A Systems Design Approach to Sustainable Development
Embracing the Complexity of Energy Challenges in Low-income Markets

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DOI
10.4233/uuid:8bbf71f1-48bd-4844-84f5-fe8c7ca5398c

Publication date
2020

Document Version
Final published version

Citation (APA)
Costa Junior, J. D. (2020). *A Systems Design Approach to Sustainable Development: Embracing the Complexity of Energy Challenges in Low-income Markets*. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:8bbf71f1-48bd-4844-84f5-fe8c7ca5398c

A SYSTEMS DESIGN APPROACH TO SUSTAINABLE DEVELOPMENT

Embracing the complexity of energy challenges in low-income markets

Jairo da Costa Junior

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PhD thesis, Delft University of Technology, The Netherlands.
Design for Sustainability Program publication nr. 37
ISBN 978-94-6384-102-3

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Cover design by Jairo da Costa Junior.
Printed by Gildeprint, The Netherlands.
Printed on 100 gr Wood free Offset (HVO).
Typeface: Proxima Nova, Mont.

This research was partially funded by the National Council for Scientific and Technological Development (CNPq), Brazil, Grant no. 202527/2011-5.

A systems design approach to sustainable development:
Embracing the complexity of energy challenges in low-income markets

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus, Prof.dr.ir. T.H.J.J. van der Hagen;
chair of the Board for Doctorates
to be defended publicly on
Monday 3 February 2020 at 12:30 o'clock

by

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To my mother, sister and wife,
who inspired me and helped
to make this work possible.

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Abbreviations

ANEEL	Brazilian Electricity Regulatory Agency
CA	Capability Approach
CEDAT	College of Engineering Design Art and Technology
CO_2	Carbon Dioxide
DfBoP	Design for the Base of the Pyramid
DfD	Design for Development
DfS	Design for Sustainability
DRE	Distributed Renewable Energy
DSM	Demand-Side Management
E-PSS	Energy Product-Service System
EPE	Energy Research Company
ERV	Eco-cost/Value Model
ESCO	Energy Service Company
EVO	Efficiency Validation Organization
FFEM	French Fund for the World Environment
GHG	Greenhouse Gas
GIZ	German Corporation for International Cooperation
HIV	Human Immunodeficiency Virus
H-PSS	Humanitarian Product-Service System
HEI	Higher Education Institution
HVAC	Heating, ventilation, and air conditioning system
IEA	International Energy Agency
ISO	International Organization for Standardization
LCA	Life-Cycle Assessment
LED	Light-Emitting Diode
LeNS	Learning Network on Sustainable
LeNSes	Learning Network for Sustainable Energy Systems
MEPSS	Methodology of Product-Service System
MMA	Ministry of Environment
MSF	Medécins Sans Frontières
NGO	Non-Governmental Organisation
OLeP	Open Learning e-Package

PEE	Brazilian Energy Efficiency Programme
PNMC	Brazil National Climate Change Plan/Policy
PSS	Product-Service System
REN21	Renewable Energy Policy Network for the 21st Century
R&D	Research and Development
CBR	Cost-Benefit Relationship (also Cost-Benefit Ratio)
RFID	Radio Frequency Identification
SA	Systems Architecture
SD	System Dynamics
SDA	Systems Design Approach
SDO	Sustainability Design-Orienting
SE	Systems Engineering
SE4ALL	Sustainable Energy for All initiative
SHS	Solar Home System
SOD	Systems Oriented Design
SPSS	Sustainable Product-Service System
SSM	Soft Systems Methodology
TNS	The Natural Step
TUD	Delft University of Technology
UN	United Nations
UNEP	United Nations Environment Programme
WBCSD	World Business Council for Sustainable Development
WCED	World Commission on Environment and Development
WSD	Whole Systems Design

“ I want to make this an
opportunity to contribute through
my profession, to where I come from
and the people with whom
I most identify. ”

Preface

The personal and professional decisions one makes through life are often very close to one's idea of what makes a fulfilling and purposeful life. When I started my doctoral education, I wanted to make this an opportunity which would allow me to contribute, through my profession, to where I come from and the people with whom I most identify. For this reason, I decided to research the topic of design for the base of the pyramid. I was particularly interested in pursuing sustainable development through better energy systems. More specifically, I wanted to focus on how to improve the living standards of people for whom the idea of sustainable development may fail to resonate due to their personal challenges. Soon, I realised the complexity associated with my goal.

While I come from a poor beginning, my professional life as a designer led me to realise that my understanding of the complex problems experienced in low-income contexts is limited. Dealing with the challenges associated with living in low-income contexts and going through everyday life with limited resources is, in itself, a complex and unique experience. Therefore, such experience can be easily overlooked or misunderstood by an outsider.

It is evident that when designing solutions for problems with high societal complexity and limited resources, which are typical in low-income markets, designers need to have a thorough understanding of the unique characteristics of the system in place. However, less obvious is how to approach such a challenge. Designers are typically educated to apply traditional design approaches which are associated with knowledge developed in the context of middle-/high-income markets. Therefore, the current expertise of designers loses relevance when developing sustainable solutions for low-income markets.

As design education and practice is expected to deal with the increasing complexity of the problems faced by society, higher education institutions become an essential agent for change from the traditional design approach to a new perspective. This thesis is intended to share lessons I have learned from developing a systems design approach to pursue sustainable development in low-income markets. Moreover, it is an opportunity to discuss some differences between low-income contexts and middle-/high-income contexts that may have implications for how designers deal with complexity.

I invite you to read this thesis with an open mind. This work builds on existing and emerging research and ultimately is intended to contribute to a large research field. It suggests new ways to look at old and complex problems and disputes some common assumptions about solving complex societal problems through design. Also, it requires acknowledgement that we might know less than we think about such problems. Often, the solutions we designers create can be more harmful than the problems we desire to solve. This complexity cannot be dismissed, but rather, it should be embraced.

“ Embracing complexity represents a significant shift from the traditional design approach to a systems design approach. ”

Summary

The societal and technical problems faced by low-income markets are increasingly seen as more complex due to environmental, social, and economic concerns. The enormous negative impacts of societal problems and the inability of designers to deal with complexity cannot be overcome without a paradigm shift in how we understand, engage with, and teach about such issues. In light of this challenge, one can pose the question, *"What is the best approach to deal with a complex societal problem?"*. A traditional approach to deal with a complex problem is to simplify it. Alternatively, as here, research may aim to provide a novel approach to handle complex societal problems, thereby embracing complexity. Thus, this research contends that embracing complexity represents a significant shift from the traditional design approach to a systems design approach for sustainable development.

The thesis focusses on theories and practices that are central and relevant to the debate on sustainability and systems thinking in design. It aims to foster designers' understanding of sustainability issues, like energy challenges in low-income markets, to contribute, through design, to solving complex societal problems. For this reason, the investigation focusses on those low-income energy markets which are particularly sizeable in emerging economies in Latin America and Africa. Generally speaking, low-income energy markets lack access to affordable, reliable, clean, and modern sources of energy, which results in pollution, health problems, and high electricity costs, amongst other issues.

Low-income energy markets represent a favourable opportunity to satisfy demand in alignment with sustainable development goals. Nevertheless, designers have struggled to support low-income communities to improve their living standards by providing sustainable energy solutions. Consensus exists that without access to sustainable energy products and related services, sustainable systems cannot be created and sustainable development cannot be achieved. However, complex societal problems in low-income energy markets are far from obvious, and solutions to these problems are far from optimal. Such problems are often very hard to define due to limited availability of information about the problem situation and the lack of context-specific knowledge. Nonetheless, these are problems that impact everyday life in low-income contexts.

While complex problems may involve high levels of technical complexity, the term *complex societal problems* adopted in this thesis refers to complex problems where technical complexity is entangled with societal complexity, and where relations among humans and institutions are central to the solution. Moreover, the concept of

complexity adopted here also refers to the lack of knowledge of the characteristics of the system in place, the lack of understanding of the problem situation at hand, and the lack, or uncertainty, of the expertise needed to handle the problem. This investigation suggests that the integration of systems thinking and design is a promising approach to address the increasing complexity of societal problems. The central research question proposes to gain insights into systems-oriented approaches to design (also referred to here as a systems design approach). In particular, I focus on systems approaches and methodologies to develop product-service systems for complex societal problems, such as those encountered in low-income energy markets.

A Product-Service System (PSS) consists of a system of products, services, supporting networks, and infrastructures which closely involve multiple stakeholders who offer functionality, utility, and satisfaction (Mont, 2002a). For many authors, the adoption of systems thinking on PSS is fundamental for a proper conceptualisation and in-depth understanding of the system in place (Afshar & Wang, 2010; Cavalieri & Pezzotta, 2012). In this context, this thesis contributes to PSS and systems design research by addressing the need for the expansion of the scope of PSS from its focus on a separable system of product-service combinations towards a whole PSS system capable of handling complex societal problems.

To this end, this doctoral research investigates systems theory and practice to understand the implications of systems thinking for design and offers recommendations for the adoption in design approaches, such as PSS design. The investigation is based on the hypothesis that the difference between traditional design approaches and systems design approaches lies in their underlying assumptions regarding the boundaries and scope of design. In other words, the latter strive to achieve a holistic, multilevel, and pluralistic perspective that embraces the complexity within the system in place. Based on the problem definition, the central research question and sub-questions are proposed as follows:

MAIN RESEARCH QUESTION:

MRQ. *How can systems thinking contribute to handling the complexity of sustainable product-service system design for low-income energy markets?*

RESEARCH STRATEGY		RESEARCH SUB-QUESTIONS
THEORETICAL PHASE (Chapter 2)		**RQ1.** What are the characteristics of complex societal problems in low-income energy markets? **RQ2.** How has systems thinking been developed as a way of handling complex societal problems? **RQ3.** To what extent does systems thinking provide the best fit to the design of solutions aimed at complex societal problems?
EMPIRICAL PHASE	**Observations of Existing Practice** (Chapter 3)	**RQ4.** What does the adoption of systems thinking as a multilevel perspective tell us about improving energy solutions in low-income energy-efficiency programmes?
	Interventions in Design Education (Chapters 4-5)	**RQ5.** How can systems thinking support design students in the development of more sustainable product-service system (PSS) concepts for low-income markets? **RQ6.** How can the capacity for design students to respond to the complexity of societal problems, such as those found in many low-income markets, be built?

Within the research structure seen above, the thesis comprises four primary studies (Chapters 2-5) published as peer-reviewed journal articles. Each publication addresses one or more sub-questions that support the answer to the main research question. It should be noted that the chapters do not reflect the chronological publication of the articles. Consequently, the knowledge creation has not been linear (e.g., a chapter might not entirely build upon the knowledge from the previous study). Nevertheless, the findings from each study come together to provide contributions to three main design areas: theory (Chapter 2), practice (Chapter 3), and education (Chapter 4-5).

Theoretical Phase

Preliminary Research

The preliminary research of this investigation is reported in Chapter 1. The first chapter introduces the rationale for the investigation. It recognises some of the limitations of using traditional design approaches to gain an understanding of complex societal problems in low-income energy markets. Moreover, it argues that a more holistic approach can be taken to complement the reductionist nature of traditional scientific methods adopted in design. Additionally, it points out that the potential to trigger radical changes in technological and socio-cultural terms lies in design approaches that consider the capacity of design to handle complexity. Besides, it focusses on energy solutions that integrate products, services, and infrastructure to offer satisfaction through better system functionality and utility.

Furthermore, Chapter 1 indicates that sustainable product-service systems (PSS) provide an opportunity to satisfy energy demand in low-income markets with solutions that are compatible with sustainable development. It demonstrates why developing sustainable product-service systems for low-income energy markets are imperative for developing and emerging economies that aim to reconcile socio-economic development with environmental protection. The preliminary literature review provides evidence that PSS is a promising concept for stimulating sustainable generation, distribution, and consumption of energy.

The results in Chapter 1 imply that however promising, PSS is often bound to fail in low-income markets due to the particular societal complexity existing in low-income contexts. In this regard, the chapter demonstrates how systems thinking can advance product-service systems for low-income energy markets. The chapter concludes that to develop more sustainable energy solutions in low-income markets, problem-solvers need to increase complexity-handling capacity by adopting four major systems thinking tenets: a holistic perspective; a multilevel perspective; a pluralistic perspective (diversity of views); and complexity-handling capacity.

Theoretical Research
The preliminary research in Chapter 1 suggests that systems thinking can advance energy solutions for low-income markets. In Chapter 2, the adoption of systems thinking in design is explored to highlight some implications of using a systems design approach for addressing complex societal problems. Chapter 2 aims to provide a systems thinking foundation for the investigation; this was developed by drawing on knowledge from all chapters. The primary goal of the chapter is to foster understanding of the implications of systems approaches and methodologies and explore the adoption of systems thinking tenets in design.

The chapter demonstrates that the underlying assumptions and tenets of systems thinking provide a valuable corrective to reductionism when using a traditional scientific method to tackle complex societal problems. An extensive literature review outlines significant aspects underlying systems thinking; appropriate systems approaches and methodologies are identified, and their contributions to handling complex societal problems in the field of design are clarified. Previous studies have attempted to explore the field of systems thinking to offer recommendations for how to apply systems methodologies and tools in design. However, little attention has been paid to how designers have interpreted and employed systems methodologies and tools to tackle complex societal problems.

Chapter 2 investigates the process of integrating systems thinking into design and provides an overview of the emerging field of a systems design approach to complex societal problems. It summarises the current state-of-the-art by describing how a selection of existing systems design approaches has provided significant contributions to the transition from a traditional design approach to a systems-oriented perspective in design. Based on these theoretical insights, the chapter emphasises the opportunity to develop systems design approaches further through the systematically and informed exploration of systems thinking. The study results in a conceptual framework that offers criteria for the integration of systems thinking into design. Accordingly, the main contribution of the study is to provide a framework that allows for developing new, and strengthening existing, systems design approaches by supporting designers to further realise the resources of systems thinking on which they can draw.

Empirical Phase

Observations of Existing Practices

Chapter 3 investigates the adoption of systems thinking as a multilevel perspective to gain a better understanding of the constraints imposed by the complexity of energy challenges in low-income energy-efficiency programmes in Brazil. Brazil is selected for this empirical study because it presents many relevant energy challenges that require urgent attention. Building on design theory grounded in systems thinking, three aggregation levels of the Brazilian low-income energy market are analysed to gain insights which are useful for the design of sustainable energy solutions. The chapter examines findings from the literature, descriptive cases, and interviews with practitioners and experts.

Previous studies have shown that, although fundamental, improvements at a technological level are limited in the creation of sustainable energy transitions. For this reason, to tackle energy challenges in low-income markets, it is necessary to move from technological improvements alone to a broader societal perspective that takes into consideration organisational and societal transformation, which implies high levels of societal complexity. This study contributes to uncovering knowledge about the complexity of low-income energy markets and to realising implications of a multilevel analysis for energy solutions. Also, it demonstrates that such knowledge is valuable to the redesign of low-income energy programmes and to inform new policy development or policy revisions.

Results show that adopting a multilevel perspective in low-income energy-efficiency programmes allows policymakers and problem solvers to identify relevant constraints and opportunities across system levels. More specifically, a multilevel analysis uncovers key aspects hindering energy solutions in low-income energy programmes to achieve higher levels of sustainability. In addition, it produces insights for recommendations to improve the current situation. Understanding and overcoming social and technical challenges hindering energy solutions is crucial for increasing the ability of energy programmes to achieve higher levels of socioeconomic benefits and lower environmental impacts on low-income communities.

The findings suggest that a systems design approach requires designers to handle a more substantial degree of complexity in comparison to other traditional approaches. Consequently, they must be equipped with a set of systems-oriented knowledge, skills, and tools, appropriate to deal with this new reality. To face this significant challenge in design education, the last two chapters of the thesis address, and so contribute to, support for the development of capacity building for a systems design approach.

Interventions in Design Education
As designers are typically educated to apply traditional design approaches, higher education institutions become an essential agent for change. Therefore, the interventions carried out in Chapters 4 and 5 explore the application of a systems design approach to design product-service systems concepts by students. The interventions allowed the research hypothesis and the theoretical model presented in Chapter 3 to be tested. Further, they provided an initial exploration of the conceptual framework described in Chapter 2.

The intervention in Chapter 4 provided an exploratory exercise in which to apply a systems design approach by students from Delft University of Technology (the Netherlands) to create product-service system concepts to identify advantages and disadvantages in this process. In Chapter 5, design students familiar with low-income energy markets tested a systems design approach to solve energy challenges faced by low-income communities in Uganda. This concluding intervention builds upon the previous chapter and seeks to gain a better understanding of the process of learning a systems design approach and the means to support that learning in design.

Chapter 4 reports a Master's course called "Product-Service System" that applies systems thinking in the development of sustainable product-service system concepts for complex societal problems. The chapter explores higher education institutions as a base for knowledge transfer between multiple stakeholders when addressing the need for affordable energy in low-income households and the implementation of humanitarian aid. In this study, multidisciplinary student teams from TU Delft (the Netherlands) use knowledge and skills based on System Oriented Design and PSS to develop twelve PSS concepts. The study was conducted in collaboration with the Federal University of Paraná (and partners) in Brazil, and the Innovation Unit of Medécins Sans Frontières (Doctors Without Borders) in Sweden. For this reason, the study's scope was extended to address the context of humanitarian aid.

The empirical data used in Chapter 4 emerge from a set of PSS concepts targeted for low-income contexts, conducted by student teams on a multidisciplinary course. Based on the design activities carried out by students and the outcome of the projects, advantages and the context- and process-related challenges of using systems thinking are presented and discussed. The findings demonstrate that a systems design approach provides students with comprehensive knowledge and skills to deal with complex societal problems. However, there remains the need to introduce appropriate systems resources (e.g., systems strategies and tools) in the current design curriculum, making the transition from a traditional design approach a challenging one. The findings imply the need for the further development of systems-oriented competencies in design students.

Chapter 5 describes a Master's course called "System Design for Sustainable Energy for All". The course proposes to develop and test teaching resources based on systems thinking and promote capacity building for a systems design approach. Ugandan design students, from the College of Engineering Design Art and Technology at Makerere University, familiar with the local context, adopt a systems design approach to solve energy challenges faced by low-income communities in Uganda. The chapter suggests key competences for skilful performance when designing product-service system concepts aimed at low-income energy markets and demonstrates the process of applying such competences. The previous chapter (Chapter 4) provides background information, which helps to develop the building blocks of a new set of knowledge, skills, and tools for addressing complex societal problems. Chapter 5 narrows the scope of the study to focus on building capacities to apply systems thinking in the development of sustainable energy PSSs.

In addition, key cognitive aspects of capacity building for a systems design approach is provided for educators. Moreover, the chapter demonstrates the process of embedding systems thinking into the course curriculum to support students in the development of sustainable solutions for low-income energy markets in Uganda. The findings support that design approaches grounded in systems thinking can help to deal with the increasing complexity of the societal problems that future generations of design professionals are expected to solve. Therefore, a significant contribution of the study for design education is to propose key competencies to address gaps in capacity building for complexity in design.

Reflection Phase

Main findings, contributions, and recommendations

Chapter 6 provides a general summary of the main findings to emerge from the thesis. Contributions to design theory, education, and practice are presented. The four main contributions provided in this research are:

- Exploring the integration of systems thinking into design, particularly by adopting a systems design approach to sustainable energy solutions for low-income markets.
- Extending the scope of product-service system design through the introduction of four major systems thinking tenets: a holistic perspective; a multilevel perspective; a pluralistic perspective; and complexity-handling capacity.
- Proposing heuristic tools for the integration of systems thinking into design, which allows for developing new and strengthening existing systems design approaches.
- Increasing capacity building for a systems design approach to address complex societal problems through design education.

The chapter contends that designing sustainable energy solutions for low-income markets requires effective interventions capable of handling high levels of societal complexity. To do so, the adoption of a systems design approach in addition to the traditional reductionist approach is required. This means embracing the complexity within societal problems, systems or contexts, and employing new thinking and skills to handle such complexity.

Keywords: Design for sustainability, complex societal problem, systems thinking, systems design approach, systems-oriented design, product-service system, low-income market, energy solution.

“ Het omarmen van complexiteit brengt een significante verschuiving met zich mee, van een traditionele ontwerpbenadering naar een systeemontwerpbenadering. ”

Samenvatting

Er is steeds meer oog voor de groeiende complexiteit van maatschappelijke en technische problemen waarmee markten met lage inkomens worden geconfronteerd, die het gevolg is van milieutechnische, maatschappelijke en economische factoren. De enorme negatieve impact van complexe maatschappelijke problemen en het onvermogen van ontwerpers om met complexiteit om te gaan kunnen niet worden overwonnen zonder een paradigmaverschuiving met betrekking tot de manier waarop we over dergelijke problemen nadenken, hiermee omgaan en hierover onderwijzen. In het licht van die uitdaging kan de vraag worden gesteld wat de beste benadering is voor de omgang met een complex maatschappelijk probleem. Een traditionele manier om een complex probleem te benaderen is om dit te vereenvoudigen. Maar onderzoek kan er ook op gericht zijn, zoals hier, om een nieuwe benadering te bieden voor de omgang met complexe maatschappelijke problemen, waarbij de complexiteit juist wordt omarmd. Daarom wordt in dit onderzoek betoogd dat het omarmen van complexiteit een significante verschuiving met zich meebrengt, van een traditionele ontwerpbenadering naar een systeemontwerpbenadering van duurzame ontwikkeling.

In dit proefschrift ligt de nadruk op theorieën en praktische handelwijzen die centraal en relevant zijn met betrekking tot de discussie over duurzaamheid en systeemdenken bij ontwerpen. Het streven is om het inzicht van ontwerpers in duurzaamheidsaspecten – zoals uitdagingen met betrekking tot energie in markten met lage inkomens – te vergroten, zodat zij door middel van hun ontwerp een bijdrage kunnen leveren aan de oplossing van complexe maatschappelijke problemen. Daarom ligt de focus van het onderzoek op energiemarkten met lage inkomens, die met name prominent zijn in opkomende economieën in Latijns-Amerika en Afrika. Algemeen gesteld ontbreekt het in energiemarkten met lage inkomens aan toegang tot betaalbare, betrouwbare, schone en moderne energiebronnen, wat leidt tot onder andere vervuiling, gezondheidsproblemen en hoge elektriciteitskosten.

Energiemarkten met lage inkomens vormen een uitgelezen kans om in een vraag te voorzien in overeenstemming met duurzame ontwikkelingsdoelstellingen. Toch hebben ontwerpers moeite gehad om gemeenschappen met lage inkomens met behulp van duurzame energieoplossingen te steunen bij het verbeteren van hun levensstandaarden. Algemeen wordt erkend dat zonder toegang tot duurzame energieproducten en bijbehorende dienstverlening geen duurzame systemen kunnen worden opgezet en duurzame ontwikkeling onmogelijk is. Maar de maatschappelijke problemen in energiemarkten met lage inkomens zijn niet duidelijk en de oplossing voor deze problemen zijn verre van optimaal. Dergelijke problemen zijn vaak erg moeilijk te definiëren als gevolg van de beperkte beschikbaarheid van informatie over de probleemsituatie en gebrek aan contextspecifieke kennis. Desalniettemin zijn dit problemen die gevolgen hebben op het dagelijks leven in omgevingen die worden gekenmerkt door lage inkomens.

Hoewel bij complexe problemen sprake kan zijn van een hoge mate van technische complexiteit, verwijst de term *'complexe maatschappelijke problemen'* in dit proefschrift naar complexe problemen waarbij technische complexiteit is verweven met maatschappelijke complexiteit en waar relaties tussen mensen en instellingen van centraal belang zijn voor de oplossing. Daarnaast verwijst het hier gehanteerde concept van complexiteit naar een gebrek aan kennis over de kenmerken van het bestaande systeem, gebrek aan inzicht in de onderhavige probleemsituatie en een gebrek aan, of onzekerheid van, de expertise die nodig is om het probleem aan te pakken. Dit onderzoek wijst erop dat de integratie van systeemdenken en ontwerpen een veelbelovende benadering is voor het aanpakken van de toenemende complexiteit van maatschappelijke problemen. De centrale onderzoeksvraag is erop gericht om inzicht te verkrijgen in een systeemgeoriënteerde benadering van ontwerpen (hier ook wel de 'systeemontwerpbenadering' genoemd). Ik focus me met name op systeembenaderingen en -methodologie voor de ontwikkeling van product-servicesystemen voor complexe maatschappelijke problemen zoals we die tegenkomen in energiemarkten met lage inkomens.

Een product-servicesysteem (PSS) bestaat uit een systeem van of producten, services, ondersteunende netwerken en infrastructuren waarbij meerdere stakeholders die functionaliteit, nut en tevredenheid bieden, nauw betrokken zijn (Mont, 2002a). Voor veel auteurs is het toepassen van systeemdenken op PSS'en van fundamenteel belang voor een correcte conceptualisering en diepgaand inzicht in bestaande systemen (Afshar & Wang, 2010; Cavalieri & Pezzotta, 2012). Daarom levert dit proefschrift een bijdrage aan het onderzoek naar PSS'en en systeemontwerp door invulling te geven aan de behoefte aan uitbreiding van de scope van PSS'en, van een focus op afzonderlijk te beschouwen systemen van product-servicecombinaties naar een integraal PSS dat geschikt is voor complexe maatschappelijke problemen.

Daarom is onderzoek gedaan naar de theorie en praktijk van systemen om inzicht te krijgen in de implicaties van systeemdenken voor ontwerp, en worden er aanbevelingen gedaan voor de toepassing hiervan in ontwerpbenaderingen, waaronder PSS-ontwerp. Bij het onderzoek is uitgegaan van de hypothese dat het verschil tussen traditionele ontwerpbenaderingen en benaderingen op basis van systeemontwerp is geworteld in de onderliggende aannames met betrekking tot de grenzen en scope van ontwerp. Met andere woorden: bij de laatstgenoemde benadering wordt gestreefd naar een holistisch, meerlagig, pluralistisch perspectief, waarbij de complexiteit van het onderhavige systeem wordt omarmd. Op basis van de probleemdefinitie zijn de volgende centrale onderzoeksvraag en subvragen geformuleerd:

HOOFDONDERZOEKSVRAAG:

HOV. *Op welke manier kan systeemdenken een bijdrage leveren aan de omgang met de complexiteit van duurzame product-servicesysteemontwerpen voor energiemarkten met lage inkomens?*

ONDERZOEKSSTRATEGIE		SUBONDERZOEKSVRAGEN
THEORETISCHE FASE (Hoofdstuk 2)		**OV1.** Wat zijn de kenmerken van complexe maatschappelijke problemen in energiemarkten met lage inkomens? **OV2.** Hoe heeft het systeemdenken zich ontwikkeld als benadering van complexe maatschappelijke problemen? **OV3.** In welke mate sluit systeemdenken aan op het ontwerpen van oplossingen voor complexe maatschappelijke problemen?
EMPIRISCHE FASE	**Observaties van de ontwerppraktijk** (Hoofdstuk 3)	**OV4.** Wat vertelt de toepassing van systeemdenken als meerlagig perspectief ons over het verbeteren van energieoplossingen voor energiezuinigheidsprogramma's gericht op lage inkomens?
	Interventies in het ontwerponderwijs (Hoofdstukken 4-5)	**OV5.** Op welke manier kan systeemdenken designstudenten steunen bij de ontwikkeling van concepten voor meer duurzame product-servicesystemen (PSS'en) voor markten met lage inkomens? **OV6.** Hoe kan het vermogen van designstudenten om in te spelen op de complexiteit van maatschappelijke problemen, zoals die in veel markten met lage inkomens worden aangetroffen, worden vergroot?

Binnen de hierboven beschreven onderzoeksopzet bestaat het proefschrift uit vier primaire onderzoeken (Hoofdstukken 2-5), die als peerreviewed tijdschriftartikelen zijn gepubliceerd of ingediend. In elke publicatie komen een of meer subvragen aan de orde die het antwoord op de hoofdonderzoeksvraag ondersteunen. Hierbij moet worden opgemerkt dat de volgorde van de hoofdstukken niet de chronologische publicatievolgorde van de artikelen volgt. Daardoor is de kenniscreatie niet lineair verlopen (zodat een hoofdstuk bijvoorbeeld niet helemaal voortbouwt op de kennis afkomstig uit het voorgaande onderzoek). Toch leveren de bevindingen uit elk onderzoek gezamenlijk een bijdrage aan de drie belangrijkste ontwerpaspecten: theorie (Hoofdstuk 2), praktijk (Hoofdstuk 3) en onderwijs (Hoofdstukken 4-5).

Theoretische fase

Vooronderzoek

Van het vooronderzoek voor dit onderzoek wordt verslag gedaan in Hoofdstuk 1. In het eerste hoofdstuk wordt de grondgedachte achter het onderzoek geïntroduceerd. Er wordt een aantal beperkingen benoemd van het gebruik van traditionele ontwerpbenaderingen voor het verkrijgen van inzicht in complexe maatschappelijke problemen in energiemarkten met lage inkomens. Bovendien wordt er betoogd dat er een meer holistische benadering kan worden gevolgd, ter compensatie van de reductionistische aard van traditionele wetenschappelijke methodes die voor ontwerp worden gehanteerd. Daarnaast wordt opgemerkt dat ontwerpbenaderingen die rekening houden met het vermogen van ontwerp om plaats te bieden aan complexiteit, radicale technologische en sociaal-culturele veranderingen kunnen opstarten. Verder ligt de nadruk op energieoplossingen waarbij producten, services en infrastructuur worden geïntegreerd om tevredenheid te realiseren door middel van betere systeemfunctionaliteit en nut.

Ook wordt in Hoofdstuk 1 aangegeven dat duurzame product-servicesystemen gelegenheid bieden om in de vraag naar energie in markten met lage inkomens te voorzien door middel van oplossingen die verenigbaar zijn met duurzame ontwikkeling. Er wordt aangetoond waarom de ontwikkeling van duurzame product-servicesystemen voor energiemarkten met lage inkomens essentieel zijn voor opkomende en in ontwikkeling zijnde economieën waarin wordt gestreefd naar de vereniging van sociaal-economische ontwikkeling en milieubescherming. Het voorbereidende literatuuronderzoek levert bewijs dat een product-servicesysteem (PSS) een veelbelovend concept is voor het stimuleren van duurzame opwekking, distributie en consumptie van energie.

De bevindingen in Hoofdstuk 1 impliceren dat een PSS weliswaar veelbelovend is, maar vaak zal falen in markten met lage inkomens, als gevolg van de specifieke maatschappelijke complexiteit die bestaat in contexten met lage inkomens. Met betrekking daartoe laat het hoofdstuk zien hoe systeemdenken een bijdrage kan leveren aan product-servicesystemen voor energiemarkten met lage inkomens. In het hoofdstuk wordt geconcludeerd dat voor de ontwikkeling van meer duurzame energieoplossingen in markten met lage inkomens probleemoplossers meer vermogen voor de omgang met complexiteit moeten ontwikkelen op basis van vier belangrijke principes uit het systeemdenken: een holistisch perspectief, een meerlagig perspectief, een pluralistisch perspectief (diversiteit aan visies) en het vermogen om met complexiteit om te gaan.

Theoretisch onderzoek
Het voorbereidende onderzoek in Hoofdstuk 1 wijst erop dat systeemdenken een bijdrage kan leveren aan energieoplossingen voor markten met lage inkomens. In Hoofdstuk 2 wordt verder ingegaan op de toepassing van systeemdenken bij ontwerpen, om de aandacht te vestigen op een aantal implicaties van het gebruik van een benadering op basis van systeemdenken voor het oplossen van complexe maatschappelijke problemen. In Hoofdstuk 2 wordt op basis van systeemdenken het fundament gelegd voor het onderzoek; dit is ontwikkeld met gebruikmaking van kennis uit alle hoofdstukken. Het voornaamste doel van dit hoofdstuk is om het inzicht te vergroten in de implicaties van systeembenaderingen en -methodologieën en de toepassing van de principes van systeemdenken bij ontwerpen te verkennen.

In dit hoofdstuk wordt aangetoond dat de onderliggende aannames en principes van systeemdenken een waardevolle correctie vormen voor het reductionisme waarmee de toepassing van een traditionele wetenschappelijke methode voor het oplossen van complexe maatschappelijke problemen gepaard gaat. In een uitgebreid literatuuroverzicht worden de contouren geschetst van significante aspecten van de grondslag van het systeemdenken, er worden passende systeembenaderingen en -methodologieën geïdentificeerd, en de bijdrage die deze kunnen leveren aan de oplossing van complexe maatschappelijke problemen op het gebied van ontwerp, wordt verhelderd. In eerder onderzoek zijn pogingen tot verkenning van het systeemdenken gedaan om tot aanbevelingen te komen met betrekking tot de toepassing van systeemmethodologieën en tools bij ontwerpen. Er is echter maar weinig aandacht besteed aan de manier waarop ontwerpers systeemmethodologieën en tool hebben geïnterpreteerd en toegepast bij het oplossen van complexe maatschappelijke problemen.

In Hoofdstuk 2 wordt het proces onderzocht waarmee systeemdenken in ontwerpen wordt geïntegreerd en wordt een overzicht gegeven van het opkomende vakgebied van systeemontwerpbenaderingen van complexe maatschappelijke problemen. Er wordt een overzicht gegeven van de stand der techniek aan de hand van een beschrijving van de manieren waarop een selectie van bestaande systeemontwerpbenaderingen significante bijdragen hebben geleverd aan de transitie van traditionele ontwerpbenadering naar een systeemgeoriënteerd perspectief op ontwerpen. Op basis van deze theoretische inzichten worden in het hoofdstuk gelegenheden benadrukt om de systeemontwerpbenadering verder te ontwikkelen op basis van een systematische en onderbouwde verkenning van het systeemdenken. Dit onderzoek levert een conceptueel kader op, inclusief criteria voor de integratie van systeemdenken in ontwerpen. De voornaamste bijdrage die dit onderzoek levert is dan ook een kader dat de ontwikkeling van nieuwe systeemontwerpbenaderingen mogelijk maakt en bestaande systeemontwerpbenaderingen versterkt, door ontwerpers te steunen bij het optimaal realiseren van de voor hen relevante middelen die systeemdenken biedt.

Empirische fase

Observaties van de ontwerppraktijk

In Hoofdstuk 3 wordt onderzoek gedaan naar de toepassing van systeemdenken als meerlagig perspectief voor het verkrijgen van meer inzicht in de beperkingen die worden opgelegd door de complexiteit van energie-uitdagingen in energiezuinigheidsprogramma's voor lage inkomens in Brazilië. Voor dit empirische onderzoek is gekozen voor Brazilië omdat dit land veel relevante energie-uitdadingen kent die urgent om aandacht vragen. Doorbouwend op een ontwerptheorie op basis van systeemdenken worden drie aggregatieniveaus van de Braziliaanse energiemarkt met lage inkomens geanalyseerd om inzichten te verkrijgen die waardevol zijn voor het ontwerp van duurzame energieoplossingen. In dit hoofdstuk worden bevindingen uit de literatuur, beschrijvende casussen en interviews met praktijkmensen en experts onderzocht.

Uit eerder onderzoek is gebleken dat verbeteringen op technologisch niveau weliswaar van fundamenteel belang zijn, maar slechts een beperkte rol spelen bij het creëren van duurzame energietransities. Daarom is het voor de oplossing van energie-uitdagingen in markten met lage inkomens noodzakelijk om verder te kijken dan alleen technologische verbeteringen en een breder maatschappelijk perspectief te kiezen waarbij rekening wordt gehouden met organisatorische en maatschappelijke transformaties, die een hoge mate van maatschappelijke complexiteit impliceren. In dit onderzoek wordt een bijdrage geleverd aan kennisvergaring met betrekking tot de complexiteit van energiemarkten met lage inkomens en bewustwording rondom de implicaties van een meerlagige analyse voor energieoplossingen. Daarnaast wordt aangetoond dat dergelijke kennis van waarde is voor het herontwerpen van energieprogramma's voor lage inkomens.

Uit de bevindingen blijkt dat het hanteren van een meerlagig perspectief binnen energiezuinigheidsprogramma's voor lage inkomens beleidsmakers en probleemoplossers in staat stelt om relevante beperkingen en kansen op verschillende systeemniveaus te identificeren. Meer specifiek maakt een meerlagige analyse essentiële aspecten zichtbaar die de realisatie van hogere duurzaamheidsniveaus door middel van energieoplossingen binnen energieprogramma's voor lage inkomens belemmeren. Daarnaast worden er inzichten gepresenteerd die kunnen worden gebruikt in aanbevelingen om de huidige situatie te verbeteren. Inzicht in, en het overwinnen van, maatschappelijke en technische uitdagingen die energieoplossingen in de weg staan is van cruciaal belang voor het vergroten van het vermogen van energieprogramma's om grotere sociaal-economische en milieutechnische voordelen te realiseren in gemeenschappen met lage inkomens.

De bevindingen wijzen erop dat ontwerpers met substantieel meer complexiteit moeten omgaan voor een systeemontwerpbenadering dan bij andere, traditionele benaderingen. Daarom moeten zij worden voorzien van een nieuwe set systeemgeoriënteerde kennis, vaardigheden en tools die geschikt zijn om deze nieuwe realiteit het hoofd te bieden. Als bijdrage aan deze significante uitdaging voor het ontwerponderwijs wordt in de laatste twee hoofdstukken van dit proefschrift ingegaan op, en een bijdrage geleverd aan, de ondersteuning van de ontwikkeling van vermogen met betrekking tot systeemontwerpbenaderingen.

Interventies in het ontwerponderwijs

Aangezien ontwerpers meestal wordt geleerd om traditionele ontwerpbenaderingen te hanteren, spelen instellingen voor hoger onderwijs een essentiële rol bij verandering. Daarom wordt bij de in Hoofdstuk 4 en 5 beschreven interventies de toepassing onderzocht van een systeemontwerpbenadering bij het ontwerpen van concepten voor product-servicesystemen door studenten. Dankzij die interventies konden de onderzoekshypothese en het theoretische model uit Hoofdstuk 3 worden getoetst. Daarnaast boden zij een eerste verkenning van het conceptuele kader beschreven in Hoofdstuk 2.

De interventie uit Hoofdstuk 4 maakte de verkenning mogelijk van de toepassing van een systeemontwerpbenadering bij het creëren van concepten voor product-servicesystemen, waarbij de voor- en nadelen van dit proces werden geïdentificeerd. In Hoofdstuk 5 testten studenten ontwerpen die bekend waren met energiemarkten met lage inkomens, een benadering op basis van systeemontwerp bij het oplossen van energie-uitdagingen waarmee gemeenschappen met lage inkomens in Oeganda worden geconfronteerd. Deze afsluitende interventie bouwde voort op het voorgaande hoofdstuk en was bedoeld om meer inzicht te krijgen in het proces van het leren van een systeemontwerpbenadering en middelen om dat leren tijdens het ontwerpen te ondersteunen.

In Hoofdstuk 4 wordt verslag gedaan van een masteropleiding 'Product-servicesysteem', waarbij systeemdenken wordt toegepast bij de ontwikkeling van concepten voor duurzame product-servicesystemen voor complexe maatschappelijke problemen. In dit hoofdstuk worden instellingen voor hoger onderwijs beschouwd als bases voor kennisoverdracht tussen meerdere stakeholders bij het voorzien in de behoefte aan betaalbare energie van huishoudens met lage inkomens en het verlenen van humanitaire hulp. In dit onderzoek maakten multidisciplinaire studententeams van de Technische Universiteit Delft (Nederland) gebruik van kennis en vaardigheden gebaseerd op systeemgeoriënteerd ontwerpen en PSS voor de ontwikkeling van twaalf PSS-concepten. Het onderzoek is uitgevoerd in samenwerking met de Federale Universiteit van Paraná (en partners) in Brazilië en de innovatie-unit van Artsen zonder Grenzen in Zweden. Daarom is de scope van het onderzoek uitgebreid met de context van humanitaire hulpverlening.

De in dit hoofdstuk gebruikte empirische gegevens zijn afkomstig van een set PSS-concepten gericht op contexten gekenmerkt door lage inkomens, die door studententeams binnen een multidisciplinaire opleiding zijn gerealiseerd. Op basis van de door de studenten uitgevoerde ontwerpactiviteiten en de resultaten van de projecten worden de voordelen en context- en procesgerelateerde uitdagingen van de toepassing van systeemdenken gepresenteerd en besproken. Uit de bevindingen blijkt dat een benadering op basis van systeemdenken studenten voorziet van de kennis en vaardigheden die zij nodig hebben om complexe maatschappelijke problemen het hoofd te bieden. Het blijft echter noodzakelijk om de juiste systeemhulpbronnen (bijv. systeemmethodologieën, tools en vaardigheden) op te nemen in het huidige curriculum voor ontwerpen, waardoor de transitie weg van een traditionele ontwerpbenadering lastig blijft. De bevindingen wijzen erop dat systeemgeoriënteerde competenties in studenten ontwerpen verder moeten worden ontwikkeld.

Hoofdstuk 5 bevat een beschrijving van een masteropleiding genaamd 'Systeemontwerp voor duurzame energie voor iedereen'. De bedoeling van deze opleiding is om onderwijsmiddelen op basis van systeemdenken te ontwikkelen en te testen en de ontwikkeling te bevorderen van het vermogen om een systeemontwerpbenadering toe te passen. Oegandese designstudenten van het College of Engineering Design Art and Technology van de Makerere University, die bekend zijn met de lokale context, hanteerden een systeemontwerpbenadering om oplossingen te vinden voor de energie-uitdagingen waarmee gemeenschappen met lage inkomens in Oeganda worden geconfronteerd. In dit hoofdstuk worden kerncompetenties gesuggereerd voor het vaardig ontwerpen van concepten voor product-servicesystemen die zijn gericht op energiemarkten met lage inkomens en wordt het proces van de toepassing van dergelijke competenties gedemonstreerd. Het voorgaande hoofdstuk leverde achtergrondinformatie op die bruikbaar is voor de ontwikkeling van de bouwstenen van een nieuwe set kennis, vaardigheden en tools voor het aanpakken van complexe maatschappelijke problemen. In hoofdstuk 5 wordt de scope van het onderzoek vernauwd, zodat de focus komt te liggen op het ontwikkelen van het vermogen om systeemdenken toe te passen bij de ontwikkeling van PSS'en voor duurzame energie.

Daarnaast worden voor opleiders belangrijke cognitieve aspecten gepresenteerd van het ontwikkelen van het vermogen om een systeemontwerpbenadering toe te passen. Daarnaast wordt in dit hoofdstuk het proces gedemonstreerd waarmee systeemdenken wordt ingebed in het opleidingsprogramma, om studenten te steunen bij de ontwikkeling van duurzame oplossingen voor energiemarkten met lage inkomens in Oeganda. De bevindingen ondersteunen de conclusie dat ontwerpbenaderingen op basis van systeemdenken een bijdrage kunnen leveren aan de omgang met de groeiende complexiteit van de maatschappelijke problemen waarvoor de ontwerpprofessionals van de toekomst geacht zullen worden een oplossing te kunnen bieden. Daarom bestaat een belangrijke bijdrage van dit onderzoek aan het ontwerponderwijs uit een aantal suggesties voor kerncompetenties waarmee het vermogen wordt ontwikkeld om bij ontwerpen om te kunnen gaan met complexiteit.

Reflectiefase

Voornaamste bevindingen, bijdragen en aanbevelingen

In Hoofdstuk 6 wordt een algemeen overzicht gegeven van de voornaamste bevindingen uit dit proefschrift. Er worden bijdragen aan ontwerptheorie, -onderwijs en -praktijk gepresenteerd. De vier voornaamste bijdragen van dit onderzoek zijn:

- Een verkenning van de integratie van systeemdenken in ontwerpen, met name door het hanteren van een systeemontwerpbenadering voor duurzame energieoplossingen voor markten met lage inkomens.
- Een uitbreiding van de scope van het ontwerp van product-servicesystemen door de introductie van vier belangrijke principes van het systeemdenken: een holistisch perspectief, een meerlagig perspectief, een pluralistisch perspectief en het vermogen om met complexiteit om te gaan.
- Suggesties voor heuristische tools voor de integratie van systeemdenken in ontwerpen, waarmee het mogelijk wordt om nieuwe systeempontwerpbenaderingen te ontwikkelen en bestaande te versterken.
- Het door middel van ontwerponderwijs ontwikkelen van meer vermogen om een systeemontwerpbenadering toe te passen bij het oplossen van complexe maatschappelijke problemen.

In dit hoofdstuk wordt betoogd dat voor het ontwerpen van duurzame energieoplossingen voor markten met lange inkomens effectieve interventies nodig zijn die aansluiten op een hoge mate van maatschappelijke complexiteit. Daarvoor is het noodzakelijk om naast de traditionele reductionistische benadering ook gebruik te maken van een benadering op basis van systeemontwerp. Dat vraagt om het omarmen van de complexiteit binnen maatschappelijke problemen, systemen of contexten naast nieuwe denkwijzen en vaardigheden voor de omgang met die complexiteit.

Trefwoorden: Ontwerpen voor duurzaamheid, complex maatschappelijk probleem, systeemdenken, systeemontwerpbenadering, systeemgeoriënteerd ontwerpen, product-servicesysteem, markt met lage inkomens, energieoplossing.

“ Abraçar a complexidade representa uma mudança significativa de uma abordagem tradicional do design para uma abordagem do design sistêmico. ”

Resumo

Os problemas enfrentados em mercados de baixa renda são cada vez mais percebidos como complexos devido às preocupações ambientais, sociais e econômicas envolvidas. Os enormes impactos negativos e a incapacidade dos designers de lidar com a complexidade desses problemas não podem ser superados sem uma mudança de paradigma na maneira como entendemos, abordamos e ensinamos sobre essas questões. No processo de enfrentar esse desafio, podemos nos fazer a seguinte pergunta: *“Qual é a melhor abordagem para lidar com um problema social complexo?”* Tradicionalmente, uma abordagem para lidar com um problema complexo é simplificá-lo. Em contrapartida, a presente tese visa oferecer uma nova abordagem para lidar com problemas sociais complexos: abraçar a complexidade. Esta pesquisa defende que abraçar a complexidade representa uma mudança significativa de uma abordagem tradicional do design para uma abordagem do design sistêmico em direção ao desenvolvimento sustentável.

Esta tese se concentra em teorias e práticas que são centrais e relevantes para o debate sobre sustentabilidade e pensamento sistêmico no design. O objetivo é avançar o entendimento dos designers sobre questões de sustentabilidade em mercados de baixa renda, como por exemplo desafios de energia sustentável em economias emergentes, para contribuir, por meio do design, para resolver problemas sociais complexos. Por esse motivo, esta investigação se concentra no setor elétrico de mercados de baixa renda, que são particularmente notáveis em economias emergentes da América Latina e África. De um modo geral, consumidores no setor elétrico de mercados de baixa renda não têm acesso a fontes de energia economicamente acessíveis, confiáveis, limpas e modernas, o que resulta, entre outras questões, em poluição, problemas de saúde e altos custos de eletricidade.

