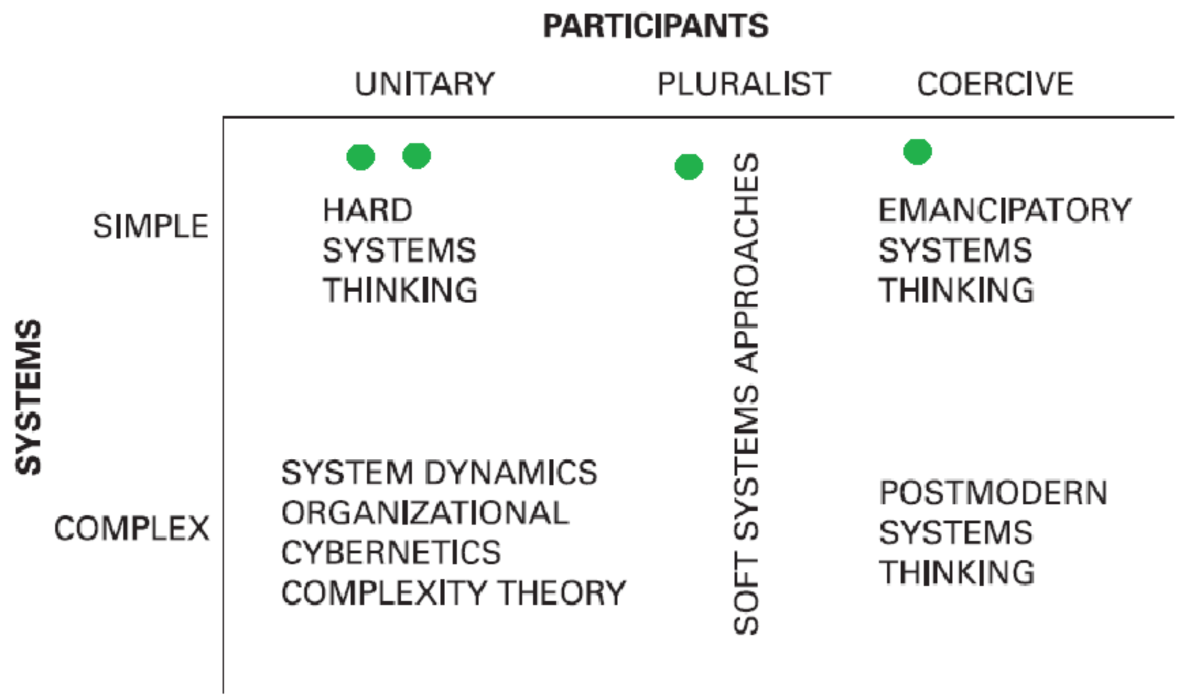

Figure 23 Plotted Jackson's SOSM (Jackson, 2003) for Step 4 of PLEEC.

In standard fashion, the goal driven and closed boundary principles are reflected, including the pluralist idea of a scope dependent number of stakeholders, that remain in SST due to the inherent assumption that they will accept a common goal. The surprising point inside the emancipatory field is due to clearly affirming that responsibility must be assigned and that every choice taken must be portrayed as transparent as possible on the public EEAP.

“Green Thoughts, Green Futures”

The conclusion of the PLEEC project delivers the report “Green Thoughts, Green Futures” (PLEEC, 2016a) and with it the overview and description of the fields the project considers fundamental. It starts by defining PLEEC as a holistic framework to achieve energy efficiency, sustainability, and smart-city status. Establishes energy as interdisciplinary and vital part of various elements of cities. Defines that it works towards the 20-20-20 EU targets and acknowledges the impact over time that planning and execution have in sustainability. Highlights the major role of social practices and individual behavior in achieving a holistic and working structure. They proclaim that clear goals are a necessity and can be satisfactorily identified as a consequence of a “shared view and agreement”.

Achieving energy efficiency involves, technology, structure, and people. Cities must “identify critical barriers” and communicate the benefits to come in the future. Building codes, Internet of Things and smart appliances, urban planning, land-use schemes, transportation habits, small steps and example as precursors of success. Promotion of resource efficiency using modelling of behaviors based on “big-data”. Application of circular economy and energy saving behavior as individual level influences. The ability to employ behavioral change is complex. Feedback as learning tool, people that embrace the suggested style of life must be able to understand and feel the effect of their actions.