Buscar soluções para o setor elétrico de mercados de baixa renda representa uma oportunidade favorável de satisfazer a demanda por energia elétrica em economias emergentes de forma alinhada às metas do desenvolvimento sustentável. No entanto, designers têm, muitas vezes, dificuldade em auxiliar comunidades de baixa renda a melhorar seus padrões de vida, por meio de soluções sustentáveis de energia. Existe consenso de que, sem acesso a produtos e serviços de energia sustentável, não é possível criar sistemas de energia sustentáveis, e consequentemente, não se pode alcançar o desenvolvimento sustentável. Por outro lado, problemas sociais complexos enfrentados no setor elétrico de mercados de baixa renda estão longe de serem óbvios, de forma que as soluções atuais para esses problemas estão longe de serem ideais. Esses problemas geralmente são muito difíceis de solucionar

devido a informações limitadas sobre a situação em questão e falta de conhecimento específico do contexto local. No entanto, são demandas que afetam a vida cotidiana da população de baixa renda e que, portanto, merecem atenção urgente.

Embora problemas complexos envolvam altos níveis de complexidade técnica, o termo *problemas sociais complexos* adotado nesta tese refere-se a problemas complexos em que a complexidade técnica está entrelaçada com a complexidade social e as relações entre humanos e instituições são centrais para a solução do problema. Além disso, o conceito de complexidade adotado nesse trabalho também se refere à falta de conhecimento das características do sistema em vigor, à falta de compreensão do problema em questão e à falta ou incerteza do conhecimento necessária para lidar com o problema. Esta investigação sugere que a integração do pensamento sistêmico e o campo do design é uma abordagem promissora para enfrentar a crescente complexidade dos problemas sociais. A pergunta de pesquisa central propõe obter *insights* sobre abordagens orientadas ao design de sistemas (também denominadas nesta tese como Design Sistêmico). Em particular, esse trabalho concentra-se em abordagens e metodologias de sistemas para desenvolver sistemas produto-serviço para problemas sociais complexos, como os encontrados no setor elétrico de mercados de baixa renda em países como Brasil e Uganda.

Sistema Produto-Serviço (PSS) consiste em um sistema de produtos, serviços, cadeia produtiva e infraestrutura que envolve diversos atores para oferecer funcionalidade, utilidade e satisfação (Mont, 2002a). Para muitos autores, a adoção do pensamento sistêmico no PSS é fundamental para uma conceituação adequada e o entendimento profundo do sistema em vigor (Afshar & Wang, 2010; Cavalieri & Pezzotta, 2012). Portanto, essa tese contribui para a pesquisa em PSS e Design Sistêmico porque aborda a necessidade de expandir o escopo do PSS, remodelando o foco em combinações de produtos e serviços em direção a um PSS mais completo, capaz de lidar com problemas sociais complexos.

Com o fim de atingir esse objetivo, a presente pesquisa investiga a teoria e a prática de sistemas para entender as implicações do pensamento sistêmico no design e oferece recomendações para a sua adoção em abordagens do design, como o PSS. Esta investigação baseia-se na hipótese de que a diferença entre as abordagens tradicionais do design e as abordagens do design sistêmico está em suas suposições em relação aos limites e escopo do design. Em outras palavras, o design sistêmico procura alcançar uma perspectiva holística, multinível e pluralista que abraça a complexidade do sistema em vigor. Com base na definição do problema, a pergunta central e perguntas secundárias da pesquisa são propostas da seguinte forma:

PERGUNTA CENTRAL DE PESQUISA:

PC. *Como o pensamento sistêmico pode contribuir para lidar com a complexidade do design sustentável de sistemas produto-serviço para mercados de baixa renda de energia?*

ESTRATÉGIA DE PESQUISA		PERGUNTAS SECUNDÁRIAS
FASE TEÓRICA (Capítulo 2)		**PS1.** O que caracteriza problemas sociais complexos no setor energético de mercados de baixa renda? **PS2.** Como o pensamento sistêmico foi desenvolvido como uma maneira de lidar com problemas sociais complexos? **PS3.** Até que ponto o pensamento sistêmico oferece a melhor abordagem para o design de soluções voltadas para problemas sociais complexos?
FASE EMPÍRICA	**Observações de Práticas Existentes** (Capítulo 3)	**PS4.** O que a adoção do pensamento sistêmico como um perspectiva multinível pode oferecer para melhorar soluções energéticas em programas de eficiência energética para baixa renda?
FASE EMPÍRICA	**Intervenções na Educação em Design** (Capítulos 4-5)	**PS5.** Como o pensamento sistêmico pode ajudar estudantes de design no desenvolvimento de conceitos de sistema produto-serviço (PSS) mais sustentáveis para mercados de baixa renda? **PS6.** Como desenvolver a capacidade nos estudantes de design de responder à complexidade dos problemas sociais, como aqueles encontrados em mercados de baixa renda?

Seguindo a estrutura de pesquisa descrita acima, essa tese é composta por quatro estudos principais (Capítulo 2-5) publicados ou submetidos como artigos de periódicos revisados por pares. Cada publicação aborda uma ou mais perguntas de pesquisa que ajudam a responder à pergunta central de pesquisa. Cabe ressaltar que os capítulos não refletem a publicação cronológica dos artigos. Consequentemente, a criação do conhecimento não é linear (por exemplo, um capítulo pode não se basear inteiramente no conhecimento gerado no estudo anterior). No entanto, os resultados de cada estudo se reúnem para fornecer contribuições para três áreas principais no campo de design: teoria (Capítulo 2), prática (Capítulo 3) e educação (Capítulo 4-5).

Fase Teórica

Pesquisa Preliminar

A pesquisa preliminar desta investigação é relatada no Capítulo 1. O primeiro capítulo introduz a justificativa e a motivação para a presente investigação. Ele reconhece algumas das limitações do uso de abordagens do design mais tradicionais para entender problemas sociais complexos no setor elétrico de mercados de baixa renda. Além disso, argumenta que uma abordagem mais holística pode ser adotada para complementar a natureza reducionista dos métodos científicos tradicionais adotados no design. Além disso, ressalta que o potencial de desencadear mudanças radicais em termos tecnológicos e socioculturais reside em abordagens do design que consideram a capacidade do design de lidar com a complexidade. Em seguida, o capítulo concentra-se em soluções energéticas que integram produtos, serviços e infraestrutura para oferecer satisfação por meio de melhor funcionalidade e utilidade para o sistema.

Além disso, o Capítulo 1 indica que os sistemas produto-serviço (PSS) sustentáveis oferecem uma oportunidade para satisfazer a demanda de energia nos mercados de baixa renda com soluções compatíveis com o desenvolvimento sustentável. Isso demonstra por que o desenvolvimento de sistemas produto-serviço sustentáveis para o setor elétrico de mercados de baixa renda é imprescindível para economias emergentes e em desenvolvimento que visam conciliar desenvolvimento socioeconômico com proteção ambiental. A revisão preliminar da literatura fornece evidências de que o PSS é um conceito promissor para estimular a geração, distribuição e consumo sustentáveis de energia.

Os resultados apresentados no Capítulo 1 sugerem que, embora promissor, o PSS geralmente fracassa em mercados de baixa renda devido à particularidade da complexidade social existente nesses contextos. Nesse contexto, o capítulo demonstra como o pensamento sistêmico pode contribuir para o desenvolvimento de sistemas produto-serviço mais sustáveis no setor elétrico de mercados de baixa renda. O capítulo conclui que, para desenvolver soluções energéticas mais sustentáveis em mercados de baixa renda, designers precisam aumentar a capacidade de lidar com problemas sociais complexos por meio da adoção de quatro princípios fundamentais do pensamento sistêmico: perspectiva holística; perspectiva multinível; perspectiva pluralista (diversidade de pontos de vista); e capacidade de lidar com altos níveis de complexidade.

Pesquisa Teórica

A pesquisa preliminar apresentada no Capítulo 1 sugere que o pensamento sistêmico pode auxiliar a desenvolver melhores soluções sustentáveis para o setor elétrico de mercados de baixa renda. No Capítulo 2, a adoção do pensamento sistêmico no design é explorada para destacar algumas implicações do uso do design sistêmico para solucionar problemas sociais complexos. O Capítulo 2 visa fornecer uma fundamentação teórica do pensamento sistêmico para a investigação e foi desenvolvido com base no conhecimento construído em todos os capítulos da tese. O objetivo principal do capítulo é promover o entendimento das implicações das abordagens e metodologias de sistemas e explorar a adoção de princípios do pensamento sistêmico no campo do design.

O capítulo demonstra que os princípios do pensamento sistêmico fornecem um valioso corretivo ao reducionismo advindo do emprego do método científico tradicional para lidar com problemas sociais complexos. Uma extensa revisão da literatura descreve aspectos significativos do pensamento sistêmico. Adicionalmente, abordagens e metodologias de sistemas apropriadas para a aplicação no campo de design são identificadas e suas contribuições para o desenvolvimento de soluções para problemas sociais complexos são propostas e debatidas. Estudos anteriores tentaram explorar o campo do pensamento sistêmico para oferecer recomendações de como aplicar metodologias e ferramentas de sistemas no design. No entanto, pouca atenção foi dada à forma como designers interpretaram e empregaram essas metodologias e ferramentas sistêmicas para lidar com problemas sociais complexos.

O Capítulo 2 investiga o processo de integração do pensamento sistêmico no design e fornece uma visão geral do emergente campo de estudo da abordagem do design sistêmico para problemas sociais complexos. O capítulo resume o estado da arte atual, descrevendo como abordagens do design sistêmico existentes vêm fornecendo contribuições significativas para a transição de uma abordagem tradicional do design para uma perspectiva orientada ao design de sistemas. Com base nesses *insights* teóricos, o capítulo enfatiza a oportunidade de desenvolver ainda mais as abordagens do design sistêmico existentes por meio da exploração sistemática e informada do pensamento sistêmico. O estudo resulta em uma estrutura conceitual que oferece critérios para a integração do pensamento sistêmico no design. Consequentemente, a principal contribuição do estudo é fornecer uma estrutura que permita o desenvolvimento de novas abordagens e o fortalecimento de abordagens do design sistêmico já existentes, auxiliando designers a utilizarem de forma plena os recursos do pensamento sistêmico.

Fase Empírica

Observações de Práticas Existentes

O Capítulo 3 investiga a adoção do pensamento sistêmico como uma perspectiva multinível que auxilia a compreensão das restrições impostas pela complexidade dos desafios energéticos em programas de eficiência energética para baixa renda no Brasil. O Brasil foi selecionado para este estudo empírico porque apresenta muitos desafios energéticos relevantes para o desenvolvimento sustentável que requerem atenção urgente. Com base em teorias do design com fundamentação no pensamento sistêmico, são analisados três níveis de agregação do setor energético brasileiro para o segmento de baixa renda com o objetive de obter *insights* para desenhar soluções energéticas sustentáveis. O capítulo é conduzido por meio de uma extensa revisão de literatura, estudos de caso descritivos e entrevistas com profissionais e especialistas.

Estudos anteriores mostraram que, embora fundamentais, melhorias à nível tecnológico são limitadas para criar transições para sistemas de energia sustentável. Por esse motivo, para enfrentar os desafios energéticos nos mercados de baixa renda, é necessário mudar o foco de atenção apenas de melhorias tecnológicas para uma perspectiva social mais ampla que leve em consideração transformações organizacionais e socioculturais, o que implica em altos níveis de complexidade social. Este estudo contribui para a evidenciação do conhecimento sobre a complexidade do setor elétrico de mercados de baixa renda e para o entendimento das implicações de uma análise multinível para o desenvolvimento de soluções energéticas mais sustentáveis. Além disso, demonstra que esse conhecimento é valioso para o redesign de programas de energia para baixa renda e para informar o desenvolvimento de novas políticas de energia e revisar políticas existentes.

Os resultados mostram que a adoção de uma perspectiva multinível em programas de eficiência energética para baixa renda permite que formuladores de políticas e solucionadores de problemas identifiquem restrições e oportunidades relevantes em todos os níveis do sistema. Mais especificamente, por meio de uma análise multinível do sistema em vigor, o capítulo revela os principais aspectos que impedem que as soluções desenvolvidas em programas de eficiência energia para baixa renda alcancem níveis mais altos de sustentabilidade. Além disso, produz *insights* para recomendações que possam melhorar a situação atual nesses contextos de baixa renda. O capítulo demonstra que compreender e superar os desafios técnicos e sociais presentes em soluções energéticas é crucial para aumentar a capacidade dos programas de eficiência energética de alcançar níveis mais altos de benefícios socioeconômicos e diminuir os impactos ambientais negativos em comunidades de baixa renda.

Os resultados sugerem que a abordagem do design sistêmico exige que os designers lidem com um grau de complexidade mais substancial em comparação com outras abordagens do design mais tradicionais. Consequentemente, eles devem estar preparados para lidar com um novo conjunto de conhecimentos, habilidades e ferramentas orientados a sistemas apropriados para lidar com essa nova realidade. Para enfrentar esse tema, que é um desafio significativo para o ensino do design, os dois últimos capítulos da tese são dedicados a trazer contribuições que apoiem o desenvolvimento da capacitação para a abordagem do design sistêmico.

Intervenções na Educação em Design
Como designers são geralmente educados para aplicar abordagens tradicionais do design, as instituições de ensino superior se tornam um agente essencial para a difusão do design sistêmico. Portanto, as intervenções realizadas nos Capítulos 4 e 5 exploram a aplicação da abordagem do design sistêmico por alunos de pós-graduação para projetar conceitos de sistemas produto-serviço sustentáveis. As intervenções permitiram testar a hipótese de pesquisa e o modelo teórico apresentado no Capítulo 3. Além disso, proporcionaram uma exploração inicial da estrutura conceitual descrita no Capítulo 2.

A intervenção no Capítulo 4 forneceu um exercício exploratório, no qual uma abordagem do design sistêmico foi aplicada por alunos da Universidade de Tecnologia de Delft (Holanda) para desenvolver conceitos de sistema produto-serviço para identificar vantagens e desvantagens nesse processo. No Capítulo 5, estudantes de design familiarizados com o setor elétrico de mercados de baixa renda testam uma abordagem do design sistêmico para responder aos desafios energéticos enfrentados pelas comunidades de baixa renda em Uganda. Esse estudo baseia-se no Capítulo 4 e busca entender melhor o processo de aprendizagem do design sistêmico e os meios para auxiliar essa aprendizagem no campo do design.

O Capítulo 4 relata uma disciplina de mestrado chamada Sistema Produto-Serviço que aplica o pensamento sistêmico no desenvolvimento de conceitos sistema produto-serviço sustentáveis para problemas sociais complexos. O capítulo explora as instituições de ensino superior como base para a transferência de conhecimento entre vários atores durante o processo de desenvolvimento de soluções focadas na necessidade de gerar energia acessível para famílias de baixa renda e implementar ajuda humanitária em situações de emergência. Neste estudo, equipes multidisciplinares de estudantes da Universidade de Tecnologia de Delft usam conhecimentos e habilidades com base em uma abordagem do design sistêmico chamada *System Oriented Design* para desenvolver doze conceitos de PSS. O estudo foi realizado em colaboração com a Universidade Federal do Paraná (e parceiros) no Brasil e a Unidade de Inovação da Organização não Governamental Médicos Sem Fronteiras, na Suécia. Por esse motivo, o escopo do estudo foi estendido para abordar o contexto da ajuda humanitária.

Os dados empíricos usados no Capítulo 4 emergem de um conjunto de conceitos de PSS desenvolvidos para mercados de baixa renda, conduzidos por equipes de estudantes em um curso multidisciplinar. Com base nas atividades de design realizadas pelos alunos e no resultado dos projetos, o capítulo apresenta e discute as vantagens e os desafios relacionados ao contexto e ao processo de aplicação do pensamento sistêmico em design. Os resultados demonstram que a abordagem do design sistêmico fornece aos alunos uma base sólida de conhecimentos e habilidades para lidar com problemas sociais complexos. No entanto, permanece a necessidade de introduzir recursos apropriados (por exemplo, metodologias, ferramentas e habilidades relacionadas ao design sistêmico) no currículo atual do design, o que torna a transição da abordagem tradicional do design para o design sistêmico um desafio. As descobertas indicam a necessidade de desenvolver novas competências orientadas ao pensamento sistêmico em estudantes de design.

O Capítulo 5 descreve uma disciplina de mestrado chamada Design de Sistemas para Energia Sustentável para Todos. O curso propôs desenvolver e testar os recursos de ensino baseados no pensamento sistêmico e promover a capacitação para a abordagem do design sistêmico. Estudantes Ugandeses de design da Universidade Makerere, familiarizados com o contexto local, adotam o design sistêmico para confrontar os desafios energéticos enfrentados por comunidades de baixa renda em Uganda. O capítulo sugere competências essenciais para o desempenho hábil ao projetar conceitos de sistema produto-serviço voltados para o setor elétrico de mercados de baixa renda e demonstra o processo de aplicação de tais competências. O Capítulo 4 fornece informações básicas, o que ajuda a desenvolver os alicerces de um novo conjunto de conhecimentos, habilidades e ferramentas para lidar com problemas sociais complexos. O Capítulo 5 restringe o escopo do estudo e concentra-se na construção de capacidades para aplicar o pensamento sistêmico no desenvolvimento de conceitos de PSS para atingir soluções energéticas sustentáveis em contextos de baixa renda.

Além disso, no Capítulo 5 é fornecida para educadores uma lista de aspectos cognitivos relevantes para a capacitação para a abordagem do design sistêmico. Ademais, o capítulo demonstra o processo de integração do pensamento sistêmico no currículo do curso para auxiliar os alunos no desenvolvimento de soluções sustentáveis para o setor elétrico de mercados de baixa renda em Uganda. As descobertas apoiam o fato de que abordagens do design baseadas no pensamento sistêmico podem ajudar a lidar com a crescente complexidade dos problemas sociais enfrentados pela sociedade, e que se espera que a futura geração de profissionais de design seja capaz de resolver. Dessa forma, uma contribuição significativa do estudo para o campo de educação em design é propor competências chaves necessárias para solucionar a lacuna em capacitação para lidar com complexidade no contexto do design.

Fase de Reflexão

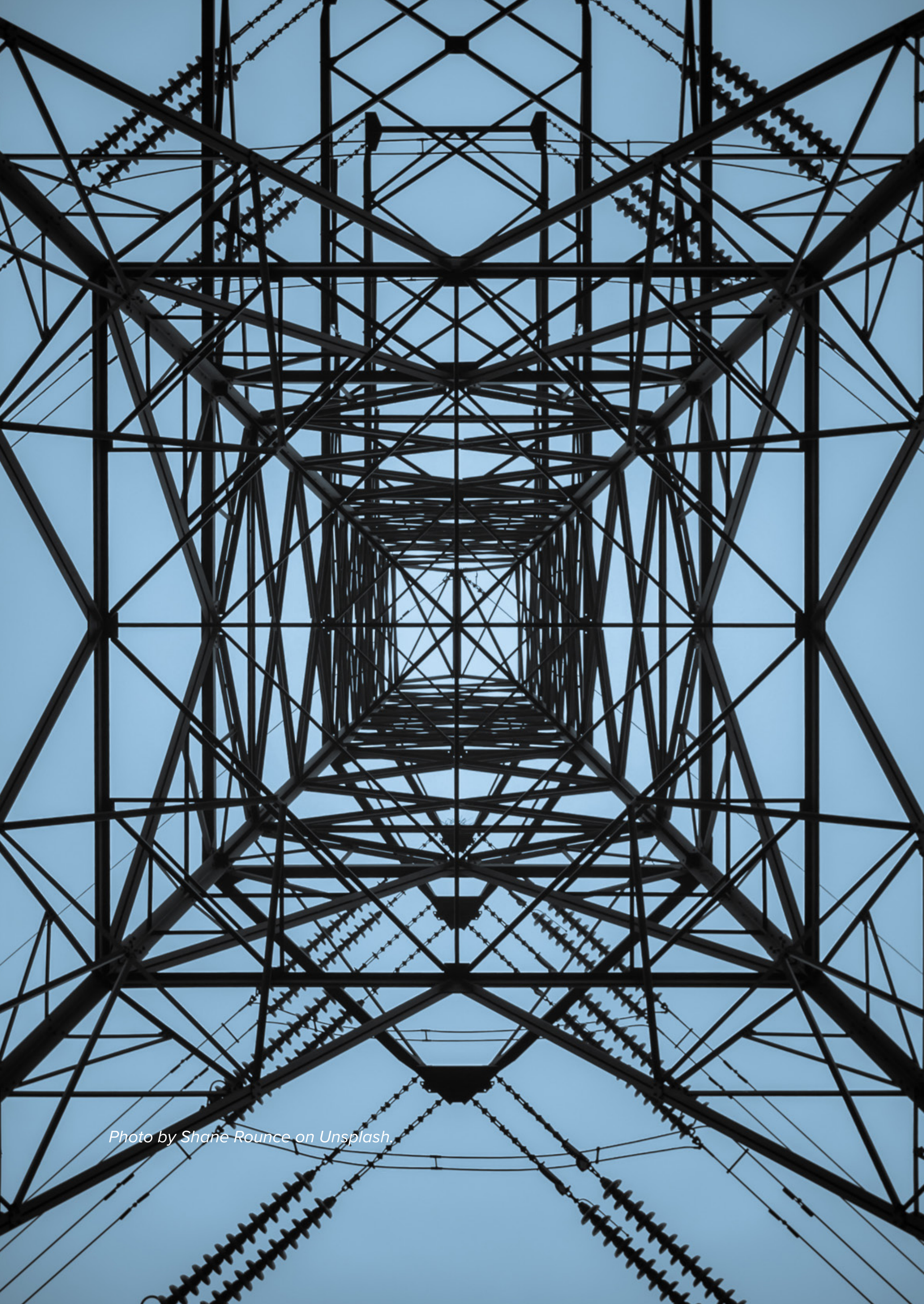
Principais resultados, contribuições e recomendações

O Capítulo 6 fornece um resumo geral das principais descobertas emergentes da tese. São apresentadas contribuições para a teoria, educação e prática do design. Quatro contribuições principais são fornecidas por esta pesquisa de doutorado:

- Explorar a integração do pensamento sistêmico no design, em particular adotando a abordagem do design sistêmico para desenvolver soluções energéticas sustentáveis para mercados de baixa renda.
- Ampliar o escopo do design de sistemas produto-serviços através da introdução de quatro princípios do pensamento sistêmico: perspectiva holística; perspectiva multinível; perspectiva pluralista (diversidade de pontos de vista); e capacidade de lidar com complexidade.
- Propor ferramentas heurísticas para a integração do pensamento sistêmico no design, que permitam desenvolver novas abordagens e aprimorar abordagens de design sistêmico já existentes.
- Aumentar a capacitação para o design sistêmico de problemas sociais complexos por meio da educação em design.

O Capítulo 6 sugere que o projeto de soluções energéticas sustentáveis para mercados de baixa renda requer intervenções eficazes, capazes de lidar com altos níveis de complexidade dos problemas enfrentados pela sociedade. Para isso, é necessária a adoção de uma abordagem do design sistêmico, como complemento para a abordagem reducionista tradicional adotada em design. Isso significa abraçar a complexidade dos sistemas, contextos ou problemas da sociedade e empregar novas formas de pensamento, conhecimento e habilidades para lidar com essa complexidade.

Palavras-chave: Design para a sustentabilidade, problemas sociais complexos, pensamento sistêmico, design de sistema, design sistêmico, sistema produto-serviço, mercados de baixa renda, soluções energéticas.



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1.

Embracing complexity to handle energy challenges in low-income markets

This chapter is partially based on the publication:
Costa Junior, J. da, & Diehl, J. C. (2013). Product-Service System Design Approach for the Base of the Pyramid Markets: Practical Evidence from the Energy Sector in the Brazilian Context. In *Proceeding of International Conference on Micro Perspectives for Decentralized Energy Supply*, 48–51. Berlin: Technische Universität Berlin.

1.1 Energy challenges in low-income markets

Among low-income markets, energy is fundamental to the achievement of sustainable development, as it plays a central role in both socioeconomic development and in environmental challenges (Modi et al., 2005). Energy services have the potential to help developing and emerging economies to achieve socioeconomic goals (Nissing & von Blottnitz, 2010). They are pivotal in enabling these economies to overcome issues, such as lack of access to safe water, lack of opportunities for income-generating activities, inadequate health care, and poor sanitation and education services challenges (Modi et al., 2005). Even though energy is not a basic human need, activities that depend on energy, such as lighting, cooking, heating, refrigeration, transportation and communication are essential for human development and the fulfilment of human needs (Bradbrook & Gardam, 2006; Kaygusuz, 2007).

To achieve higher standards of socioeconomic development, developing and emerging economies need to increase their energy consumption (Geller et al., 2004). This will contribute to the expectation that global energy consumption will increase by 48% between 2012 and 2040 (IEA, 2016) and, despite new developments and policies, it will continue to increase as a direct result of rising living standards (IEA, 2012) and strong long-term socioeconomic development in emerging economies (IEA, 2016). For instance, based on studies of energy policies and economic development, it is expected that electricity consumption in Brazil will grow between two and four times its recent level in the coming years (Giannini Pereira et al., 2012; Luomi, 2014). Consequently, millions of households will be lifted above the poverty line, and the resulting energy demand will impact environmental challenges, such as global warming (Sadorsky, 2009; Salim & Rafiq, 2012).

Global warming is a phenomenon characterised by a rise in the world's average temperature and is caused predominantly by increasing greenhouse gas (GHG) emissions. One of the main GHGs is carbon dioxide (CO_2), generated by the burning of fossil fuels. Even with growing investments in renewable energy, fossil fuels remain the main source of energy in the global energy matrix, accounting for over 78% of total energy consumption (REN21, 2016). Given this scenario, overcoming energy challenges related to global climate change is a matter of great importance for developing and emerging economies where their aim is to reconcile socioeconomic development with the protection of the climate system.

Accordingly, providing sustainable energy solutions is especially important in low-income markets since they will experience the most significant increase in energy demand and carbon dioxide emissions in the short-term (Sadorsky, 2009; Salim & Rafiq, 2012). In this thesis, I focus on low-income energy markets in Latin America and

Africa. More specifically, I seek to respond to energy challenges in low-income energy markets in emerging and developing countries like Brazil and Uganda by proposing a novel approach to design suitable product-service systems. A product-service system (PSS) consists of a network of product, services and stakeholders that collectively strives to fulfil people's need while minimising resources and reducing environmental impacts. Detail information about the concept of PSS and its particular relevance for low-income energy markets is presented in Section 1.5.

Although there is widespread agreement on the importance of energy in developing and emerging economies, low-income households often have either no connection to the national grid or, where they are connected, receive poor quality services with an intermittent and unreliable energy supply. Therefore, to examine those and other energy challenges, I focus on low-income energy markets that are particularly sizeable in developing and emerging economies. Overall, low-income energy markets lack access to affordable, reliable, sustainable, and modern sources of energy, which results in, amongst other issues, pollution, health problems, electricity theft, high electricity costs and inefficient energy-using devices (Hammond et al., 2007).

Sustainable development can be defined as a "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987, p.43). The concept of sustainable development has been extensively discussed, and the notion that it requires a balance between environmental, economic, and social sustainability (i.e., Triple Bottom Line) has been widely shared across disciplines. This thesis concerns itself with the central and relevant theories and practices that contribute to the sustainability debate on design and engineering disciplinary domains, referred to here, for the sake of simplicity, as *design*. It aims to foster designers' understanding of sustainability challenges in low-income energy markets in order to contribute, through design, to the handling of complex societal problems.

Sustainability challenges recently highlighted by the United Nations (UN) within the Sustainable Energy for All initiative (SE4ALL), are primarily concerned with energy challenges in low-income markets. To overcome these challenges, the UN aims to ensure universal access to modern sources of energy, to double the global rate of improvement in energy efficiency, and to double the share of renewable energy in the global energy matrix by 2030 (United Nations, 2010). Due to the adverse impact of energy production and consumption in low-income markets, the energy resources and technologies chosen by developing and emerging economies will affect future living conditions of their populations, as well as the environmental conditions. Since these negative impacts have a dramatic effect on the world's ability to limit the risk of global warming, the energy choices in low-income markets will ultimately lead to an effect on the populations of other countries (Geller et al., 2004). In light of this issue, a consensus emerges that without access to sustainable energy products and related services, sustainable systems cannot be created and sustainable development cannot be achieved (Bhattacharyya, 2012; Giannini Pereira, Sena, et al., 2011).

Global awareness of the importance of energy to poverty alleviation and environmental issues has brought government, public utilities, and civil society under increased pressure. These stakeholders are expected to reduce the environmental impacts and increase the socioeconomic benefits of the generation, transmission, distribution, and consumption of energy. Accordingly, opportunities are recognised for investments in infrastructure, product, and service developments that can lead to solutions that do not repeat the environmental mistakes made by developed economies over the last decades (e.g., fossil fuel dependency and high-energy consumption per capita). Sustainable energy solutions for low-income markets present "a historic opportunity to satisfy demand in ways that are compatible with sustainable development" (Kaygusuz, 2007, p.74).

1.2 Complexity of low-income markets

System(s) is a word that takes on distinct meanings in different contexts. In the context of design, a system can be defined as an emergent or designed network of interconnected functions that fulfil an intended unit of satisfaction (e.g., system outcome, functionality or utility) (Jones, 2014). Additionally, system(s) has been described as a holistic, embodied way of thinking about reality (Nelson, 2008a). Accordingly, the term system(s) represents both a *way of inquiry* and an *object of inquiry* (Nelson, 2005, 2008a). In the context of this study, system(s) embodies both a way of designing and an object of design, and the primary contributions of this thesis focus on systems as an approach to improve the way of designing.

Low-income markets are complex societal systems comprised of individuals and households living in substandard housing conditions, lacking basic services and infrastructure, with low literacy and often operating in an informal economy (Hammond et al., 2007; London & Hart, 2011; Prahalad, 2005). The needs of those individuals in these markets are based on life experiences shaped by psychological, physical, economic, and social constraints (Viswanathan & Sridharan, 2012). Therefore, in low-income markets behaviours toward a product or service tend to be profoundly influenced by local norms, beliefs, and circumstances (Viswanathan & Sridharan, 2012). A major challenge facing problem solvers is to increase the wellbeing of those individuals by providing access to solutions that respect the balance between socioeconomic development and resulting environmental impacts (Hart & Prahalad, 2002).

The populations of low-income countries suffer from complex societal problems, and solutions for those problems are far from obvious or optimal. These are real life problems that impact everyday life and most frequently involve socioeconomic and environmental issues (DeTombe, 2013, 2015a). They are often very hard to define due to limited information about specific problems and lack of contextual knowledge. They involve multiple stakeholders in an intertwined and dynamic network that may change over time and have an impact on multiple aggregation levels of the socio-technical system in place. A socio-technical system is a number of clustered elements, such as technology, policies, stakeholders practices, markets, culture, and infrastructure, which are linked together to attain a specific functionality in a system (Geller et al., 2004).

As a consequence of the complexity of these problems in low-income markets, problem solvers must overcome constraints (also referred to as system handicaps) different from the ones found in middle-/high-income markets, in order to develop effective, sustainable solutions. The understanding of complex societal problems seems alien to many problem solvers, such as designers (Siddiqi et al., 2014). Designers are typically educated to apply traditional design approaches, which are associated with middle-/high-income markets, and acknowledged by some authors as unsuitable for the development of innovative solutions for low-income markets (Chavan et al., 2009; Mahajan & Banga, 2005; Viswanathan & Sridharan, 2012).

A major drawback of traditional design approaches is that the existing knowledge base (e.g., methods, performance metrics, and techniques to communicate with stakeholders) can limit design thinking, thereby creating an inability to understand and cope with the complexity of low-income markets (e.g., due to misjudgement of the context) (London & Hart, 2004). From the point of view of the designer, the concept of complexity adopted in this thesis refers to the lack of understanding of the characteristics of the system in place, the characteristics of the problem situation, and the lack and uncertainty of the knowledge needed to address the problem. To this end, equipping future designers to deal with complexity requires further attention to emerging and new approaches to design education and practice.

1.3 Complexity of energy challenges in low-income markets

The energy challenges faced by the low-income population are becoming increasingly complex as a result of limited financial resources and poor infrastructure among other existing system handicaps (constraints) in low-income markets. Moreover, they are becoming increasingly important due to concerns over sustainable development. For these reasons, energy challenges offer both an opportunity to appreciate the impact on sustainable development and a representable case for studying the complexity of design problems in low-income markets. Given the complexity of energy challenges in low-income markets, it is likely that improvements on a technological level, although fundamental, are limited to create sustainable energy transitions. In fact, the complexity of energy challenges, as discussed above, implies that sustainable energy systems cannot be conceived by technological improvements alone. In such complex systems, social and organisational practices can be complex, unstructured and messy, and technologies may be appropriated and incorporated into everyday practice rather than integrated rationally (Jones, 2014). The transition to sustainable energy systems in low-income markets requires profound institutional and sociocultural transformation, which creates high levels of societal complexity.

Societal complexity refers to the nature of problems situations where the relations between humans and institutions are central to any solution. In systems with high societal complexity, the interplay between technologies, policy instruments, and stakeholders behaviours, among other societal factors, can create many more variables and forces than problem solvers are used to handling. An example is the realisation that solutions for low-income energy markets are more likely to impact multiple levels of society at once, i.e.: at the micro level with product-technology interventions and individual/collective actions (e.g., supporting the creation of new consumption patterns); at the meso level with product-service arrangements, infrastructure improvements and organisational change (e.g., encouraging collaboration between government, end-users and NGOs); and at the macro level with societal trends and policy choices (e.g., stimulating the creation of economic and regulatory instruments). Table 1.1 illustrates the socio-technical system of energy supply, paying particular attention to factors that may contribute to technical and societal complexity in low-income markets when compared to middle-/high-income markets.

Table 1.1 Complexity within the socio-technical system of energy supply in low-income markets.

Components of the socio-technical system	**Examples of system handicaps faced in low-income energy markets**
Infrastructure (e.g., electrical grid)	Technical constraints (e.g., lack of infrastructure)
Knowledge production and transfer (e.g., universities, research institutions, R&D departments, capacity building)	Institutional constraints (e.g., misalignment of priorities and agendas amongst stakeholders) and user constraints (e.g., low literacy)
Maintenance and distribution network (e.g., electricity distribution companies, maintenance services, electricians, hardware stores)	Technical constraints (e.g., lack of maintenance and local expertise)

Culture and symbolic meaning (e.g., individual, collective, shared)	Socio-ethical constraints (e.g., lack of equity and social cohesion, exclusion of the minority) and user constraints (e.g., unpredictable behaviour and unknown cultural norms)
Resources (e.g., fossil fuels and renewables)	Environmental constraints (e.g., rebound effects[1] due to lack of environmental awareness)
Market and stakeholders practices (e.g., energy consumption patterns, energy sectors, distributed generation)	Economic constraints (e.g., lack of access to credit and energy poverty)
Regulatory and economic instruments (e.g., subsidies, social tariff, energy programmes, policy support)	Regulatory and organisational constraints (e.g., restrictive, or lack of, regulations, laws, and policies)

Based on Geels (2005).

At the crossroads of energy and design, sustainable energy solutions can be developed by deploying new technologies and promoting changes in lifestyle (Reinders et al., 2012). The term “energy solution” refers to energy systems and comprises energy’s technical and financial aspects, as well as societal and user aspects. According to Reinders et al. (2012), as complexity and functionality increases, energy solutions need to be integrated into a system of products and services that closely interact with various elements of the socio-technical system.

The development and implementation of sustainable solutions for low-income energy markets demand attention to multiple technical and societal factors and changes at multiple levels (Elzen et al., 2004), exerting a considerable complexity. In this context, as the complexity of the problem increases, designers must combine a range of comprehensive products, services and systems to provide access to sustainable solutions. In addition to the ability to deal with increased complexity, better design and system practices are required (Sevaldson, 2013). As shown in the following section, over time designers have become increasingly interested in moving from product-centred solutions to systems-oriented solutions. This has led to the creation of various approaches to design for sustainability and development in an attempt to address the complex problems facing our society.

1 Rebound effects occur when a product or service increase in consumption due to improvements in energy efficiency meant to decrease total consumption (e.g., energy becomes cheaper, so an individual consumes more energy for mobility or climate control). Rebound effects often result in loss of energy conservation (Berkhout et al., 2000).

1.4 Design for sustainability and development

Since the late 1960s, the production and consumption methods used by society to fulfil human needs have given serious cause for environmental concern. When concerns over environmental challenges were voiced in the 1970s (Meadows et al., 1972), criticism was centred on Design. Industrial Design was perceived as contributing to environmental and social problems, rather than as creating solutions (Papanek, 1972). This criticism remained on the agenda in the following decades with calls for more socially responsible design, e.g., Whiteley's book Design for Society (1993). In the 1990s, the growth in knowledge about sustainability in the field of design resulted in emerging design approaches, which provided new methods, strategies, tools, and techniques to support sustainable development.

The principles underlying early design approaches towards sustainability were, among others, renewable resource use, minimization of resource use, dematerialisation, recycling, reuse, remanufacturing, end-of-pipe techniques, and eco-efficiency. Based on these principles, the concept of Design for the Environment, also referred as Eco-design, has gained popularity. Design for the Environment takes into consideration environmental aspects at all stages of the product life cycle in order to lower negative impacts (Brezet & Van Hemel, 1997). Other relevant design approaches that emphasise environmental and economic sustainability are identified in the literature, namely: Eco-efficiency (WBCSD, 1998); Cleaner Production (WBCSD, 1998); Biomimicry (Benyus, 2002); Life Cycle Assessment (LCA) (ISO, 2006); Design for "X" (Factor 4, 10, 20); Eco-cost/Value Model (ERV) (Vogtländer et al., 2002, 2001); Cradle to Cradle (Braungart & McDonough, 2002); and Design for Disassembly (Thompson, 1999).

These attempts to incorporate sustainability into design are associated with improving environmental performance and reducing environmental impact. Such environmental considerations, while important, have mainly addressed the physical nature of sustainability challenges and focus on technological improvements. Recently, emerging design approaches have recognised the need for a broader agenda — a societal perspective — which considers the capability of design to improve people's wellbeing by meeting the basic needs of current generations while, at the same time, fostering sustainable production and consumption. For example, to an increasing extent design approaches aim to improve primary social-ethical and economic sustainability performance, such as: Design for the Base of the Pyramid (Crul & Diehl, 2006); Socially Responsible Design (Melles et al., 2011); Design with the other 90% (Smith, 2011) and Design for Well-Being (Mink, 2016).

More recently, some design approaches have advocated the provision of solutions capable of responding to environmental, economic, and social challenges. Those attempts to address all dimensions of sustainability with a comprehensive solution have encouraged designers to expand the scope of design theory and practice. Aiming at a broader design agenda, promising approaches that focus on shifting to a systems orientation have emerged, e.g.: Product-Service Systems (Goedkoop et al., 1999); Eco-efficient Producer Services (Bartolomeo et al., 2003); Sustainable Consumption and Production (Andersen & Tukker, 2008; Lebel & Lorek, 2008); System Design for Sustainability (Vezzoli, 2010); Systems Oriented Design (Sevaldson, 2013; Sevaldson et al., 2010); and Whole-Systems Design (Blizzard & Klotz, 2012; Blizzard et al., 2012) and Holistic Sustainability Design (Reubens, 2016).

These approaches corroborate that the transition from one existing pattern of production and consumption to another demands systems-oriented solutions that go beyond product-centred approaches. Moreover, the implementation of systems-oriented solutions depends on the adoption of methodologies, strategies, and tools, which tend to belong to design for sustainability approaches that take into consideration the system as a whole and thereby integrate products and services to offer functionality, utility, and satisfaction.

According to Ceschin and Gaziulusoy (2016), the field of design for sustainability and development has broadened its theoretical and practical scope from product level to a socio-technical system level, and expanded from single products to complex systems. This "evolution" of design for sustainability and development is observed in a shift of focus in design for sustainability approaches over the years (see Figure 1.1). That is, focus has shifted in three ways: from technical aspects of sustainability to recognition of the importance of the role of the various stakeholders; from environmental aspects of sustainability to increasing integration of socio-ethical and socio-economic aspects; and from insular to systemic design innovation. The authors of this study contend that in order to address sustainability challenges, an integrated set of design for sustainability approaches are required, and solutions to those challenges need to cover a broad span of innovation levels.

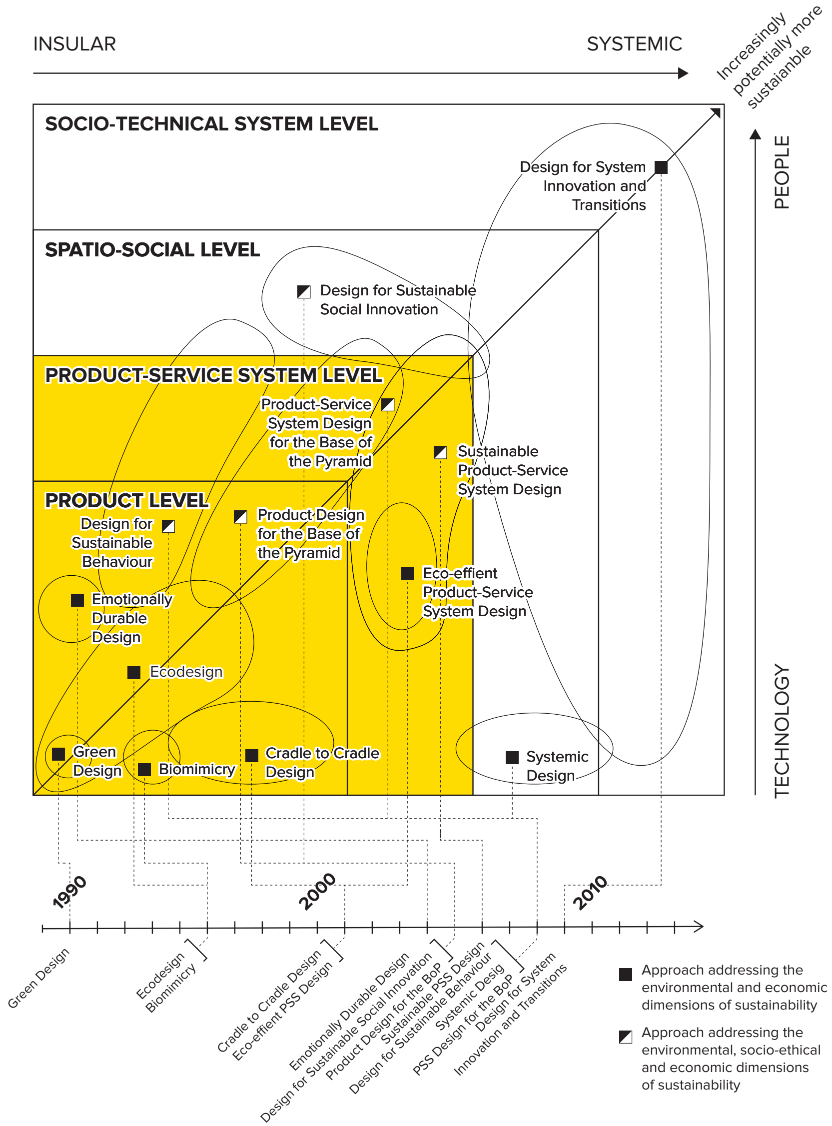


Figure 1.1 Evolutionary framework of design for sustainability approaches. Adapted from Ceschin and Gaziulusoy (2016).

1.5 Sustainable energy product-service systems

In the early 1980s, Stahel and Reday-Mulvey (1981) proposed a ground-breaking hypothesis that by focusing on function fulfilment and utility (satisfaction of needs) instead of on the sale of products, new jobs could be created and energy consumption decreased. This hypothesis led markets to focus on integrated products and services capable of fulfilling people's demands for individual and collective solutions to their problems, rather than to simply offer a product. This paradigm shift in production and consumption is considered an effective strategy for minimising resources and reducing environmental impacts, which ultimately facilitates sustainable development (Lee et al., 2012). In the literature, the integration of product and services is called Product-Service Systems (PSS), and consists of a system of products, services, supporting networks, and infrastructures, which closely involve end consumers and other stakeholders in the value chain (Mont, 2002a). The early definition of PSS is attributed to Goedkoop et al. (1999, p.18), who define it as "a marketable set of products and services capable of jointly fulfilling a user's need."

A broader analysis of the literature reveals similar conceptualisation used to describe the same, or similar concepts, namely: functional economy (Stahel, 1997); functional sales (Lindahl & Ölundh., 2001); functional product (Alonso-Rasgado et al., 2004; Kumar & Kumar, 2004); dematerialization (Dobers & Wolff, 1999); servitization (Vandermerwe & Rada, 1988); and Industrial Product-Service Systems (Meier et al., 2011); sharing economy (Hamari et al., 2016). Those concepts present similarities and share the same fundamental assumption underlying PSS, i.e., to provide functionality and utility to fulfil human needs through the integration of product and services. These concepts can be found across different disciplines, such as: Operational Research; Information Systems; Systems Engineering; Cyber-Physical Systems; Innovation and Business Management; and Marketing. Among the disciplines, the sustainability perspective of PSS is more often discussed in the field of design. In this respect, sustainability is often associated with studies that aim to decrease resource and energy consumption (e.g., Bartolomeo et al., 2003), implement sustainable business models (e.g., Dobers & Wolff, 1999; Friebe et al., 2013) and, to some extent, increase social or socioeconomic benefits (e.g., Halme et al., 2004).

The concept of PSS holds considerable relevance to the focus of this thesis on account of its application in the energy sector (Bandinelli & Gamberi, 2011; Bartolomeo et al., 2003; Emili et al., 2016; Friebe et al., 2013; Vezzoli, Ceschin, & Diehl, 2015; Vezzoli, Ceschin, Osanjo, et al., 2015; Vezzoli, Delfino, et al., 2014). Moreover, although PSS has been mostly developed in the context of middle-/high-income markets, the ability to provide a higher level of wellbeing at a lower cost as a result of its higher system efficiency (Tukker & Tischner, 2006; UNEP, 2002) shows promise for its application in low-income markets (Castillo et al., 2012; Diehl, 2009; Mukaze & Velásquez, 2012; A. Santos et al., 2009).

For instance, PSS facilitates long-term socio-cultural and socio-economic changes by moving from the need of individual consumption/ownership of goods to a more accessible, low-tech, low resource intensive service economy (Castillo et al., 2012).

According to Castillo (2012), among design for sustainability approaches, PSS has the potential to trigger incremental and radical changes in technological and socio-cultural terms, and therefore to create sustainable alternatives for low-income markets.

An example that illustrates the characteristics of a sustainable energy PSS is the "Solar Heat Service" by AMG (UNEP, 2002). The company shifted its business model from selling heating equipment and distributing methane to selling heat as a finished product. In other words, rather than selling products (heating system), or charging the client for the methane consumed, AMG offers a performance-based contract (functionality/utility) for heat produced (in terms of thermal kilowatts consumed for heating water). AMG remains the owner of the heating system and uses different energy sources, such as methane, electricity, and solar energy, to achieve higher levels of energy efficiency.

Several authors (Manzini & Vezzoli, 2003; UNEP, 2001, 2002) agree that PSS solutions, like the "Solar Heat Service", can stimulate major changes in current production and consumption patterns for an environmentally sound path to socioeconomic development by re-orienting current unsustainable trends and practices. However, some authors (Hekkert et al., 2001; Tukker & Tischner, 2006) argue that PSSs are not inherently environmentally friendly and mostly incremental environmental improvements can be expected from the optimisation of the product or service utility (Hekkert et al., 2001). Moreover, other authors call for further studies to consider systems thinking (Cavalieri et al., 2012; Vasantha et al., 2012) and social aspects of PSS (Beuren et al., 2013).

To contribute to this endeavour, this thesis explores *systems-oriented energy PSS in low-income markets.* Such exploration allows us to see more clearly how product-service systems can address energy challenges by broadening their theoretical and practical scope. Therefore, in an attempt to develop a general research approach that can take into account the transition from a product-service system level to a socio-technical system level (see Figure 1.1). In the following section, I discuss product-service systems theory and practice.

1.6 Towards systems-oriented energy solutions

As discussed earlier in this chapter, the initiatives underpinning the development of sustainable energy solutions for low-income markets are threefold: the deployment of new technologies; the adoption of emerging and new approaches; and the promotion of changes in production and consumption. Given the complexity of energy challenges facing low-income markets, previously referred to as complex societal problems, it is likely that improvements at the product-technology level are not sufficient to allow for the creation of sustainable energy transitions. In this sense, traditional design approaches offer limited support to design better energy solutions for low-income markets.

Technological improvements, although fundamental and necessary, make a partial contribution to the advancement of long-term sustainability for society as a whole. For this reason, to tackle sustainability challenges, it is necessary to move from technological improvements only to a wider societal perspective that takes into consideration “new potential ways of satisfying the social demand of wellbeing” (Ceschin, 2012, p.1). Such change requires a broader perspective of design that considers societal aspects often underrated and neglected as systemic by designers (i.e., considered as an isolated entity, group, or component of a system). At the same time, characteristics found in PSS, such as holistic perspective, co-creation, and low environmental impact, can offer an advantage over other design for sustainability approaches to address sustainability challenges at a socio-technical level in low-income markets.

Due to system handicaps in low-income markets, it is not sufficient to introduce a system of distinct products and services as separate offerings on the market, rather a *whole system of integrated products, services, stakeholders, regulatory instruments and infrastructure is required.* The issue, as mentioned above, is evident in the two examples described in the next paragraphs. The IndiGo solar power system is an example of an energy solution that focuses limited attention to its systems aspects. In contrast, in the second example, EnDev Kenya programme demonstrates the application of PSS at a socio-technical system level.

The company Eight19 developed the IndiGo solar power system (see Box 1.1) to address the lack of home lighting in Kenya (Africa) by introducing the PSS concept of Pay-As-You-Go. The company created an off-grid application that uses the increasing need for individuals to be able to charge mobile phones in rural areas, and in low-income communities, as a basis for its product, service, and infrastructure. Despite the successful implementation of the energy system, unanticipated challenges were reported by the company, illustrating the complexity of energy supply in low-income markets. In particular, distribution has proven very costly because many areas served by the company were remote villages with low population density. Ultimately, the constraints associated with distribution have become a major barrier and have limited the processes of introducing and scaling up the energy solution.

Box 1.1 IndiGo Solar Power System

The IndiGo solar power system allows users to buy electricity using mobile phones. The system consists of a solar panel (ranging from three, 10, 40, to 80 watts), a battery, two LED lamps, a phone charging unit and a module. The equipment installation costs 10 dollars, and customers are charged a fixed fee of 1 dollar a week for its use. Customers add credit to their solar power device using a scratch card validated on a standard mobile phone via a text message. They receive a passcode that they enter into the IndiGo unit, which then operates for, typically, a period of a week. The power generated is sufficient to charge a mobile phone and to give eight hours of light in two rooms. In Kenya, people tend to spend about 2 dollars per week on kerosene to light their houses and 1 dollar on power for mobile phones. The use of the IndiGo system offers considerable financial savings and eliminates the harmful emissions caused by burning kerosene and health problems associated with it.

http://www.azuri-technologies.com

An example of a PSS solution at socio-technical system level is seen in improvements in cooking stoves in Kenya by the EnDev Kenya programme (see Box 1.2). Advantages of the use of these stoves include: considerable improvement in terms of the health conditions surrounding their use (e.g., reducing indoor smoke); reduced pressure on natural resources (e.g., increasing fuel efficiency and protecting natural resources); and substantial reductions in harmful emissions (e.g., reducing air pollution) (Shrimali et al., 2011). Since technologies are reasonably well-established, in order to achieve scale and become self-sustaining the employment of improved cooking stoves requires a network of local-partner organisations committed to facilitating the development, dissemination, monitoring, maintenance, fuel supply and evaluation of the system. Moreover, there is a strong relationship between the part of the energy sector concerned with energy for cooking, and other sectors pivotal to development, such as agriculture, education, health, and water. To address this context, GIZ (German Corporation for International Cooperation GmbH) have created a programme called EnDev Kenya that implements a product-service system comprised of improved cooking stoves and related services. According to SEI[2], a major success factor associated with EnDev is the holistic approach taken in the development of improved cooking stove systems as part of a broader initiative to improve health (e.g., income generation opportunities to HIV infected and affected persons), education (e.g.,

2 www.sei-international.org

improved cooking facilities in schools), energy (e.g., promoting clean sources of energy), and agro-industry (e.g., introducing improved cooking stoves to tea and coffee farmers and workers).

Box 1.2 EnDev - Energising Development Kenya Programme

EnDev Kenya is an energy programme comprised of three sub-programmes: improved cooking stoves; small-scale solar lighting systems; and biogas plants. The improved cooking stoves programme facilitates the implementation of a product-service system consisting of two improved cooking stove models (i.e., the portable stove Jiko Kisasa, and the fixed structure Rocket Stove) and related services (e.g., training, installation, and maintenance). The programme supports the technical, commercial, and organisational aspects involved in producing, distributing, and installing the improved cooking stoves, as well as training the end-users. By 2014, more than 1.45 million stoves had been installed in Kenya serving over seven million people, directly employing over three thousand people, saving over one tonne of firewood, and reducing about one million tonnes of carbon dioxide CO_2 emissions.

https://www.giz.de/en/worldwide/21975.html

The first example (Box 1.1) illustrates a product-service system that draws less attention to its systems aspects. However promising, at this level PSS lacks a comprehensive approach to encompass the various technical and societal factors involved in the design process, which are fundamental to a proper conceptualization and in-depth understanding of the system in place (see Cavalieri & Pezzotta, 2012). From the unanticipated challenges experienced by the company to introduce, and scale up, the PSS solution, the lack of a holistic approach is observed. To tackle this issue, and in order to address complex societal problems, it is contended that it is necessary to gain a better understanding of the complexity of the technical and societal factors that influence a given system.

In the second example (Box 1.2), I illustrate the application of PSS at a systems-oriented level. At this level, PSS solutions adopt systems thinking to achieve broad success in low-income markets by upscaling and embedding the solution into the socio-technical system. Systems thinking is an approach suitable for handling complex societal problems; it considers all parts of a system as intertwined and interactive components rather than each part as an independent entity within a system. In this investigation, the concept “systems thinking” conveys four major tenets that encompass other more specific principles: a holistic perspective; a multilevel perspective; a pluralistic perspective (diversity of views); and complexity-handling capacity.

A holistic perspective is paramount to tackle complex societal problems such as those concerning energy challenges in low-income markets (Blizzard & Klotz, 2012; Cardenas et al., 2010; Clegg, 2000; Forlizzi, 2012; Jones, 2014). Moreover, a pluralist perspective supports a participatory problem-solving and decision-making process capable to considers the intricate relationships among stakeholders in low-income markets (Matos & Silvestre, 2013, Laszlo et al., 2009, Daellenbach, 2001; Jackson, 2003; Jackson & Keys, 1984). Finally, systems thinking allows for handling high levels of complexity (Ackoff, 1974; DeTombe, 2015b, 2015a; Espinosa et al., 2008), as well as looking at multiple aggregation levels of a problem situation (DeTombe, 2015b; Elzen et al., 2004; Geels, 2005; Joore & Brezet, 2015).

Low-income energy markets face complex societal problems where systems thinking can be at its most fruitful. A traditional design approach, although it can work, it is not optimal in low-income markets. The adoption of a systems approach can achieve radical improvements necessary for transitions to sustainable energy systems. Therefore, to gain a better understanding of the implications of systems thinking for product-service system design, the challenges associated with achieving higher sustainability levels through sustainable energy solutions for low-income markets are identified throughout this investigation. It shows that design education and practice has traditionally focused on energy systems as technical systems where the boundaries are well defined and encompass materials, machines, and constructed facilities. For that reason, the current expertise of designers loses its relevance when addressing energy challenges in low-income energy markets, where technical and societal factors are entangled. Notably, because the latter (i.e., societal factors) become major variables in creating successful interventions. Therefore, based on the problem definition, the central research question is: *How can systems thinking contribute to handling the complexity of sustainable product-service system design for low-income energy markets?*

1.7 Overview of this thesis

This thesis aims to embrace complexity in order to address sustainability challenges in low-income markets, and to contribute, through design, to the handling of complex societal problems. To do so, this research consists of three constituent parts: a theoretical phase; an empirical phase; and a reflection phase (see overview in Figure 1.2). In the first phase, a preliminary research and a theoretical research consist of two reviews reported in Chapters 1 and 2. The first phase explores existing theories and approaches to gain a better understanding of their nature. The empirical phase comprises observations of existing practice and two interventions in design education, presented in Chapters 3, 4, and 5, respectively. Finally, a reflection phase presented in Chapter 6 provides a general summary of the main findings of the research and illustrates its overall contribution to design theory, education, and practice.

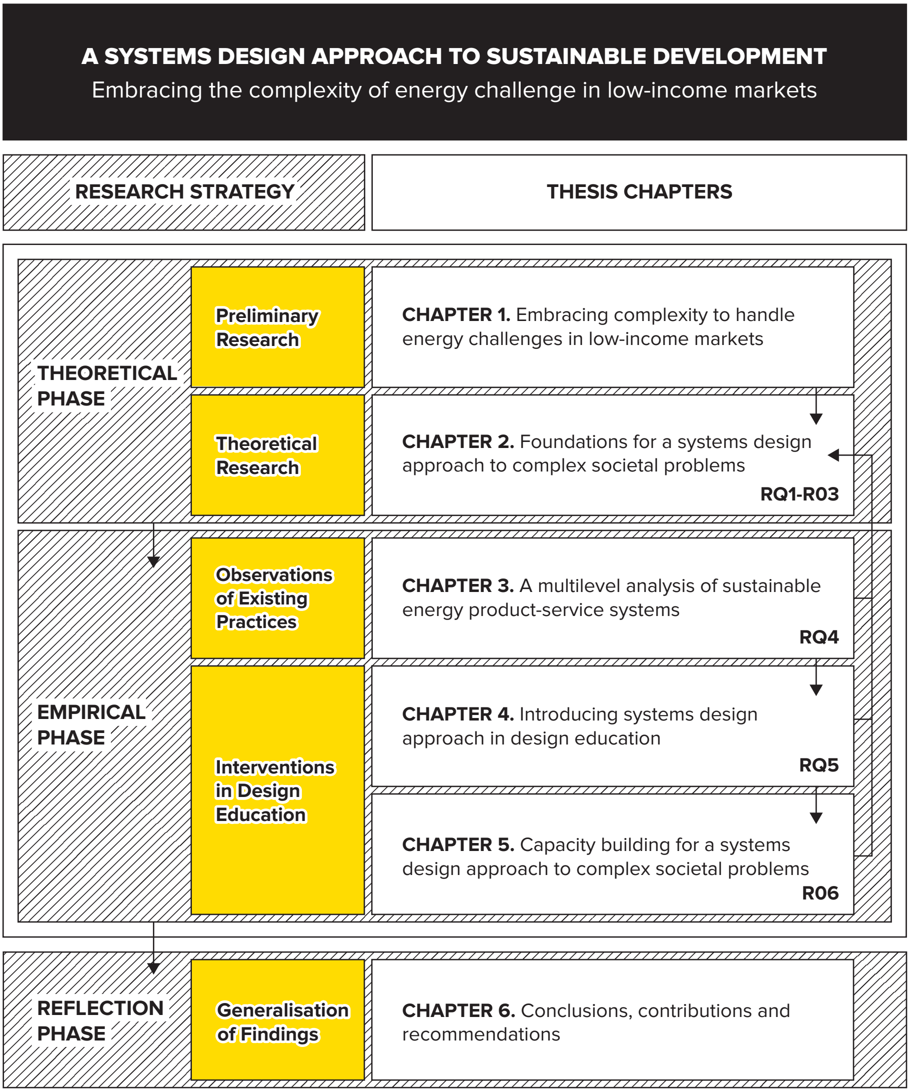


Figure 1.2 Thesis outline.

1.8 How to read this thesis

The thesis contains four primary studies, namely a theoretical inquiry (Chapter 2) and three empirical inquiries (Chapters 3, 4, and 5), published as peer-reviewed journal articles. It is worth mentioning that the structure of the chapters does not reflect the chronological publication of the articles. Moreover, the various studies can be grouped into three main areas: theory (Chapter 1-2), practice (Chapter 3), and education (Chapter 4-5).

For a "quick read" through the content of this thesis, please read the summary. For an introduction to the rationale for the investigation, read Chapter 1. Chapter 2, which was built upon the knowledge acquired throughout the whole investigation, presents the theoretical foundation of this work. To learn more about the context of the research and gain a better understanding of the existing practices, read Chapter 3. Chapter 4 and 5, provide an extensive overview of the development and evaluation of the work presented in this thesis in the context of design education. For a general summary of the main findings, contributions, limitations and recommendations for future research, read Chapter 6.

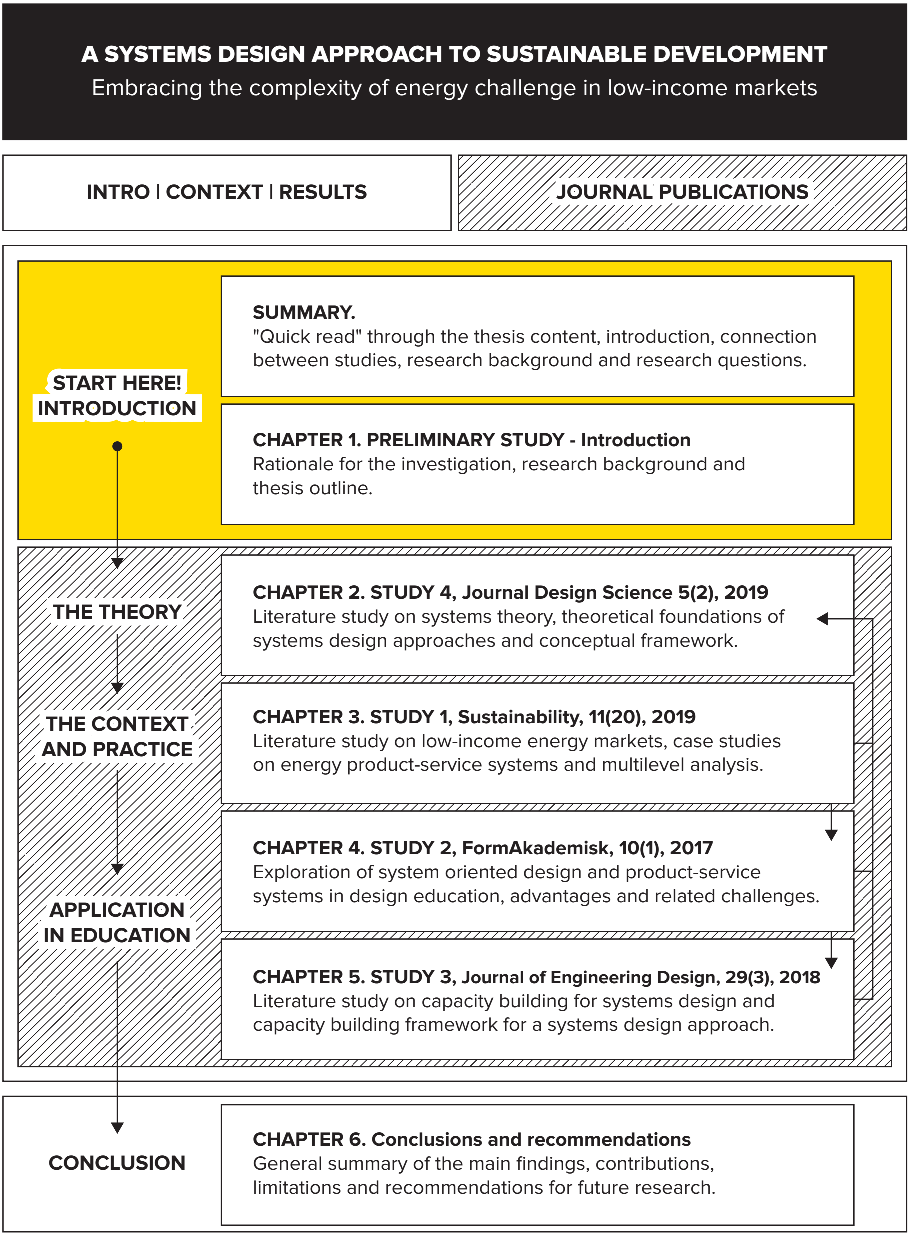


Figure 1.3 Reader's guide.

Photo by Nick Nice on Unsplash.

2.

Foundations for a systems design approach to complex societal problems

This chapter is based on the publication:
Costa Junior, J., Diehl, J. C., & Snelders, D. (2019). A framework for a systems design approach to complex societal problems. *Design Science, 5* (e2), 1-32. doi: 10.1017/dsj.2018.16

Societal problems concern the complexity of technical, organisational, social, and political issues. The enormous negative impacts of these problems and the inability of designers to deal with high levels of complexity cannot be overcome without a paradigm shift in how we understand and engage with such issues. Two domains have been helpful in bringing about such a shift: Systems Thinking and Design. Although these domains express mutual interest in socio-technical systems and complex problem solving, in the literature, there are few attempts of bringing the compatibility between them to the attention of designers. This chapter aims to contribute to this endeavour by uncovering the process of integrating systems thinking in design, and by providing an overview of the field of systems design approach. By doing so, it presents a systems thinking foundation for this research, which is developed by drawing on knowledge from all chapters presented in this doctoral dissertation (Chapter 3-5). An extensive literature review outlines significant aspects underlying systems thinking to support its use and further development in design. This chapter provides a conceptual framework structured in five clusters: mindset, methodology set, knowledge set, skill set and tool set. The framework is meant to assist designers in integrating systems thinking into design and thereby enable them to better handle complex societal problems.

2.1 Systems-oriented approach to complex problems

Complex societal problems that underlie challenges such as sustainability call for solutions that are entangled in a manifold of social and technical processes. The processes involved in these problem situations profoundly influence each other in a network of institutions, organisations, phenomena, and stakeholders (DeTombe, 2015a). In addition, the complexity of societal problems may be dependent on an observer's knowledge and capacity to act (Murthy, 2000). Problem solvers from different disciplinary domains have suggested using tools and methodologies that embody the principles of systems thinking in addition to more conventional methods for studying and responding to societal problems more effectively. (Espinosa et al., 2008; Murthy, 2000; Stjepandić et al., 2015). Despite these efforts, the literature shows a significant gap between the complexity of societal problems and problem solvers' capacity to understand and deal with them (DeTombe, 2013). Such a knowledge gap cannot be overcome without a paradigm shift in how we understand and address such issues (Espinosa et al., 2008).

The science of complexity has been studied in different scientific fields, including the natural, social, and systems sciences. Especially in the social and systems sciences, the understanding of complexity and problem solving has been consistently linked to social processes. Scholars in these fields have developed and employed a transdisciplinary research approach to address complex, multi-stakeholder, real-world problems (see Gaziulusoy, 2015; Gaziulusoy & Boyle, 2013; Jones, 2014). This approach, called systems thinking, is underpinned by three central claims. First, systems thinking is a problem-solving approach capable of handling the inherent complexity of societal problems (Ackoff, 1974; DeTombe, 2015a, 2015b; Espinosa et al., 2008). Second, it allows designers to adopt a holistic perspective through a specific set of assumptions, premises, and axioms (Blizzard & Klotz, 2012; Cardenas et al., 2010; Clegg, 2000; Forlizzi, 2012; Jones, 2014). Third, systems thinking has the potential to incorporate differing worldviews through a pluralistic perspective (Daellenbach, 2001; Jackson, 2003; Jackson & Keys, 1984).

In addition, the failure to address societal problems, such as those underlying sustainability challenges, has led problem solvers to express interest in adopting systems thinking in the context of design (Sevaldson et al., 2010). However, in the design field few contributions touch upon systems thinking and transitions for sustainability (Gaziulusoy, 2015), even though the scope of design has shifted over time from the development of physical objects, to integrated product-services, to complex systems (Ceschin & Gaziulusoy, 2016; Joore & Brezet, 2015). A potential reason for such relative underperformance might be a lack of pragmatism (Lilienfeld, 1985). Therefore, some authors have called for integrating systems thinking with design practice (Jones, 2014; Sevaldson, 2014a). In fact, decades ago systems thinkers like Russell Ackoff (see Ackoff, 1993) and Bela H. Banathy (see Banathy, 1996) openly discussed the purposeful design of human social systems and the capacity of problem solvers to empower individuals, groups, and organizations to take part in the design of the system in which they live and work (Metcalf 2014). In more contemporary systems thinking these discussions have been followed through, and design now sits at the core of the emerging concept of systems methodology (Gharajedaghi, 2011).

The relationship between systems thinking and design can also be observed in recent transdisciplinary research, which points towards the formulation of a systems-oriented design practice, which will be referred to here as a systems design approach (see Charnley et al., 2011; Jones, 2014; Nelson & Stolterman, 2012; Sevaldson, 2011). Such existing and still evolving approaches integrate systems thinking and design competencies to handle complex problems. Moreover, they aim to deal with problem situations characterised by complexity, uniqueness, value conflict, and ambiguity over objectives and goals (Ryan, 2014). Finally, they differ from traditional design approaches in terms of scale, societal complexity, and integration (Jones, 2014).

This chapter aims to contribute to a systems design approach by providing an overview of the developments that are leading to such an approach. It will present an extensive review of systems thinking, drawing insights from a broad body of literature. It will then attempt to gain a better understanding of complex societal problems in the light of systems thinking (as addressed by different systems approaches), and will relate systems thinking to design in a conceptual framework for systems design approach. The study builds on the assumption that integrating systems thinking into design is a promising approach for tackling complex societal problems. It further builds on the position that design has the capacity to create holistic solutions to problems, and can potentially develop both fields (Nelson, 2008a; Sevaldson, 2014a). With respect to this last point, an additional and more tentative aim of this chapter is to provide an initial exploration of a systems thinking foundation for design.

2.2 An interdisciplinary and systematic literature review

To ensure scientific relevance relevant publications were collected from multiple disciplinary and interdisciplinary domains. The central questions which guide this literature review are: *What are the characteristics of complex societal problems in low-income energy markets?; How has systems thinking been developed as a way of handling complex societal problems?; and, To what extent does systems thinking provide the best fit to the design of solutions aimed at complex societal problems?*.

This study adopts a heuristic and reflective tool to review, evaluate, and report transdisciplinary literature (based on work by Gaziulusoy & Boyle, 2013). Hence, the literature review is conducted through an extensive search filtered across four levels: paradigm; problem/solution; context/scope; and knowledge/skills. Paradigm level filters are used to generate criteria based on the visions, norms, and values adopted in the identified research areas. The problem/solution level supports the creation of filters for the specific concerns and solutions shared across the different disciplinary and interdisciplinary domains. The context/scope level helps to create filters that both identify and delimit the broader context of the problem. Finally, the knowledge/skills level guides the generation of filters based on the knowledge base and expertise required to address the central problem of the research.

Each filter level is applied with the support of reflective questions formulated to assist in the literature review. For instance, to apply the problem/solution filters, I reflect, among others, on the following questions: “Which disciplinary and interdisciplinary domains are relevant to the problem?”; “What is already known about the problem?”. By reflecting on these questions, various key-words were generated and used as search terms in the literature search process. This process was applied to limit the scope of the literature review and to prioritise some literature over others (Figure 2.1).

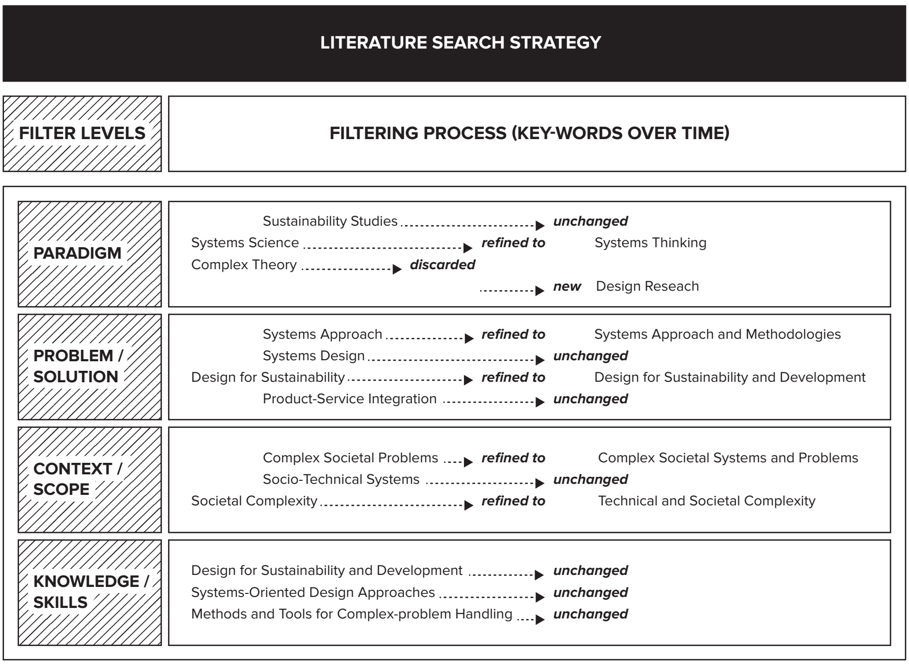


Figure 2.1 Literature search process. Based on Gaziulusoy and Boyle (2013).

The search strategy was conducted by first defining the search terms based on the literature review filters, and the relevant data sources and time frame. An initial (preliminary and broad) literature review was conducted using combinations of relevant search terms (e.g., system* design, system* approach*, whole system*, system* thinking, complex societal problem*) in title and keywords searches of the selected databases (ScienceDirect, Scopus, SpringerLink, Emerald, SAGE, SciELO and Google Scholar). The preliminary search selected 351 entries, which represent full peer-reviewed articles and books published in English in the leading academic journals related to the subject. Since the integration of systems thinking into design is a relatively new phenomenon, the focus of this review was, at a first step, on literature published in or after 1987 until 2017. The preliminary search aimed to create an understanding of cross-disciplinary influences and to identify existing reviews and primary studies relevant to the literature review. Next, to conduct the main literature review, I read the title, abstract, and keywords of the collected publications. In addition, the refined literature review filters were considered (see Figure 2.1). This process has reduced the list of collected material to 156 publications. Finally, the relevant publications were read in full, and an additional search was conducted based on their reference lists and bibliographies in order to identify additional, relevant studies. This final process has added 20 publications to the literature review portfolio. The reference management software Mendeley Desktop was used to support the inclusion and exclusion of publications.

The choices made at the different filter levels influenced the overall process of prioritising streams of literature. For instance, an important choice was made at the paradigm level, the concepts of complexity, holism, and sustainability were adopted as major values and norms to generate paradigm filters. As a result, systems theory became the focus over complex theory because it provides a better fit to the initial research intention, which was to focus on inquiry and action aimed at embracing a more radical idea of holism. While conceptual overlap exists, based on the analysis of the preliminary search, the literature review showed that complexity theory and systems theory diverge in their basic premises with which they interpret complex systems (Phelan, 1999). The former assumes that the complexity of systems arises from the simple and specific behaviour of a system's parts (Ibid). On the other hand, systems theory defines system complexity as a result of the number and type of a system's parts, as well as the interaction between parts (DeTombe, 2015b). Another important choice in prioritising streams of literature happened at the problem/solution level. Concerning this, the choice was made to focus the search on problems/solutions in two areas which systems thinking was most developed: the areas of sustainability and development.

2.3 Uncovering the foundations of systems design approach

2.3.1 Traditional scientific method

Design is a unique form of inquiry and action that aims to create and transform systems to fulfil human needs (Nelson, 2005; Nelson & Vanpatter, 2004). Historically, designers have used scientific methods in an attempt to explain, predict, and control social, economic, and environmental transformations that take place in the real world. In general, the scientific method follows certain major steps, which have been summarised by Skyttner (2006, p.16): reduction of complexity through analysis; development of hypotheses; design and replication of experiments; deduction of results; and finally, rejection of hypotheses. Traditionally, scientific method adopts reductionism and analytical thinking to handle problems.

Reductionism contends that explaining phenomena on one level (i.e., fundamental parts) allows the deduction of explanations from a higher level (i.e., entire system). In other words, reductionism believes that everything can be reduced, or disassembled, to its fundamental and independent parts. It provides a foundation for analytical thinking, which from the property of the fundamental parts deduces the behaviour of the whole (Skyttner, 2006). Analytical thinking believes that combining the explanation of the behaviour of these fundamental parts leads to an explanation of the whole. In this thesis, I refer to the use of reductionism and analytical thinking to explain and investigate phenomena as the traditional scientific method. In the context of design, the use of the traditional scientific method often leads to the following problem-solving process: define a problem; reduce the problem into sub-problems; find solutions for each sub-problem (sub-solutions); aggregate all sub-solutions in an overall solution that addresses the problem as a whole.

2.3.2 Complementing reductionism and analytical thinking

Aristotle stated that unity relates to things “which have several parts and in which the totality is not, as it were, a mere heap, but the whole is something besides the parts” (Metaphysics, 1045a8–10, from www.plato.stanford.edu). Almost a century ago this idea of a transcendent existence of unitary wholes got translated by Gestalt psychologist Kurt Koffka as the now famous dictum of “the whole is other than the sum of the parts” (Koffka, 1935, p.176). It is a principle that in the literature has come to be known under the term *holism*. The holistic perspective presumes a synthetic mode of thinking, which “[...] is more interested in putting things together rather than in tearing them apart analytically.” (Misra, 2008, p.14). Systems science was among the first to suggest holism as a valuable corrective to reductionism, particularly when employing traditional scientific methods to understand social phenomena (Gharajedaghi, 2011; Jackson, 2001, 2003). It has been pointed out, however, that such criticism is not wholly justified because an inquiry which starts from the analysis of the parts still considers their interdependency to the whole through some principles and axioms (Murthy, 2000). Nevertheless, the notion of holism also implies approaching problem handling and stakeholder values using methodologies, tools, and techniques that are associated with a systems language.

While it is not the intention here to comment on the limitations of reductionism, this study contends that it is unlikely that the traditional scientific method alone can address the future consequences of present actions (e.g., sustainability issues). At best, it will prove ineffective in handling the vast majority of complex real-world problems (DeTombe, 2015a; Sterman, 2000; Taket, 1992) due to the lack and uncertainty of the knowledge needed to address the problem, and the lack of understanding of the characteristics of the system in place. At worst, the unanticipated side effects of the proposed solutions may create new problems (Sterman, 2000), and a degree of blindness for them. For instance, a personal transportation solution intended to be environmentally friendly by offering technological improvements in energy efficiency may result in side effects (rebound effects), such as an increase in the number of vehicles, an increase in energy consumption, and an increase in miles travelled (see Greening, Greene, & Difiglio, 2000). To address such a scenario, the integration of systems thinking into design approaches is proposed as a complement to the traditional use of reductionism and analytical thinking.

2.3.3 Systems thinking

Systems thinking comes from systems science, which is an interdisciplinary field that studies simple to complex systems in nature and society. In the context of this study, systems thinking is an approach to problem solving that considers the parts of larger systems as intertwined components rather than independent entities. Such an approach helps to gain an understanding of the relations and interactions between the various components of a system. The adoption of systems thinking can be especially helpful in illustrating the complexity inherent in socio-technical systems through better problem definition processes and visualisations (DeTombe, 2015a; Dzombak et al., 2014; Sevaldson, 2013, 2015); synthesising complex wholes, as opposed to breaking them into parts (Nelson, 2005); understanding causal relationships between parts (Dzombak et al., 2014); and putting forward differing worldviews by creating awareness of the differences in social relations (Daellenbach, 2001; Phelan, 1999; Zheng & Stahl, 2011). In fact, the integration of systems thinking into design theory and practice has been advocated as a promising approach to address the increasing complexity of societal problems over the years (Blizzard & Klotz, 2012; Blizzard et al., 2012; Jones, 2014; Sevaldson, 2013; Vanpatter & Jones, 2009).

By adopting various systems approaches and methodologies, systems thinkers have contributed to tackling complex societal problems, including those underlying sustainability challenges, by offering valuable strategies, tools, and techniques (Espinosa et al., 2008). For example, System Dynamics can help to gain a better insight into the role of stakeholders in complex decision-making processes (den Uijl & Bahlmann, 2002). Another example is seen in the Complex Problem Analysing Method (Compram) developed by DeTombe (2013, 2015a). The Compram methodology offers a multidisciplinary method of handling complex societal problems with the collaborative involvement of policymakers and other stakeholders (DeTombe, 2013). The approach is based on the understanding that societal problems are ill-defined and dynamic (i.e., they change over time), and that they involve multiple stakeholders who may have different perceptions regarding the ideal solutions to the problem (pluralistic perspective). Moreover, Meadows (1999) is an example of actionable systems strategies to identify important points for intervention in order to bring about change in complex systems. The author offers a scale of twelve leverage points, which are places in a system where small shifts can produce a significant change in the whole. Identifying critical leverage points can help considering the environmental limits of economic growth when intervening in complex systems.

2.3.4 Complex problems

Researchers use the term *problem* to describe a situation in which the actual and future desired state diverge. According to Ackoff (1981), a problem is a dilemma that cannot be solved within the current worldview. Looking at a problem situation, one can consider two distinct dimensions: problem complexity and diversity of views (Jackson & Keys, 1984). Regarding complexity, problems can be classified as simple, complicated, or complex (Valckenaers & Van Brussel, 2016). This classification relies on the number and types of components and characteristics of the problem situation, and on the interactions between them. The classification also refers to how problems can be defined, described, and structured, and to how unpredictable the problem situation is likely to be (DeTombe, 2015a; Valckenaers & Van Brussel, 2016). For example, designing a chair can be considered a simple problem, while in comparison, designing a bus comprised of thousands of mechanical parts is relatively complicated. Both simple and complicated problems, in these examples, are easier to define than complex problems because they describe, structure, and present relatively more simple and predictable behaviours. Complex problems on the other hand, like designing a sustainable transportation system, follow more unpredictable rules because of the different nature of the components and characteristics, number of components and interactions between them (Valckenaers & Van Brussel, 2016).

Moreover, a problem situation can result in a diversity of views, due to multiple values and interests among the involved and affected stakeholders, leading to different goals, expectations, and concerns about the problem situation. Another source of diversity can be differences in social relations in terms of power, domination, and alienation (Daellenbach, 2001), as existing between individuals and groups in different hierarchical, economic, and political positions. Two major types of complexity are considered here: technical complexity and societal complexity. Technical complexity concerns the physical nature of a problem situation. This kind of complexity often arises in technical systems where boundaries are relatively well defined, well described, and well structured, with little diversity the in views of involved stakeholders. The components of systems with high levels of technical complexity often encompass materials, products, machines, and constructed facilities. For example, product complexity comprises factors such as a higher number of functions and physical parts, which contribute to technical complexity. Furthermore, societal complexity is associated with the relationships between the stakeholders within a system. Societal complexity increases in systems where relations between humans and institutions are central to the problem situation, such as sustainability challenges in low-income markets.

2.3.5 Complex societal problems

In the disciplinary domain of design, little attention has been paid to handling complex problems or systems. What designers have gained in terms of expertise and understanding of complex problems, they have gained through practice rather than education (Siddiqi et al., 2014). In addition, handling complexity in design is often associated with technical systems with well-defined requirements, well-described starting conditions, and well-structured courses of action. Since complex societal problems also have a strong social side to them, most knowledge in design about complex problem-solving has limited application. Seen in this light, the expertise of designers, which builds upon traditional design approaches, has limitations to address problem situations where technical and societal complexity are entangled, especially since the latter form of complexity is most important for creating successful interventions (Moser & Wood, 2015; Siddiqi et al., 2014). Thus, design approaches to complex societal problems should devote a great deal of attention to social processes, stakeholders relationships and their interrelation with technical factors (Metcalf, 2014).

Complex societal problems are real-world problems, mostly ill-defined, involving multiple stakeholders in an intertwined and dynamic network that may change over time, and that affects multiple aggregation levels of the socio-technical system in place (DeTombe, 2015a). Complex societal problems are far from obvious, and solutions for those problems are far from optimal. They are often very hard to define due to limited information about specific problem situation and lack of context-specific knowledge. Nevertheless, they are problems that impact everyday life, as is the case with sustainability issues in developing countries (DeTombe, 2013, 2015a). For example, the complex societal problem of providing access to affordable, reliable, and sustainable energy in low-income households is hard to define, describe, and structure based on the available resources, infrastructure, and demand (see Costa Junior, Diehl, & Secomandi, 2018). While complex systems or problems may involve a high level of technical complexity, the term *complex societal problems* adopted in this thesis refers to complex problems where technical complexity is entangled with societal complexity, and relations between humans and institutions create additional complexity.

2.4 Systems approaches

Over time, systems thinking has followed multiple systems traditions, also referred to by systems thinkers as "systems approaches". A classification of systems approaches is explored, which aims to identify relevant criteria for the adoption of systems thinking into design. Accordingly, based on problem complexity and stakeholders' diversity of views, one can classify systems thinking along three major systems approaches: Hard Systems Thinking; Soft Systems Thinking; and Critical Systems Thinking (Figure 2.2).

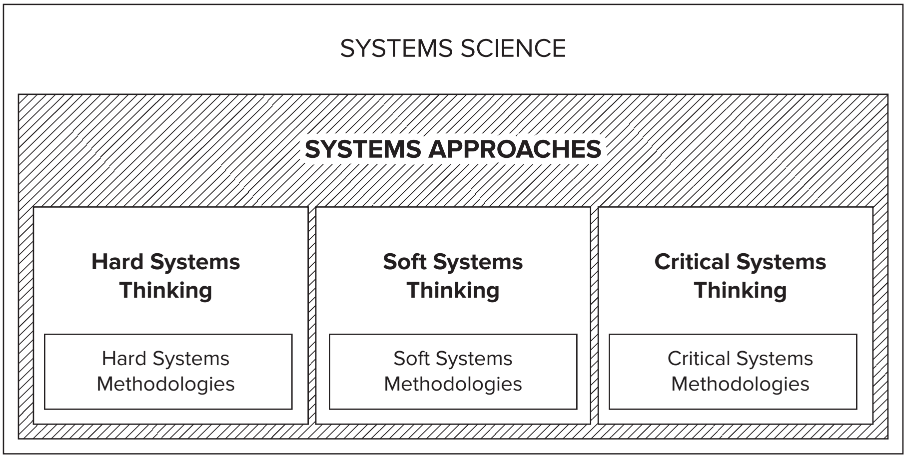


Figure 2.2 Systems Approaches.

According to Jackson (1991), systems approaches can be discussed in terms of the appropriate problem-solving approach, the social context within which related methodologies are used, and the consequences of its use. As such, the presented classification allows us to point to the underlying assumptions, the strengths and weaknesses of these different systems approaches. As we shall see, the various systems approaches have certain domains for which their application is most appropriate and effective.

2.4.1 Hard systems thinking

Hard systems thinking is based on the assumption that a problem situation is best addressed by optimising the performance of the system to achieve clearly defined objectives and goals (Checkland, 1978). This approach understands systems as “objective” aspects of reality, comprised of relatively hard (immutable), observable, and real objects. The understanding of systems is therefore considered largely independent of the observer and value-free (Oliga, 1988). Hard systems methodologies generate an objective account of the system of concern (Jackson, 2003) and aim to generate material well-being by increasing efficiency, improving productivity, and optimising performance.

Hard systems methodologies include, for example, Classical (also referred to as traditional) Operational Research (Churchman, 1957), Systems Engineering (Hall, 1962) and Systems Analysis (Optner, 1973). In general, each involves the use of quantitative models (e.g., spreadsheets, diagrams, and computer simulations) capable of dealing with highly complex physical relationships (Daellenbach, 2001) and simulating the system’s performance under different conditions (Jackson, 1985). These methodologies are often employed in an attempt to predict and control the behaviour of the system. Other systems methodologies question the limits of assumptions underlying hard systems while trying to pursue similar goals (i.e., to determine key aspects that lead to system viability and performance). These systems methodologies, namely: System Dynamics (Forrester, 1971; Meadows et al., 1972); Organizational Cybernetics (Beer, 1972); and Complexity Theory (see Anderson, 1999), are classified separately from hard systems thinking by some authors (e.g., DeTombe, 2015b; Jackson, 2003).

2.4.2 Soft systems thinking

Aware of the limitations of functionalist hard systems approaches, systems thinkers have developed systems methodologies which assume that problem situations may present predominantly societal complexity (Ackoff, 1979; Checkland, 1978, 1981; Oliga, 1988). This concern suggests that very few real-world problems manifest themselves in terms of systems with clearly defined goals and objectives. Hence, to extend the application of systems thinking to ill-defined problem situations, systems thinkers (e.g., Churchman (1971), Ackoff (1972), and Checkland (1981)) have developed systems methodologies which assume that problem situations have to be handled, rather than solved. Soft systems thinking adopts a “subjectivist” perspective to systems thinking, in which the problem situations reflect a social world of subjective meaning and intention (Oliga, 1988).

Soft systems methodologies seek to understand particular interpretations of the social world, to create shared understanding and consensus so that mutual agreement can emerge about action to be taken (Jackson, 1991; Oliga, 1988). Soft Systems Methodology (Checkland, 1981), Inquiring Systems Design (Churchman, 1971) and Social Systems Design (Gharajedaghi, 2011) illustrate systems methodologies that put stakeholders' values and interests at the core of their purpose. For instance, Soft Systems Methodology (SSM) is a methodology for systems development that accounts for the social system into which a technical system must integrate (Baskerville et al., 2009).

2.4.3 Critical systems thinking

Critical systems thinking emerged as a response to the limitations of hard and soft systems thinking. A major shortcoming of hard systems thinking is that the decision-making process can enforce the development and implementation of an "ideal" problem solution to the detriment of other opportunities (Bausch, 2014). In addition, as Jackson (1982) observes, the interpretative assumptions underlying soft systems thinking constrain the ability of soft systems methodologies to ensure a fair debate among stakeholders in many problems situations. Notably, the co-participative debate that is key to the success of soft systems thinking cannot be achieved when problem situations are dominated by coercive relationships (Jackson, 1991).

Critical systems methodologies aim at the prevention of technical and social (political) influences in communication, which can interfere with the achievement of an open and free debate during the design and implementation of a system. For instance, Critical Systems Heuristics (Ulrich, 1983) provides guidelines for action in coercive problem situations, to promote open debate between those involved in the design of the system and those affected by the designed system. According to Jackson (1991, p.142), critical systems thinking "is about putting all the different systems approaches to work, according to their strengths and weaknesses and the social conditions prevailing", to result in a more general emancipatory design.

2.5 Systems methodologies

In previous sections, I described how a classification based on complexity and social processes is useful for the assessment of the relative strengths and weaknesses of systems approaches, and the consequences of employing different systems methodologies. Hence, the systems methodology of choice depends crucially on the type of problem situation (Jackson & Keys, 1984). When systems thinkers attempt to address a problem situation, they systematically use various systems skills, techniques, and tools, and by doing so employ a systems methodology (Jackson, 2003). The different characteristics of systems approaches imply various forms of inquiry and action that underwrite different systems methodologies. A designed system can be developed from many points of view, which can be seen as complementary rather than competitive (Skyttner, 2006). Building on the analysis of the three systems approaches seen in Section 2.4, this section reflects on the linkages between the various systems methodologies and the field of design.

2.5.1 Reflections on hard systems methodologies: Modelling and simulation

Within hard systems, the problem-solving process is closest to that traditionally used in design. Notably, problem solutions are deliberated, preferred solutions are selected, and a "final" chosen solution is further developed, implemented, and evaluated (Bausch, 2014). This approach works well to optimise results when starting conditions are known, and the problem is well-defined. On the other hand, a major drawback is the implication that a problem solution is put forward at the expense of other possibilities (Bausch, 2014). Nevertheless, research on modularisation and customisation of engineering products and systems have contributed to the development of methods to prioritise the development of components for modularisation, predict change propagation and design for customisation (Clarkson et al., 2001; Koh et al., 2015).

The technical nature of hard systems thinking assumes that the real world comprises systems that can be "designed". Therefore, it implies that models of those systems can be made and their behaviour can be simulated (Checkland, 1985). A model is a tool used to gain insights into phenomena and stakeholders, and the relations between them (DeTombe, 2015b). Modelling and simulation tools represent a significant contribution from hard systems methodologies to design and engineering. For example, System Engineering (SE) is an established hard systems methodology for handling complexity and tackling the challenges of product development (Biahmou, 2015). System Engineering applies development models, such as product lifecycle models, functional flow block diagrams, and data flow diagrams to synthesise data as a basis for better decision-making processes.

Previous research in design has explored the relevance of hard systems methodologies to handle complexity and develop product-service systems. Cavalieri and Pezzotta (2012) provide an up-to-date review of the literature on SE, paying particular attention to how SE can support the design and development of services either as a system or as a product-service combination. Afshar and Wang (2010) use System Dynamics (SD) to develop models and simulate system behaviour quantitatively, allowing designers to handle the structural complexity of product-service systems. The authors of the study have employed SD tools to represent systemic relationships among stakeholders, economic activities, and material flows, as well as to simulate cause and effect relationships among those components.

2.5.2 Reflections on soft systems methodologies: Participatory design

The paradigm shift towards societal perspective in design has slowly moved stakeholders from their traditional role as a "passive audience" to become "co-creators of value" (Prahalad & Ramaswamy, 2000, p.80). Other authors share similar presumptions about participation in design (Cross, 2001; Nelson, 2008a). Design as a social process takes place in a conglomerate of interactions and negotiations between stakeholders who bring with them their individual worldviews, comprised of their specific knowledge and awareness of aspects of the system under design (Metcalf, 2014). Therefore, there is a need for collaboration among those who design the system, those affected by the designed system, and those invested in the outcome of the system but who are not directly served by the outcome (Nelson, 2008a).

Soft systems methodologies can assist in bringing about accommodation between distinct value positions and can generate commitment among stakeholders to implement agreed objectives (Jackson, 2003). Soft systems thinkers such as Churchman, Ackoff, and Checkland, through their systems methodologies, advocate respect for the worldviews, goals, and objectives of all the stakeholders involved in the problem situation and affected by the problem solution (Jackson, 1985). Another major aspect of soft systems is their attempt to avoid formulating problems according to one particular perspective to the exclusion of others. Using open-framed problem definitions and open-ended solutions equip designers with the ability to adapt and reconfigure solutions to better fit the needs of the system during the project development. Moreover, such adoption allows designers to deal with higher levels of uncertainty and unpredictability.