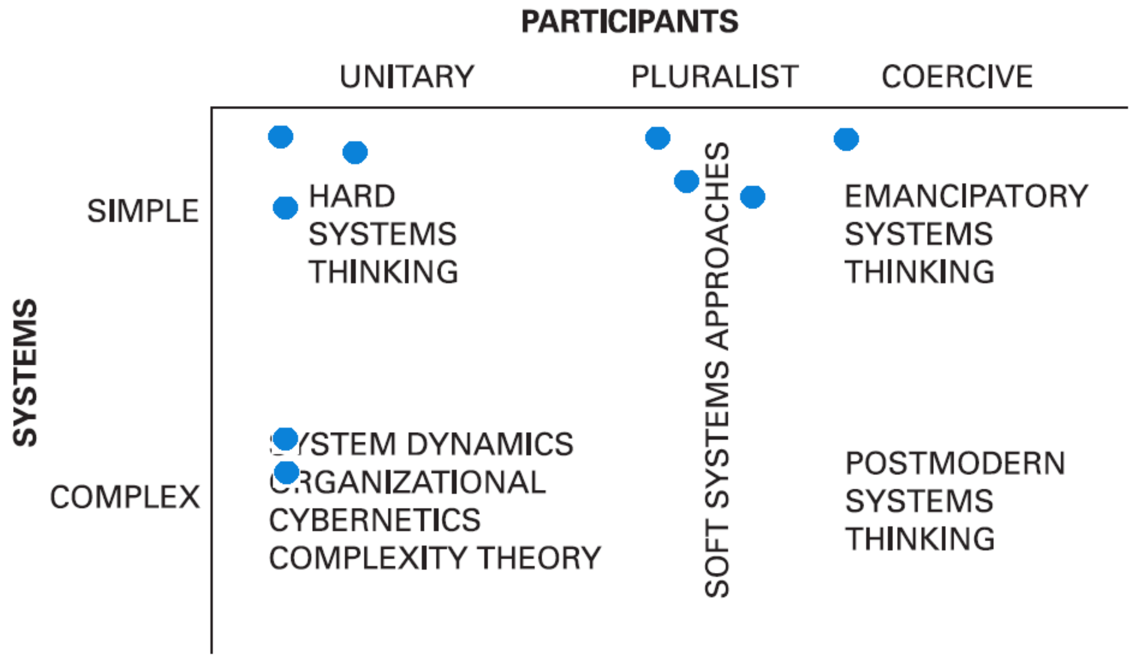

Figure 24 Plotted Jackson's SOSM (Jackson, 2003) for "GT/GF"

Strong in holistic approach and interdisciplinarity as in the framework's steps, it confirms that the framework is goal driven, there is no interest in defining system's structure. It displays it pluralist mindset once more by exiting cities to approach different methods to defined problems. Once more it lands in the dialectic and the willingness to debate of SST. Bio cybernetics establishes recycling as a practice of viable systems. It expresses some new principles when compared to the steps in revealing the interest of defining leverage points, they called them critical barriers. As well as firmly supporting the use of system dynamics to manage and promote energy efficient behavior based on quantitative results and models to study future conditions. They provide insight that small steps lead to big changes in systems, this is a principle I link to complexity theory, due to the lack of accompanying characteristics of that level, it will be represented as a move further down the complexity axis but closer to SD and OC (fig.21).

5.2 Conclusions

Cities are leverage points on the global systems by sheer volume of influence, as well as being part of the fundamental structure of the global system. Energy consumption and energy efficiency are a couple of wicked problems inherently interdisciplinary. EE is one of the fields of focus in the battle towards sustainability due to energy being a basic need for life since many years now. Society is demanding sustainable development, for the sake of future generations and the survival of the ecosystem. Urban Energy Metabolism tackled the problem, but it is not enough alone. UM philosophies can be found inside of Systems Thinking.

System Thinking is a broad subject encompassing several approaches that stemmed from the general systems theory. Many philosophical foundations and concepts motivated different branches that cover a diversity of principles and categories. The basic traits all of the approaches share that they are a set of different elements, interconnected, working together. They follow a hierarchy and are self-organizing. There is a need to assign a boundary when dealing with systems, based on the purpose of the activity, to interact along a certain degree of sense with the system. Cities are complex systems and systems thinking enables man to develop a way to interact and evolve together toward sustainability.

Energy Efficiency planning is at the center of the sustainability debate apart from energy security and economic relevance. The EU established targets and developed PLEEC to achieve success. The framework does not tackle the complexity of energy in cities. It introduces elements of several systems theories, but in a low level of complexity. Recommendations and guidance does not account for the behavior of complex systems. The biggest stride in the complexity axis of the SOSM is due to the motivation towards versatility and modeling of quantitative reductions by dynamics of energy and carbon flows. It does perform better on the participant spectra of system thinking. Focusing on interlevel, multi-stakeholder, transparent planning. It still does not reach the coercive debate; the framework moves along its steps and processes assuming a synthesis between stakeholders is achieved. This happens presumably by the nature of politics in real practice.

This is first time I dealt with systems thinking. The subject is a fascinating field that is met with fear due to mental impressions the public has when hearing complexity. The experience was fulfilling and motivational, systems thinking is not popular but it is necessary. Basic knowledge of systems theory must be a requisite for scientific work. The world feels different depending on the lens used, ST is a philosophy and tool that enhances every part of it.

5.3 Further study and recommendations

The framework should engage deeper into complexity by applying more of the system approaches that facilitate it. First example being the CAS studies. The point to which it dwells in to pluralist but not coercive participation is understandable, but the inclusion of a framework to deal with this, the 12 questions of CSH as an example.

This work could be expanded to include each work package and breakdown every methodology applied in the framework thoroughly. The adaptation of the TSI methodology should be revised and refined by practitioners with more expertise.

Research in system thinking application is growing, proof is that before PLEEC was finished the EU had already launched a systems thinking based energy efficiency planning project, focused on problem structuring as well than solving, STEEP (STEEP Project , 2015). As a theoretical approach, it can help people understand and as practical tools, intensify the path towards sustainability.

Introduction of systems thinking as a mandatory requisite for sustainability studies, and promote it for all the other disciplines and general public.

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Declaration in lieu of oath

By

René Alfonso Paz Guerrero

This is to confirm my Master’s Thesis was independently composed/authored by myself, using solely the referred sources and support.

I additionally assert that this Thesis has not been part of another examination process.

Place and Date *Signature*