Soft systems move from the idea of "optimising" to the concept of "learning" (Checkland, 1985). Such methodologies are also influenced by research fields like action research and participatory action research. These provide human-centred approaches like Participatory Learning and Systems Learning (see Flood, 2010; Ison et al., 1997)**.** Influences of this type of research can be seen in emerging design approaches, such as human-centred design (ISO, 2010), customer-centred design (Beyer & Holtzblatt, 1997), people-centred design (Wakeford, 2004), user-centred design (Vredenburg et al., 2002), and Participative Ecodesign (Ison, 1993).

2.5.3 Reflections on critical systems methodologies: Design ethics

The integration of critical systems methodologies into design practice involves two major aspects: design ethics and implications of design practice. Scholars have raised concerns about the design of social systems and the underlying ethical choices of designers (see Banathy, 1996; Manzini, 2006). According to Manzini (2006), when a solution is dictated by coercive relationships and technical constraints, there is no design in place. Manzini challenges the idea of wellbeing socially constructed over time in design, which is based on the democratisation of access to products (product-based wellbeing). Instead, he proposes the conception and development of systems that consider and enable people's capabilities and promote sustainable well-being. Similarly, others advocate that people in the system should become the experts, rather than the design being brought from experts (Metcalf, 2014).

The second aspect, which concerns the implications of design practice, refers to the social consequences of design action and choices concerning specific methods, tools, and techniques. Choices made by designers with strong systems thinking background are guided with respect to the appropriate way to engage the problem regardless of the situation (Bausch, 2014). Critical systems thinking provides valuable insights into criteria for complex problem-solving methods, tools, and techniques (Murthy, 2000). For example, some authors have provided insight to increase understanding of the strengths, weaknesses, and theoretical underpinnings of available systems methodologies (critical awareness) (Oliga, 1988); to make explicit the social consequences of using different systems methodologies (social awareness) (Jackson, 1985); to promote human emancipation (Jackson, 2001; Ulrich, 1983, 2013); and to support systems practice (pragmatism) (Jackson & Keys, 1984).

2.6 A selection of systems design approaches

This thesis builds on central and relevant theories and practices that contribute to the debate of systems thinking and sustainability in design. It aims to foster designers' understanding of systems thinking in order to contribute, through design, to the handling of complex societal problems. It should be emphasised that in this study, a systems design approach differs from a systems approach. As presented in Section 2.4, systems approaches are concerned with the various traditions of systems thinking. It implies different ways of thinking about how a systems approach relate to each other and how they use distinct sets of methodologies, knowledge, skills, and tools to solve problems. A systems design approach refers to the mental model through which designers can frame the world using systems thinking. It guides designers in their interpretation of systems approaches and methodologies to handle complex problem situations and design better systems.

Figure 2.3 illustrates the process in which systems theory is incorporated into the design's core competences (see Conley 2004), and therefore, allows the development of design theory grounded in systems theory. Conley (2004, p.46) proposes seven core competences to designers: (I) The ability to understand the context or circumstances of a design problem and frame them in an insightful way; (II) The ability to work at a level of abstraction appropriate to the situation at hand; (III) The ability to model and visualise solutions even with imperfect information; (IV) An approach to problem-solving that involves the simultaneous creation and evaluation of multiple alternatives; (V) The ability to add or maintain value as pieces are integrated into a whole; (VI) The ability to establish purposeful relationships among elements of a solution and between the solution and its context; and, (VII)The ability to use form to embody ideas and to communicate their value.

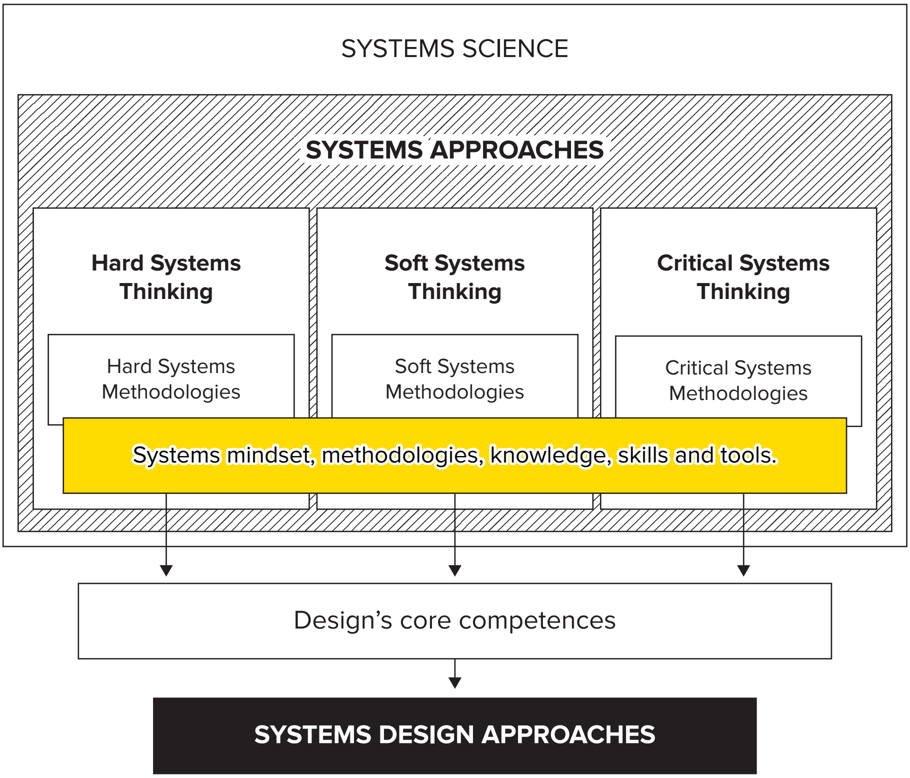


Figure 2.3 Systems design approaches.

So far, I have attempted to gain a better understanding of systems thinking. In the next sections, I capture examples from the literature that illustrate how the design community has interpreted and employed systems methodologies to tackle complex societal problems. In particular, I strive to identify critical factors that contribute to enhancing integration.

2.6.1 Whole system(s) design

Whole system(s) design (WSD) is a collaborative and integrative approach that aims to enhance the collective response to complex societal problems, such as sustainability challenges (Pittman, 2004; Stasinopoulos et al., 2009). It uses learning principles based on a holistic approach to systems inquiry and design practice (Nelson, 2005; Nelson & Vanpatter, 2004). While systems thinking provides a base for synthesising knowledge, design practice supports innovative inquiry and creative action (Nelson, 2005). Through this approach, designers make decisions and choices on what systems methodologies and design tools to employ based on their understanding of each problem situation and their expertise (Nelson, 2004).

Whole system(s) design exploits soft systems methodologies like Inquiring Systems Design (Churchman, 1971), and Social Systems Design (Churchman, 1971; Ulrich, 1983). This systems design approach contends a co-participatory approach to the problem situation, where solutions should not be imposed. Rather, stakeholders should be empowered in the functioning of the system. Moreover, stakeholders actively participate in the conceptualisation and implementation of the newly designed system (Nelson, 2004). Box 2.1 provides a summary of a worked example that demonstrate the application of WSD to redesign a residential heating, ventilation, and air conditioning system (HVAC).

Box 2.1 Using Whole Systems Design to a redesign temperature control system

The Natural Edge Project is a collaborative research project which focuses on innovation for sustainable development. In this project, the Whole Systems Design (WSD) was applied as a worked example for redesigning a residential heating, ventilation, and air conditioning system (HVAC) (see Stasinopoulos et al., 2009). Major WSD strategies were used: model the system (e.g., calculate the HVAC system based on cooling land and heat gain); review the system for potential improvements (e.g., focus on heat gain for reducing cooling loads); design and optimise subsystems in the right sequence (e.g., maximise effectiveness by structuring the sequence of passive and active technologies); design and optimise subsystems to achieve compounding resource savings (e.g., adopt electrical appliances with minimal energy requirements); design and optimise the whole system (e.g., allow flexibility in terms of house component combinations when comparing system performance and costs).

The project's results report that the WSD solution has a cooling load 29% lower than that of the conventional solution. By complementing active technologies, like air conditioning units and artificial lighting, with passive technologies, like shading and solar heating, the overall demand for energy consumption was reduced. In addition, the WSD solution resulted in lower greenhouse gas emissions, greater viability for the application of renewable energy technologies, and higher thermal, visual, and acoustic comfort by operational cost.

http://www.naturaledgeproject.net

2.6.2 Systems oriented design

Systems Oriented Design (SOD) is a skill-based approach intended to develop better designs, visualisations, and systems practices (Sevaldson, 2010, 2011, 2013). This holistic approach was developed in project-based education with the intention of creating a new generation of designers who can cope with enhanced complexity (Sevaldson, 2011, 2013; Sevaldson et al., 2010). It considers different hierarchies and boundaries within a particular socio-technical system to increase the capacity of the system to address its function and achieve sustainability (Reinders et al., 2012; Sevaldson et al., 2010). As such, it proposes the design of a coherent combination of processes and product-services combinations that together can fulfil the function of the system.

According to Sevaldson (2008, 2015), early systems thinking research followed a mechanistic approach which regards systems as mechanical, cause-effect driven networks, and therefore, offers a limited fit for the scope of Systems Oriented Design (SOD). Hence, SOD adopted a pragmatic view on modern systems thinking rooted in soft and critical systems thinking which “deals with the dynamic complexity of real-world problems in a pragmatic way” (Sevaldson, 2013, p.3). For example, from Systems Architecture (SA), SOD explores the capability to synthesise complex problem situations (Sevaldson, 2009). Moreover, Soft Systems Methodology (SSM) offers helpful tools like the Rich Picture (Checkland, 1981). The concept of Rich Picture was reformulated to create a generative mapping tool called GIGA-mapping (Sevaldson, 2011). GIGA-mappings are large and information-dense diagrams that act as a bridge between inquiry and design (see Box 2.2). Such visualisation maps are used to synthesise and interrelate knowledge, and they promote a shared understanding of the system among stakeholders (Sevaldson, 2013, 2015). Figure 2.4 provides an overview of the knowledge system within SOD (Sevaldson, 2019).

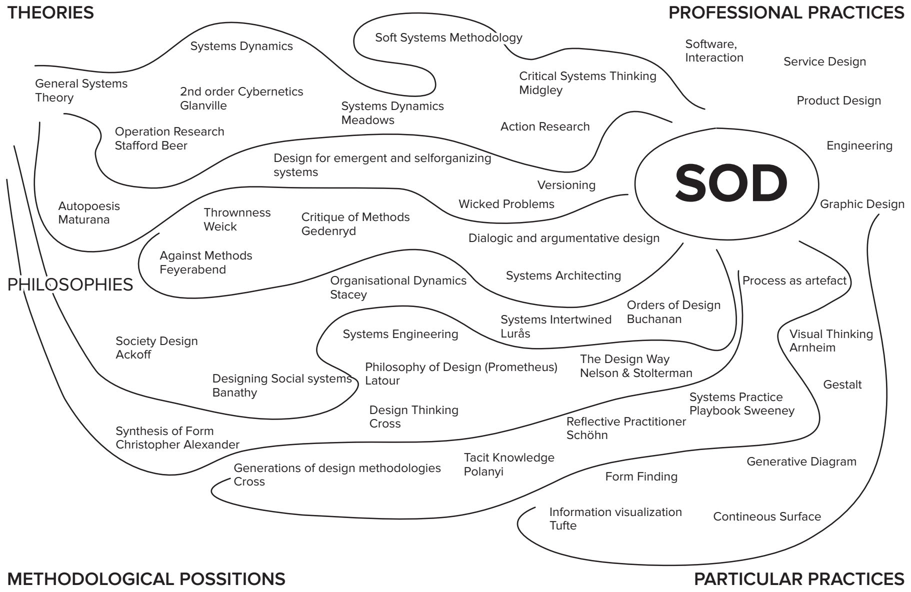


Figure 2.4 Knowledge system within SOD (Image © Birger Sevaldson, used with permission). Source: B. Sevaldson (personal communication, December 11, 2019).

Box 2.2 GIGA-mapping as a tool for learning about complexity

GIGA-mapping is an important tool for design inquiry in Systems Oriented Design (SOD). This map aims to gain better understanding of the complexity of the system at hand and to promote a dialogue between involved and affected stakeholders. It draws on many other well-established tools, including rich picture, mind mapping, causal loop model, service blueprint, scenario, user journey and collage (Sevaldson, 2015). GIGA-mapping has been used in design education as a way of teaching students to better cope with complexity through visualisation, visual thinking, and generative diagramming. It can assist learning, research, imagination, management, planning, mapping, innovation, and implementation (Sevaldson, 2011). The Institute of Industrial Design at the Oslo School of Architecture has employed this tool to address complex societal problems in project-based courses. For example, Master's student Francesco Zorzi used GIGA-mapping to demonstrate the feasibility of designing a small-scale energy harvesting system. The project aims to make small everyday objects into energy-harvesting, rather than energy-consuming, devices.

http://www.systemsorienteddesign.net/index.php/projects/master-projects/aho-2009/55-small-scale-energy-harvesting

2.6.3 Product-service systems

In the literature, the integration of product and services is most often called a Product-Service System (PSS). However, the fundamental assumption underlying PSS, i.e. to provide functions which fulfil human needs through product-service combinations, is found across different disciplines, such as Operational Research, Information Systems, Systems Engineering, Cyber-Physical Systems, Innovation and Business Management, and Marketing. While there is no consensus regarding the roots of PSS in Systems Science, many authors provide corroboration that this approach fundamentally follows a holistic mindset (Briceno & Stagl, 2006; Coley & Lemon, 2009; Geum & Park, 2011; Lindahl et al., 2007; Mukaze & Velásquez, 2012).

Previous studies have attempted to combine PSS and the field of systems thinking (Afshar & Wang, 2010; Cavalieri et al., 2012; Ceschin, 2012b; Joore & Brezet, 2015; Vezzoli et al., 2008). For instance, Afshar and Wang (2010) propose employing System Dynamics (SD) in PSS as a tool for analysing/synthesising causal loops (e.g., systemic relationships among stakeholders, economic activities, and material/energy resources) and simulating the dynamic behaviour of systems quantitatively (simulate system's behaviour). Also, Joore (2010) proposes a multilevel approach that takes into consideration the development of PSS in relationship to the changes that happen within its socio-technical systems. Box 2.3 presents an example of a product-service system solution that adopts the Methodology of Product-Service System (MEPSS) (Halen et al., 2005).

Box 2.3 Product-Service System for sustainable cooking

The project Monno (modular oven supporting online-community based services) employed the Methodology of Product-Service System (MEPSS) (Halen et al., 2005) in order to generate systems-oriented solutions to the act of cooking in a sustainable way (see Costa Junior et al., 2010) (Written in Portuguese). The proposed solution aims to reduce the material content needed to satisfy user needs and lower the overall environmental impact during the product life cycle. To accomplish this task, the project turned attention from products to relations (e.g., materials, services and financial flows). In particular, the tool systems map was central to gaining better understanding of the systemic relations among stakeholders, activities, knowledge, economic and material resources.

http://www.mepss.com

2.6.4 Design for Development

Both the need to support increasing changes in the scale of the challenges facing the development of society's infrastructure and resource limitations, have led to the emergence of new fields of design. The adoption of systems thinking in design is perhaps most needed in the context of developing economies, where almost no formal systems are in place and where there is a lack of socio-technical networks and infrastructures (Sklar & Madsen, 2010). Design for Development (DfD) includes design approaches aimed at marginalised groups, where problem solutions assist social, human, and economic development (Donaldson, 2002). Those emerging approaches recognise the need for a societal perspective which considers the capacity of design to improve stakeholders' well-being by meeting currently unmet basic needs of existing generations while fostering sustainable production and consumption for future generations.

For instance, some approaches aim to improve social and economic sustainability performance, such as Design for the Base of the Pyramid (DfBoP) (Crul & Diehl, 2006). Other approaches focus on assisting stakeholders to employ personal resources (individual capabilities), and problem solutions to which they have access, like the Capability Approach (CA) (Mink et al., 2018; Nussbaum & Sen, 1993) (see also Box 2.4). According to Oosterlaken (2009), DfD approaches have raised awareness about how designers practice design. For the author, to expand human capacities of marginalised groups with the help of design, systems thinking needs to be integrated into design, as in approaches like Whole System Design (WSD) and Product-service system (PSS).

From a systems thinking point of view, designers should empower communities to solve their own problem situations (Meadows, 2008). Oosterlaken (2009), Mink (2016) and Mink et al., (2018) discuss at length the relationship between design and the Capability Approach (CA) and highlights the differences in social relations of power as a major issue in the expansion of human capabilities and agency by design. Furthermore, Zheng and Stahl (2011, 2012) argue that CA fails to consider issues of distribution of power and conclude that Critical Theory, as applied by Information Systems and Science and Technology Studies, can be beneficial. Critical Theory follows two major approaches: Critical research in information systems; and Critical theory of technology. Similar to Critical Systems Thinking, these approaches aim to reveal the social structure of power, control, domination, and oppression, and thereby promote emancipatory social practices (Zheng & Stahl, 2011).

Box 2.4 Systems-oriented approach in DfD projects

Despite the designers' best intentions, practices, and beliefs, the outcomes of a Design for Development (DfD) project can still fail to improve the well-being of users. With the aim of creating awareness of designer's biases and assumptions regarding the beings and doings which users' value, Mink (2016) developed a systems-oriented approach to obtain comprehensive insights in peoples' well-being. Based on Sen's Capability Approach (CA), Mink provides analytical and practical guidance to take people's personal characteristics and their circumstances into account when exploring the lives of potential users in DfD projects. The research results consist of a Capability Design Driven Approach (CA-based thinking framework), and an Opportunity Detection Kit (thinking framework, guidelines, themes, questions, techniques, and tools).

http://www.design4wellbeing.info

2.7 Results: Conceptual framework for a systems design approach

Design is an approach to inquiry and action not limited to the creation of physical products or structures. Rather, it is "an approach to human agency in a complex world" based on foundational ideas inclusive of systems thinking (Nelson 2008a, p.2). According to Checkland (2000), systems practice, or when a problem solver knowledgeably applies a systems methodology to improve a perceived problem situation, involves three fundamental elements: the underlying methodology; the perceived problem situation; and the stakeholders involved and affected by the use of the approach. Systems practice is helpful to generate an understanding of how a systems design approach **(A)**, which is the application of different systems methodologies and design methodologies **(M)** supports stakeholders **(S)**, whether those users are involved or affected stakeholders, to handling a problem situation **(P)**.

For instance, Systems Oriented Design (SOD) **(A)** (Sevaldson, 2011, 2013) builds on largely in three systems methodologies, Soft Systems Methodology and Systems Architecting and Visual Thinking **(M)** (Sevaldson, 2011). This systems design approach relies heavily on the technique of GIGA-mapping, which is a holistic mapping tool for boundary critique (e.g., boundary judgments concerned to what observations are to be considered relevant or not) to the conception and framing of complex systems (Sevaldson, 2011). Developed using SOD, the project ECO CAP (ecological capsule for cloning trees) proposes a holistic evaluation of economic and social factors in rural communities to engage in the local production of seedlings and the planting of trees as an alternative to public-private partnerships (Sevaldson, 2009). The Institute of Industrial Design at the Oslo School of Architecture **(S)** has used this approach to address complex societal problems **(P)** in small communities in Oslo **(S)**.

Existing systems design approaches, such as those presented in Section 2.6 have provided a significant contribution to the transition from a traditional design approach to a systems-oriented perspective in design. Based on these theoretical insights, I emphasise the need for developing new and strengthening existing systems design approaches. Therefore, this chapter proposes a conceptual framework that aims to support new and existing approaches to explore the resources of systems thinking from which they can draw. The following sections present the main discussions involving the five major clusters or set of elements of the framework and demonstrate how they influence each other in an iterative process: mindset, methodology set, knowledge set, skill set and tool set.

Mindset concerns the understanding of the assumptions underpinning systems thinking. It supports designers to reflect on the need to complement traditional design approaches with a systems-oriented perspective when addressing complex societal problems. The *methodology set* deals with identifying a dominant way of thinking adopted by a systems methodology and creating alignment with the designer's problem-solving approach. By identifying the dominant stance of the systems methodologies adopted, a better understanding of the appropriate knowledge required to address a problem situation can be created. Based on the result of this stage, through *knowledge set* is possible to determine the appropriate knowledge that needs to be generated to address the problem. The *skill set* covers the complementary skills to design's core competencies required to support the production of knowledge required for handling the problem or system. Finally, *tool set* covers tools and techniques that can be used to explore competencies in order to mediate and facilitate reasoning, visualising, modelling, sense-making and sense-sharing.

Whichever systems approach is taken, it is important to acknowledge that each approach has different strengths and weaknesses. Therefore, any systems approach is better introduced into design through a combination of aspects from different systems methodologies. This makes it interesting to reflect on the overlaps and distinctions between the various systems approaches and methodologies which were presented in previous sections. The conceptual framework that emerged from the literature review offers criteria for systematically and informed exploration of systems thinking. It is proposed and discussed largely in terms of Ryan's (2014), Nelson's (2004, 2005), Jackson and Keys' (1984), Banathy's (1987) and Habermas' (1972) formulations. This framework supports new thinking through the cross-fertilisation of knowledge and perspectives focusing on systems practice (see Figure 2.5).

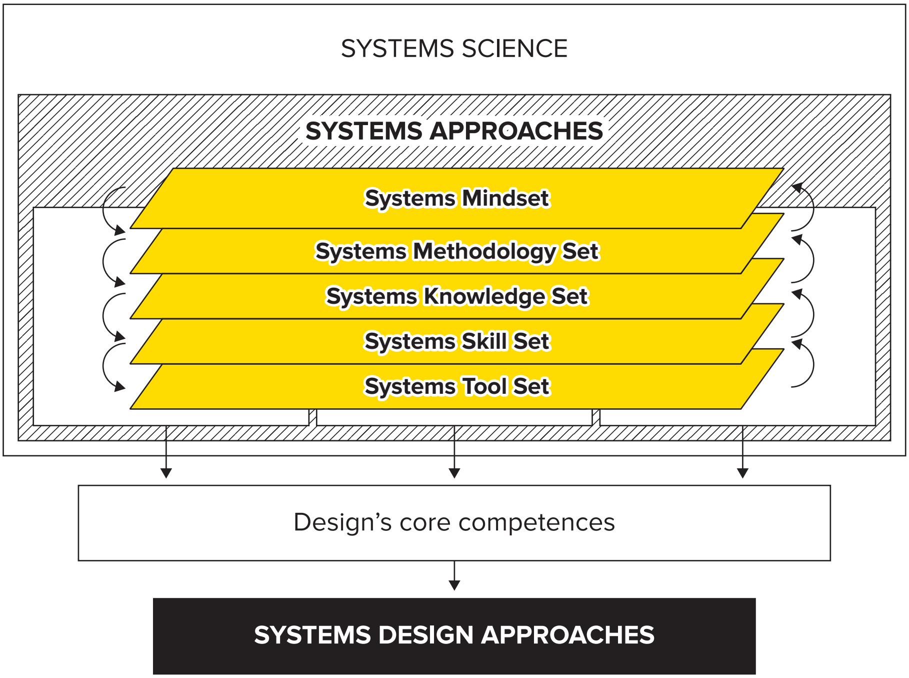


Figure 2.5 Conceptual framework for systems design approach.

It is not intended that the framework represent a tool for choice of methodology. Instead, it is meant to provide support for the exploration and interpretation of systems theory in the context of design. It predicates the appropriateness of different systems methodologies through reflection on the nature of the problem situation and the relationship between stakeholders. Answers to reflective questions assist in the systematic identification of relevant characteristics of the problem, system, and stakeholders, which are helpful in making decisions and selecting resources such as methodologies, tools, and techniques (see Table 2.1). Given these considerations, the proposed framework is an attempt to support designers to tailor a traditional design approach to a systems-oriented approach by integrating systems thinking into design through the consideration of five set of elements described in sections 2.7.1 to 2.7.5. Along with the explanation of each cluster, I provide a hypothetical example that illustrates the application of each element of the framework.

Table 2.1 Overview of the conceptual framework for systems design approach.

Resources	Process	Reflective questions	Examples
Mindset	Reflect on the need to complement the current design approach with systems thinking tenets	What are the main assumptions underlying the current design approach?	Holism, pluralism, analytical thinking, reductionism.
		What are the limitations of the current design approach?	Lack of interrelatedness, inability to cope with complexity, closed problem definition and framing.
Methodology set	Evaluate the effectiveness of systems methodologies	What is the fundamental nature of the problem?	Technical complexity, societal complexity.
		What are the predominant relationships among stakeholders?	Unitary, pluralist, coercive.
		What is the main focus of the current design approach?	Optimise performance, create shared understanding, emancipate or empower stakeholders.
		What are the underlying paradigms that guide the application of the systems methodology?	Functional, interpretative, emancipatory.
		What is the level of objectivity and value neutrality acknowledged?	Influence of the observer moral judgment and values, bias, activism.
		What is the perceived complexity of the problem?	Relatively well-defined, ill-defined.
Knowledge set	Determine the appropriate knowledge creation process	What are the types of data required and how they can be collected, processed and analysed?	Qualitative, quantitative, data requirements, data collection, data processing, data analysis.
		What are the key factors influencing the creation and understanding of knowledge?	Human interest, design knowledge.
		What is the type of knowledge required to address the problem?	Instrumental, practical, emancipatory.

Skill set	Identify the need for complementary skills	What are the key collective competencies required? What are the key individual competencies required?	Complexity-handling, human-centred perspective, sense making, co-creation, teamwork.
Tool set	Define appropriate tools and techniques	What tools can explore, mediate and facilitate collaborative inquiry and reasoning?	Root definitions, mental models, causal/feedback Loop, stock/flow diagram.
		What tools can explore, mediate and facilitate collaborative sense-making and sense-sharing?	Generative, participatory and Iterative tools.
		What tools can explore, mediate and facilitate collaborative visualising, simulation and modelling?	Computer-based models and simulation, systems maps.

2.7.1 Systems mindset: Establishing the need for systems thinking

This framework element is broadly applicable to complex societal problems. Fundamentally, systems mindset is proposed as a complement to, rather than a replacement for, traditional design approaches. Designers should reflect on the main assumption underlying the current design approach to reveal its limitations. In a hypothetical energy solution for low-income households in rural areas, the design team may recognise that the current design approach lacks resources to examine the problem of energy access from multiple perspectives. Nevertheless, the attention to the diversity of views of stakeholders and the impacts of energy solutions across system levels of the low-income energy market is paramount to bring about transitions to sustainable energy systems. Once the limitations are outlined, system-thinking tenets can be put in place to ensure that the desired outcome can be achieved. As proposed in the framework, the shift to systems design approach concerns the adoption of four major systems thinking tenets: a holistic perspective; a pluralistic perspective (diversity of views); a multilevel perspective and complexity-handling capacity.

First, corroboration exists that a holistic perspective to the problem solution is paramount when designing solutions for complex societal problems such as those concerning sustainability issues like energy challenges in low-income markets (Blizzard & Klotz, 2012; Cardenas et al., 2010; Clegg, 2000; Forlizzi, 2012; Jones, 2014). A major challenge in complex societal systems is that system components in isolation do not achieve sustainability for the whole. In contrast, if the system of concern is sustainable, then the system components therein can be regarded as sustainable (Gaziulusoy, 2015).

Second, many authors agree that systems thinking has the potential to hold differing worldviews (Daellenbach, 2001; Jackson, 2003; Jackson & Keys, 1984) and promote a participatory design process that considers the interconnections between stakeholders and others components of the socio-technical system (Laszlo et al., 2009). This pluralistic perspective is particularly relevant in low-income energy markets because designing effective solutions involves multiple stakeholders including private companies, government, energy utilities, end-consumers, knowledge producers, community representatives and non-governmental organisations.

Finally, systems thinking is a problem-solving approach capable of handling high levels of problem complexity (Ackoff, 1974; DeTombe, 2015b, 2015a; Espinosa et al., 2008), as well as multiple aggregation levels of a problem (DeTombe, 2015b; Elzen et al., 2004; Geels, 2005; Joore & Brezet, 2015). Given the complexity of energy challenges in low-income markets, it is likely that improvements on a lower level (e.g., new products and technologies), although fundamental, are limited to create sustainable energy transitions. The transition to sustainable energy systems in low-income markets requires profound technological, institutional and sociocultural transformation, which requires the attention to multiple aggregation levels of the socio-technical system in place.

2.7.2 Systems methodology set: Identifying a dominant way of thinking

Systems methodology set concerns the understanding of the underlying paradigms that guide the interpretation of systems approaches and the application of systems methodologies. Systems approaches are structured and dominant ways of thinking that follow different theoretical reasoning, namely functionalist, interpretative, and emancipatory (Daellenbach, 2001; Jackson, 2001). For this reason, it is important to take account of the dominant epistemological stance of a given systems approach. The stance adopted can affect whether a piece of information generated or collected using a given systems methodology is accurate or not to develop a solution, given the characteristics of the problem and the relationship between stakeholders of the system.

For example, for the case of an energy solution for low-income households in rural areas, the design team would likely adopt a participatory approach in which all parties need to be willing to share information to achieve shared understanding, giving the users the role of co-creators. This process plays an important role in the outcomes of the system, in particular if the low-income population have limited access to information and education and do not actively participate in the definition of policies and solutions for the problems of the communities in which they live. Energy-related issues are often hard to tackle due to limited information about specific problems that impact the everyday life of the population and the societal complexity within the network of stakeholder involved. In this context, the design team would greatly benefit from the application of resources from interpretative and emancipatory systems methodologies.

There are two major aspects involving stakeholders' relationships in societal complexity. The first is the impact of individual and group relations in social processes, while the second, and perhaps more crucial, is the impact of human relations and social processes on society as a whole. In this context, individuals and groups within a system may exhibit (dis)similar values, beliefs, and interests, and exert (un) equal influence in decision-making processes. Based on these characteristics, the relationship of those concerned with the problem situation (stakeholders) can be classified as unitary, pluralist, or coercive (Jackson & Keys, 1984). Stakeholders in a unitary relationship have similar values, beliefs, and interests; they share common objectives and are all involved in the decision-making process to some extent. Stakeholders in a pluralistic relationship may not share the same values and beliefs. However, through debate, disagreement, or even conflict, compromises are made, and shared understanding can be reached in a participatory decision-making process. In a coercive relationship, stakeholders usually share little interest and experience conflicting values and beliefs. Furthermore, the decision maker can enforce the implementation of a solution and compromises are hardly possible (Daellenbach, 2001).

Table 2.2 Characteristics of systems methodologies.

	Hard Systems	Soft Systems	Critical Systems
Core Idea/ Focus	Aims to optimise the performance of a system in pursuit of clearly identified, agreed upon goals and objectives	Seeks to accommodate conflicting worldviews and to create sufficiently shared understanding to carry on consensual actions	Strives to emancipate those affected by the system outcomes, but who may not have a voice in the decision-making process
Stakeholders Relationship	Predominantly unitary relationships	Strives towards pluralistic relationships	Strives against coercive relationships
Problem Complexity	Relatively well-defined, well-described, and well-structured	Messy, ill-defined, ill-described, and ill-structured	Messy, ill-defined, ill-described, and ill-structured
Underlying Paradigm	Functional	Interpretative	Emancipatory
Nature of the Problem	Largely technical	Largely societal	Largely societal
Objectivity	Observer independent	Observer dependent	Observer dependent
Values	Predominantly value-free	Predominantly value-neutral[3]	Predominantly normative approach[4]

Table 2.2 provides an overview of the general characteristics of systems methodologies based on their fundamental systems approach and can be used as a starting point to gain a better understanding of systems practice. Hard systems thinking is a functionalist approach, which is most effective when the desired end state of the system is known and the problem addressed is large of technical complexity. Conversely, this approach has limitations in handling problem situations with significant societal complexity (Daellenbach, 2001) because it assumes that stakeholders' values and beliefs are simple enough to be modelled or simulated (Jackson, 2003).

3 The inquiry strives to remain impartial, and overcome their biases and value judgments during the course of the study with the goal of producing sound factual knowledge (Hammersley, 2017).

4 One acknowledges the influence of value conclusions or value commitments, which contain subjective or value-related judgments, when producing knowledge (Hammersley, 2017).

Soft systems thinking is an interpretative approach which assumes that social processes depend on the worldview of their interpreters (Bausch, 2014). Soft systems thinking can cope with a fair degree of societal complexity (Daellenbach, 2001). On the other hand, this approach cannot be applied if the conditions for open debate and shared understanding are absent (Jackson, 1985; Oliga, 1988).

Critical systems thinking is an emancipatory approach that takes into account that stakeholders are often unequal regarding power over the problem situation, and therefore, certain stakeholders' views may be privileged over others (Phelan, 1999). It contends that functionalist and interpretive systems approaches neglect the existing structures of inequality of power, wealth, status, and authority which may be operative without the stakeholders concerned being aware of them (Oliga, 1988). Therefore, critical systems thinking aims to expose such inequalities so that radical change to emancipate those who are often most affected by the system outputs take priority over the interests of the decision maker.

2.7.3 Systems knowledge set: Determining the knowledge creation process

Knowledge emerges from data and information. It is best defined as the theoretical and practical understanding of a subject. By using different systems approaches and methodologies, data can be collected in quantitative and qualitative form for the purpose of explaining, interpreting, and reflecting on the various aspects of a system. The creation of knowledge is influenced by a variety of human interests (Habermas, 1972): a technical interest in the prediction and control of natural and social systems (causal explanation); a practical interest in communication and creation of shared understanding among all stakeholders in social systems (practical understanding); and an emancipatory interest in humans to protect them from constraints imposed by power structures (reflection). According to Jackson (1991), Habermas' Theory of Knowledge and Human Interests helps to adequately assess the theoretical and methodological legitimacies and limitations of different pieces of knowledge. Such an assessment provides criteria for careful consideration of the relationships of those concerned with the problem situation and the knowledge creation process.

In the case of an energy solution for low-income households in rural areas, relying largely on data from national household consumption surveys conducted by official national statistic offices would likely restrict the design process creating an inability to understand the unique characteristics of the local context. Instead, the design team should produce context-specific knowledge because end-user behaviour and habits towards energy consumption in low-income communities tend to be profoundly influenced by a number of local norms, beliefs and circumstances that are not contemplated in large-scale national surveys. Moreover, to realise a transition to a sustainable energy-efficient rural community the design team should generate different types of knowledge such as knowledge about the system components relevance to the transition, knowledge on how to realise the transition from "current" to "future" state (scenarios), and knowledge of the desired state (vision) (see Gaziulusoy, 2010).

Table 2.3 Knowledge creation in systems approaches.

	Hard Systems	**Soft Systems**	**Critical Systems**
Data Analysis	Predominantly prediction in quantitative form	Predominantly interpretation in qualitative form	Predominantly reflective interpretation in quantitative and qualitative form
Problem Analysis	Analysis conducted in systems terms	Creative analysis that may not be carried out in systems terms	Analysis carried out to reveal who is disadvantaged by the current system
Type of Knowledge	Instrumental (causal explanation)	Practical (understanding)	Emancipatory (reflection)

Table 2.3 provides an overview of the characteristics of knowledge creation in different systems approaches, and it is helpful in defining the appropriate knowledge that needs to be acquired during design inquiry and applied in design action. Design action needs to take into account both the human interest underlying knowledge generation and the embodied understanding of designers, referred to by Nelson (2005) as design knowing. Design knowing includes: knowing based on reason (conscious knowing); intuition (unconscious knowing); imagination (subconscious knowing); and conscious not knowing (Nelson, 2005, p.4).

2.7.4 Systems skill set: Identifying the need for complementary skills

Systems thinking skills provide a new foundation for design's core competencies and skilful performance when tackling complex problem situations. Conley (2004) proposes seven core design competencies: understand the context or circumstances and frame the problem; define the appropriate situations level of abstraction; model and visualise solutions, even with ill-defined information; simultaneously create and evaluate multiple alternatives to the problem; add and maintain value as the process of problem solving unfolds; establish purposeful relationships among elements of a solution and between the solution and its context; and finally, use form to embody ideas and to communicate their values. When addressing complex societal problems, problems solvers realise that the skills they acquired during traditional design training do not align with the nature of the challenges that they are expected to tackle, and therefore, new skills are required. Systems skill set comprises a set of novel abilities that complement design competencies by providing a new foundation for dealing with complexity. I suggest five key systems skills necessary for skilful performance when tackling complex societal systems or problems (see Table 2.4). More information about systems skills can be found in Section 5.2 of this thesis.

Table 2.4 Key systems skills.

Skill	Description	Resources
Multilevel Analysis	The ability to analyse problem situations at different scales and aggregation levels of the problem	(Elzen et al., 2004; Geels, 2011; Jones, 2014; Joore & Brezet, 2015; Mulder et al., 2012)
High Complexity-handling	The ability to handle complex problem situations	(DeTombe, 2015a, 2015b; Murthy, 2000; Nelson, 2008b; Valckenaers & Van Brussel, 2016)
Adaptability	The ability to deal with high levels of uncertainty and unpredictability	(Conklin et al., 2007b; Gharajedaghi, 2011; Mulder et al., 2012)
Multiple Stakeholders Collaboration	The ability to handle differing points of view in multi-stakeholder environments	(Matos & Silvestre, 2013; Phelan, 1999; Sevaldson, 2010)
Multidisciplinary teamwork	The ability to work in multidisciplinary teams	(Mulder et al., 2012; O'Rafferty et al., 2014)

For instance, in the case of an energy solution for low-income households in rural areas, a design team with a multilevel perspective would strive for an energy solution with the ability to create impact at multiple aggregation levels of the system: at micro-level by improving existing or developing new energy efficient products and promoting more sustainable consumption patterns; at meso-level by creating new product-service systems and facilitating the collaboration between energy utilities, non-governmental organisations and community facilitators; and at the macro-level by striving towards the adoption of policy choices that stimulate the creation of economic and regulatory instruments favourable to the implementation of systemic solutions. Because the competences required to achieve such solutions are interdisciplinary and diverse, the design team is likely to build a multidisciplinary project team. Moreover, adopting an open-framing[5] approach to the problem allows the team to cope with the uncertainty and unpredictability involving low-income energy markets. Finally, the

5 In an open-framing approach, the processes of problem definition and framing focus on the final function, utility, or user satisfaction, rather than on a product or technology. By adopting an open framing approach, reframing the problem becomes available at any stage of the design process.

team should acknowledge that each stakeholder may exhibit a different perception of the functionality and adequacy of the energy solution and a particular motivation to engage in the development of the system.

2.7.5 Systems tool set: Defining appropriate tools and techniques

Taking our example, to gain a better understanding of energy demand and consumption patterns in low-income contexts, a design team tackling the lack of energy access for low-income households in rural areas would benefit from soft systems thinking tools such as rich picture, root definition and conceptual model (see Checkland, 1981). For instance, visualisation tools such as rich picture can be used to synthesise and interrelate knowledge, communicate complexity, and to facilitate a shared understanding of the system among stakeholders (see Figure 2.6).

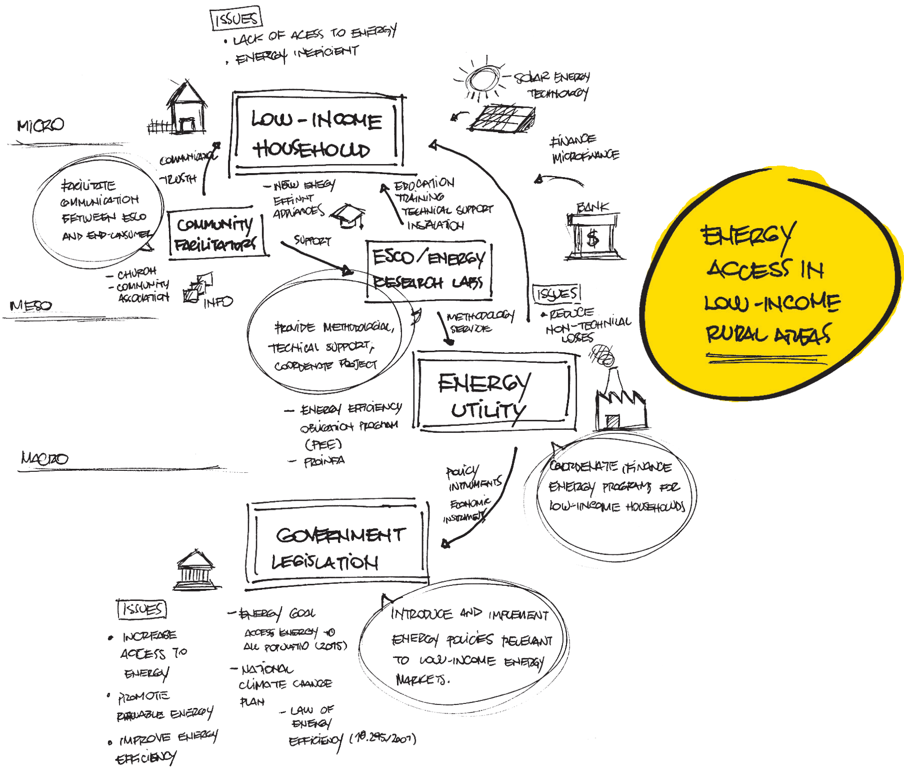


Figure 2.6 Rich picture of the problem of energy access in low-income rural areas. Based on Checkland (1981).

For Jackson (2001), the application of systems tools and techniques should consider the following guidelines. Tools and techniques, as applied in hard systems methodologies, aim to gain knowledge of the real world and capture the logic of the problem situation. The outcomes of these tools are mainly connected with the purpose of the design and provide input to improve the problem situation. Soft systems methodologies employ tools to deepen understanding of the real world and promote debate about feasible and desirable actions for change. In critical systems methodologies, tools and techniques focus on creating awareness among marginalised groups about their situation and suggesting improvements in their problem situation.

2.8 Conclusion

In this chapter, an attempt has been made to explore the integration of systems thinking and design, and some of its applications. It covers a portion of the vast field of systems thinking research and focuses on its contributions to design. Based on the selected theoretical foundations of systems thinking, the chapter elaborates on three systems approaches unfolding in their capacity to handle complex problems and to conduct a social inquiry. The different systems approaches can be appropriate to address different types of (complex) problem situations in which designers are required to intervene. I demonstrate that each systems approach is useful in terms of managing a particular combination of complexity and stakeholder relationships, and should be used in such appropriate/specific circumstances. To support this process, I provide a conceptual framework for systems design approach applied to complex societal problems.

Although the framework focuses on the broader context of complex societal problems, it was developed within the narrow context of energy solutions for low-income markets, which may contribute to bias due to their particular focus on energy product-service systems. For that reason, further case studies are needed to assess the use of the framework in conjunction with other traditional product-service approaches in multiple industry and service sector such as healthcare. Moreover, although the framework helps to identify the resources (e.g., systems skills) required to the application of systems thinking into design, those resources still need to be developed by designers or outsources in order to be applied in design practice. Similarly, identifying the strengths of different systems approaches and the appropriateness of different systems methodologies does not create the perfect fit to handle all real-world problem situations. Future studies on the main topic described in this chapter are therefore required to test and validate the framework as well as research on the process of capacity building for systems design approach.

Despite the limitations of the contributions of this chapter, the findings point towards a better understanding of systems design approaches and their ability to address complex societal problems. In contrast, the eventual lack of thoughtful exploration hinders designers from making a more significant contribution to this domain. The framework offers designers insights to promote informed decision-making and a systematically application of systems thinking to increase the competency and effectiveness of their approach to complex societal problems. In practice, there are many challenges in the implementation of systems design approaches. At the same time, this conceptual framework can assist in addressing some of these challenges and support emerging research on the integration of systems thinking into design.

Photo by Ali Grivani on Unsplash.

3.

A multilevel analysis of sustainable energy product-service systems

This chapter is based on the publication:
Costa Junior, J., Diehl, J. C., Secomandi, F. (2019). Towards systems-oriented energy solutions: A multilevel analysis of a low-income energy-efficiency programme in Brazil. *Sustainability, 11*(5799). doi: 10.3390/su11205799

There is a consensus among scholars and practitioners that energy solutions, such as electricity services and related products and systems, are paramount to the ability of nations to overcome environmental and social issues. As a result, policymakers and problem solvers in emerging economies have shown a keen interest in the transition to sustainable energy systems. Nevertheless, the design of sustainable energy solutions in low-income markets presents many challenges, such as those related to limited financial resources and poor infrastructure. In low-income markets, the adoption of a systems-oriented approach to product-service combinations may represent a promising alternative to traditional design approaches and result in a more socially and environmentally sound path to economic development. Building on design theory grounded in systems theory, this chapter analyses multiple aggregation levels of the socio-technical system of a low-income energy-efficiency programme in Brazil. In this study, I examined findings from the literature, carried out a descriptive investigation of cases, conducted field observations and had discussions with practitioners and experts. The study identifies constraints that hinder energy solutions which could achieve higher levels of socioeconomic and environmental benefits in low-income energy markets. Based on the findings, the chapter provides insights into sustainable energy transitions and concludes that low-income energy-efficiency programmes can be improved through design-led policy and stakeholder collaboration.

3.1 Energy solutions in low-income markets

In the literature, a path towards tackling energy challenges and improving living conditions in low-income contexts refers to the access to modern sources of energy, the promotion of energy efficiency, and improvements in affordability (Giannini Pereira, Vasconcelos Freitas, et al., 2011; Schaeffer et al., 2005). Moreover, increasing the use of renewable energy sources is especially important in emerging economies since they will experience the most significant increase in energy demand and carbon dioxide emissions as they continue to develop (Sadorsky, 2009; Salim & Rafiq, 2012). To address these energy challenges, the United Nations (UN), within its Sustainable Energy for All initiative, established three primary global energy goals: (I) ensure universal access to modern sources of energy; (II) double the global rate of improvement in energy efficiency; and, (III) double the share of renewable energy in the global energy matrix by 2030 (United Nations, 2010).

The combination of poor electricity services and the increase in electricity demand and consumption results in major energy challenges in emerging economies like Brazil. For instance, low-income households struggle with issues such as penalties imposed due to electricity theft (Filippo Filho et al., 2014), dependency on economic instruments (e.g., subsidies), use of energy-inefficient household appliances (Jannuzzi, 2007), lack of awareness and information (Borger et al., 2011), and an unreliable electricity supply (e.g., blackouts and shortage of electricity) (Geller et al., 2004). In past decades, the Brazilian Electricity Regulatory Agency (ANEEL) has taken measures to develop a new regulatory framework to address the most significant national energy challenges: (I) to provide universal access to energy; (II) to increase energy efficiency; and, (III) to increase the use of renewable energy. New energy policies have been developed and introduced to achieve these three primary national energy goals, which align with global efforts (MMA, 2008; MME, 2007): (I) increase the electricity supply in isolated areas by 2014; (II) provide electricity access to all households by 2015; (III) decrease the projected greenhouse gas emissions by between 36.1% and 38.9% by 2020; (IV) decrease electricity consumption by 10% by 2030; and, (V) diversify the energy matrix through investments in renewable energy sources.

To address the national energy goals and reconcile the socioeconomic development with the protection of the climate system, the Ministry of Environment (MMA) established the Brazil National Climate Change Plan (PNMC). Moreover, to tackle energy challenges faced by the Brazilian low-income population, ANNEL established obligations to energy utilities to promote energy efficiency R&D and consumer-oriented energy efficiency programmes. Among the national energy programmes relevant to the low-income sector, the Brazilian Energy Efficiency Programme (PEE) has gained prominence. PEE is an incentive programme that promotes the efficient use of electric power. The PEE programme has 14 project typologies, of which two (i.e., low-income and pilot project) are suitable to tackle energy challenges faced by the Brazilian low-income energy market.

The “pilot project” typology supports innovative projects (e.g., unprecedented projects, new technologies, and new methodologies) that allow replication and future upscaling. The “low-income” typology comprises projects with investments in low-income communities and consumer units benefiting from the social tariff (more information about social tariff is given in the section 3.4.3). Low-income projects consist mainly of demand-side management (DSM) focusing on changing consumer demand for electricity. Common activities adopted in the PEE low-income typology include: replacement of inefficient household appliances; educational actions; regularisation of illegal connections; improvements in residential electrical installation (e.g., home wiring and electric power meter upgrade); the use of incentivised renewable energy sources, such as solar water heating and solar home systems.

According to Geels (2004), technology plays an important role in fulfilling societal functions. Nevertheless, only in association with other elements of the socio-technical systems that technology can create the large-scale transformations required for system innovation. Based on the definition of socio-technical systems by Geels (2004), Table 3.1 illustrates the complexity of the socio-technical system in low-income energy markets. In low-income markets, technological substitution and the effective implementation of DSM strategies must overcome a number of constraints (see Table 3.1).

Table 3.1 Complexity within the socio-technical system in low-income energy markets.

Socio-technical systems for low-income energy market	**Low-income market constraints**	**Examples**
Market and stakeholders practices (e.g., user preferences, electricity consumption patterns)	User	High illiteracy rate among stakeholders
Culture and its symbolic meanings (e.g., ways of living, individual and collective habits)		
Maintenance and distribution network (e.g., maintenance services, repair shops, local electrician, hardware stores)	Technical	Unskilled technical personnel, lack of energy-saving features, poor heating and insulation standards (dwelling)
Infrastructure (e.g., electrical grid, housing conditions, shared products and facilities)		
Knowledge production and transfer (e.g., universities, research institutions, R&D, capacity building)	Institutional	Lack of trust between stakeholders (e.g., between low-income population and state-owned utilities)
Stakeholder relationships (e.g., hierarchy, economic classes, political position)	Socio-ethical	Electricity access as a campaign tool to attract votes from minorities.
Regulatory and economic instruments (e.g., policies, energy efficiency and electrification programmes, subsidy, social tariff)	Economic	High dependency on subsidies.
	Regulatory	Lack of policies relevant to energy poverty
Resources (e.g., fossil fuel, renewables)	Environmental	Lack of environmental awareness

Based on Geels (2004) and Costa Junior et al. (2017).

These constraints constitute barriers to problem solvers and affect the development and implementation of energy solutions in ways vastly different from constraints experienced in middle-/high-income contexts (Costa Junior et al., 2017). Consequently, sustainable energy solutions must integrate a range of comprehensive products, services, and systems to overcome constraints and provide access to affordable, reliable, and clean energy solutions in low-income markets. In the literature, the integration of products, services, supporting networks, and infrastructures as a commercial solution is called Product-Service System (PSS) (Goedkoop et al., 1999).

A considerable amount of literature has been published which focuses on low-income energy markets and PSS (Bandinelli & Gamberi, 2011; Bartolomeo et al., 2003; Costa Junior et al., 2018; Emili et al., 2016; Friebe et al., 2013; Vezzoli, Ceschin, & Diehl, 2015; Vezzoli, Ceschin, Osanjo, et al., 2015; Vezzoli, Delfino, et al., 2014). These studies contend that the dematerialisation of products can lead to decoupling economic growth from resource consumption and increasing the incentive for energy efficiency. Similarly, other relevant studies (Friebe et al., 2013; Reinders et al., 2012) have concluded that a considerable number of sustainable technologies already exist. However, the short and long-term effectiveness of energy solutions largely relies on the link between products and related services, the interaction with stakeholders and its surroundings, and the way in which they are offered to the market.

The PSS concept is potentially suitable to address the issues in low-income energy markets as it provides a higher level of wellbeing at a lower cost as a result of its higher system efficiency (UNEP, 2002). Notably, the requirements for creating a sustainable transition in low-income energy markets may only be possible with significant changes in existing energy systems (Kaygusuz, 2007). As a result, studies which consider PSS at a systems-oriented level have emerged (Ceschin, 2012b, 2014; Emili, 2017; Gaziulusoy, 2015; A. L. R. Santos, 2015). Although several authors acknowledge that PSS has an inherent holistic perspective (Briceno & Stagl, 2006; Coley & Lemon, 2009; Geum & Park, 2011; Lindahl et al., 2007; Mukaze & Velásquez, 2012), consensus exists over the need for further development of its systems-orientation (Cavalieri & Pezzotta, 2012; Vasantha et al., 2012).

However promising, PSS lacks a comprehensive approach to encompass all the different technical and societal factors involved in the design process. To tackle this issue, it is necessary to gain a better understanding of the complexity of the technical and societal factors that influence a given system. One way to do so is to approach problem-solving and stakeholder values using tenets, methodologies, tools, and techniques that are associated with systems thinking. Adopting a design approach toward PSS that considers the parts of the system as intertwined components, rather than as independent entities, is fundamental for a proper conceptualisation and in-depth understanding of the system in place (Afshar & Wang, 2010; Cavalieri & Pezzotta, 2012). Moreover, the integration of systems thinking on PSS is fundamental because it enables upscaling and embedding solutions into the socio-technical system to achieve radical improvements (Ceschin, 2012b).

In order to contribute towards filling this gap, this study adopts a systems design approach based on a multilevel perspective that builds upon the work of Elzen et al., (2004) and Geels (2005). The chapter presents a multilevel model and carries out a multilevel analysis of an energy-efficiency low-income programme in Brazil. The multilevel analysis allows problem solvers to look into low-income energy markets' constraints to identify misalignments between various societal and technical factors across system levels. The findings produce insights as to how constraints faced in those markets influence the design and implementation of energy solutions. Based on the results, the chapter proposes recommendations to the improvement of Brazilian low-income energy-efficiency programmes through design-led policy and stakeholder collaboration.

In the following sections, the integration of systems thinking into design is explored with particular attention paid to the increasing complexity of energy challenges in low-income markets. Next, the multilevel model is explained, examples are provided, and the methodology is described. Then, based on the multilevel analysis, the findings are discussed. Following the presentation of the main results, the chapter offers insights into decision-making and problem-solving aimed at improving energy solutions for low-income energy-efficiency programmes in Brazil. Finally, concluding remarks are presented.

3.2 A multilevel perspective on energy product-service systems

At the crossroads of Energy and Design, sustainable energy solutions can be developed by deploying new technologies to generate sustainable energy and promoting changes in lifestyle to save energy (Reinders et al., 2012). According to Reinders et al. (2012) as complexity, functionality, and user interaction increase, energy solutions have to be integrated into a system of products and services which closely interacts with stakeholders and the surroundings (Figure 3.1).

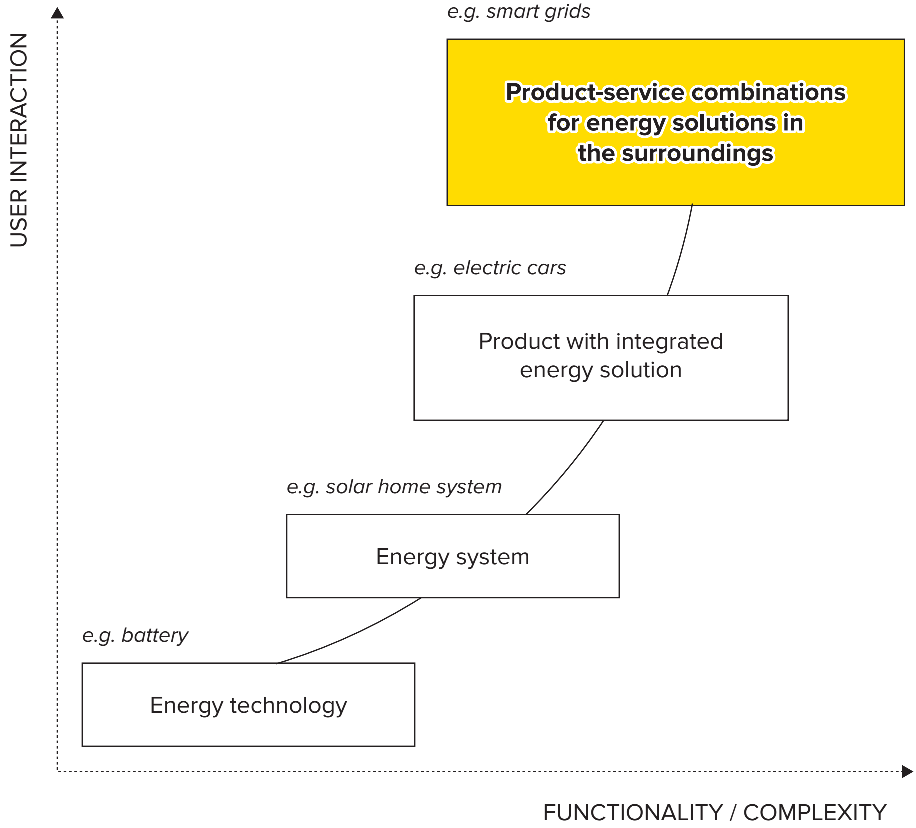


Figure 3.1 Energy solutions in relation to an increased degree of integration with products, services, stakeholders, or environments. Reinders et al. (2012).

It is likely that the transition from one existing pattern of production and consumption to another demands solutions that go beyond product-centred innovation approaches (Brezet, 1997). Given the complexity of energy challenges in low-income markets, it is clear that improvements on the product-technology level, although fundamental, are not enough to create the radical improvements necessary for sustainable transitions. Moreover, complex systems, such as a sustainable energy system, cannot be conceived by technological solutions alone. In such a complex system, the social and organisational practices are complex, unstructured, and messy, and technologies are appropriated and incorporated into everyday practice rather than integrated in a rational way (Jones, 2014). Furthermore, energy systems in low-income markets often involve multiple stakeholders, including private companies, government, energy utilities, end-consumers, knowledge producers, community representatives, and non-governmental organisations that influence each other. For these reasons, sustainable energy solutions for low-income markets require a holistic approach and a multilevel perspective which entails complex relations and interconnections between components of the socio-technical system (Geels, 2011).

A multilevel perspective employs the notion that an energy solution can be designed at different system levels, or different aggregation levels of the societal and technical components of the system. This study contends that to achieve higher levels of sustainability and innovation, the value creation should occur across multiple system levels. Moreover, it should acknowledge the interconnections amongst components of the socio-technical system within the whole system. To support problem solvers to do so, this study explores a multilevel model that builds on Innovation Theories, such as Technological Transition (Geels, 2002) and System Innovation, and the Transition to Sustainability (Elzen et al., 2004; Geels, 2005). Additionally, it considers design studies such as those exploring the Design for System Innovations and Transitions (Gaziulusoy, 2010, 2015; Gaziulusoy & Brezet, 2015) and the integration of Product-service systems to System Innovation and Transition Theories (Ceschin, 2012a, 2014; da Costa Junior et al., 2019; Joore, 2008, 2010; Joore & Brezet, 2015).

The multilevel model allows for the analysis of a socio-technical system regarding alignments between components across multiple system levels and their implications for product-service development (energy solutions). The multilevel analysis is adopted to consider three primary aggregation levels as follows: the micro level focuses on product-technology interventions and behaviour change; the meso level devotes attention to product-service arrangements, infrastructure, and organisational change; and, the macro level puts emphasis on design visions, policy-making, and societal change. The model can be used to analyse individual design interventions (see Sections 3.2.1 to 3.2.3) or to compare various solutions across different levels of a given socio-technical system (Figure 3.2).

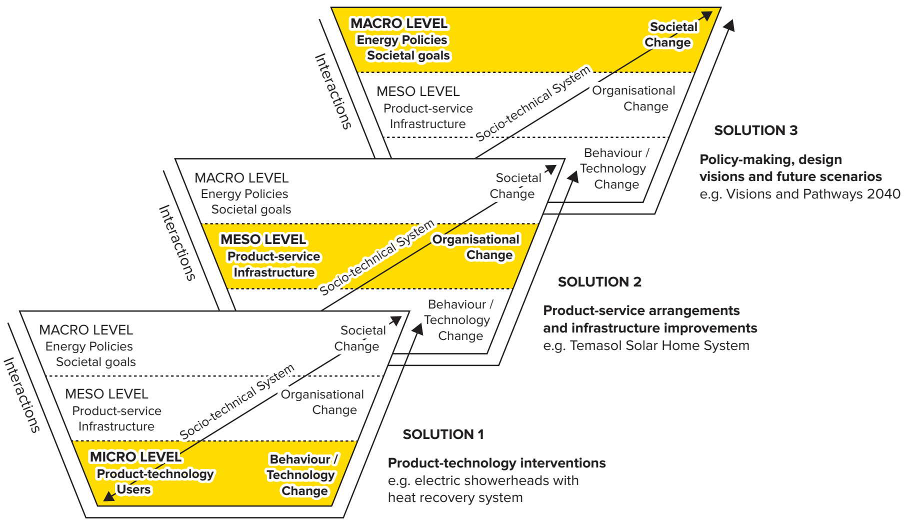


Figure 3.2 Visual representation of a multilevel analysis of three energy solutions using the Multilevel Model (see more details about each solution in Sections 3.2.1 to 3.2.3). Based on Elzen et al. (2004) and Geels (2002, 2005).

The three aggregation levels are not meant to offer an optimal description of reality, rather they are a heuristic tool for reflection, analysis, and synthesis. Moreover, by describing a socio-technical system using the multilevel model, I do not intend to suppose that overlap between the levels does not exist. Similar phenomena can manifest across levels in different ways. For instance, at the macro level, "economic factors" can be described as economic instruments created by the government to support new energy policies that generate opportunities for investments in low-income energy-efficiency programmes. At the meso level, such factors might represent budget allocation introduced by energy utilities to realize investment in voluntary actions against energy poverty. Finally, at the micro level, economic factors can manifest as economic constraints for product-service development created by the low purchasing power of end-consumers. Table 3.2 illustrates how design interventions take place across different systems levels based on the multilevel model.

Table 3.2 How design intervention manifests at different socio-technical aggregation levels.

Description	MICRO	MESO	MACRO
Core Idea/ Focus	Improving existing or developing new technologies, products, services and behaviours.	Improving existing or developing new integrated product-service combinations, infrastructure, and new business models.	Promoting change on how societal needs are fulfilled, to support the transition to a new socio-technical system.
Primary agent fostering the change	Individuals, households, and communities.	Organisations, institutions, and companies.	Governments and world organisations.
Scale of change	Behaviour, surroundings, and technological change.	Infrastructure and organisational change.	Societal change.
Types of interventions	Product-technology and services.	Product-service systems.	Systems-oriented PSSs, designs, visions and future scenarios

In the next sections, each aggregation level is described in greater detail. Examples are presented to demonstrate how an energy solution (design intervention) introduces changes in the system dynamics from the level of user behaviour and infrastructure development to the level of regulatory instruments and system transitions. The examples demonstrate that it is unlikely that energy solutions implemented at the micro and meso levels (e.g., new energy technologies and infrastructure improvements) will be able to replace existing systems with sustainable energy systems without changes at the macro level (e.g., regulatory frameworks, policy revisions and future planning). Therefore, the capacity to analyse a complex system at different aggregation levels is of paramount importance to create the potential to achieve radical improvements in existing and future systems (Joore & Brezet, 2015; Mulder et al., 2012).

3.2.1 Micro level: Example 1 - Electric showerhead with heat recovery

A design intervention at the micro-level focuses on improving existing or developing new technologies, products, services, and behaviours. Energy solutions fulfil a primary function and are usually characterised by a dominant product-technology. At this aggregation level, energy solutions aim at improving existing, or developing new, products and services. New technological developments (e.g., renewable energy technology, energy efficient products) and energy practices (e.g., more efficient consumption patterns) emerge to satisfy the immediate needs of the system. An example is electric showers with a water heat recovery system adopted in low-income energy-efficiency programmes in Brazil.

Electric resistance showerheads are an alternative to water heating and are widely adopted by Brazilian low-income households. Although electric showerheads are low-cost devices, they account for 20% of the residential energy consumption in a household (Ghisi et al., 2007), which therefore accounts for a considerable part of the household expenditure on electricity. Moreover, these devices present a significant peak load problem for energy utilities because they account for 43% of the consumption peak between 6 and 9 pm (Passos et al., 2014). For these reasons, in low-income households, a heat recovery system for electric showerheads has been proposed as a solution for increasing energy efficiency and decreasing the negative consequences of high peak demand in the quality of the electricity supply at peak time. The heat recovery system absorbs the heat of the water that goes down the drain and transfers part of the thermal energy to the water that will go into the shower, which reduces electricity usage.

3.2.2 Meso level: Example 2 – Solar home systems by Temasol

At the meso-level, design interventions often focus on integrated combinations of products and services and new business models. Energy solutions fulfil one or more comprehensive system functions that are likely to involve product-service combinations, infrastructure improvements, and organisational arrangements. This aggregation level concerns the configuration of a number of components necessary to support the integration of products and services and, therefore, fulfil the system functions. Among others, certain technologies, stakeholders practices, regulatory instruments, business models, cultural meaning, market structures, and infrastructure are essential for the operationalisation of the energy solution. An example of an energy solution at the meso-level is the Solar Home System (SHS) by TEMASOL.

The project (Global Rural Electrification Programme) was a public-private partnership combined with international cooperation for rural electrification that supplied solar electricity at affordable rates to over 24 thousand rural households between 2002 and 2008 in Morocco. The Moroccan Government subsidised the equipment costs through the National Electricity Office (ONE), which became the equipment owner. In addition, the system comprised five major stakeholders: TEMASOL to supply, install, and coordinate maintenance of the SHS Kits; ONE to subsidise 90% of the equipment cost; French Fund for the World Environment - FFEM to provide technical assistance and environmental funding; KfW Development Bank to give a grant to ONE in order to finance a large part of the programme; and local communes to facilitate the installation and maintenance of the SHS kits. The values of the installation ranged between

82 to 470 dollars (about 10% of the equipment cost), and the equipment cost and monthly fee (ranging between eight to 18 dollars) were paid over ten years by the end-consumers (Allali, 2011).

3.2.3 Macro level: Example 3 - Visions and pathways for low-carbon resilient futures in Australian cities

Design interventions at the macro-level focus on changes in how societal needs are fulfilled to support the transition to a new socio-technical system. Energy solutions at the macro level aim to meet a societal function and comprise a combination of material, organisational, policy, socio-cultural, and infrastructural components. This aggregation level aims to promote radical changes that influence how societal needs, like the demand for energy, are satisfied, but which are often beyond the control or direct influence of the problem solver.

An example of energy solutions at the macro-level is the Visions and Pathways 2040 introduced by the Victorian Eco-innovation Lab (Australia). Drawing on a design-led visioning and a multilevel model of system innovation, the project carries outs participatory visioning exercises (workshops) to explore how four Australian cities could become low-carbon and maintain resilience by reducing their greenhouse gas emissions by 80% by 2040. The project resulted in various future scenarios (or visions) and innovation pathways for policy and design interventions that can reorient current development towards future cities capable of dealing with transitions to sustainable, resilient, and low-carbon societies (C. Ryan et al., 2016).

3.2.4 Multilevel analysis of a low-income energy-efficiency programme

The multilevel perspective proposed in this chapter leads to the identification of several societal and technical factors that may present challenges or answers to improving energy solutions for low-income markets. This is represented in a multilevel model concerned with looking at social, economic, and environmental impacts of PSSs on the system as a whole. The study contends that a multilevel model can support problem solvers to gain a better understanding of the socio-technical systems for the design of energy solutions capable of solving energy challenges in low-income energy markets. To do so, a multilevel analysis is applied to a major energy efficiency programme project in Brazil (PEE). In this context, the study addresses the following question: *What does the adoption of systems thinking as a multilevel perspective tell us about improving energy solutions in a low-income energy-efficiency programme?* Based on the multilevel analysis, recommendations regarding the improvement of energy solutions in national low-income energy-efficiency programmes are produced.

3.3 Methodology for the case study

The research design in this study draws on a literature review, a descriptive investigation of cases, field observations, an interview with a key informant, and a focus group discussion with stakeholders. Case study is adopted because it allows appreciation of the various societal and technical factors involved and the complexity of their interaction across system levels. As a starting point, a literature review and overview of the Brazilian electricity distribution sector was carried out to gain a better understanding of the Brazilian low-income energy market as a socio-technical system and to identify relevant cases. The strategy implied the intensive observation of a major empirical case (Case 1) and the analysis of two additional cases built upon secondary data (Cases 2 and 3) (see Table 3.3). The sample is meant for descriptive, not inferential, generalisation. The cases were selected based on the literature review and how they meet the following criteria: (I) a public-private partnership aiming at (II) energy product-service combinations for (III) low-income households in (IV) Brazil. The study deliberately selected public-private partnership cases to contemplate the complexity of social relations commonly involved in such solutions for low-income contexts.

Table 3.3 Overview of cases and adopted data collection techniques.

Case	Programme name	Research techniques	Description of the DSM strategies
1	Programme COPEL: Energy Efficiency for low-income communities of Paraná	Review of available reports, databases, scientific papers, field observations, interview with a key informant, and focus group discussion with relevant stakeholders.	- Affordability: guidance to the utilisation of government subsidies; - Educational actions: a cycle of lectures on the topic of efficient and rational use of electricity; - Energy efficient analysis: diagnostics to identify energy waste and determine the technological upgrade suitable for each residential consumer unit; - Non-technical losses: regularisation of illegal connections; - Product-technology intervention: some households receive a solar thermal heating system. - Surveys: conduction of socioeconomic and user behaviour surveys; - Product replacement: replacement of energy inefficient appliances and devices.
2	Programme Agent COELBA: Energy Efficiency for low-income communities of Bahia	Review of available reports, databases, and scientific papers (secondary data).	- Affordability: adjust energy consumption (bills) of the customer to their ability to pay and increase utilisation of government subsidies; - Educational actions: guidance by community agents on the topic of safe and efficient use of electricity; - Income generation: training and employment of local community agents. - Non-technical losses: regularisation of illegal connections; - Stakeholders relationship: improve customer relationship through the mediation of agents embedded in the communities.
3	Programme ECOELCE: Exchanging recyclable waste for a discount in the energy bill	Review of available reports, databases, and scientific papers (secondary data).	- Affordability: provide discounts to the energy bills of customers in exchange for solid waste with market value and increased utilisation of government subsidies; - Educational actions: a cycle of lectures on the topic of environmental sustainability and rational use of electricity; - Non-technical losses: regularisation of illegal connections; - Stakeholders relationship: promote the collaboration between recyclers, associations, government agencies, and private companies; - Surveys: conduct socioeconomic, environmental, and user behaviour surveys.

3.3.1 Data collection and analysis

Empirical data were collected from the project “COPEL in the Community” (Case 1), which is part of the broader “COPEL Energy efficiency programme for low-income communities of Paraná”. The project proposed stimulation of the rational use of electric power in low-income households in the State of Paraná (Brazil). The data presented in the Results section (Section 3.4) were collected during fieldwork observations at the community Madre Teresa de Calcutá in the metropolitan region of Curitiba. The observations provide insights into the everyday life of the local community and aim to understand the social process resulting from the introduction of the low-income energy-efficiency programme in the local setting. Additionally, an informal, semi-structured and open-ended interview was conducted with a representative of the state-owned electricity utility, COPEL (Interviewee C), to produce better insights regarding challenges for achieving compliance within national regulatory frameworks. Furthermore, to appreciate the challenges and opportunities of developing and implementing energy solutions in low-income contexts, a focus group discussion was carried out with three researchers/practitioners from the Institute of Technology for Development Lactec (Interviewees A, B, and D) actively involved in Case 1. Also, an expert in design for sustainability and former member of Lactec with extensive experience in energy PSS projects for low-income markets participated in the focus group discussion at the research centre (Interviewee E).

The structure of the interview and focus group discussion was supported by the overview of the Brazilian electricity distribution sector and complemented by secondary cases (Case 2 and 3). Secondary data were collected and analysed for Cases 2 and 3 to enrich the study by looking at similarities to the main empirical case. Background information, such as energy policies, identity of stakeholders, and additional information about the primary and secondary cases, was obtained from the following main sources: (I) national reports conducted by government regulatory agencies and Ministry of Mines and Energy; (II) national household consumption surveys conducted by national and international statistics offices; (III) international reports, such as those published by the World Resources Institute, the World Bank, and the United Nations Environmental Programme; and finally, (IV) cases reported in scientific journals.

Based on the multilevel model, the data collected were analysed across system levels and results were grouped at three aggregation levels. Each level attempts to describe the interplay of societal and technical factors in terms of linkages between the energy solution and the socio-technical system. The various types of information collected during the literature review, observations, interview, and focus group were compared with each other. Further triangulation occurred by using data from all cases to inform the analysis. In the following sections, the main results of the multilevel analysis are presented.

3.4 Multilevel analysis of a low-income energy-efficiency programme in Brazil

3.4.1 Macro level: Energy policies for low-income markets

Policy choices have a significant impact on energy trends, socioeconomic development, and environmental quality in emerging economies (Geller et al., 2004). For instance, to comply with Law 9.991/2000 of Brazil's legislation, an amount of not less than 1%[6] of COPEL's (energy utility) net operational revenue must be allocated to projects whose purpose was to promote energy efficiency, R&D, and consumer-oriented energy efficiency programmes (PEE). This law was essential for the development of the low-income energy market because it mandates the application of the majority of the investments in energy solutions for low-income households. According to Interviewee C, at least 60% of this investment needs to be implemented in energy solutions for low-income communities. In addition, energy programmes under Law 9.991/2000 had to comply with the following requirements: (I) Cost-benefit relationship (CBR) ≤ 0,80; (II) Products with energy efficiency label PROCEL[7]; (III) Measurement and verification of results; (IV) Performance contract; and, (V) Administrative costs lower than 5% of the investment.

Since previous legislation required energy utilities to provide electricity access to all Brazilian households by 2015, electricity has become a widely available public service when compared to other public services like water supply, sanitation, and garbage collection. For this reason, many of the national energy programmes relevant to low-income households focus on two main priority areas: improvements in energy efficiency and affordability; and adoption of incentivised renewable energy (see for an overview Table 3.4).

6 Until December 2014, an amount of 0,5% was destined for R&D and 0,5% for consumer-oriented energy efficiency programmes. After January 2015, these amounts changed to 0,25% for R&D and 0,75% for consumer-oriented energy efficiency programmes.

7 PROCEL labels is a regulatory instrument that aims to stimulate the production and marketing of energy efficient products by endorsing the most energy-efficient appliances in the market. It provides customers with information (label) about which devices are the best to buy to lower energy consumption.

Table 3.4 Overview of national energy programmes relevant to the low-income energy market.

Year	Regulatory instrument	Energy goals	Short description (target)
1996	National Programme for Energy Development of States and Municipalities (PRODEEM)	Renewable Energy Access to energy	Promote the use of solar photovoltaic (PV) systems in off-grid rural areas.
1998	Energy Efficiency Obligation Programme - Energy Efficiency Programs of Electricity Concessionaires and Utilities (PEE)	Energy Efficiency	Promote energy efficiency R&D and consumer-oriented energy efficiency, particularly, to low-income communities.
1999	National Rural Electrification Programme (Luz no Campo)	Access to Energy	Provide electrical power to one million rural homes, benefiting approximately five million people. It was the most extensive rural electrification programme implemented in Brazil
2002	Programme of Incentives for Alternative Electricity Sources (PROINFA)	Renewable Energy	Propose to invest in small hydropower plants (SHP), biomass, and wind power. Also, it aims to reinforce the national policy of diversification of the Brazilian energy matrix and stimulate the development of renewable energy sources.
2003	Electrification Programme Light for All (Luz para Todos)	Access to energy Renewable Energy	Propose to increase the electricity supply in isolated communities of the Amazon region and other isolated rural areas. Moreover, it aimed to expand the national photovoltaic industry and increase the use of photovoltaic solar energy. It started in 2003, was repeatedly prolonged and remained active until 2014.
2006	Programme to Encourage the Use of Solar Water Heating	Renewable Energy Energy Efficiency	Focus on gathering information about national and international initiatives, and proposing measures to encourage the use of solar heating systems in Brazil.
2009	Brazilian Labelling Program (PBE)	Energy Efficiency	Promote the use of energy efficient devices through informative labels.

Based on MMA (2008), IEA (2016), and GLOBALDATA (2017).

Low-income energy-efficiency programmes like PEE are possible due to the regulatory obligations imposed on energy utilities and the use of subsidies (Interviewee B). Indeed, between 2008 and 2012, most energy efficient projects were implemented in the low-income electricity distribution sector because PEE mandates the application of 60% of the investment in this sector. However, due to declining returns on PEE resources, adjustments to the regulations were made in 2013, including the non-obligation to invest in low-income communities. According to interviewee A, there are many studies in the electricity distribution sector which show that the kilowatt saved per hour in such programmes is often more expensive than the kilowatt that could be generated for consumption. In other words, although the cost-benefit relationship is a choice criterion for projects, it is often more expensive to decrease energy consumption in low-income energy efficiency programmes than to generate it for consumption.

In contrast**,** *"[...] such calculations do not take into consideration the whole lifecycle of the programme."* (Interviewee A). Moreover, the measurement and verification methodology adopted by the energy programmes have limited criteria suitable for evaluation of low-income contexts (Interviewee A), which can limit the ability to assess the real benefits of the programme (see Patrzyk, 2014; Patrzyk & Medeiros, 2015) (see also Box 3.1). Another challenge emphasised in the focus group discussion is that non-measurable and non-economic benefits have a marginal impact as selection criteria for projects. Although they can be included in the measurement and verification plan, they do not have a sufficient impact on creating incentives or encouraging innovative solutions.

Box 3.1 Educational methodology for energy efficiency applied to early childhood

Patrzyk's research (2014) aims to examine the relationship between energy consumption and energy-usage habits of households based on existing energy efficiency educational projects in Brazil for children aged four to five. This research considers the influence of social relations to observe the relationship between educational activities and energy-usage habits, and if the attitude towards energy by students leads to reducing the electricity bills in their homes. The data evaluation shows a positive impact on decreasing energy consumption, with an economy of energy saved during the study period of 4%. The data analysis considers a correction temperature factor since 2013 is set at a lower temperature than those related to the year before. As for the control group, who did not have the educational methodology applied, the data suggest an increase in energy consumption of 47% per month. Results indicate that the methodology developed in this study can be incorporated in the school curriculum aimed at sustainable energy consumption, to disseminate information, create awareness, and tackle energy waste.

http://sistemas.institutoslactec.org.br/mestrado/dissertacoes/arquivos/FabianaPatrzyk.pdf (in Portuguese)

3.4.2 Meso Level: Stakeholders motivations and collaboration

In low-income markets, the complexity and ambiguity between the interests and views of the stakeholders is higher than in traditional markets (Matos & Silvestre, 2013). Therefore, the collaboration between energy utilities, non-governmental organisations, and community associations (or community facilitators) plays an important role (Gradl & Knobloch, 2011). Case 1 comprises the following major stakeholders: COPEL to coordinate and finance the project and to carry out energy usage diagnostics (energy usage diagnostics and surveys are also conducted by third-party companies); COHAPAR to install energy efficient lights and replace old refrigerators and electric showers; Community associations to facilitate communication with the community; End-consumers who are responsible for implementing new energy saving habits. Based on the data analysis, it became evident that stakeholders exhibited different perceptions regarding the benefits of energy solutions and a particular motivation to engage in the development and implementation of the energy programme.

In Case 1, COPEL, in partnership with the social-housing company COHAPAR, aimed to tackle the waste of energy in low-income consumer units through technological upgrading and behavioural change. To do so, COPEL and Lactec carried out diagnostics to identify electricity waste in residential consumer units. The procedure included a socioeconomic survey, evaluation of household appliances and other electrical devices, and a user behaviour survey (Interviewee C). Through this diagnosis, it was possible to identify changes that could be performed by the customer to improve electricity use and determine the technological upgrade suitable for each residential consumer unit. Additionally, low-income customers took part in a cycle of lectures on the topic of efficient and rational use of electricity.

Energy utilities relied on partnerships with NGOs, community associations, and key community individuals to facilitate communication with the communities where customers live. In Case 1, a third-party company was hired to search for and contact a community leader and/or a local church to help disseminate information and to create awareness (Interviewee A). Such interaction is essential to improve the company's relationship with customers, allowing better control and a reduction in household energy consumption. Also, it facilitates the implementation of educational campaigns, promotes behavioural change, and results in more effective, lasting solutions (see also Box 3.2). Such social processes play an essential role in the outcomes of the programme since the low-income population generally has limited access to information and education, lacks trust in the government and state-owned companies (e.g., energy utilities), and does not actively participate in the definition of policies and priorities for the communities in which they live.

Box 3.2 Case 2 – Low-income energy-efficiency programme in Bahia

The Programme Agent COELBA is an energy efficiency initiative for low-income communities created in 1999 and carried out by the non-governmental organisation CDM (Cooperação para o Desenvolvimento e Morada Humana) in the city of Salvador (Brazil). The Program was coordinated and financed by COELBA (Companhia de Eletricidade do Estado da Bahia) with the aim of assisting low-income households by providing information to customers about the safe and efficient use of electricity (COELBA, 2015).

Furthermore, according to AVSI Foundation (AVSI Foundation, 2010), the programme has the following objectives: reduce illegal connections and commercial losses from non-paying legally connected customers; adjust energy consumption (bills) of low-income consumers to their ability to pay; invest in customer relations through the mediation of agents embedded in communities; use a combined approach of information and energy efficiency improvements delivered by community agents together with increased utilisation of government subsidies (e.g. social tariff); and, rely on an intermediary NGO to reach customers.

The system comprises the following major stakeholders: COELBA, who coordinated and financed the programme; AVIS Foundation, who offered methodological support; CMD, who carried out the project, supported the community agents, and facilitated communication with the community; Community Association, who oversaw the implementation and monitored activities with a high level of community engagement; End-consumers, who implemented the new habits and regularised electrical connections.

Box 3.2 Case 2 – Low-income energy-efficiency programme in Bahia (Continued)

The Programme Agent COELBA reached over 100 communities and 1.5 million low-income customers were served. In the beginning, the project had six facilitators who supported five communities. In 2010, the network grew to 102 facilitators providing services to 67 communities in the metropolitan area of Salvador and other cities of the state of Bahia. Besides facilitating the lives of consumers and strengthening the relationship with the community, COELBA focused on introducing low-income youth to the labour market (COELBA, 2015). The project and the related energy efficiency components generated employment for over 200 people (AVSI Foundation, 2010). The energy efficiency initiatives involved the replacement of energy inefficient appliances, like incandescent light bulbs and old refrigerators.

As part of COELBA's project, the "Programa Nova Geladeira" (Programme New Refrigerator) sold 18 thousand new, high-efficiency refrigerators at a fraction of their retail cost. In 2008, to allow access to more efficient refrigerators, a 100% subsidy was offered to 51 thousand residential consumer units who met the following criteria: they had regular electricity connection; they paid their electricity bill on time; and, they were registered for the social tariff. Additionally, 525 thousand high-efficiency lamps were distributed. A survey applied among the communities targeted by the programme (Nova Geladeira) confirmed a reduction of 33% in energy consumption in 2008 compared to the previous year, and a 46% reduction compared to a projection of consumption without the project intervention.

Corroboration exists in that the rationale which underlies the attention paid to energy challenges by different stakeholders varies. For example, interest from energy utilities is often the result of the need for compliance to legislation, or in anticipation of future policy instruments, rather than being a voluntary action (see (Cleff & Rennings, 1999; Gaziulusoy, 2015)). According to the interviewees, for end-consumers, a major driving force behind the engagement in sustainable energy initiatives is gaining access to affordable and new product technologies (e.g., energy efficient household appliances). The main interests for the energy utility COPEL in Case 1 were to: (I) save energy; (II) avoid demand at peak time; (III) postpone investment in the grid; (IV) decrease non-technical losses and illegal connections to the grid; and, (V) promote institutional marketing (Interviewee C).

In contrast, a dominant driving force for low-income consumers' adoption of the energy programme was to have old/inefficient appliances replaced with new energy-efficient devices, such as household appliances (e.g., refrigerators, freezers, clothes washers, and air conditioners), lighting products and systems (compact fluorescent and LED lighting), alternatives to electric resistance water heaters with minimum efficiency standards (solar thermal and heat recovery system). For example, to attract customers participation in the education actions in Case 1, COPEL exchanged three incandescent light bulbs for three fluorescent lamps (in some cases two fluorescent and one LED light bulb) for each attendee taking part in a cycle of lectures (Interviewee C). Table 3.5 presents an overview of stakeholders' drives based on the findings of this investigation.

Table 3.5 Main stakeholders' drivers in low-income energy markets.

Stakeholder	Drivers
Energy utility	- Reduce commercial losses from non-paying legally grid-connected customers and the number of illegal connections; - Increase the utilisation of government subsidies; - Invest in customer relationships.
Users	- Achieve higher living standards through access to clean and modern sources of energy; - Find alternatives to afford electricity services; - Benefit from low-income energy-efficiency programmes (e.g., technological upgrade and infrastructure improvements at household level);
NGO's	- Increase wellbeing of the low-income population through electricity services; - Facilitate the interaction between government, private companies, and end-consumers; - Stimulate entrepreneurship and create employment conditions in low-income communities.
Government	- Increase access, quality, and affordability of energy solutions; - Support income generation capacity in rural remote and low-income areas; - Increase access to information to improve energy efficiency and conservation at household level; - Promote the use of renewable energy resources.

3.4.3 Micro level: Affordability, efficiency and awareness

The development of energy solutions for low-income households faces many economic barriers that make it difficult to create economically viable solutions (Interviewee A). For example, the considerable initial cost involved in the implementation of energy solutions is considered a major barrier by most interviewees. Although the available income of the Brazilian low-income population is increasing, the families observed in the study still experience a certain degree of difficulty in reaching the end of the month with income still available. Additional evidence concerning the issues is that Brazil's transmission and distribution losses are higher than the averages of other emerging economies, such as Russia, China, and South Africa (The World Bank, 2014). The high total losses are likely reinforced by non-technical losses (distribution) due to electricity theft and illegal connections. In the cases analysed, instances of this occurred because customers were either unwilling or unable to pay electricity bills prior to engaging in the energy programmes.

Another issue pointed out by the interviewees was challenges associated with variable tariffs and changes in electricity costs due to the tariff flag system[8]. The electricity distribution has different electricity tariff rates that are compatible with the electricity consumption of the household, as well as other variable factors like consumption time, weather conditions, local infrastructure, and non-technical losses. Although variable tariff rates (e.g., lower prices during off-peak hours) can result in significant energy savings for middle- and high-income consumers, it was pointed out by interviewees that is very challenging to exploit such mechanisms to create similar benefits in low-income contexts. *"In my technical opinion, I would believe much more in high-income consumers."*. They have a good infrastructure and energy consumption that can be manoeuvred (Interviewee A). Furthermore, consumers have to know *"how much they consume"* and *"when they consume*" (Interviewee A). Moreover, such mechanisms are more successful when sufficient understanding of the energy tariff system exists (e.g., how to benefit through the use of different tariffs) and when the use of smart meters is possible. In light of the problem, and to address the issue of affordability, energy utilities and government have focused on economic incentives such as subsidies, discounts, appliance upgrade and exchange (see Box 3.3).

8 Energy utilities issue indicative "tariff flags" to inform customers if energy will cost more or less depending on the conditions for its generation (e.g., rainfall forecast in hydroelectric reservoirs); the flags are green (i.e., no additional charges), yellow, or red (i.e., additional charges per 100-kilowatt hour apply).

Box 3.3 Case 3 - Exchanging recyclable waste for discounts in the electricity bill

The Programme ECOELCE aims to provide discounts to the energy bills for COELCE (Companhia Energética do Ceará) customers, most of them low-income, in exchange for solid waste with market value. The ECOELCE pilot project was launched in 2006 for low-income communities in the city of Fortaleza (Brazil), and in 2007 was officially available to all COELCE customers (Lima et al., 2009). After five years, it was implemented throughout the State of Ceará (Brazil), and had 64 collection posts (38 fixed and 26 mobile posts) across 27 cities, serving about 90 communities. The programme involves 42 partners among recyclers, associations, government agencies, and private companies (COELCE, 2015b).

To identify the problem and develop a systematic solution, COELCE surveyed 184 low-income communities located in Fortaleza. This survey showed a relation between the low purchasing power of the population, the large volume of solid residues improperly disposed in the environment, and high rates of energy theft leading to an increase in power losses and inefficient use of power (Borger et al., 2011). The city of Fortaleza generates more than 41 thousand tons of solid residues per month, from which 14.9 thousand are potentially recyclable. However, only three thousand tons were recycled per month in 2004 (Lima et al., 2009).

The system comprises the following major stakeholders: COELCE to manage the collection system and provide the credits to the energy bills; Collection Posts to register customers, collect and weigh recyclable residues; Waste Collection companies to determine destinations for the residues from different industries; Customers who collect and exchange the recyclable residues for energy credits. The main economic impact of the programme was the decrease in illegal connections and non-paying legally connected customers. The customers, particularly those in low-income communities, benefit from discounts in their energy bill. In some cases, the customer achieves a reduction of over 90%, or even the total liquidity of the energy bill. After five years, the programme provided over than 800 thousand Brazilian reais in discounts on energy bills.

Box 3.3 Case 3 - Exchanging recyclable waste for discounts in the electricity bill (Continued)

Additionally, 57% of defaulting customers participated in the first year of the programme, resulting in a significant reduction of debts to COELCE and illegal connections (Lima et al., 2009). The Program resulted in an energy economy of 11,684.87 MWh per year, which is related to the yearly amount of recycled material collected (COELCE, 2015a). The programme reached about 405 thousand registered customers and received 12.700 tons of recyclable residues. The communities served experienced improved living conditions through the reduction in the volume of solid waste improperly disposed in the urban environment.

The main economic instrument created by the Brazilian government to tackle the issue of affordability in low-income households is the social tariff. The social tariff is a subsidiary tariff that can range between giving a 10 to 100% reduction to the regular residential electricity tariff. The conditions for consumers to qualify for the social tariff are based on consumption level, connection type, ethnicity, income level, and subscription to other social benefits. The families that participated in the project analysed in Case 1 were oriented by COHAPAR to get their Social Identification Number (NIS) which identifies low-income households that qualify for the social tariff. When the monthly consumption did not exceed 100 kilowatt-hours, the electricity bill was paid by the state government through an energy programme called Fraternal Light.

Although the low-income households analysed met the socio-economic requirements for participating in the social tariff, they often could not benefit from this economic instrument. The main reason was that they failed to meet the required minimum consumption level (Interviewee A). Similarly, in cases where the families receive the social tariff, they often lose the benefit within a few months. According to Interviewee E, the major issue is that they do not have an understanding of proper energy consumption and conservation practices (see also (Schäfer et al., 2011)). This situation is a major issue because the inclusion of low-income households in the social tariff can make viable the implementation of shorter payback periods for the newly implemented energy solution due to the reduction of energy costs (Interviewee E). The study showed that the inability of low-income households to maintain low energy consumption levels related to four major factors: (I) deficiency in thermal insulation of the dwelling; (II) low energy efficiency of household devices; (III) undesirable behaviour toward energy use; and, (IV) end-consumers with lack of education of and/or information.

The deficiency in thermal insulation has a significant negative effect on energy consumption and conservation in low-income households and results in the low environmental performance of the dwelling (Interviewee D). Renovations and expansion made in low-income households by untrained or unskilled personnel are a major cause of the problem and result in air leaks, inefficient doors and windows, incorrectly installed heating and cooling equipment, poorly sealed ducts and poorly insulated ceilings (Interviewee A). For example, in some extreme cases reported during the focus group discussion, low-income consumers used “barbed wire” as electric cable and “plastic bags” as insulating tape (Interviewee A).

Another factor mentioned is that low-income households often use inefficient energy-using devices such old, poorly maintained or damaged refrigerators, incandescent lightbulbs, and low energy efficiency shower heads. In low-income communities, such devices are accessible and affordable (Interviewee E). Although the substitution of old and inefficient household appliances and lighting by more energy efficient ones resulted in significant emission reductions, interviewees reported challenges related to the behaviour of low-income consumers towards such devices. For example, post-occupation surveys showed that low-income households continued using incandescent lightbulbs instead of LED lighting after energy programmes were implemented. Many low-income customers avoided using LED lighting because they associated better lighting (brighter light) with higher energy consumption, or they replaced broken LED lights with incandescent light bulbs due to financial reasons (Interviewee A). Similarly, Interviewee C reported an instance where the measurements performed at the end of the energy programme revealed that a consumer was using the new refrigerator as an alternative to an air conditioner. *“They were leaving the refrigerator door open for cooling the house.”* (Interviewee C).

A major issue is that the low-income population has limited access to education and lacks awareness or knowledge about energy savings potential and environmental impact. The majority of Brazilian consumers do not read their electricity bill because they cannot understand it (Interviewee A). For this reason, low-income energy-efficiency programmes are often associated with education projects. To be part of an energy programme, the consumer must attend educational lectures and training (Interviewee A). Nonetheless, illiteracy, alongside lack of education and awareness, makes it very challenging to promote supportive attitudes on energy and results in negative energy consumption behaviours during and after the programme’s implementation (Interviewee A). Furthermore, low-income consumers struggle to carry out self-service activities, such as guided equipment installation and maintenance (Interviewee D).

Corroboration among the interviewees exists that behaviour change is a long-term process and the training promoted by energy programmes has its limitations. *"I cannot change the culture with a lecture"* (Interviewee B). Even after the energy programmes were implemented, some consumers were unable to see the long-term negative consequences of their behaviour, such as electricity theft, meter tampering (fraud), irregular hookups to the network, and damages to public or shared energy devices and systems. *"I saw cases [...] where water heating solar thermal systems were installed in entire communities, and users were removing them. The problem was lack of maintenance or that the users were selling the equipment."* (Interviewee E). Similarly, in Case 1, instances occurred where consumers sold the refrigerators replaced by COPEL. With the money raised, they bought old refrigerators and used the balance for other expenditure (Interviewee C).

3.5 Discussion: Insights from the multilevel analysis

Drawing on a multilevel perspective, this chapter analyses Brazilian electricity distribution by focusing on energy solutions for low-income households. The insights from this analysis have been synthesised in a multilevel analysis at three aggregation levels: macro level, which described the relevant energy policies, regulatory frameworks, and the intended societal transformation required to achieve the national energy goals; meso level, which focused on product-service arrangements, stakeholders' relationships, infrastructural development, and organisational changes taking place in the electricity distributions sector; and micro level, which looked at product-technology intervention and behavioural change at household level. The study identified several aspects that contribute to the hindering of energy solutions which could increase the ability of low-income energy-efficiency programmes to reduce environmental impacts and increase the socioeconomic benefits of electricity distribution in low-income contexts. Results show that adopting a multilevel perspective allows new insights and identification of relevant constraints and opportunities across different system levels.

Notably, because there is high top-down interaction between levels, elements at the micro-level have difficulty breaking out from the lower level and making contributions at higher levels. For instance, in the present study, the interviewees emphasised during focus groups the lack of mechanisms to apply lessons learned from vernacular solutions in low-income households (e.g., renovations and expansion) to inform new energy programmes, new policy development or policy revisions. It is clear that the adoption of regulatory and economic tools is a success determinant for problem solvers tackling energy challenges in low-income energy markets. In contrast, there is a missed opportunity for the collection of insights from emerging energy solutions and DSM business models for low-income contexts to support policymakers in future national energy planning. The study shows that promoting the long-term transition to sustainable energy systems in low-income energy markets does not only involve the adoption of energy policies and regulatory frameworks, but also depends largely on changes to infrastructure, stakeholders' networks, technology, stakeholders practices, and culture. Therefore, policymakers and problem solvers have to work towards increasing the alignment between components at lower and higher system levels, in other to create new opportunities for the improvement of energy solutions for low-income households in Brazil.

3.5.1 Towards systems-oriented energy solutions

The study has highlighted that in the Brazilian Energy Efficiency Programme (PEE) low-income category, mostly incremental improvements can be achieved with current energy solutions (e.g., replacement of inefficient energy devices or addition of a complementary energy source). Although the activities in PEE projects are not limited to demand-side management (DSM), energy utilities are reluctant to approve new projects that differ from more established methodologies. PEE programmes have rigid methodologies for their implementation, and opportunities for radical improvements are limited to the typology "Pilot Project". In contrast, projects in the "low-income" typology face many challenges to develop and implement solutions that go beyond incremental improvements.

It is worth noting that projects need to be contracted through public calls that must respect specific laws and procedures regarding the bidding for products and services. Therefore, new products and services that do not follow previously established methodologies, although they may be implemented as a "pilot project", need to be evaluated and approved by ANEEL. Moreover, it is time-consuming and bureaucratic for energy utilities to purchase products and services that can only be designed by one specific company (e.g., due to exclusive rights over certain technologies or methodologies), which can discourage energy service companies (ESCOs) from participating in such programmes through energy performance contracts. Nevertheless, the adoption of alternative measurement and verification tools and metrics could be an option to increase the feasibility and viability of new projects that aim to create radical improvements.

The measurement and verification methodology adopted in the PEE programmes is the International Protocol for Measurement and Verification of Performance by Efficiency Validation Organization (EVO). Energy utilities are required to comply with targets and protocols that reinforce the assessment of impact by predominately quantitative performance measures. For instance, the impact of energy efficiency programmes is primarily assessed based on the expected cost-benefit relationship (CBR). Therefore, outcomes that cannot be objectively measured and quantified, but which are relevant to low-income markets, such as increased wellbeing, long-term effects, and indirect effects of behavioural change, are often overlooked. In particular, for the low-income category, PEE could use a mixture of measurement and verification methodologies that consider the social and technical analysis of the low-income context prior to and post implementation of the energy programme.

Another challenge identified concerns the timeframe of PEE projects. The societal and technological developments taking place in energy systems have different paces of change, particularly in low-income communities. Such developments are strongly influenced by aspects such as local socioeconomic development and infrastructure change. In the cases analysed, the implementation of the energy programme had a shorter time frame when compared with the desired societal transformation (e.g., behaviour change and local infrastructure development). In addition, energy programmes often do not consider the whole life-cycle of the energy solutions implemented. For example, the families observed in the study faced many challenges after the implementation of the energy programme. Some of the challenges identified were the dependency on economic instruments, lack of repair or maintenance of the newly installed devices and appliances, lack of trained technicians, and persistent undesirable behaviour towards energy use. A long-term sustainable energy system can only be achieved through continuous development and investment in the community. Policy options could include follow-up energy programmes designed to ensure long-lasting solutions by means of enhancing local capacity, improving local servicing infrastructure, and promoting income-generating activities.

3.6 Conclusion

This chapter has discussed the adoption of systems thinking as a multilevel perspective to analyse energy PSSs and gain insights that lead to the improvement of Brazil's low-income energy-efficiency programmes. The cases analysed were those in national energy programmes that provide integrated electricity services and related products for low-income communities, promoting clean energy solutions, changes in lifestyle, and favouring the efficient use of resources. The results were synthesised in three aggregation-level analyses that require careful attention during the development and implementation of energy solutions and conclude that value creation should occur across the multiple levels.

The requirements of long-term national energy goals are not likely to occur through technological improvements alone. In this context, incremental innovation has its limitations. The development of energy PSSs integrating systems thinking gives opportunities for shifting from the current technological paradigm to a socio-technical paradigm. However, results show that barriers from policies, infrastructure, and stakeholder interests hinder opportunities to promote radical innovation through new energy solutions for low-income households.

It is important to emphasise that challenges associated with the collection of information from stakeholders at higher system levels may be considered a methodological artefact in this study. Accordingly, it is recommended that future studies include stakeholders from governmental and/or regulatory agencies. Sensitising policymakers to the unique challenges associated with providing energy solutions to low-income energy markets is an important role to be contemplated by energy utilities and problem solvers, such as designers, in future research and practice. Creating communication channels between government and problem solvers can facilitate policy revisions and future energy planning favourable to the development of the low-income energy market towards the transition to sustainable energy systems.

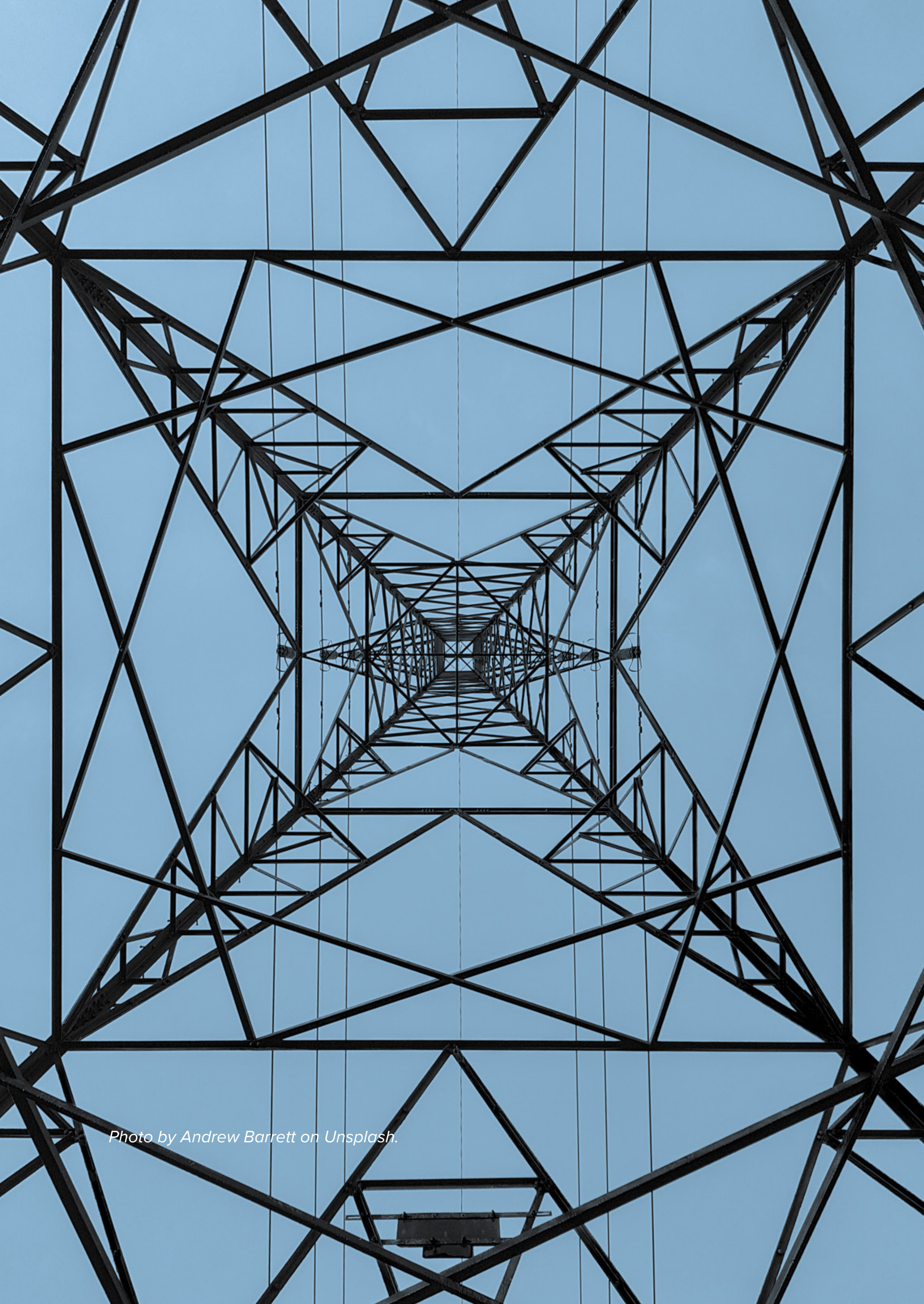


Photo by Andrew Barrett on Unsplash.

4.

Introducing systems design approach in design education

This chapter is based on the publication:
Costa Junior, J. Da, Santos, A. L. R. dos, & Diehl, J. C. (2017). Introducing systems oriented design for complex societal contexts in design engineering education. *FormAkademisk, 10*(1), 1–20. doi: 10.7577/formakademisk.1460

Faced with complex societal problems that include global warming, resource depletion, poverty, and humanitarian emergencies, society needs new and more appropriate reasoning models. As designers are typically educated to apply traditional design approaches, higher education institutions become an essential agent for change. To help design students to tackle the problems mentioned above, the interventions carried out in Chapters 4 and 5 explore the application of a systems design approach in design education. Besides, these interventions adopt findings from the theoretical model presented in Chapter 3. Moreover, Chapters 4 and 5 provide an initial exploration of the conceptual framework described in Chapter 2. Systems design approaches are widely recognised as promising in that they can support designers when addressing these complex societal problems. This chapter explores the adoption of a systems design approach comprised of the integration between Systems Oriented Design and Product-Service Systems for the development of concepts for sustainable energy systems in Brazil by student teams in a multidisciplinary Master's degree course at Delft University of Technology. The resulting twelve concepts were analysed using a case study approach, describing the advantages, and the context- and process-related challenges of using such approach. From an educational perspective, the results demonstrate that a systems design approach provides students with a broad knowledge base and the skills needed to address complex societal problems. However, there remains a need to introduce appropriate scope and depth into the design curricula, making the transition from traditional product design a challenging one.

4.1 Broadening the scope and complexity of design

Humanitarian organisations, governments, and companies face major challenges in providing essential services, such as energy and healthcare, in contexts where poor financial and infrastructural resources exist. Stakeholders in these contexts often create an informal market and use unconventional methods for product distribution and servicing which, in most cases, customers or end-users cannot afford. Thus, alternatives to traditional business and social relations are required for the successful provision of goods and services (Nielsen & Santos, 2013). Additionally, in such resource-limited contexts, the complexity and ambiguity of stakeholders' interests is higher than in traditional businesses (Matos & Silvestre, 2013), and the end-users are generally considered passive recipients, depending on their own coping mechanisms in terms of gaining benefit from the products and services provided.

In addressing complex societal problems, such as those mentioned in the contexts above, from a product-service development perspective, there is evidence that systems design approaches — in particular, Systems Oriented Design — are likely to achieve better and more sustainable results than traditional design approaches (Jones, 2014; Sevaldson, 2008, 2009, 2013; Sevaldson et al., 2010). Systems Oriented Design (SOD) is a design method that seeks to develop better designs, visualisations, and systems practices to create a new generation of design professionals who are equipped to cope with increased complexity (Sevaldson, 2011, 2013; Sevaldson et al., 2010). Moreover, SOD takes account of different system levels within a given socio-technical system.

Design has traditionally relied on a classical model of thinking, characterised by reductionism and rationality. Although this reasoning model is the basis of modern science, its assumptions have proved less effective in dealing with societal complexity (Gershenson & Heylighen, 2004; Nelson, 2008b). Therefore, a broader perspective, such as systems thinking, is needed to complement these limitations. For instance, in isolating the components of a given socio-technical system, a reductive analysis is likely to destroy the connections between those components, making it difficult to understand and to describe the behaviour of the system (Gershenson & Heylighen, 2004; Jones, 2014; Sevaldson et al., 2010). By adopting a systems design approach such as SOD, designers can handle a larger degree of complexity and make more sustainable changes by considering value creation within a long-term timeframe involving a larger network of stakeholders (Jones, 2014; Sevaldson, 2010). In contrast, relying solely on existing product-service development knowledge (i.e., methods, tools, and techniques) restricts the design process and results in an inability to understand the local context (London & Hart, 2004).

By broadening the scope and complexity of design practice, systems design approaches increase the capacity of the socio-technical system to function and to achieve sustainability (Reinders et al., 2012; Sevaldson et al., 2010). In low-income markets, (re)designing products to be affordable is not in itself enough to ensure their adoption for comprehensive accomplishment of the system's function (Brezet, 1997; Gaziulusoy, 2015). For that reason, a radical paradigm shift is needed in how we educate future designers (Cardenas et al., 2010; Raduma, 2011; Sevaldson, 2008). A systems design approach proposes the design of a coherent combination of processes and product-services to fulfil that function, leading problem solvers to look beyond technology and consider aspects such as business, lifecycle, and stakeholder motivations (Baines et al., 2007; Vasantha et al., 2012). As designers and researchers are typically educated to apply traditional design approaches, higher education institutions (HEIs) become essential partners for system change in this novel innovation network (Vezzoli et al., 2008).

HEIs play a crucial role in the introduction of knowledge and skills for dealing with complex societal problems. According to Raduma (2011), there is both a strategic opportunity and a challenge for HEIs when they confine their attention to traditional design approaches because they need to build capacities beyond the creation of products and services in design education. Additionally, Raduma (ibid) observes that design students are increasingly tasked by industry and the service sector to develop projects that will promote enormous societal change. To address such a challenge, HEIs must lead a radical shift in how students are educated, including creating and applying new and emerging pedagogical methods and skills (Cardenas et al., 2010; Raduma, 2011; Sevaldson, 2008; Vanpatter & Jones, 2009).

This study explores higher education institutions as a base for knowledge transfer between multiple stakeholders when addressing the need for affordable energy in low-income households and the implementation of humanitarian aid. It aims to contribute to the field of systems design education by exploring the integration of System Oriented Design and PSS Design to develop PSS concepts. The study was conducted in collaboration with the Federal University of Paraná (and partners) in Brazil, and the Innovation Unit of Medécins Sans Frontières (Doctors Without Borders) in Sweden. For this reason, the study's scope was extended to address the context of humanitarian aid. The chapter addresses the following research questions: *How can systems thinking support design students in the development of more sustainable product-service system (PSS) concepts for low-income markets?*

For the purpose of this chapter, a systems mindset is adopted by combining Systems Oriented Design (Sevaldson, 2013) to Product-Service Systems Design (Crul & Diehl, 2006; Halen et al., 2005). The chapter also describes the use of HEIs as a base for knowledge transfer between multiple stakeholders in emerging economies as they address the need for affordable energy in low-income households, the humanitarian provision of medical equipment, and cold chain monitoring of vaccines and medicines. The study was conducted as part of an elective course called Product-Service Systems in the Industrial Design Engineering Master's Programmes at the Faculty of Industrial Design Engineering at Delft University of Technology (TU Delft), in collaboration with the Federal University of Paraná (and partners) in Brazil, and the Innovation Unit of Medécins Sans Frontières (MSF) Sweden.

The chapter is structured as follows. The next section presents an overview of the relevant literature on low-income markets, PSS, and SOD. The research methodology is then described, followed by a detailed account of data collection and analysis. The main findings are then presented, and the advantages and challenges of applying the proposed approach are discussed. The chapter concludes with implications for future studies and impacts on design education.

4.2 Designing products, services and systems for low-income markets

Product-service system development in low-income contexts, such as low-income energy markets and humanitarian aid situations, has received little attention in the literature (Betts & Bloom, 2014; Viswanathan & Sridharan, 2012), which has tended to focus both theoretically and empirically on middle-/high-income contexts. To properly address complex societal problems in contemporary society, designers must overcome this knowledge gap and apply new models of reasoning (Cardenas et al., 2010; Tatham & Houghton, 2011; Tischner & Verkuijl, 2006).

There is evidence that many products and services have failed to meet the needs of low-income markets because of a failure to understand the local context (Chavan et al., 2009; Duflo et al., 2012; London & Hart, 2004). It has been suggested that the product-service system development knowledge associated with middle-/high-income contexts is unsuited to the generation of innovative solutions for low-income markets (Chavan et al., 2009; Mahajan & Banga, 2005; Viswanathan & Sridharan, 2012). This existing knowledge base (e.g., traditional approaches, methods, tools, and techniques) restricts the design process and limits designers' ability to understand and address the constraints and complexities of low-income markets (London & Hart, 2004). Everyday life in such markets makes for a distinct physical and mental environment (Hart & Sharma, 2004) where stakeholders' needs are shaped by psychological, physical, economic, and social necessity. In these conditions, behaviours and habits related to a product or service tend to be profoundly influenced by local norms, beliefs, and/or circumstances (Viswanathan & Sridharan, 2012).

Humanitarian emergencies, such as natural disasters or conflicts, have a particularly strong impact on low-income markets because of contextual vulnerabilities. In particular, the number and types of humanitarian organisations supporting relief and reconstruction activities add to the complexity of the context by creating a parallel market (Binder & Witte, 2007) in which products and services, ranging from basic sanitation to complex healthcare initiatives, are provided through intricate collaborations of donors, private services, and various government and non-government organisations. In these circumstances, the development of products and services must overcome a number of constraints distinct from the ones experienced in middle-/high-income contexts (see Table 4.1).

Table 4.1 Challenges faced in product-service development for low-income markets.

Constraints	Examples	Authors
User	Illiteracy; low literacy; functional illiteracy; lack of empowerment; behavioural constraints; unknown cultural norms.	(Boeijen & Stappers, 2011a, 2011b; Mays et al., 2012; Ramalingam et al., 2009; Schäfer et al., 2011; Viswanathan & Rosa, 2007)
Technical	Lack of infrastructure and maintenance.	(Crul & Diehl, 2006)
Regulatory	Restrictive or missing regulations, laws and policies.	(Mahajan & Banga, 2005; Webb et al., 2010)
Institutional	Misalignment of priorities and agendas amongst stakeholders; issues of trust.	(Francois, 2002)
Socio-ethical	Lack of equity and social cohesion; exclusion of minorities.	(Cozzens, 2012; Margolin, 1995; Penin, 2006; Rocchi, 2005; Tischner & Verkuijl, 2006)
Economic	Affordability; limited access to credit; informal economy; poverty penalty.	(Prahalad & Ramaswamy, 2004; Webb et al., 2010)
Environmental	Environmental impacts; rebound effects; lack of environmental awareness.	(Arnold & Williams, 2012)

Designing long-term product-service systems (PSSs) for low-income markets requires designers to change the intrinsic characteristics of products and services. This task demands radical transformations in the expectations, values, and cultures embedded in the relation between products and humans, and new ways of understanding the role of products and services (Cardenas et al., 2010). Despite having extensive technical knowledge and the technical skills needed to solve complex problems, designers might exhibit a limited understanding of the complex societal problems facing low-income markets. Moreover, while designers can have a view regarding a context, it is always an assumption influenced by personal experiences and points of view (Sleeswijk Visser et al. 2005). When the personal experiences of a design distance from the context in place, they most likely experience unfamiliarity with many of the practicalities of these contexts and associated product-service requirements.

4.3 Systems-oriented PSS design for low-income markets

Achieving or maintaining high levels of sustainable socio-economic development in low-income markets requires major changes in existing patterns of production, distribution, and consumption, with radical solutions that go beyond traditional product-centred innovation (Brezet, 1997; Sevaldson, 2013). Such solutions depend on a broader innovation perspective that considers policy choices, infrastructure change, product-service technology, and consumer behaviour. Figure 4.1 provides an overview of approaches to designing sustainable products, services, and systems.

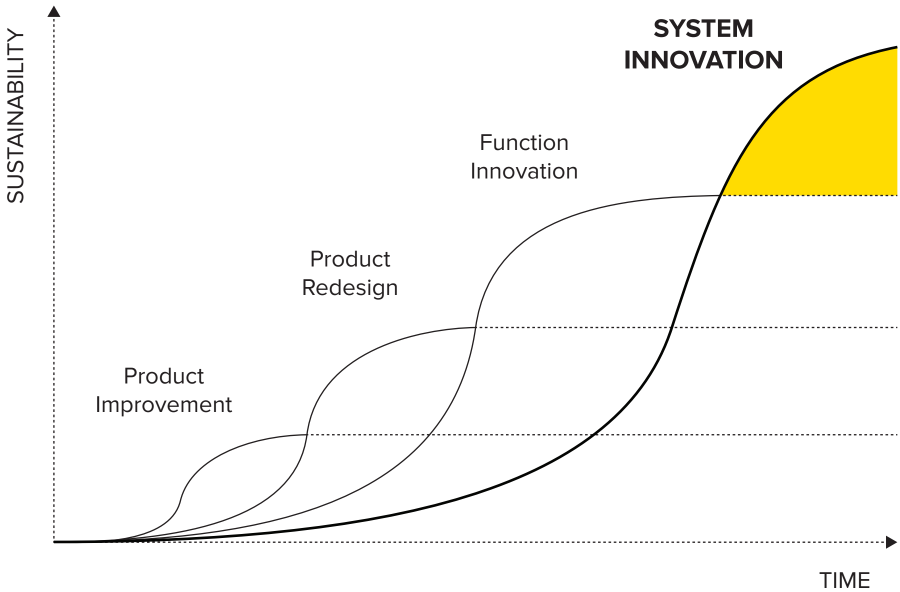


Figure 4.1 Levels of innovation for sustainability. Adapted from Brezet (1997).

To meet this increasing need for system innovation, Systems Oriented Design (SOD) adopts a systems mindset which takes holism as a fundamental assumption underlying design thinking and practice (Sevaldson, 2009). This novel approach takes account of the whole system and its relations and interconnections as a basis for innovation, combining needs and opportunities to tackle environmental, socio-ethical, and economic challenges, and to improve the effectiveness and sustainability of the total system (Joore, 2008). The systems methodology set guiding the interpretation of systems thinking adopted by SOD is based on interpretative and emancipatory methodologies and approaches (see Section 2.6.2), such as Soft Systems Methodology and Critical Systems Thinking (Sevaldson, 2011). By employing SOD, designers apply modern systems theory to design practice, grounding design theory in systems theory (e.g., PSS and service design).

Several scholars agree that PSS can stimulate progress towards sustainability in low-income markets (Penin, 2006; UNEP, 2002; Vezzoli, Kohtala, et al., 2014). PSS is a system of products, services, supporting networks, and infrastructure. It closely involves final consumers and stakeholders in the value chain and beyond, and thus is designed to be competitive and to satisfy customer needs with lower environmental impact than traditional business models (Mont, 2002a). To strengthen the systems thinking orientation of PSS and so enhance its capacity to deal with complexity, the present approach integrates Systems Oriented Design (Sevaldson, 2013) (see also Section 2.6.2) to Product-Service Systems Design (Crul & Diehl, 2006; Halen et al., 2005). Doing so, it attempts to equip design students with the ability to develop solutions with the appropriate scope, depth, and feasibility to address complex societal problems.

PSSs show promise as solutions capable of stimulating the changes in current production and consumption patterns necessary for an environmentally sound socio-economic development trajectory (Manzini & Vezzoli, 2003; Mont, 2002b; UNEP, 2001, 2002). These innovative solutions can help to promote more sustainable lifestyles and strengthen awareness of the environmental, socio-ethical, and economic consequences of production and consumption of products and services. Given that a considerable number of sustainable technologies already exist, the effectiveness of such innovations relies largely on their affordability and how they are introduced to the market (Reinders et al., 2012).

PSS combines a range of comprehensive products, services, and systems to provide access to affordable, reliable, and clean design solutions. For instance, in the context of low-income energy markets, the electricity distribution sector could benefit from sustainable PSSs, such as pay-per-use systems, solar photovoltaic off-grid solutions for remote areas, and combinations of energy-related products and services to support income generation in low-income communities. The characteristics of PSS change with the principal value proposition of the offer, which may meet consumer needs with more material (e.g., products) or with immaterial components (e.g., services and experiences). Among the classifications proposed in the literature, three major PSS categories can be distinguished (Figure 4.2): product-oriented, use-oriented, and result-oriented (Tukker, 2004).

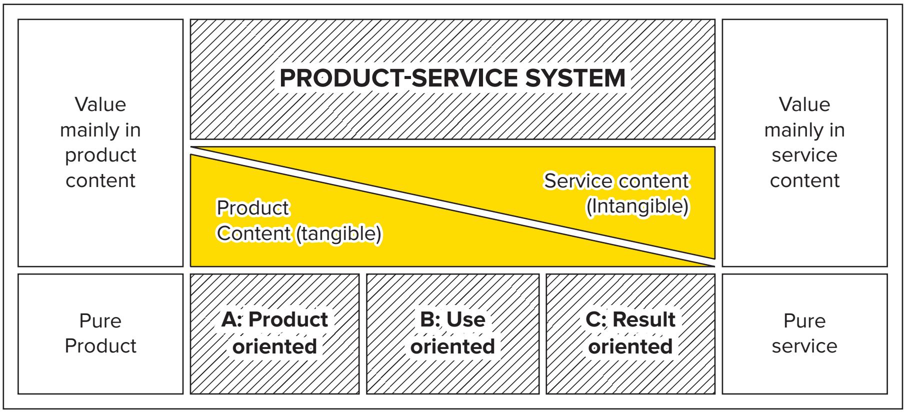


Figure 4.2 Main product-service system categories. Adapted from Tukker (2004).

In the product-oriented PSS, the business model is organised mainly around the sale of products. Usually, the end-user owns the product and its functionality is offered for a given period with the support of services such as installation, maintenance, and warranty. Additional services add value to the product and assist in lifecycle management. While product-oriented PSS is clearly focused on adding value to the product, its successful implementation often requires change in infrastructure and user practice (Bartolomeo et al., 2003).

In the use-oriented PSS, on the other hand, while the product may still play a central role, the business model does not focus on the sale of a product but on the “sale of use”. In this case, the company is motivated to increase the efficiency of the product, and to extend the life of the materials used in its production (Baines et al., 2007). In addition, because the product remains the property of the provider, the company can integrate additional services into the product’s life cycle, such as exchange, upgrade, reuse, and disposal. This category of PSS seeks to make better use of under-utilised devices through such mechanisms as renting or leasing a product (Bartolomeo et al., 2003).

Finally, in a result-oriented PSS, the solution essentially involves applying the most suitable combination of products and services to meet the customer’s need. In this business model, the customer and the supplier agree in principle on a specific outcome and, for that reason, no predetermined product or technology is necessarily involved. The result-oriented PSS offers companies an opportunity to analyse the supply chain interacting with the service at all stages of the process. The aim is to establish partnerships which enable the construction of a network of stakeholders interested in working together to manage the products and services offered.

4.4 Methodology for the educational experiment

This chapter introduces a Master's elective course called Product-Service Systems, which was delivered at TU Delft by the author in collaboration with another researcher over a period of seven weeks in the academic year 2013–2014. The data reported here comes from a set of PSS concepts targeting complex societal problems in low-income markets as developed by student teams within the course. This educational experiment was designed to apply knowledge and skills based on SOD and PSS theories, strategies, tools, and other resources that might be useful in making design choices during product-service system development.

Using a case study research methodology supported by thematic analysis, the sampled cases were for descriptive purposes rather than for inferential generalisation. The case study approach enabled comparison and comprehensive, detailed description of the students' design activities. Each project was analysed as a unique case in order to characterise and highlight similarities and differences in how students used systems thinking to develop more sustainable solutions. This approach is particularly suitable for improving understanding of the problem, and for theorising about new contexts (Berg, 2001).

4.4.1 Sample of students

The initial sample consisted of 12 multidisciplinary teams of three to four students from Master's programmes in Industrial Design Engineering, Industrial Ecology, and Sustainable Energy Technology. At the beginning of the first workshop, all students completed a questionnaire about their educational background and their familiarity with low-income markets, SOD, and PSS design. To ensure students had the same level of basic knowledge about the main study domains, two workshops were conducted to which experts in the field of sustainable PSS design and SOD were invited.

4.4.2 Course structure

The course focused on the development of new PSS concepts as an approach to sustainable innovation in low-income markets. Each class (workshop) comprised an introductory lecture, an explanation of one major phase of the PSS design process (see Figure 4.3), an inspiring lecture by a professional with experience in the relevant domain, and finally, a hands-on exercise using one of the systems-oriented tools. The design assignments were derived from real problems faced by two real clients: to develop an innovative and sustainable lighting product-service system for Accord

Illumination, a medium-sized enterprise in Brazil; and to develop autoclave and cold-chain business model solutions for the innovation section of the international organisation Medécins Sans Frontières (MSF) Sweden.

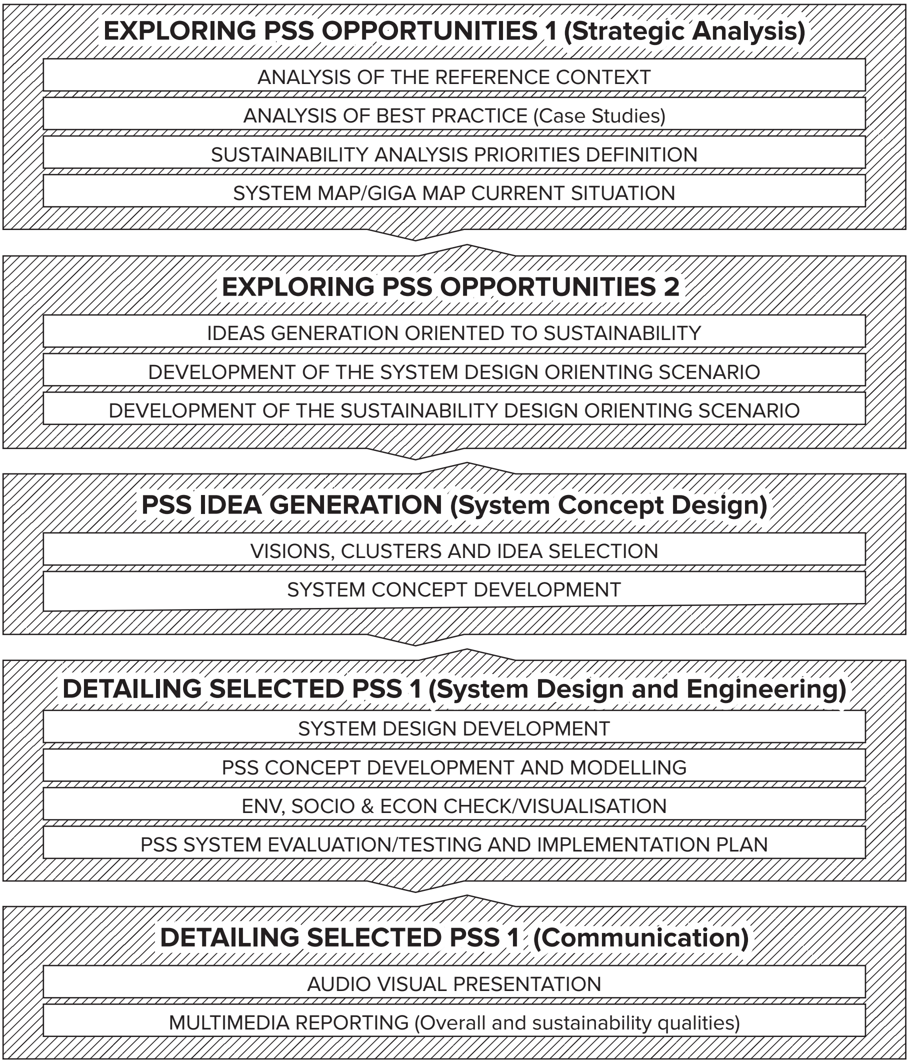


Figure 4.3 Product-service system design process. Adapted from LeNSes e-learning packge[9].

9 LeNSes | The Learning Network for Sustainable Energy Systems, available at http://www.lenses.polimi.it

The course set five major student learning objectives: to provide a broader knowledge base (systems mindset) and skillset grounded in systems thinking (systems skill set); to share basic knowledge of theory, concepts, approaches, methods, and tools for Design for Sustainability, Sustainable System Innovation, Systems Oriented Design (systems methodology set, systems knowledge set and systems tools set), PSS Design, and Behaviour Change; to provide insights into PSS implementation conditions, drivers, and obstacles in practice, with particular reference to low-income contexts; to provide knowledge and skills in the development and assessment of business models supporting successful introduction of the new PSS via existing businesses or new ventures; and, to develop understanding and design skills for multi-stakeholder environments.

The course resulted in twelve comprehensive PSS concepts, including six energy product-service systems (E-PSS) (assignment I) and six humanitarian product-service systems (H-PSS) (assignment II) (see Table 4.2).

Table 4.2 Overview of PSS concepts developed within the course.

No.	Project description	Assignment
1	Pay-per-use (card) LED light system	E-PSS
2	LED lighting products to empower local craftsmen	E-PSS
3	Self-sufficient solar LED leasing system enabling energy sharing	E-PSS
4	Local shop/school of modular LED light products to empower craftsmen	E-PSS
5	Lighting PSS based on local resources	E-PSS
6	Modular LED lighting kit for craftsmen	E-PSS
7	Sustainable leasing model of sterilisation equipment	H-PSS
8	Maintenance lab for medical devices	H-PSS
9	Digital sharing platform for cooling boxes	H-PSS
10	RFID monitoring system	H-PSS
11	Visual communication paper form to create awareness among cold chain drivers	H-PSS
12	Improved vaccine monitoring device	H-PSS

The PSS concepts were developed by the student teams under the author's supervision, with regular interaction with the two clients.

4.4.3 Data collection and analysis

A thematic analysis was employed in the examination of design activities to capture the influence of PSS and SOD on participants' cognitive skills and abilities. Thematic analysis is a method of analysing qualitative data, in which the researcher identify common themes in the data collected. The analysis was applied to the transcript of the data collected. For example, the transcript of the participants' verbal accounts of their own cognitive activities. The data retrieved served to illustrate how participants collected, generated, and transformed context-specific information while developing solutions for the design assignments.

The PSS concepts were designed to take account of SOD-based training resources, including sustainable PSS design processes and tools (Crul & Diehl, 2006; Halen et al., 2005; Vezzoli, 2010); sustainable design strategies (Vezzoli, 2010); and system design theory applied to design (Jones, 2014; Joore, 2010; Sevaldson, 2014a). PSS concepts developed by the students were presented in the form of a report, visualisations, and a final audio-visual presentation during an evaluation session with a jury panel composed of experts, scholars, and the clients (n = 5). Concept evaluation employed the Sustainability Design-Orienting Toolkit (SDO toolkit) (Vezzoli & Tischner, 2005) which guides the design process towards sustainable solutions based on sustainability criteria along three main dimensions: environmental, socio-ethical, and economic sustainability. The tool generates visualisations (i.e., radar diagrams) of potential environmental, socio-ethical, and economic improvements that characterise the new product-service system (see Figure 4.4). Students were allowed to adapt the SDO toolkit criteria for their specific contexts as necessary.

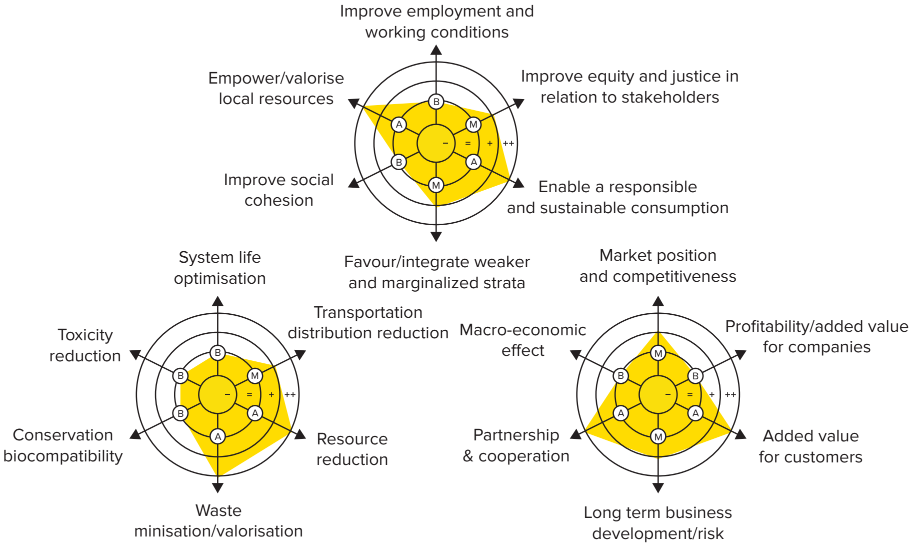


Figure 4.4 Example of a visualisation of SDO toolkit results. Adapted from Vezzoli and Tischner (2005).

Analysis of the concepts followed a systematic three-step procedure. First, student teams were asked to critically evaluate their own design by comparing their idea's radar diagram with the current target context situation. They then cross-compared each PSS idea generated. Second, the author evaluated students' concepts using the SDO toolkit checklist and the Student's Assignment Grading Tool. Third, the complete data set was used to analyse how each of the student teams applied SOD, potential improvements resulting from the application of this approach, main advantages, and finally, any context- and process-related challenges.

The jury panel evaluation was carried out in the last session of the course during the final audio-visual presentations. The jury panel used a specific evaluation matrix focusing on the following areas: context understanding; PSS design process; audio-visual presentation; and visualisations (e.g., poster, tools). Triangulation of these evaluations generated the overview presented in Table 4.3 and Table 4.4, which summarise the teams' attempts to promote potential environmental, socio-ethical, and economic improvements in the PSS concepts.

4.5 Results

This section describes the application of SOD in the development of the twelve PSS concepts. These concepts include that of local shops providing energy-saving bulbs in Brazil for the company Accord Illumination, a sustainable leasing model of sterilisation equipment for MSF, and a web-based monitoring platform for cooling boxes with vaccines. Box 4.1 and Box 4.2 describe two student team projects in more detail.

As mentioned previously, the design briefing of the course addressed two real problems faced by the partner organisations. In the first assignment, the medium-sized enterprise Accord Illumination sought support to develop an innovative and sustainable lighting product-service system for social housing in Brazil. Such a solution should address low-income households live in poverty, which can afford only little more than the necessary to meet their most essential needs. In the second assignment, MSF was looking for: (I) a solution that allowed to monitor medicines being taken to the end-user employing a user-friendly, reliable and accurate system; and, (II) a solution for the autoclave business model that focused on a profitable, efficient and sustainable system.

Box 4.1 H-PSS Concept 9 - A digital sharing platform for cooling boxes

The Zazu system is an online platform that connects stakeholders in the humanitarian cold chain to each other and provides information about transported medicines through Radio Frequency Identification technology (RFID) in the cooling boxes. In the proposed PSS, new measuring devices that allow greater control of the cold chain process will replace the existing time-temperature monitoring devices. The solution includes a new cooling box design and an information system managed by humanitarian organisations and/or local governments. In the cooling box, medicines are kept cool by ice, as was the case in the original solution, because energy resources in remote areas cannot be relied upon. Individual medicine packages have a passive RFID tag which carries information about the content of the package and its use. Information about medicine temperatures and locations is stored in the Zazu database and can be retrieved by stakeholders. The accessibility of these data allows organisations to make logistical decisions based on the condition of the medicines at a given moment (e.g., allowing avoidance of the transport of medicines which have been exposed to excessive temperatures). The passive RFID tags do not rely on a power source, this makes them adaptable and suitable for large-scale implementation.

Box 4.2 E-PSS Concept 3 - A sustainable product-service system for energy sharing

Light Energy aims to introduce a sustainable lighting system for Brazilian low-income households through a solar, LED, rent-to-own system. This PSS enables end-users to save, produce, and share their energy for lighting locally. Light Energy delivers a complete solution — an affordable, self-sufficient solar LED rent-to-own system for low-income households in the state of Paraná, Brazil. The system will be offered by Light Energy, a cooperative based on the partnership between Accord, the local energy utility Copel, and the housing company COHAPAR.

In this collaboration, Accord's key contribution is their expertise in lighting systems, specifically in the new LED technology. Copel's key contribution is their expertise in all energy-related matters. To launch the system and its products successfully into the market, Light Energy will exploit COHAPAR's existing community network, and use it as a communication channel between Light Energy and the end-user in order to raise awareness and, ultimately, to recruit and educate members of the community as "Accord ambassadors". These ambassadors will be key to building the Light Energy customer base as they communicate the benefits of the new system directly to other members of the community. As part of the low-income community themselves, they can readily communicate the value and benefits of the new Light Energy PSS.

This initiative allows people to experience the value of energy through the act of producing and sharing it within their personal network, supporting their relatives, friends, and neighbours. The system enables users to engage in behavioural change for their own benefit. In addition, the PSS creates awareness of energy consumption and stimulates a new value perception that will make lower-income users more willing to pay for (legal) energy. The proposed solution includes options for multiple levels and types of subscription, matching PSS to the different needs and financial resources of members of the lower-income community. Additionally, where people improve their financial status over time, they can choose to upgrade their subscription.

Based on the data retrieved from the students' reports, visualisations and audio-visual presentations, and from the hands-on workshops, I analysed the design choices made by each team. The analysis considered the attention given by students to each of the three dimensions of sustainability (i.e., socio-ethical, economic, and environmental), revealing their priorities and struggles in approaching the complexity of the given problem. Three major trends were identified: the need to adapt predefined criteria and strategies of the sustainability dimensions to better fit contextual needs; the prioritisation of one dimension over others; and a better understanding of the criteria and strategies of one dimension over others. The next section details these observations in terms of the specific dimensions of sustainability.

4.5.1 Need for context-specific information

During project development, the student teams expressed a need to introduce changes in the tools and strategies used to address the different dimensions of sustainability, especially with regard to the socio-ethical and economic dimensions (see Table 4.3). When applying PSS tools to these dimensions, the teams often created new criteria and strategies that were a better fit to the challenges their projects presented. For instance, in H-PSS concepts where there was the need to focus on more organisational issues, it was of paramount importance to specify social aspects around a specific stakeholder (e.g., communication and knowledge transfer, safety, and usability), and economic aspects around organisations (e.g., scaling up business models and looking for R&D opportunities). Across the cases, it was observed that in order to overcome existing socio-ethical constraints and increase social benefits, the teams had to uncover, and rely heavily on, context-specific information, which in some cases were not accessible in large-scale national or international surveys.

4.5.2 Prioritisation of sustainability dimensions

The analysis of PSS tools and final deliverables demonstrated that one particular dimension of sustainability tended to offer the most significant potential improvements. In the case of H-PSS concepts, the most significant improvement was achieved in the socio-ethical dimension; for E-PSS concepts, the economic dimension offered the most significant potential improvements. In some groups, E-PSS affordability was seen as the key to successful implementation of the project. For example, during idea generation teams discussed a range of different payment systems, such as pay-per-use, rent-to-own, lease, or supplementary payment for electricity bills (e.g., exchanging discounts for services provided by users). Further, some ideas involved product-service combinations to support income generation in low-income communities. Analysis of the PSS concepts indicated that in seeking to promote profound change, teams prioritised the dimension of sustainability considered essential in meeting the needs of the target socio-technical system.

4.5.3 Environmental sustainability bias

The analysis established that teams achieved a better understanding of the criteria and strategies of the environmental dimension of sustainability, and all proved more assertive in applying the strategies and tools for this dimension. This was observed mainly in the report and visualisations, which presented a clearer and more complete description of environmental improvements when compared to other dimensions. I contend that these results are correlated with the design curriculum of the Master's programmes at TU Delft, which offer multidisciplinary courses with particular emphasis on (environmental) sustainability.

4.5.4 Potential environmental, socio-ethical and economic improvements

To validate whether the potential improvements achieved by the PSS concepts could be traced back to the application of SOD, an in-depth analysis looked at how the teams applied the course content. This was done using a student assignment-grading tool, which contained a systematic list of the theories, methods, strategies, and tools that students were expected to apply. The application of SOD resulted in potential environmental, socio-ethical, and economic improvements in PSS concepts when compared to the current situation. Table 4.3 indicates the intention of student teams to promote environmental, socio-ethical, and economic improvements in the development of PSS concepts. For instance, five out of six (5/6) student teams applied strategies for "Improving employment and working conditions" in developing their E-PSS and H-PSS concepts.

Table 4.3 Overview of strategies applied to promote improvements in the PSS concepts.

Sustainability Dimension	SDO Criteria	PSS Concepts	
		E-PSS	H-PSS
Social	Improving employment and working conditions	5/6	5/6
	Justice and equity on the part of stakeholders	3/6	1/6
	Enabling responsible, sustainable consumption	6/6	3/6
	Fostering and integrating the weak and marginalised	2/6	2/6
	Improvement of social cohesion	4/6	1/6
	Reinforcement/valorising of local resources	5/6	3/6
	* Knowledge transfer and communication between stakeholders	1/6	5/6
	* Awareness of effects on the environment	1/6	0/6
	* Improving quality of life/living conditions	4/6	0/6
	* Health and safety	1/6	2/6
	* Social awareness and education	1/6	2/6

Economic	Market position and competitiveness	6/6	1/6
	Profitability/added value for businesses	5/6	2/6
	Added value for clients	5/6	5/6
	Long-term business development	6/6	5/6
	Partnership/cooperation	6/6	4/6
	Macroeconomic effect	4/6	2/6
	* Consumer lock-in	1/6	0/6
	* Quality perception by user of brand or product	0/6	2/6
	* Scalability/modularity to other organisations and sectors	0/6	2/6
	* Proactive search for R&D opportunities	0/6	1/6
	* Implementation/initiation/change costs	0/6	2/6
Environmental	System life optimisation	6/6	4/6
	Reduction in transport/distribution	4/6	3/6
	Reduction in resources	6/6	1/6
	Waste minimisation/valorisation of resources	5/6	5/6
	Conservation/biocompatibility	6/6	0/6
	Non-toxicity	3/6	0/6

*SDO toolkit criteria formulated by the student teams.

Based on project priorities, student teams created solutions for each criterion at different levels of intervention: “major improvement”; “incremental improvement”; “no significant change”; and finally, “worse” where students opted to intentionally diminish the performance of a criterion. The teams were encouraged to customise, replace, or even omit the SDO toolkit criteria to generate strategies that would better meet the needs of their specific context. Changes made by the teams to SDO criteria were not considered where the description of the new criterion was equivalent to the existent criterion (e.g., changing a criterion name, but retaining the same strategy).

4.6 Discussion

The results reported in the previous section illuminate how SOD can support student teams in developing sustainable solutions for low-income markets. This section discusses the major advantages of using SOD as identified by this study, and considers context- and process-related challenges. Finally, I discuss how future designers and engineers can be better prepared and equipped to deal with the complex societal problems which face low-income markets.

4.6.1 Advantages of applying a systems design approach

Based on an analysis of the potential impacts of SOD, those potential impact factors were qualitatively categorised (using the SDO toolkit radar and each group's criteria), and clustered into groups of advantages. Table 4.4 summarises the identified advantages of SOD in developing solutions for low-income markets.

Table 4.4 Advantages of SOD when designing for low-income markets.

Sustainability Dimension	Advantages	Example of application from evaluated concepts
Social	- Think beyond the concept of affordability towards a concept of value creation. - Consider a broad network of stakeholders and their motivations for change as well as roles for new stakeholders from parallel industries. - Promote social integration and cohesion. - Empower the (local) end-user through education, employment and leadership. - Promote knowledge exchange and communication for improved awareness and consumption.	- E-PSS Concept 3 benefits from local ambassadors who connect and communicate with members of the community to convey the value and benefits of the new system. - H-PSS Concept 7 proposes a co-creation platform "from client to partner" that enables the continuous participation of different stakeholders through serious gaming facilitation. - H-PSS Concept 11 focuses on the acknowledgement and education of an often neglected, but important, stakeholder (local medicine transporters).
Economic	- Increase competitiveness and innovation. - Promote sharing of responsibilities and gains amongst stakeholders. - Consider positive macroeconomic impacts. - Design affordable solutions. - Offer benefits for business. - Design scalable solutions with a long-term business perspective.	- E-PSS Concepts 6 and 3 use rent-to-own payment systems that allow ownership by paying the PSS over time. - H-PSS Concept 12 redesigns an existing solution, maintaining cost and focusing on increasing its value for organisations while optimising information and safety.

Environmental	- Consider technological and organisational dependencies of products. - Optimise lifecycle of products and services from manufacturing to disposal. - Valorise local material resources. - Reduce dependence on material resources and environmental footprint. - Promote awareness and choice of environmentally friendly resources.	- E-PSS Concept 1 promotes a pay-per-use system that encourages rational use of resources. - E-PSS Concept 4 uses a business model in which Accord provides product components and transfers knowledge to local branches to support them in running the business themselves. - H-PSS Concept 9 allows organisations to learn and to make logistical decisions through the cold chain monitoring process, which includes reducing the number of unnecessary trips. - H-PSS Concepts 9 and 10 emphasise the need to share and reuse devices.

Analyses of the case studies shows that a SOD approach could impact the different dimensions of sustainability. Table 4.4 illustrates several strategies repeatedly used by the teams to overcome project challenges. In particular, I observed that SOD stimulated student teams to embrace innovative approaches to decision-making about people, resources, economics, politics, markets, functions, needs, and so on. As noted by other authors (Cardenas et al., 2010), SOD has shown to be effective in increasing tolerance for uncertainty and encouraging a holistic approach to deal with complex problems.

The identified advantages confirm that student teams had to rely heavily on context-specific knowledge, thereby gaining a thorough understanding of the unique characteristics of those contexts. On the other hand, traditional product-service development knowledge often offers methods, tools, and strategies that isolate the components of the socio-technical system. For example, traditional design approaches produce changes along horizontal systems dynamics; individual changes, such as product influence on users; organisational changes, such as manufacturer influence on service providers; and societal changes, such as policy instruments that influence societal trends. In fact, the complex dynamics of low-income markets exert both “horizontal” and “vertical” influences on the construction of the socio-technical system (Figure 4.5) (Elzen et al., 2004).

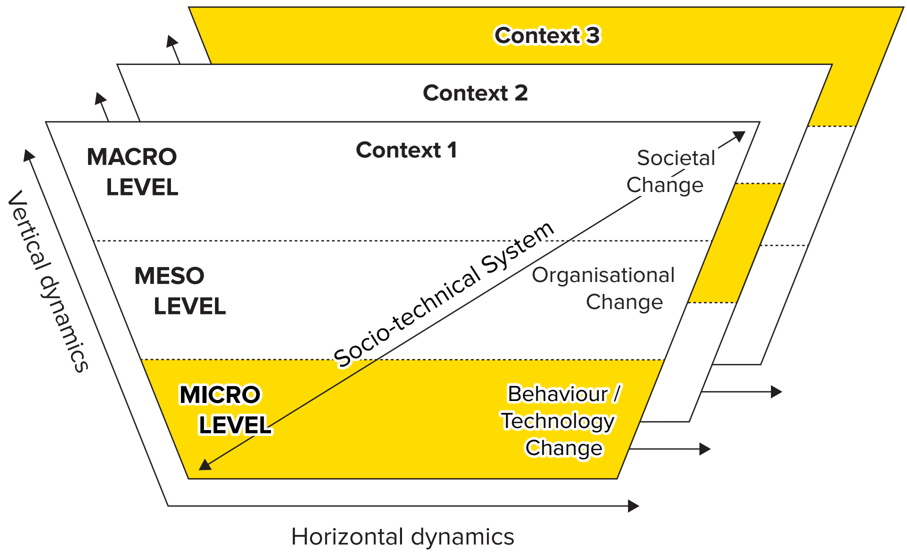


Figure 4.5 Dynamics of the construction of a socio-technical system showed across different contexts. Adapted from Elzen et al. (2004).

As a systems mindset for understanding and framing problems while investigating solutions, SOD offers students a novel and broader perspective on both the vertical and horizontal dynamics of socio-technical systems. For example, the Stakeholders Motivation Matrix (Vezzoli, Delfino, et al., 2014) tool visualises multiple functional relations between stakeholders and explores the solution from the stakeholders' point-of-view by cross-referencing their motivations, interests, and expectations (Morelli & Tollestrup, 2006). This tool enabled the teams to examine the influence of each stakeholder at different system levels simultaneously. In this way, the interrelations between stakeholders are preserved, decreasing potential conflicts and increasing synergy throughout the network of stakeholders.

4.6.2 Challenges of applying systems design approach

Along with the advantages, several challenges were identified in respect of context specificities and the PSS design process itself. These challenges are listed in Table 4.5. Although promising, application of SOD revealed a number of context- and process-related challenges. For example, student teams faced organisational barriers when presenting their ideas to the clients. Although the expansion of the stakeholders' network meant risk reduction for the organisation in most projects, the clients resisted opening up their operations and collaborating with new actors.

Table 4.5 Context- and process-related challenges identified in the study.

Challenges	Description
Context-related	- Diversity of contexts at state or country level (e.g., government influence, infrastructure and education level) - Responsibility distribution among stakeholders in the long-term (e.g., international versus national) - Prioritisation/budget allocation due to dependency on donor or subsidy system - Poor diversity of available skills/expertise within the stakeholder network - Local end-user practices as coping mechanisms to overcome system difficulties
Process-related	- Communication within teams and with partners (e.g., mapping complexity versus structuring visualisations of systems) - Detailed information about context - Lack of organisational knowledge - Ideology-motivated decision making - Limitation of academic programs for project follow-up - Management of expectations about innovation outcomes (e.g., occasional feedback versus co-creation)

4.6.3 Towards a systems design approach in design education

Based on the results of this study, the recommendations for design educators set out below (Table 4.6) aim to achieve better results when applying SOD in educational settings.

Table 4.6 Recommendations for the use of SOD in educational settings.

Competency	Recommendation
Be aware	- Dependency on donor or economic instruments, such as subsidies and taxes, as a determinant of decision-making and priority setting - Diversity of local contexts, which are influenced by local norms, beliefs and circumstances (e.g., differences between local and regional contexts) - Poor diversity of available skills/expertise within the network of stakeholders - Ideologically motivated decision making
Ensure	- Engagement with the motivation of each stakeholder to assure their commitment to the project - Respect for local end-user practices
Communicate	- Hands-on process and visualisations to communicate complexity (e.g., system maps and GIGA-maps) - Involvement of maximum number of stakeholders in the process of creating visualisations to work as a shared mental model

Familiarise	- Stakeholders to be familiarised with the concept of PSS - Deficits in organisational knowledge addressed by developing preliminary strategic analysis or guaranteed access to vertical hierarchy of client
Manage	- Expectations regarding results, participation, and shared responsibility.
Create an experimentation space	- Universities as spaces where knowledge is transferred and ideas are developed and tested - Support for follow-up projects within the University's staff/courses/programmes

4.6.4 Role of the university: Future directions at TU Delft

PSS has been formally taught at TU Delft and at a range of other design engineering schools (e.g., Politecnico di Milano, Brunel University, and Aalto University). However, few publications describe the effective conceptualisation and implementation of PSSs (see Diehl & Christiaans, 2015), especially in low-income contexts. Also, few studies have considered PSS at system level (exceptions include Ceschin, 2012b; Gaziulusoy, 2015; Santos, 2015). Although previous experiences of teaching PSS remain poorly reported in the literature, some authors have identified a number of reasons for shifting design education from product design and service design to PSS design and beyond (Cardenas et al., 2010; Diehl & Christiaans, 2015; Park & Benson, 2013).

In this study, the university played a central role as mediator in generating and transferring knowledge from the context to stakeholders. In addition, the university provided a new knowledge base and expertise for students and clients to address the complexity of the assigned problems. Finally, the university prepared both organisations and students for the openness required to embrace a different reasoning model. In this role, the author, as a design researcher, provided a knowledge base and the skills required based on SOD. However, this cannot replace the participation and openness of clients and other stakeholders. Often keen to redefine a problem assignment, designers' interests are usually triggered more by the problem-owner than by the information provided.

In PSS development, designers need to be equipped with appropriate methods, tools, and strategies and must be prepared to engage with long-term development issues in multi-stakeholder environments (Diehl & Christiaans, 2015). This novel approach to complex societal problems requires new skills that are often overlooked in design curricula. Based on this experience, preliminary guidelines for PSS application in low-income markets will continue to be developed in enhancing the future Product-Service System course at TU Delft.

4.7 Conclusion

Throughout this chapter, I have emphasised that traditional product-service system development knowledge may not be suitable to deal with the large-scale problems faced by contemporary society. The major drawbacks of the traditional knowledge include limitations of rationale, lack of a holistic approach, and an inability to cope with complexity. Drawing on systems thinking, design for sustainability strategies, System Oriented Design literature and PSS literature, I analysed the development of twelve PSS concepts designed by student teams on a multidisciplinary Master's course to demonstrate the applicability of SOD to PSS design. SOD offers design students a broad knowledge base and the skills required to address complex societal problems with appropriate scope, depth, and feasibility. The adoption of SOD in this education experiment served to identify the advantages and challenges of applying this approach in low-income contexts, such as low-income energy markets and humanitarian aid projects. In this process, the university played a crucial role in transferring knowledge between multiple stakeholders and fostering this novel approach in design education.

Although the study achieved its aims, there are limitations which affect the interpretation of the findings. For example, this educational experiment was conducted with a small sample of participants. In addition, the design assignments may contribute to bias due to their particular focus on energy and healthcare services. Despite confirming the promise of this approach in dealing with complex societal problems, further case studies are needed to assess the use of SOD in conjunction with other traditional product-service approaches. Finally, this chapter makes no attempt to propose specific tools for SOD as an over-reliance on methods and tools may undermine the benefits of a systems design approach (Ryan, 2014). Rather, I propose a radical shift in approach that will stimulate students to embrace complexity and assess the long-term feasibility of their solutions when addressing complex problems. For this radical shift to occur, and to progress these concepts, the future collaboration of problem-owners, governments, companies, and non-governmental organisations is both needed and welcomed.

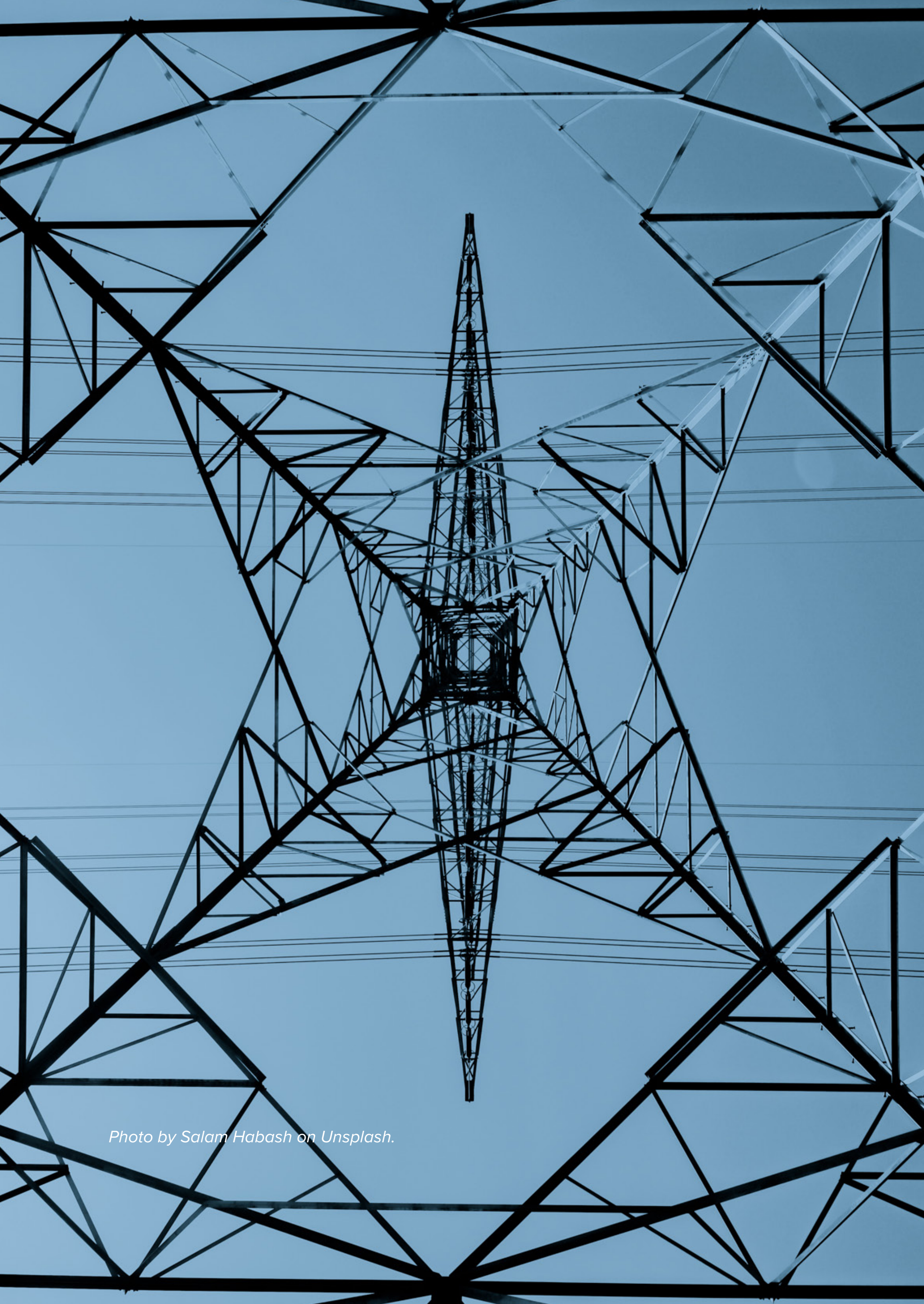


Photo by Salam Habash on Unsplash.

5.

Capacity building for a systems design approach to complex societal problems

This chapter is based on the publication:
Costa Junior, J. da, Diehl, J. C., & Secomandi, F. (2018). Educating for a systems design approach to complex societal problems. *Journal of Engineering Design, 29*(3), 65–86. doi: 10.1080/09544828.2018.1436162

Design education has devoted little attention to the topic of societal systems transformation in the context of low-income markets. This chapter reports on a Master's course that aims to build the capacity for design students to adopt a systems design approach comprised of the integration of Product-Service System (PSS) and Systems Thinking, in order to develop sustainable energy solutions. In the previous chapter, I presented an exploratory exercise in which I equipped students from TU Delft to apply a systems design approach to create product-service systems to address complex societal problems in low-income markets. In this chapter, local design students familiar with low-income energy markets tested a systems design approach to solve energy challenges faced by low-income communities in Uganda. The intervention carried out in the present study builds upon the previous chapter and seeks to gain a better understanding of the process of learning a systems design approach. For this purpose, it identifies key factors for skilful performance when designing solutions for complex societal problems, such as those faced in low-income markets. The findings suggest that design approaches grounded in systems thinking are promising for dealing with the increasing complexity of the societal problems which future generations of design professionals are expected to solve. I argue that capacity building for a systems design approach to complex societal problems, such as those faced in low-income energy markets, can support future generations of designers to take an active role in the development and widespread implementation of sustainable energy systems.

5.1 Capacity building for complexity

Societal challenges faced globally by civil society, governments, humanitarian organisations, private companies and non-governmental organisations (NGOs) continue to grow in complexity and scope (Conklin et al., 2007a; Lopes et al., 2012). In developing and emerging economies, problem solvers from these entities come under increasing pressure to reduce environmental impacts and to increase social benefits associated with the production, distribution, and consumption of such basic resources as energy, water, and food (Hammond et al., 2007). More specifically, there is a great need for investments in solutions related to infrastructure, products, services, and systems that do not repeat the environmental or social mistakes witnessed over the last decade in more developed economies (Kaygusuz, 2007).

Key complex societal problems, such as global warming, resource depletion, and poverty alleviation, impose major constraints and a high level of complexity for problem solvers, including designers. These challenges can be even harder to overcome in the context of low-income markets, where financial and infrastructural resources are often lacking. Education is generally regarded as a way of properly equipping designers to successfully handle the complexity of societal problems (Adams et al., 2003; Sevaldson, 2009). This chapter addresses the question: *How can the capacity for design students to respond to the complexity of societal problems, such as those found in many low-income markets, be built?*.

To meet this challenge, I introduce a systems design approach which build on systems thinking tenets as a way to handle complex societal problems (see Blizzard & Klotz, 2012; Charnley et al., 2011; Jones, 2014; Nelson & Stolterman, 2012; Sevaldson, 2011). Despite the acknowledged relevance of systems thinking in dealing with complexity in technology and engineering education, thus far issues relating to capacity building in design education have received little attention (Barak & Williams, 2007). This study is based on a pilot course, conducted in 2015 with engineering master's students from a university in Uganda, which explored complex societal problems in low-income energy markets of East Africa. This pilot was part of a broader project, called LeNSes, whose objective is to support Higher Education Institutions (HEIs) to introduce sustainable design methodologies into their curricula (Vezzoli, Ceschin, Osanjo, et al., 2015).

This chapter is structured as follows. In the next section, I present a literature review of systems design approach with a focus on capacity building in design education. Following this, the research methodology is presented; this includes a detailed description of the educational experiment, the procedures for data collection, and their interpretation. In the subsequent sections, the main findings are presented and discussed. First, key cognitive aspects for capacity building for systems design approach is provided for educators. Next, I explore the contributions made by embedding systems thinking into the pilot course's curriculum to support students in the development of sustainable solutions for low-income energy markets in East Africa. The chapter concludes with a summary of the findings and their impact on design education and practice.

5.2 Capacity building for complex societal problems: key factors

In recent years, HEIs have acknowledged the need, and the potential, for new approaches to design theory and practice. According to Conklin et al. (2007b) and Raduma (2011), complex societal problems pose strategic opportunities and challenges for design education, calling for an expansion of current curricula. Raduma (2011), for example, points out that many young professionals may be properly equipped to create new products and services in traditional settings, however, when faced with projects requiring more pervasive societal change their competence begins to falter. In fact, current complex societal problems are not easily understood within traditional problem-solving and decision-making techniques (Jones, 2014). Therefore, the integration of systems theory into design theory and practice has been advocated as a promising approach for addressing the increasing complexity of societal problems over the years (Blizzard & Klotz, 2012; Blizzard et al., 2012; Jones, 2014; Sevaldson, 2013; Vanpatter & Jones, 2009).

A systems design approach is a mental model through which designers can frame the world using systems thinking. Systems thinking is a powerful problem-solving approach for the analysis and synthesis of the entities and their relations in complex phenomena (DeTombe, 2015b, 2015a; Sevaldson et al., 2010). A systems design approach guides designers to interpret and embed systems-oriented resources into design to handle complex problem situations and design better systems: a systems mindset (e.g., radical holism); systems approaches (e.g., Hard Systems, Soft Systems, and Critical systems approaches); systems methodologies (e.g., Soft Systems Methodology (Checkland, 1981), Systems Engineering (Hall, 1962), and Critical Systems Heuristics (Ulrich, 1983)); systems skills (e.g., complexity-handling and human centred perspective); and systems tools (e.g., systems maps, rich picture, and causal loop diagrams) (see conceptual framework for systems design approaches in Chapter 2).

Complex societal problems, following DeTombe's (DeTombe, 2015a) definition, represent real-world problems, mostly ill-defined, ill-described, and ill-structured, in which human and institutional relations create high levels of complexity, and solutions to problems can exert an impact on multiple aggregation levels of the socio-technical system. When addressing this class of problems, young designers realise that the know-how and skill set they acquired during traditional education does not align with the nature of the challenges that they are expected to tackle (Raduma, 2011). Thus, to better support future generations of designers, design education needs to build the capacity in students for addressing the increasingly challenging requirements of professional practice (Sevaldson, 2011, 2013; Vanpatter & Jones, 2009).

When viewed from a historical perspective, the development of design education can be said to undergo paradigm shifts in response to structural changes happening in society (O'Rafferty et al., 2014). Vanpatter and Jones (2009) advance a useful framework for explaining how design has evolved in response to key factors, including the complexity of practical challenges addressed (see Table 5.1).

Table 5.1 Design domains.

Domain	Design 1.0	Design 2.0	Design 3.0	Design 4.0
Challenge	Artefacts, communications	Product, services, experiences	Organisations, industry, systems	Societal transformation
Scope	Classical design practice	Design for value creation	Work practice, strategy, organisational change	Complex societal systems, policy-making, community design
Time	1960s	1970s	1980s	2000s
Perspective	Traditional product development	Traditional product-service development	Systems design approach	Systems design approach

Adapted from Jones (2014) and Vanpatter and Jones (2009).

In addition to the factors mentioned above, design domains from 1.0 to 4.0 can also differ in terms of scale, adaptability, design process, stakeholders' involvement, team composition, and supporting tools (Jones, 2014; Vanpatter, 2014; Vanpatter & Jones, 2009). These factors are not intended as universal or absolute, but rather as useful markers for assessing whether design performance is sufficient to address the particular problems of different design domains (Jones, 2014). Also, according to this model, design competence is transferable from higher domains to lower ones, but not the other way around. In other words, Design 3.0 and 4.0 require competences that cannot be simply acquired from Design 1.0 and 2.0. More importantly, lower level domains are subordinate to higher ones, in the sense that the successful development of solutions for Design 1.0 or 2.0 can be powerfully influenced by aspects such as policy instruments and culture, which are systemic components of Design 3.0 and 4.0 (Jones, 2014; Vanpatter & Jones, 2009).

Until the early 1980s, design education concentrated on building capacity in students to address design problems at Design 1.0 and 2.0. Raduma (2011) remarks that around the world many HEIs overlooked the need for building capacity for Design 3.0 and 4.0. For this reason, design approaches taught to students, in particular those which focused on traditional product or product-service development, had drawbacks in terms of addressing complex societal problems (Jones, 2014). That is because traditional design approaches generally aim at creating transformation at lower aggregation levels (see examples of micro and meso aggregation levels in Section 5.2.1), whereas addressing complex problems requires a systems design approach which includes elements that are characteristic of Design 4.0, such as a pluralistic perspective, public policy-making, and community design (Jones, 2014).

Educators and institutions should explore and embrace broader possibilities for design practice and acknowledge the need for paradigm change in design education (Raduma, 2011). Systems thinking, more particularly, has been largely neglected as a potential approach to update design education (Sevaldson, 2009). These are important concerns considering that institutions exert a crucial influence in determining the constraints and opportunities associated with capacity building (Baser & Morgan, 2008).

Capacity building is a process through which individuals, organisations, and communities obtain, maintain, or improve individual competences and collective capabilities over time in order to achieve successful outcomes (Baser & Morgan, 2008; O'Rafferty et al., 2014). The process of capacity building is comprised of three major elements: foundational components (e.g., information, culture, and values); competences (e.g., skills, behaviours, and knowledge); and capabilities (e.g., a range of collective skills and competences) (O'Rafferty et al., 2014). For this study, capability is understood as an aptitude of a group, team, or organisation to carry out a task, function, or process that enables a system to achieve goals and sustain itself (Baser & Morgan, 2008). Competences, in turn, refer to an individual's ability to do something (in particular to carry out technical tasks), which can be influenced by motivations, points-of-view, and expertise (ibid). Competences and capabilities are essential parts of the broader concept of capacity building.

This investigation contends that design education helps to develop collective capabilities in students and that these are involved in the capacity building of future professionals. Following Baser and Morgan (2008), there are five core collective capabilities. They are the capability to: (I) commit and engage; (II) carry out technical, service delivery, and logical tasks; (III) relate and attract; (IV) balance diversity and coherence; and finally, (V) adapt and self-renew.

In addition, the present investigation holds that with time and practice, design education helps students to develop general core capabilities into core design competences. Conley (2004) proposes the following seven core competences of design: (I) understand the context or circumstances and frame the problem; (II) define the situation's appropriate level of abstraction; (III) model and visualise solutions, even with ill-defined information; (IV) simultaneously create and evaluate multiple alternatives to the problem; (V) add and maintain value as the process of problem solving unfolds; (VI) establish purposeful relationships among solution elements and between the solution and its context; and finally, (VII) use form to embody ideas and to communicate their values.

To enlighten the issue of capacity building for systems design approach, I gained theoretical insights into how to introduce systems thinking tenets into design competences. Based on Conley (2004), O'Rafferty et al. (2014), and Baser and Morgan (2008), I developed a theoretical framework to embed systems thinking in the process of capacity building for design students when designing sustainable product-service systems (Figure 5.1). Baser and Morgan (2008) and O'Rafferty et al. (2014) have offered a basis for the structure of the framework, which takes into consideration six clusters which build on systems thinking that align with Conley's (2004) core design competences.

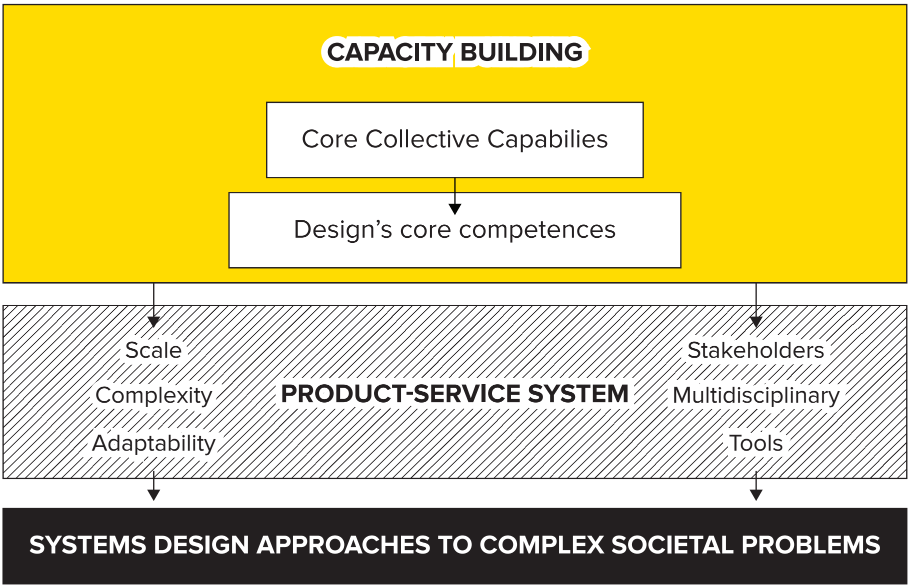


Figure 5.1 Capacity building framework for a systems design approach to complex societal problems.

The capacity building framework emerging from this literature review is comprised of key factors that stand out as necessary for skilful performance at Design domains 3.0 and 4.0: scale; complexity; adaptability; multiple stakeholders; multidisciplinary teams; and systems-oriented tools. As explained below, these key factors aim to enhance the design competences – thus, the capacity building of students – to support the development of appropriate solutions for complex societal problems.

5.2.1 Scale: Recognising problem scale

Complex systems display an interplay between a number of socio-technical components at three aggregation levels (see also Chapter 3): macro level, meso level, and micro level (Geels, 2011; Joore, 2010; Joore & Brezet, 2015). The macro level presents a broader perspective on systems and focuses on societal transformation (e.g., at planet, country, and society problem scale level). The meso level focuses on system infrastructures and institutional arrangements (e.g., at industry, organisation, and subsystems level). Problem solutions at this level often aim at organisational transformation. At the micro level, specific technologies and market offerings are explored to result in product-service and individual transformations (e.g., at experience, service, product, and communication level). In summary, the development and implementation of solutions for complex societal problems can occur at multiple aggregation levels: at the micro level of product-technology interventions; at the meso level of organisational and infrastructure rearrangements; and at the macro level of policy redesign and future planning (Elzen et al., 2004).

Depending on their capacity building, designers can be more or less empowered to adjust the scale of the outcomes they intend to create. In other words, the outcomes of design solutions can aim to introduce changes in system dynamics from the level of stakeholders behaviours and infrastructure development to the level of regulatory instruments and system transitions. For instance, it is unlikely that a sustainable innovation at the micro and meso levels (e.g., new technologies and market offerings) will be able to replace existing systems without changes at the macro level (e.g., support from economic instruments and regulatory frameworks). In summary, the capacity to analyse a complex system at different aggregation levels (problem scale) using systems thinking as a multilevel perspective is of paramount importance (Joore & Brezet, 2015; Mulder et al., 2012).

5.2.2 Complexity: Handling high levels of complexity

Gershenson and Heylighen (2004) conducted a comprehensive study of the basic tenets of complexity. According to the authors mentioned above, throughout the years, scholars and practitioners have relied on a classical model of thinking, one which emphasises reductionism, predictability, objectivity, and rationality. Although this mode of thinking has provided the basis for scientific models over time and has been highly effective in explaining complex natural phenomena, it also has some inherent drawbacks when dealing with complexity of a societal kind (Gershenson & Heylighen, 2004; Nelson, 2008b). Classical thinking assumes invariant, fixed distinctions, whereas complex societal systems are comprised of intertwined components and properties that cannot be separated or distinguished absolutely (Gershenson & Heylighen, 2004). The role of systems thinking is to offer a broader perspective that complements the more fragmented, fact-oriented, and controlling aspects of classical thinking (Sevaldson, 2009).

Recent interdisciplinary research has corroborated the adoption of systems thinking as a problem-solving approach capable of handling the inherent complexity of societal problems (DeTombe, 2015b, 2015a; Gaziulusoy, 2015; Gaziulusoy & Boyle, 2013). Generally speaking, a problem can be classified as simple, complicated, or complex, depending on the number, types, features and interactions of its components, as well as the characteristics of a problem situation (DeTombe, 2015b; Valckenaers & Van Brussel, 2016). Complex societal problems are comprised of interconnected components affected by multi-causes, multi-effects, and, therefore, multi-solutions (Baser & Morgan, 2008). Moreover, as with other problems tackled by the field of design engineering, complex problems are social and technical in nature. Hence, one can describe complex societal problems in terms of the balance between two major dimensions: technical complexity and societal complexity. While technical complexity concerns the physical components of a problem situation, including materials, artefacts, machines, and facilities, societal complexity is associated with the relations between humans and institutions within the system.

In this sense, the first step to deal with complex systems or problems is to acknowledge the dynamic complexity of its multi-causal problems and the cognitive factors involved in understanding the relations embedded in the problem complexity (Jones, 2014). As clarified by Gershenson and Heylighen (2004), an analytical method that takes apart the components of a given complex system will destroy the connections between components, making it difficult to understand and describe the behaviour of the system as a whole. This notion is particularly relevant to design practice since design solutions are the result of the interplay between various components of the socio-technical system. According to Buchanan et al. (1992), design solutions aimed at complex systems can produce innumerable possible outcomes. Therefore, the design orientation should remain flexible and intuitive, rather than analytical and procedural.

5.2.3 Adaptability: Adapting to unexpected events

Complex systems or problems are intrinsically unpredictable (Johnson, 2005). Therefore, designers must attempt to create solutions capable of reconfiguring and adapting to unexpected events, rather than try to control, predict, or determine the behaviour of the system (Gershenson & Heylighen, 2004). According to Mulder et al. (2012), designers should strive for long-term vision with an awareness that such longer-term processes cannot be fully controlled. Goals, problems, and constraints are often context dependent and may change as the design problem is explored (Lemons et al., 2010). Furthermore, when reconfiguring a system or adapting to system changes, whether anticipated or not, the interventions created by problems solvers must preserve the system's dynamics, such as human relations and material flows (Gershenson & Heylighen, 2004).

A systems design approach advocates an open-framing approach[10] to complex problems rather than product-service presumptions (Conklin et al., 2007b). To cope with the unpredictability of complex systems, problems solvers can rely on multiple problem definitions (Conklin et al., 2007b) and alternative futures (scenarios) consistent with long-term strategic goals or visions (Jones, 2014). In such an approach, the problem definition evolves in parallel with the solution formulation and emerges from a nonlinear process that emphasises problem understanding (Conklin et al., 2007b). Ultimately, a systems design approach disputes the effectiveness of controlled, planned, engineering solutions, since the tight design and control of outcomes may cloud unexpected opportunities for innovation (Morgan, 2006).

Another factor responsible for increasing complexity in systems is self-organisation. Self-organising systems search for solutions by themselves, without the need for intervention. This behaviour occurs as a result of coping mechanisms that emerge from the need to self-maintain the functionality of the system (Gershenson & Heylighen, 2004), and it poses additional challenges to design intervention.

10 An open-framing approach refers to a problem definition and framing that focuses on the final function, utility, or user satisfaction, rather than on a specific solution (e.g., product or technology). The goal of open framing is to accommodate shared meaning and understanding among stakeholders so that reframing is possible at any stage of the design process.

5.2.4 Multiple stakeholders: Collaborating with multiple stakeholders

Complex systems are comprised of multiple stakeholders, which include private companies, government, clients, end-users, knowledge producers, community representatives, and NGOs. In resource-limited contexts (e.g., low-income markets and developing economies), the complexity and ambiguity of the interests within the network of stakeholders are higher than in traditional systems (Matos & Silvestre, 2013). Conklin et al. (2007a, 2007b) refer to the distinctive trait shared by complex problems or systems which makes it almost inconceivable to completely understand, control, predict, or determine their behaviours. Scholars acknowledge that addressing a complex societal problem requires engaging in conversation with multiple stakeholders (Conklin et al., 2007a, 2007b; Sevaldson, 2008; Sevaldson et al., 2010). In this process, designers must acknowledge that each stakeholder may have a distinct perception of the functionality of the system and a particular motivation to engage.

5.2.5 Multidisciplinary teams: Working in multidisciplinary teams

Complex societal problems, in particular ones concerned with sustainable development, imply that competences required to achieve effective solutions are interdisciplinary (Mulder et al., 2012), transdisciplinary, and diverse (O'Rafferty et al., 2014). According to Jones (2014), in a complex system it is nearly impossible for any single expert to understand the entire system, and thereby, it is not possible to achieve optimal problem solving and decision making based on sufficient individual knowledge. A design project team can conceive solutions at a lower level design domain. On the other hand, societal and organisational transformations (concerning higher design domains) are likely to be achieved by multidisciplinary project teams (Vanpatter, 2014).

5.2.6 Systems-oriented tools: Employing systems-oriented tools

Effective interventions for complex societal problems can benefit from inventive sense making, sense sharing, and visualisation tools. In these contexts, designers face the need to reframe boundary settings, perform trial-and-error of design options, and apply multiple ways of evaluation (Jones, 2014). Solutions for the problem situation emerge while designers understand the dynamics of the components of the socio-technical system embedded in the problem. A major challenge is to translate contextual information into useful insights for the design process. Supporting tools applied in a systems design approach provide the means to explore and develop capabilities into design competences, and to facilitate collaborative inquiring, reasoning, visualising, modelling, simulating, and making (Jones, 2014; Skyttner, 2006).

Systems-oriented tools as applied in systems methodologies can help gain knowledge of the real world and capture the logic of the problem situation, to deepen understanding of the real world and promote debate about feasible and desirable actions for change, and focus on creating awareness among marginalised groups about their situation and suggest improvements in their problem situation (Jackson, 2001).

5.3 Methodology for the educational experiment

5.3.1 Contextualisation

This section reports on an educational experiment carried out as a pilot course for design students, where a systems design approach was introduced as a way to address complex societal problems in low-income energy markets in Uganda. The course was carried out as an elective in the master's programmes of the College of Engineering Design Art and Technology (CEDAT) of Makerere University in Uganda. This initiative was part of the Learning Network on Sustainable Energy Systems (LeNSes) project, an African-European multipolar network for curricula and lifelong capacity development on sustainable design (DfS) (Edulink Programme, 2013–2016). LeNSes aims to address the challenge of providing a platform for curricula development and lifelong learning about sustainable Product-Service System (PSS) and Distributed Renewable Energy[11] (DRE) (Vezzoli & Ceschin, 2011; Vezzoli et al., 2007).

Distributed Renewable Energy (DRE) refers to the combination of a decentralised and distributed generation of renewable energy sources, such as solar, biomass, and hydro (Emili et al., 2016). Product-Service System (PSS), in turn, is a design approach that has been extensively described in the sustainability literature as suitable to address complex societal problems, such as those encountered in the application of DRE in low-income energy markets (Bandinelli & Gamberi, 2011; Bartolomeo et al., 2003; Emili et al., 2016; Friebe et al., 2013; Vezzoli, Ceschin, & Diehl, 2015; Vezzoli, Ceschin, Osanjo, et al., 2015; Vezzoli, Delfino, et al., 2014).

11 According to the LENSes project, the DRE can be defined as follows: "A small-scale generation plant sourced by renewable energy resources (such as sun, wind, water, biomass and geothermal energy), at or near the point of use, where the user is the producer, whether an individual, a small businesses and/or a local community, and the generation plants are connected with each other to share the energy surplus".

In the literature on sustainable design, the application of PSS models to DRE has been advocated as a suitable approach for the development of sustainable energy solutions in low-income and emerging economies (Costa Junior & Diehl, 2013; Costa Junior et al., 2017; Emili et al., 2016; Vezzoli, Ceschin, & Diehl, 2015). For the purposes of this study, the intention of the pilot course was to test the integration of systems thinking and PSS design as a way to build capacity for design students at that Ugandan university. The course took place in the academic year of 2015; it required 70 hours of study from students, including time spent attending and completing teamwork sessions, lectures, mentoring sessions, practical assignments, and fieldwork.

5.3.2 Sample of students

The initial sample consisted of 14 students who voluntarily participated in the experiment. As the course progressed, a convenience sample of one female and nine male students (n=10) who successfully completed the course were analysed. The sample comprised participants with no significant difference in age. The participants in the course were divided into two multidisciplinary teams with backgrounds in Master's programmes in Power Systems Engineering, Renewable Energy, and Technology Innovation and Industrial Development. They were analysed as both individuals (e.g., performing individual tasks) and as individuals as part of a team (e.g., collaborating with others and performing the task as a group).

All participants were born in Africa, had background education from local universities, and were familiar with the local context of energy services. At the initial stage of the course all participants filled in a questionnaire about their educational background and familiarity with the concepts of Systems Design Approach and Product-Service System (see Table 5.2). For example, all participants (ten) indicated that they have previously worked on a sustainable energy systems project in Uganda. Moreover, most of the participants (six) confirmed previous or current experience in student projects adopting systems design approaches.

Table 5.2 Participants and their main characteristics (number of participants in parentheses).

Characteristics of participants	Description
Participation in previous or current projects related to sustainable energy systems	(4) No past or current experience; (1) Small scale sustainable Organic Rankine Cycle for electricity generation; (2) Solar Tracking Photovoltaic Internet Laboratory; (1) Viability Study of Biogas Production for electricity generation; (1) Energy facility audit; (1) T-junction tragfic light control.
Familiarity with Systems Design Approach	(3) Not Familiar; (0) I have heard about it; (3) I know examples, but not in depth; (2) I have worked on it; (2) It is my area of expertise.
Familiarity with Product-Service System Design	(3) Not Familiar; (4) I have heard about it; (3) I know examples, but not in depth; (0) I have worked on it; (0) It is my area of expertise.
Educational Background	(2) Not specified; (6) MSc in Renewable Energy; (1) MSc in Power Systems Engineering; (1) MSc in Technology Innovation and Industrial Development.

5.3.3 Data collection and analysis

In this study, I used an observational and participatory research approach to collect and analyse the design activities carried out by students. In this empirical method, I relied on verbal accounts given by individual students and individuals within student teams to analyse their cognitive activities (e.g., recalling what one was thinking while performing a design task). More specifically, it aims to analyse design activities, particularly for capturing the cognitive skills and abilities of designers and understanding the interrelation of different factors determining design processes (Günther et al., 1996). Data were collected in the form of audio-visual recordings, questionnaires, and transcripts made of student team work. From the data retrieved, I gained insights into how participants collected, generated, and transformed information, and finally went about developing the solutions for the design problem.

A series of observations were performed in order to understand the implications of systems thinking for the design process and the performance of the design tasks. Design tasks were undertaken by means of design assignments and hands-on workshops. Examples of design tasks performed by students were: evaluating best practices in energy-related products from a human centred design perspective (Assignment 2); generating and selecting promising PSS ideas (Assignment 3); generating business models for energy access (Assignment 4); and evaluating and visualising PSS concepts (Assignment 5). Guidance was provided in the classroom by the author and other mentors, and occasionally by invited experts, to assist students by employing teaching and learning resources grounded in systems thinking. The use of verbal accounts occurred in two ways. In design tasks carried out in groups, I limited the intervention (e.g., remind student to recall what they were thinking during the task) to avoid interference in the dynamics within student teams. Hence, the analysis of individual students within student's teams was based on the observation of the communication between them while performing the design tasks. On the other hand, in design tasks carried out individually by students, when necessary, students were prompted to "think aloud". In all cases, participants were asked to pay close attention to the advantages and challenges of applying the methods, strategies, and tools based on a systems design approach, while carrying out design tasks and completing design assignments. Participants expressed their learning by relying on verbal accounts and responding to an evaluation questionnaire.

5.3.4 Course materials and pedagogical strategy

The course was structured around ten learning sessions comprised of traditional classroom sessions, hands-on workshops, and a field trip to the company SolarNow Uganda. Classroom sessions focused on introductory lectures, presentations of case studies (e.g., bio-gasification and electricity distribution on islands, and energy needs in the Ugandan healthcare sector), and inspiring lectures by professionals (experts) with experience in sustainable energy projects (e.g., Design without Borders and Energy Kiosks). The hands-on workshops were aimed at the use of systems-oriented tools to support students in carrying out design assignments.

Lectures were given on six major subjects: (I) Sustainable Energy for All; (II) Sustainable Product-Service System (S.PSS) Design; (III) Systems Design for Sustainable Energy for all; (IV) Distributed Renewable Energy (DRE) systems; (V) Lifecycle Design of DRE; and, (VI) Human Centred Design for DRE. Figure 5.2 describes the design strategy adopted by the course which allowed students to build systems skills and to apply systems knowledge through individual and collaborative design tasks.

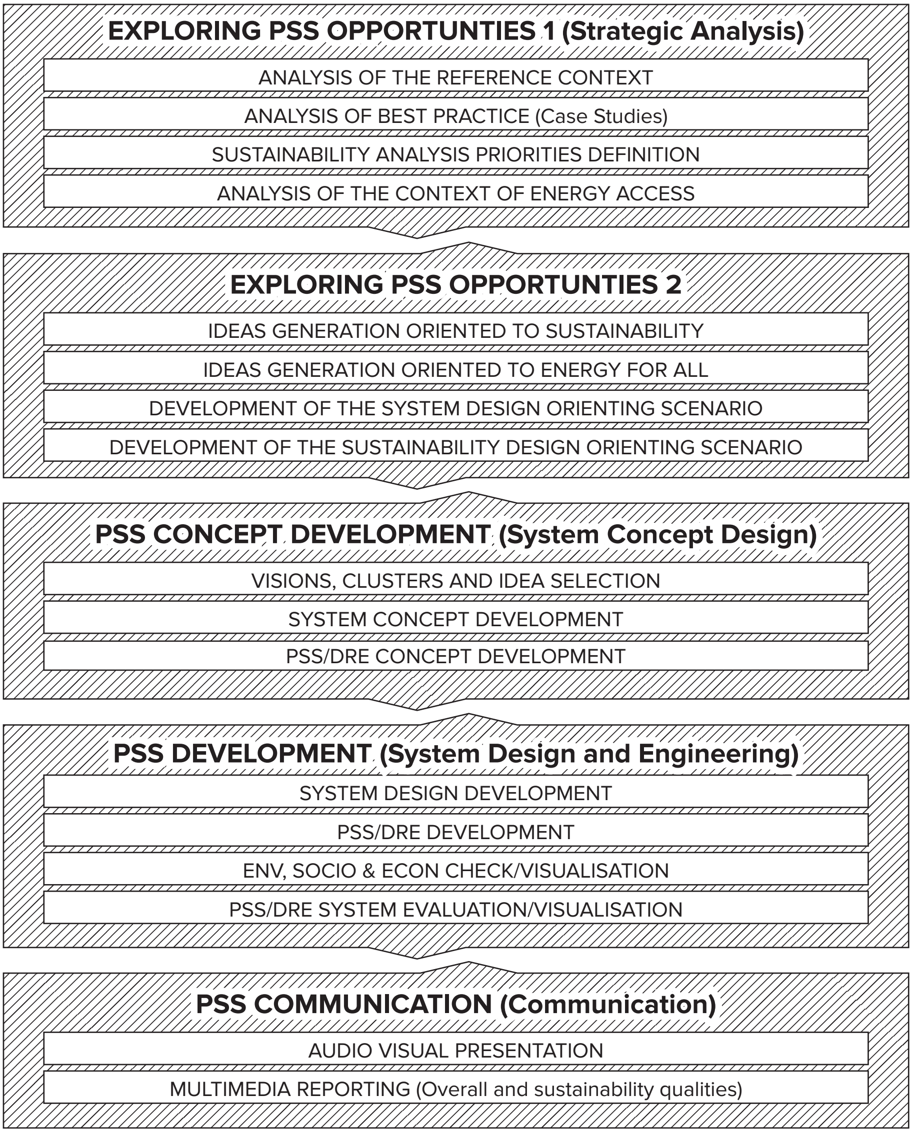


Figure 5.2 Product-service system design (available at the LeNSes website[12]).

The (major) design assignment for the course, Assignment 1, addressed two real problems faced by local communities in Uganda. That is, students were asked to: (I) develop an off-grid biogas-based energy distribution system for the small communities on the Ssese Islands; or, (II) design a distributed (renewable) energy system for one or more levels of the Ugandan Rural Healthcare System.

12 LeNSes | The Learning Network for Sustainable Energy Systems, available at http://www.lenses.polimi.it

The course's major learning objectives were that students should be able to successfully address complex societal problems, such as those experienced in low-income energy markets by: having a basic knowledge of theory, concepts, approaches, methods, and tools for systems-oriented PSS Design; gaining insights into conditions, drivers, and obstacles for PSS and DRE implementation in practice; acquiring knowledge and skills in the development and assessment of business models that support the successful introduction of innovative and sustainable energy delivery systems; and finally, developing an understanding of and the skills required to design in multi-stakeholder environments.

Active learning, by means of a project-based approach, was emphasised during the full-time two-week course programme. This pedagogical approach is highly effective for learning systems thinking, and interdisciplinary skills (Barak & Williams, 2007; Segalàs et al., 2010; Sevaldson, 2008, 2013). The author participated as course tutor, employing both formative assessments (e.g., observation, visual mapping, and questioning), to monitor student learning, and summative assessment (e.g., final project and questionnaire), to measure the effectiveness of the proposed design approach. For instance, to measure learning, students were asked to reflect upon their tasks and use verbal accounts to express their understanding of the topic during classroom presentations or design assignment submissions. Moreover, at the end of the course students were asked to reflect on their experiences with traditional design approaches and to respond to an evaluation questionnaire about their current experience with the systems design approach adopted by the course.

As complementary resources to traditional design approaches adopted by students, the course tutors applied aspects of the capacity building framework elaborated on in the previous section of this chapter. The following represents some of the general pedagogical guidelines for introducing a systems design approach to deal with complex societal problems:

- During the course the tutors introduced real life assignments, hands-on activities, and external stakeholder mentors. Learning systems and interdisciplinary skills required for capacity building for systems design approach are better achieved by active and participatory learning processes, such as project-based and inquiry-based.
- Tutors attempted to shift the students' attention from artefacts and entities (technical systems) to the relations and interactions between them (socio-technical systems). The systems design approach was adopted as a general

philosophy that guided the overall goal of the design tasks. It was seen as a mental model (systems mindset) through which students could contextualise and frame problems.

- Tutors encouraged a certain level of tolerance to uncertainty. By using an open-framed problem definition, and open-ended solutions development, they provided students the opportunity to adapt and reconfigure solutions to better fit the needs of the system during the project development. However, they emphasise that adopting such a nonlinear process can lead to unpredictable patterns, disorder, and messes as the design task unfolds.
- Tutors clearly communicated that the information gathered by students regarding the context should be used to understand, explain, and adapt the solutions to system's events, rather than to try to control, predict, or determine the system's behaviour.
- Tutors focused on helping students to embrace the complexity within the system and to preserve the aggregative relations between the system's components (e.g., the interplay between process, environment, people, and technology). An appropriate manner to address complex societal problems is unfolding the design problem in the context of the whole system, rather than reducing it to the system's components.

More specifically, tutors explored the following key factors which lead to a skilful performance when facing complex societal problems: scale; systems-oriented tools; complexity; and, adaptability. Due to the limitations of this experiment, multiple stakeholders and multidisciplinary teams could not be incorporated into the course's pedagogical approach. Table 5.3 describes the approach used for embedding systems thinking as a way to build capacity in participants of the course.

Table 5.3 Embedding systems design approach in the course curriculum.

Systems thinking perspective	**Core design competences**	**Systems design approach resources**	**References**
Scale	- Understand the context and frame the problem; - Define the appropriate situation's level of abstraction.	- Systems Oriented Design; - Systemic Design Principles; - Multilevel Design; - System Innovation.	(Elzen et al., 2004; Geels, 2005; Joore, 2010; Joore & Brezet, 2015; Sevaldson, 2014b)
Systems-oriented tools	- Model (i.e., describe, simulate, reconfigure) and visualise solutions, even with imperfect information; - Use form to embody ideas and to communicate their values.	- GIGA-Map; - Stakeholders' System Map; - Interaction Table and Storyboard; - Sustainability Design-orienting (SDO) Toolkit; - Satisfaction Offering Diagram; - Stakeholders' Matrix Motivation.	(Halen et al., 2005; Sevaldson, 2011, 2014b; Vezzoli, 2010; Vezzoli & Tischner, 2005)
Complexity	- Simultaneously create and evaluate multiple alternatives to the problem; - Establish purposeful relationships among elements of a solution and between the solution and its context.	- Systems Oriented Design; - Systemic Design Principles; - Multilevel Design; - Complex Societal Problems.	(Buchanan, 1992; Conklin et al., 2007a, 2007b; DeTombe, 2015b, 2015a; Jones, 2014; Joore & Brezet, 2015; Sevaldson, 2014b)
Adaptability	- Add and maintain value as the process of problem-solving unfolds.	- Systems Oriented Design; - Systemic Design Principles; - Complex Societal Problems.	(Buchanan, 1992; Conklin et al., 2007a, 2007b; DeTombe, 2015b, 2015a; Mulder et al., 2012)

5.4 Results

The course led to two comprehensive sustainable energy PSS concepts, which are briefly presented in Box 5.1 and Box 5.2. In addition to the results described here, other immediate results were achieved, including the provision of academic training for ten design students and the delivery of appropriate learning strategies by means of an Open Learning e-Package (OLeP). The OLeP is comprised of learning resources, such as slide shows, texts, audios, and videos, which were made available online to support HEIs in the decentralised and collaborative production and widespread application of Sustainable PSS and DRE projects.

Box 5.1 Hydropower plant for the Rwagimba Health Centre III and rural community

In rural areas of Uganda, access to the government grid is limited to 28% of the health facilities and only to 11% of the rural population. In light of this issue, the project carried out by Group 1 aimed to develop a pico hydropower plant (<5 kW) to generate and distribute electricity for the Rwagimba Health Centre III (HC III) and nearby communities located in the rural area of the Rwenzori Mountains. The energy requirements of the HC III are mainly for lighting, refrigeration, and storage. In addition to supplying the HC III and nearby communities, the project aimed to support the development of income-generating activities by establishing the health facility as a customer service point for selling solar products, renting solar PV systems, and charging equipment and devices, such as solar lights and cell phones. The service point offers solutions for local business by providing energy for lighting and communication and provides affordable products and services for the poorest households of the community.

Box 5.2 Electricity generation from biomass gasification for the Lutoboka Village

This project aimed to develop an off-grid biogas-based energy distribution system for Lutoboka Village. Lutoboka is a small village with a population of approximately 500 households, and it is located in the Ssese Islands (Uganda). In the village, fishing and tourism are the mainstays of the economy. Lutoboka energy supply is not connected to the mainland electricity grid, and therefore the village has very limited access to energy. Electricity is often supplied by expensive and unclean sources of energy, such as diesel generators, even though biomass is widely available. Group 2's goal was to generate electricity from biomass gasification of water hyacinth, fish wastes, agro wastes, and biowastes, and distribute to households and fishermen. The energy will be distributed mainly by battery charging stations geographically distributed throughout the village.

During the educational experiment, I observed that the mindset and reasoning model followed by students (e.g. reductionism) influenced the way in which individual students and student teams discussed and solved conflicts, and how they made decisions aimed at solving complex problems. Since complex societal problems are intrinsically unpredictable, in this educational experiment I trained students to accept that they would not be able to completely control or predict the behaviour of the system. The adoption of systems thinking supported students in understanding the need for tolerance to uncertainty and promoted a holistic approach to dealing with complex problems. Below, I provide more detail about the process of capacity building for a systems design approach observed throughout the course.

5.4.1 Considering problem scale and complexity

Many conventional technologies first considered by students were limited by lock-in mechanisms (see Geels, 2011), such as lack of local infrastructure, investments, and competences. In this sense, the dominant way of designing, producing, and consuming energy has restricted the introduction of a new sustainable energy system. Systems thinking supported students in gaining awareness about the interplay between technology and factors influenced by these lock-in mechanisms (e.g., shared beliefs, political lobbying, market, and culture). The challenge was to promote systems thinking during the sense making stage (Exploring PSS Opportunities), and then to promote change by taking advantage of technical skills and knowledge of the students. *"We, first of all, begin to look at the energy requirements [...], but there is a [water] stream [...]; this is what we decided to look at when it comes to systems requirements. So, we decide to go with a Pico Hydro Scheme."* (Student 4).

Some students reported that while the design assignments posed many technical challenges in their conceptualisation, the adoption of systems thinking has facilitated the identification of a number of unfamiliar regulatory and socio-cultural challenges embedded in the societal context. *"[The] Integration of different aspects was mind blowing to me; really found it practically [sic] very applicable in our communities."* (Student 1).

The awareness of contextual factors prompted students to understand (and question) how the components of the socio-technical systems actually work, as opposed to the participants' perceptions of how these factors should work. *"This concept [Product-Service System] can help me to design a more people-centred project ensuring that all parties involved are equally satisfied."* (Student 2).

Additionally, students showed increase awareness about the interplay between artefacts and its surroundings, and design. *"[The value of a Systems Design Approach and PSS are] Design considerations for products that eliminate the stakeholders' problems, [are] affordable and [are] not deadly for the environment; the ability to produce commodities and offer services to the community in order to fully satisfy consumers."* (Student 3).

5.4.2 Increasing adaptability

The student teams showed considerable technical knowledge and technical skills suitable for the creation of solutions for the design assignments. However, students reported that relying solely on technical skills and technological solutions created limitations during the performance of the design task. For instance, both student teams started the design process by predicting energy demand and making calculations about the energy outputs of the system (e.g., biodigester size and generator's power) before taking the step to make sense of the problem situation.

As a result of their strong technical orientation, students tended to approach the design problem by working directly on detailed (sub)solutions. Such a premature approach resulted in faulty conceptual development and limited the opportunity to form open-ended solutions from which new analyses and reflections could be drawn to formulate a better solution. As the course unfolded, the systems thinking perspective discouraged this behaviour. *"The concept [Systems Design Approach] is especially useful when dealing with cross-cutting issues like social, economic, environmental, and technical."* (Student 2).

The adoption of a systems design approach raised awareness amongst students that the design assumptions made in early design phases can result in a struggle to change or adapt the solution in later stages of the design process. Since problems situations were context dependent and changed as the project developed, when addressing the design problem, students showed a high dependency on the contextual information of the situation at hand. Therefore, they were stimulated to reflect on their actions and the results of these actions throughout the project. *"I will use this method to re-evaluate our approach to designing the systems and services we offer to our target groups."* (Student 4).

5.4.3 Using systems-oriented tools

The systems design approach offered students a range of tools and strategies which allowed them to consider the complexity of the socio-technical system. In the context of highly complex socio-technical systems, there is a need to create significant understanding before promoting transformation. The increasing need for context-specific knowledge and understanding has significant implications for the final solution. Therefore, students used tools such as the Stakeholders' Motivation Matrix and the Sustainability Design-Orienting Toolkit (SDO toolkit) to gain a better understanding of the system in place and support the design process. Stakeholders' Motivation Matrix is a reflective tool that aims at understanding relationships among stakeholders of the system, and identifying motivations, benefits and contributions that each one of them may have or make while participating in the system (Morelli &

Tollestrup, 2006). Sustainability Design-Orienting Toolkit (SDO toolkit) is a visualisation tool that assists evaluating how different concept ideas score in sustainability impact (social, environmental and economic) (Vezzoli & Tischner, 2005).

By using the Stakeholders' Motivation Matrix tool (see Halen et al., 2005; Vezzoli, 2010), student teams were able to examine the influence of each stakeholder at different system levels at once, preserving the interrelations between stakeholders, and, therefore, decreasing the potential conflicts and increasing the synergy throughout the network of stakeholders. *"[…] the most powerful tool was how [the] analysis was made to involve all the various stakeholders. I believe that this will be very applicable to my life as power systems engineer and the final implementation of my [graduation] project."* (Student 5). In addition, the Sustainability Design-Orienting Toolkit (SDO toolkit) was utilised to guide the design process towards sustainable solutions, thereby allowing a comparative analysis of the actual system and the new concept, and the creation of multiple future scenarios or predictions. *"Being able to include current and future predictions that may have an effect on the system is very mind opening."* (Student 6).

Making use of visualisation tools, such as the Stakeholders' Systems Map (Halen et al., 2005; Vezzoli, 2010) and GIGA-map (Sevaldson, 2011, 2014a), students created large maps that were capable of describing multiple layers and scales as well as relations and interconnections of the systems. *"Systems maps are also very useful in helping us understand the way the entire system with materials, stakeholders, and partners interact with each other."* (Student 4). In the course, visualisation became a powerful tool for analysing, understanding, and communicating complex problems. *"We will use the systems map to help us understand the entirely [sic] of our systems."* (Student 1).

5.5 Conclusion

Designers often apply traditional approaches and classical thinking to deal with complex societal problems. The literature presented in this chapter shows that a traditional design approach often overlooks the complexities of societal problems, such as those found in low-income energy markets. Low-income energy markets face complex societal problems where a systems design approach can be very valuable, and therefore, at its most fruitful. In this context, I argue the need for enhancing design students' competences to better deal with complexity. In particular, I gained insights into the process of capacity building for systems design approach to the development of sustainable PSS by design students. By embedding systems thinking into the course curriculum, tutors equipped students of the pilot course with a knowledge base comprised of adequate resources for developing solutions for dealing with complex societal problems. Hence, this investigation contends that integrating systems thinking into a traditional PSS design method can enhance students core design competences, and thereby the chances that these professionals will be ready to tackle the challenges when faced with complex societal problems, and so help to implement more sustainable energy systems.

This chapter provides general recommendations for building capacity in future generations of designers, as opposed to proposing specific teaching resources. It is important to emphasise that the findings of this study present limitations due to restrictive factors, such as the course structure, design assignments, and the size of the student sample. Generalisation could be enhanced by using a larger sample of students drawn from different low-income countries, and by carrying out different archetypal models of PSS applied to DRE. Although these factors limit the generalisability of the results, the study provides valuable insights into the process of capacity building for systems design approach.

The author acknowledge that paradigm shifting of mental models and developing capacities can take years. Moreover, the success of initiatives, such as the LeNSes project, depends on the implementation and evaluation of these resources by the academic community. However, training programmes similar to LeNSes and other more immediate actions aimed at capacity building can encourage those involved in design education to draw attention to the development of design competencies beyond product and service creation, and which are suitable to deal with highly complex societal problems.

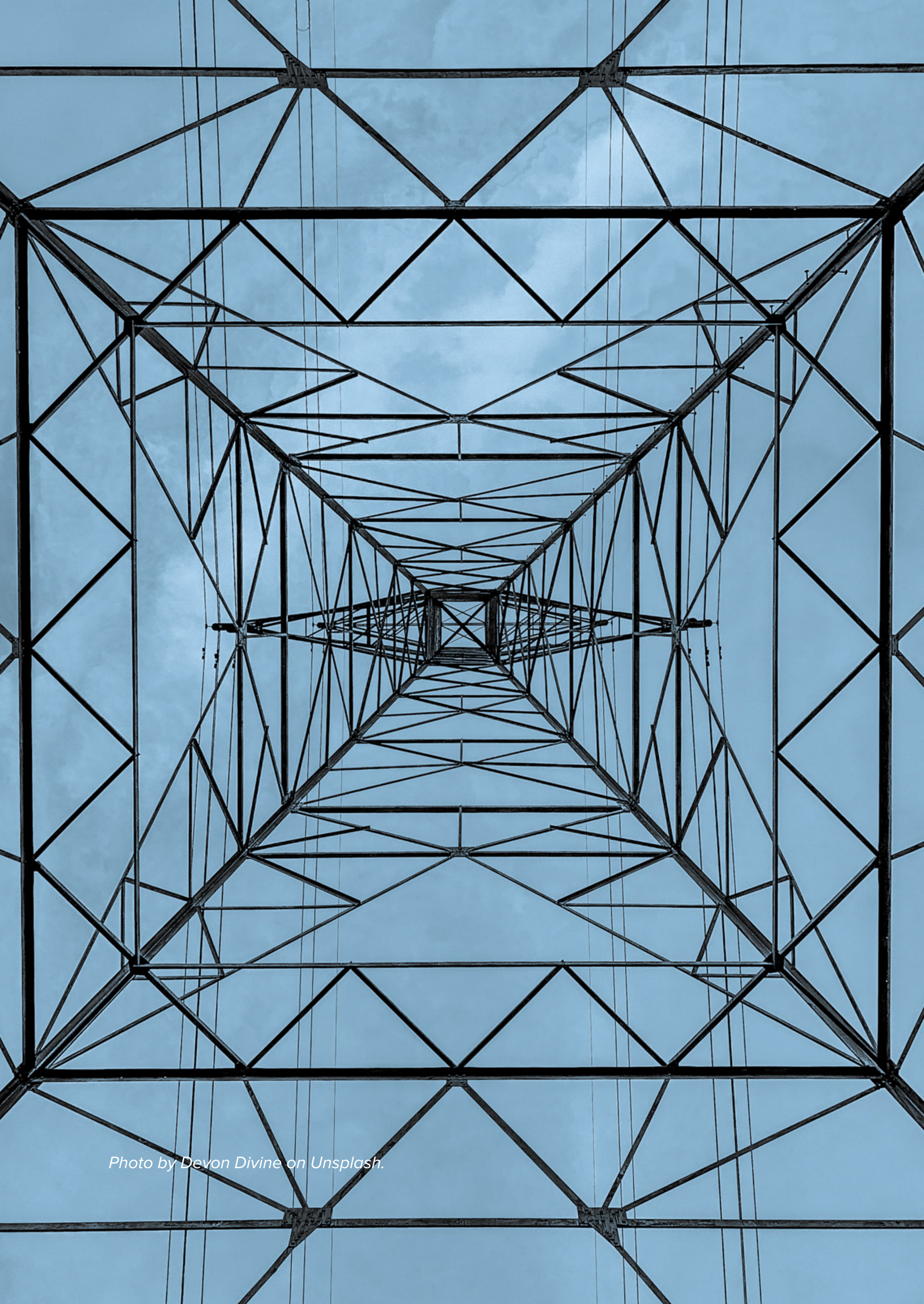


Photo by Devon Divine on Unsplash.

6.

Conclusions, contributions and recommendations

6.1 Introduction

The main goal of this thesis was to foster designers' understanding of systems design approaches and the increasing complexity of societal problems in order to contribute, through design, to solving energy challenges in low-income markets. To do so, this investigation sought to integrate systems thinking into design to favour a more holistic, multilevel, and pluralistic perspective (diversity of views) that embraces the complexity within the problem situation to design more sustainable systems. In this thesis, system(s) embodied both a way of designing and an object of design, and its primary contributions focus on systems thinking as an approach to *improve the way of designing*. Accordingly, the broader concept of complexity adopted concerned the existing knowledge gap of designers. This knowledge gap results from a lack of knowledge of the characteristics of the system in place, a lack of understanding of the problem situation at hand, and a lack of, or uncertainty about, the expertise needed to handle the problem.

Many authors make the claim that product-service systems (PSSs) have the potential to trigger incremental and radical changes in technological and societal terms, and therefore show promise for the creation of sustainable alternatives in low-income markets (Castillo et al., 2012; Diehl, 2009; Manzini & Vezzoli, 2003; Mukaze & Velásquez, 2012; A. Santos et al., 2009; Tukker & Tischner, 2006; UNEP, 2001, 2002). On the other hand, the literature on PSS reveals a knowledge gap concerning its social and systems aspects (Beuren et al., 2013; Cavalieri et al., 2012; Vasantha et al., 2012). Corroboration exists in the belief that bridging the gap between PSS and systems thinking can support in-depth understanding of the problem situation and the system in place (Afshar & Wang, 2010; Cavalieri et al., 2012; Vasantha et al., 2012). Therefore, this thesis contributes to PSS research by addressing the need for the expansion of the scope of the PSS — *from its focus on a separable system of product-service combinations towards a whole PSS system capable of handling high levels of complexity.* Thereby, addressing the following main research question and subsquestions across the chapters:

MAIN RESEARCH QUESTION:

MRQ. *How can systems thinking contribute to handling the complexity of sustainable product-service system design for low-income energy markets?*

RESEARCH STRATEGY		RESEARCH SUB-QUESTIONS
THEORETICAL INQUIRY	CHAPTER 2	**RQ1.** What are the characteristics of complex societal problems in low-income energy markets? **RQ2.** How has systems thinking been developed as a way of handling complex societal problems? **RQ3.** To what extent does systems thinking provide the best fit to the design of solutions aimed at complex societal problems?
EMPIRICAL INQUIRIES	CHAPTER 3	**RQ4.** What does the adoption of systems thinking as a multilevel perspective tell us about improving energy solutions in low-income energy-efficiency programmes?
	CHAPTER 4	**RQ5.** How can systems thinking support design students in the development of more sustainable PSS concepts for low-income markets?
	CHAPTER 5	**RQ6.** How can the capacity for design students to respond to the complexity of societal problems, such as those found in many low-income markets, be built?

The research strategy adopted to answer the main research question involved four main studies comprised of a theoretical inquiry (Chapter 2) and three empirical inquiries (Chapters 3, 4, and 5) published as peer-reviewed journal articles. Each study addressed one or more sub-questions in support of the answer to the main research question. The main studies were preceded by a preliminary research (Chapter 1) and followed by a reflection phase (Chapter 6). It is important to emphasise that the organisation of the chapters does not reflect the chronological publication of the articles. For this reason, it should be also noted that the knowledge creation was not linear. For instance, the conceptual framework presented in Chapter 2 was built upon knowledge gained throughout the investigation. Nevertheless, the findings from each study come together to provide contributions to design theory, practice, and education.

Chapter 1 identified the limitations of using traditional design approaches to tackle complex societal problems in low-income markets. Moreover, it demonstrated that, while promising, PSSs often fail in low-income markets; it also illustrated how systems thinking could be used to complement the reductionist nature of traditional approaches. This chapter provides initial insights into the transition from a product-service system level to a socio-technical system level of solutions for low-income markets. It suggest that this can be achieved by extending the scope of product-service system design through the introduction of four major systems thinking tenets: a holistic perspective; a multilevel perspective; a pluralistic perspective; and complexity-handling capacity.

In the first study of the research (Chapter 2), a theoretical inquiry explored existing theories and approaches to lay the theoretical foundation for the investigation. Chapter 2 proposed a conceptual framework for systems design approaches that allow designers to make informed choices systematically while integrating systems thinking into the PSS design. In the second part of the thesis, three empirical inquiries were conducted through case studies (Chapter 3) and two interventions in design education (Chapters 4 and 5). Chapter 3 investigated the adoption of systems thinking as a multilevel model for low-income energy-efficiency programmes. It identified critical aspects that hinder energy solutions to achieve higher levels of socioeconomic and environmental benefits in low-income markets. It provided several recommendations for designing better energy PSSs and supporting future energy policies. Chapters 4 and 5 developed and tested a set of systems-oriented resources (i.e., systems mindset, methodology set, knowledge set, skill set and tool set). Two interventions on design education were carried out to equip design students to deal with complex societal problems and facilitate a transition from a traditional design approach to a systems design approach.

The remainder of this chapter answers the research sub-questions, thereby allowing the presentation of the main findings of the thesis, in addition to assessing implications for theory, practice, and education (Section 6.2). It also discusses the research limitations and offers recommendations for future research (Section 6.3).

6.2 Main research findings

This section provides a general summary of the main findings to emerge from the thesis and which have contributed to an answer to the main research question. It presents all sub-questions posed across each research phase.

6.2.1 Theoretical studies: Main findings and contributions

In Chapter 2, the following research questions were raised:

RQ1. What are the characteristics of complex societal problems in low-income energy markets?

The concept of complex societal problems adopted in this thesis focussed on real-world problems that impact everyday life in low-income markets, as is the case with energy challenges in those markets. Such problems are hard to define because they involve multiple stakeholders, there is limited information about them available, they depend on context-specific knowledge, and they require solutions capable of promoting change at multiple aggregation levels of the socio-technical system in place. While complex systems, or problems, may involve a high level of technical complexity, the term *complex societal problems* has been addressed in this thesis with the aim of tackling complex problems where technical complexity is entangled with societal complexity, and where relations between humans and institutions create additional complexity. Therefore, this investigation focussed on providing access to affordable, reliable, and clean energy PSSs to low-income markets. Such a complex societal problem is particularly sizeable in emerging and developing economies in Latin America and Africa. More specifically, this investigation sought to develop better sustainable energy solutions for low-income markets in Brazil and Uganda.

Low-income markets are complex societal systems comprised of individuals and households living in substandard housing conditions and facing complex societal problems due to, for example, lack of access to energy and the increase in energy demand and consumption. Low-income households often have either no connection to the national grid or, where they are connected, receive poor quality residential electricity services with an intermittent, unreliable and unsustainable energy supply. This results in, amongst other issues, pollution, health problems, electricity theft, high electricity costs and inefficient use of energy.

Low-income levels constitute a major barrier to the introduction of reliable and clean electricity services. In addition, in low-income energy markets, behaviours toward a product or service tend to be profoundly influenced by local norms, beliefs, and circumstances. For example, some households are not used to pay for electricity bills and are unable to see the long-term negative consequences of their behaviour (myopic view), such as illegal grid-connection and damages to public or shared electricity energy devices or systems. Moreover, in low-income energy markets, transmission and distribution losses are high, likely reinforced by poor infrastructure and non-technical losses (e.g. electricity theft).

In summary, the energy challenges faced by populations in low-income countries, and solutions for those problems are far from obvious or optimal. These are real-life problems that are often very hard to define due to limited information about the context and involve multiple actors in an intertwined and dynamic network of stakeholders. This investigation demonstrates that it is unlikely that energy solutions implemented at the micro and meso levels, such as technological and infrastructure improvements, have the potential to replace existing systems with sustainable energy systems. Therefore, such interventions must be further developed in order to introduce significant changes at the macro level (e.g., design-led policies, influence in policy revisions and collaborative policy planning).

RQ2. How has systems thinking been developed as a way of handling complex societal problems?
As demonstrated throughout this thesis, traditional design approaches present limitations to attempts to gain a better understanding of complex societal problems. The preliminary research showed that the potential to trigger radical changes in technological and societal terms lies in design approaches that go beyond product-centred innovations. In recent years, the design community, particularly in the field of design for sustainability, has shifted in three ways to achieve such change: from technical aspects to recognition of the importance of multiple stakeholders' participation; from environmental aspects to increasing integration of socio-ethical and socio-economic aspects of sustainability; and from insular (fragmented) to systemic (holistic) design innovation. To tackle sustainability issues, it was necessary to move from mere technological improvements to a broader societal perspective that considers solutions across system levels.

Therefore, within the research questions above, the goal was to gain a better understanding of complex societal problems as addressed by different systems, approaches, and methodologies, and ponders its application in the field of design. Systems thinkers have contributed to tackling complex problems by developing a variety of strategies, tools, and techniques. Modelling and simulation tools represent a significant contribution from hard systems methodologies to design and engineering. Soft systems methodologies offer strategies to bring about accommodation between distinct value positions to generate commitment among stakeholders and to implement agreed objectives. This advocates respect for the worldviews, goals, and objectives of all the stakeholders involved in, and affected by, the problem and/or solution, which is especially relevant in low-income contexts. Moreover, critical systems methodologies have supported the debate of design ethics and the implications of design practice. By addressing this question, this study proposes an initial exploration of a systems thinking foundation for the investigation.

RQ3. To what extent does systems thinking provide the best fit to the design of solutions aimed at complex societal problems?
In Chapter 2, an extensive interdisciplinary literature review was carried out to provide the means with which to explore the roots of systems design approaches. A classification of systems approaches based on problem complexity and social processes were explored and led to identification of criteria for the integration of the various systems methodologies into design. Moreover, the study discussed the overlaps and distinctions between the different systems approaches and their systems methodologies.

The study described in Chapter 2 summarises the current state-of-the-art by assessing the relative strengths and weaknesses of systems approaches and realising the implications of employing systems methodologies in design. Moreover, a selection of existing systems design approaches was analysed to grasp how the design community has interpreted and employed systems approaches and methodologies. Based on the findings, the investigation brings to light the process of integrating systems thinking into design, which resulted in a conceptual framework. The framework can potentially support designers in their exploration and interpretation of systems approaches and methodologies to design better systems. Furthermore, it can be used as a valuable heuristic tool for the transition from traditional design approaches to a systems-oriented perspective in design. The study, therefore, contributes to advance systems design research by providing a means for the development of new approaches, and also for strengthening existing systems design approaches.

The conceptual framework for a systems design approach is based on five groups of systems-oriented resources: mindset, methodology set, knowledge set, skill set, and tool set. The framework offers designers a tool which allows detail consideration of systems thinking resources. By using the framework, designers can make informed decisions and increase competency and the effectiveness of their approach to the problem. Consequently, the framework can potentially lead to improvements in the processes of decision-making and problem-solving for complex societal problems.

6.2.2 Observations of existing practice: Main findings and contributions

In Chapter 3, the following research questions was raised:

RQ4. What does the adoption of systems thinking as a multilevel perspective tell us about improving energy solutions in low-income energy-efficiency programmes?

Designing sustainable energy solutions for low-income markets presents many challenges for designers. Such solutions typically involve multiple stakeholders and depend on complex relations and interconnections between components of the socio-technical system. This intertwined and dynamic network of components, such as stakeholders, technology, policies, and infrastructure, are linked together and changes have an impact at multiple aggregation levels of the socio-technical system in place. For that reason, the capacity to analyse an energy system at different aggregation levels using a multilevel model is of paramount importance to achieve radical improvements, which are required for the transition to sustainable systems.

The above question aimed to explore systems thinking as a multilevel model that focussed on the misalignments between various societal and technical factors and their interconnections across system levels. The three-level model proposed aims to support reflection, analysis, and synthesis of socio-technical systems for the low-income energy market. The model comprises three system levels, as follows: the micro level focus on product-technology interventions and behavioural changes; the meso level focus on product-service arrangements, infrastructure improvements, and organisational change; and the macro level focus on policy choices, societal trends, and societal change. The application of the multilevel model in a main case study produced recommendations for creating new opportunities and uncovering constraints that resulted in barriers for the development and implementation of energy solutions. The findings suggested that improvements of low-income energy-efficiency programmes can be achieved through design-led policy and stakeholders collaboration.

The results of this study have potential implications for design practice. The study concludes that developing and implementing an energy solution that builds on lower system levels limits the ability of the given solution to handle the complexity of challenges faced by low-income markets. In other words, although improvements at the micro level are fundamental, they are not enough for the creation of sustainable energy transitions. In this sense, energy solutions intended to create radical improvements and promote societal changes must consider the alignments between the lower and higher levels and focus on the intended societal transformation required to support sustainable energy transitions.

6.2.3 Interventions in design education: Main findings and contributions

In Chapters 4 and 5, the following research questions were raised:

RQ5. How can systems thinking support design students in the development of more sustainable product-service system (PSS) concepts for low-income markets?
This thesis recognises that by broadening the scope and complexity of design practice, systems thinking increases the capacity of design to achieve sustainability. Consequently, adopting a systems design approach requires designers to look beyond technology and consider societal aspects such as policy, stakeholder motivations, and socio-cultural norms. By dealing with this vast amount of information, designers experience numerous unfamiliar constraints and high levels of complexity. In fact, when tackling complex societal problems, they realise that the know-how and skills acquired during traditional education does not align with the nature of the problems that they are expected to solve.

Based on the literature review in Chapter 4, it became evident that when addressing sustainability issues, design students struggle with the knowledge gap between the skills they acquired during traditional design training and the complex societal problems they are expected to solve. An initial contribution from the study was to identify major constraints that designers must overcome when developing PSSs for low-income markets. This aspect of the study was relevant because the traditional design knowledge previously acquired by students was mostly developed both theoretically and empirically based on middle-/high-income contexts. Therefore, what design students have gained in terms of expertise and understanding of complex problem solving builds upon design approaches for middle- and high-income contexts, which presents limitations when tackling problem situations in low-income contexts.

The findings suggest that there is a need to support future generations of designers in building capacities beyond the creation of products and services through design education. As designers are typically educated to apply traditional design approaches, a radical shift is necessary in how design students are trained by creating and implementing new and emerging pedagogical methods and developing new systems-oriented knowledge and skills. With the question posed above, the aim was provided insights into the advantages and challenges of using a systems design approach in design education and discussed how future designers could be prepared and equipped to deal with complex societal problems. To investigate the potential advantages, I analysed how students teams applied systems design approach and measured the resulting potential improvements in each dimension of the sustainability (see Table 4.4). Along with the advantages, I uncovered several challenges related to the context and the design process itself (see Table 4.5).

RQ6. How can the capacity for design students to respond to the complexity of societal problems, such as those found in many low-income markets, be built?
In Chapter 5, the groundwork for a set of methodologies, knowledge, skills, and tools based on systems thinking were proposed. The study identified key factors necessary for skilful performance when dealing with problem situations characterised by complexity, uniqueness, value conflict, and ambiguity. These key factors are described as follows: (I) understand the scale of the problem; handle high levels of complexity; (II) adapt to unexpected events; (III) collaborate with multiple stakeholders; work with multidisciplinary teams; (IV) and, employ systems-oriented skills and tools. By comparing these key factors with core design competencies acquired though design education, the study uncovers significant gaps in capacity building for complex societal problems.

To address the issue of capacity building, the chapter seeks insights as to how to introduce systems thinking tenets into designer's core competencies to achieve systems-oriented competences. Therefore, a major contribution of the study was to develop a capacity-building framework for a systems design approach (see Figure 5.1) and demonstrate how this resource can be embedded in the design curriculum. Moreover, general pedagogical guidelines were introduced to help educators to implement systems design approaches in project-based disciplines.

6.3 Research limitations and recommendations for the future

In each chapter, limitations were outlined that concern the research method applied to that particular part of the investigation. In addition to those limitations, this section presents general research and design limitations that require attention for the proper generalisation of the findings. Furthermore, recommendations for future research are presented.

6.3.1 Scope of the research
This thesis has attempted to integrate systems theory into design theory and education. The presented research covered a portion of the vast field of systems thinking research and focussed on its contributions to the field of design. The literature review in each chapter was comprised of multiple disciplinary and interdisciplinary domains and integrated insights from a large body of literature to ensure scientific relevance. However, some restrictions were introduced to reduce the scope of the investigation and make the research manageable. In Chapter 2, a heuristic and reflective tool for the review, evaluation, and report on the extant literature was adopted (Gaziulusoy & Boyle, 2013). Because this chapter provided the theoretical foundation for the thesis, it was essential to select an appropriate tool to narrow the scope of the literature review and to prioritise relevant studies.

Although this thesis focusses on the broader context of sustainability issues and complex societal problems, it was developed within the narrower topic of energy challenges in low-income markets. Energy challenges were selected for this research because they represent real-world problems that impact the everyday life of low-income populations. Ultimately, the energy resources and technologies chosen by low-income countries will affect the future living conditions of their communities, as well as global environmental conditions. For these reasons, the relevance of the topic to the field of design for sustainability and sustainability studies is considerable. Moreover, energy challenges in low-income markets are hard to define due to the limited information about specific problems experienced in the low-income households and the lack of contextual knowledge available. Also, they involve multiple stakeholders with very distinct motivations to engage in the development and implementation of the energy solution. Low-income energy markets face complex societal problems due to, for example, poor energy services and the increase in energy demand and consumption, and therefore systems thinking may be the most fruitful support for the transition to sustainable systems.

Within this narrow field of sustainability issues, the conclusions drawn are, therefore, limited to this type of complex societal problem. Similarly, the methodologies, knowledge, and solutions which have resulted from the thesis are most appropriate for application in the context of low-income energy markets in emerging and developing economies. However limited, the outcomes can still have implications for other contexts. For example, the capacity building framework and the pedagogical guidelines developed in Chapter 5 can be applied in various design project topics. Nevertheless, further case studies in multiple sectors of industry and service, like healthcare and transportation, are required to assess the effectiveness of the models and frameworks proposed in this thesis. In future studies, it is recommended that the scope of the research be extended, from low-income energy markets to low-income markets, by the adoption of a more diverse sample of societal problems commonly faced by emerging and developing countries. Besides, the conclusions in Chapter 3 were drawn from a sample of three low-income energy-efficiency programmes. Therefore, the results may not be generalisable to other types of energy programmes or solutions. In future research, the inclusion of cases from different low-income countries and low-income energy programmes types is recommended to verify if similar findings emerge from a larger and more diverse sample of cases.

6.3.2 Limitations of the framework for a systems design approach

Throughout this thesis, I have offered a number of resources to integrate systems thinking into design. In Chapter 2, a conceptual framework was developed to assist designers as they navigate the various systems approaches and methodologies. The framework also helps to reflect on the appropriate resources for handling problem situations based on the problem complexity and the relationship between stakeholders. It must be noted that the framework is not intended as a tool for choosing methodology because identifying the strengths and weaknesses of different systems approaches and methodologies does not ensure a perfect fit which will handle all kinds of complex societal problems. Moreover, although the framework provides the information and basic structure for employment of a systems design approach, the implementation of the framework still requires designers to develop or outsource essential systems-oriented skills (e.g., multilevel perspective, complexity handle capability, adaptability and multidisciplinary teamwork). Those skills are imperative to complement design competencies and provide a knowledge-base necessary to realise the resources of systems design approaches. Notwithstanding its limitations, the framework is helpful as a heuristic tool for reflection and decision-making and can support designers to identify critical resources which complement a traditional design approach towards the transition to a systems design approach. Future studies are required to test and validate the framework so that more context-specific knowledge can be generated to address the diversity of real-world problems faced in low-income markets.

6.3.3 Design and policy-making

The findings presented in this thesis suggest that the success of design interventions in low-income energy markets depends significantly on system components at the macro-level. For this reason, a high top-down interaction between components across system levels was observed in which interventions at a lower level (e.g., technology) depend on developments at a higher level (e.g., policy). In contrast, elements at the micro-level have difficulty breaking out from the lower level to promote changes at higher levels (e.g., design-led policy). In this context, there is opportunity to create communication channels between government, problem owners, and problem solvers to facilitate policy revisions and future planning favourable to the development of the sustainable systems.

This thesis contends that a long-term transition to sustainable systems in low-income markets depends largely on the future collaboration between governments and those at the other end of the spectrum. Nevertheless, although there is an international trend towards design-led policy projects, in the context of low-income markets the integration of design-led socioeconomic and environmental requisites into policymaking is still poorly explored. For example, overly objective assessment of impact and lack of opportunity for product-service innovation were some of the constraints against improving the effectiveness of policymaking in low-income energy markets identified in this thesis. On the other hand, according to Bason (2016), it is crucial to re-think the practice of public policy to allow for societal complexity, uncertainty, and unpredictability in the design of public outcomes. Moreover, policymaking that is based heavily on rational and objective models precludes experimentation and learning (Bason, 2016). In this context, sensitising policymakers to the unique challenges associated with providing sustainable solutions for low-income markets becomes a vital element to be considered by problem solvers, such as designers, in future research and practice.

References

Ackoff, R. L. (1972). On purposeful systems. Chicago: Aldine-Atherton.

Ackoff, R. L. (1974). Redesigning the Future: A systems approach to societal problems. New York: Wiley.

Ackoff, R. L. (1979). The Future of Operational Research is Past. Journal of the Operational Research Society, 30(2), 93–104. https://doi.org/10.1057/jors.1979.22

Ackoff, R. L. (1981). Creating the Corporate Future. John Wiley & Sons.

Ackoff, R. L. (1993). Idealized design: Creative corporate visioning. Omega, 21(4), 401–410. https://doi.org/10.1016/0305-0483(93)90073-T

Adams, R. S., Turns, J., & Atman, C. J. (2003). Educating effective engineering designers: the role of reflective practice. Design Studies, 24(3), 275–294. https://doi.org/10.1016/S0142-694X(02)00056-X

Afshar, M., & Wang, D. (2010). Systems thinking for designing sustainable product service systems: A case study using a system dynamics approach. Design Principles and Practices, 4(6), 259–273.

Allali, B. (2011). TEMASOL: Providing Energy Access to Remote Rural Households in Morocco. In United Nations Development Programme. Retrieved from http://www.growinginclusivemarkets.org/media/cases/Morocco_Temasol_2011.pdf

Alonso-Rasgado, T., Thompson, G., & Elfström, B.-O. (2004). The design of functional (total care) products. Journal of Engineering Design, 15(6), 515–540. https://doi.org/10.1080/09544820412331271176

Andersen, M. M., & Tukker, A. (2008). Perspectives on Radical Changes to Sustainable Consumption and Production. International Journal of Sustainability in Higher Education, 9(3). https://doi.org/10.1108/ijshe.2008.24909cae.001

Anderson, P. (1999). Complexity Theory and Organization Science. Organizational Science, 10(3), 216–232. https://doi.org/10.2307/2640328

Arnold, D. G., & Williams, L. H. D. (2012). The paradox at the base of the pyramid: environmental sustainability and market-based poverty alleviation. International Journal of Technology Management, 60(1/2), 44. https://doi.org/10.1504/IJTM.2012.049105

AVSI Foundation. (2010). Case Study : COELBA Community Agent Program for Slum Electrification and Energy Efficiency in Salvador, Bahia, Brazil.

Baines, T. S., Lightfoot, H. W., Evans, S. ., Neely, A. ., Greenough, R. ., Peppard, J. ., ... Wilson, H. . (2007). State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 221(10), 1543–1552. https://doi.org/10.1243/09544054JEM858

Banathy, B. H. (1987). Choosing design methods. Proceedings of the 31st Annual Meeting of the International Society for General Systems Research, 54–63. Budapest.

Banathy, B. H. (1996). Designing Social Systems in a Changing World. In Springer. https://doi.org/10.1007/978-1-4757-9981-1

Bandinelli, R., & Gamberi, V. (2011). Servitization in oil and gas sector: outcomes of a case study research. Journal of Manufacturing Technology Management, 23(1), 87–102. https://doi.org/10.1108/17410381211196302

Barak, M., & Williams, P. (2007). Learning elemental structures and dynamic processes in technological systems: a cognitive framework. International Journal of Technology and Design Education, 17(3), 323–340. https://doi.org/10.1007/s10798-006-9006-0

Bartolomeo, M., dal Maso, D., de Jong, P., Eder, P., Groenewegen, P., Hopkinson, P., ... Zaring, O. (2003). Eco-efficient producer services—what are they, how do they benefit customers and the environment and how likely are they to develop and be extensively utilised? Journal of Cleaner Production, 11(8), 829–837. https://doi.org/10.1016/S0959-6526(02)00157-9

Baser, H., & Morgan, P. (2008). Capacity, Change and Performance: Study Report. Brussels.

Baskerville, R., Pries-Heje, J., & Venable, J. (2009). Soft design science methodology. Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology, (May 2016). https://doi.org/10.1145/1555619.1555631

Bason, C. (2016). Design for Policy. In Design for Policy. https://doi.org/10.4324/9781315576640

Bausch, K. C. (2014). The Theory and Practice of Third Phase Science. In G. S. Metcalf (Ed.), Social Systems and Design. https://doi.org/10.1007/978-4-431-54478-4

Beer, S. (1972). Brain of the firm. London: Allend Laner.

Benyus, J. M. (2002). Biomimicry: Innovation Inspired by Nature. Harper Perennial.

Berg, B. L. (2001). Qualitative research methods for the social sciences. In Qualitative Research (7th ed.).

Berkhout, P. H. G., Muskens, J. C., & W. Velthuijsen, J. (2000). Defining the rebound effect. Energy Policy, 28(6–7), 425–432. https://doi.org/10.1016/S0301-4215(00)00022-7

Betts, A., & Bloom, L. (2014). Humanitarian Innovation: The state of the art. In OCHA policy and studies series (Vol. 9).

Beuren, F. H., Gomes Ferreira, M. G., & Cauchick Miguel, P. A. (2013). Product-service systems: a literature review on integrated products and services. Journal of Cleaner Production, 47, 222–231. https://doi.org/10.1016/j.jclepro.2012.12.028

Beyer, H., & Holtzblatt, K. (1997). Contextual Design: Defining Customer-Centered Systems. Elsevier Science.

Bhattacharyya, S. C. (2012). Energy access programmes and sustainable development: A critical review and analysis. Energy for Sustainable Development, 16(3), 260–271. https://doi.org/10.1016/j.esd.2012.05.002

Biahmou, A. (2015). Systems Engineering. In J. Stjepandić, N. Wognum, & W. J.C. Verhagen (Eds.), Concurrent Engineering in the 21st Century (pp. 221–254). https://doi.org/10.1007/978-3-319-13776-6_9

Binder, A., & Witte, J. M. (2007). Business engagement in humanitarian relief: key trends and policy implications. In An HPG Background Paper. London.

Blizzard, J. L., & Klotz, L. E. (2012). A framework for sustainable whole systems design. Design Studies, 33(5), 456–479. https://doi.org/10.1016/j.destud.2012.03.001

Blizzard, J. L., Klotz, L., Pradhan, A., & Dukes, M. (2012). Introducing whole-systems design to first-year engineering students with case studies. International Journal of Sustainability in Higher Education, 13(2), 177–196. https://doi.org/10.1108/14676371211211854

Boeijen, A. Van, & Stappers, P. (2011a). Preparing Western designers for the use of contextmapping techniques in non-Western situations. Proceedings Engineering and Product Design Education Conference, (September), 1–6.

Boeijen, A. Van, & Stappers, P. J. (2011b). Serving the Underserved: What Can Designers Learn From Rural Appraisal Techniques? Proceedings of IASDR2011, 1–9. Delft, The Netherlands.

Borger, F. G., João, B. N., Serralvo, F. A., & Cardoso, O. O. (2011). Social Innovation and Sustainability: case studies for the bottom of the pyramid in Brazil. Journal of Academy of Business and Economics.

Bradbrook, A. J., & Gardam, J. G. (2006). Placing Access to Energy Services within a Human Rights Framework. Human Rights Quarterly, 28(2), 389–415. https://doi.org/10.1353/hrq.2006.0015

Braungart, M., & McDonough, W. (2002). Cradle to Cradle: Remaking the way we make things. North Point Press.

Brezet, H. (1997). Dynamics in ecodesign practice. Industry and Environment, 20(1–2), 21–24.

Brezet, H., & Van Hemel, C. (1997). Ecodesign, A promising approach to sustainable production and consumption. In United Nations Environment Programme.

Briceno, T., & Stagl, S. (2006). The role of social processes for sustainable consumption. Journal of Cleaner Production, 14(17), 1541–1551. https://doi.org/10.1016/j.jclepro.2006.01.027

Buchanan, R. (1992). Wicked Problems in Design Thinking. Design Issues, 8(2), 5. https://doi.org/10.2307/1511637

Cardenas, C., Sosa, R., Moysen, R., & Martinez, V. (2010). Sustaining Sustainable Design through Systemic Thinking. International Journal of Engineering Education, 26(2), 287–292.

Castillo, L. G., Diehl, J. C., & Brezet, H. (2012). Design Considerations for Base of the Pyramid (BoP) Projects. Proceedings of the Cumulus Helsinki 2012 Conference, 1–15. Retrieved from http://cumulushelsinki2012.org/cumulushelsinki2012.org/wp-content/uploads/2012/05/Design-Considerations-for-Base-of-the-Pyramid.pdf

Cavalieri, S., & Pezzotta, G. (2012). Product–Service Systems Engineering: State of the art and research challenges. Computers in Industry, 63(4), 278–288. https://doi.org/10.1016/j.compind.2012.02.006

Cavalieri, S., Pezzotta, G., & Shimomura, Y. (2012). Product–service system engineering: From theory to industrial applications. Computers in Industry, 63(4), 275–277. https://doi.org/10.1016/j.compind.2012.03.001

Ceschin, F. (2012a). Critical factors for implementing and diffusing sustainable product-Service systems: insights from innovation studies and companies' experiences. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2012.05.034

Ceschin, F. (2012b). The introduction and scaling up of sustainable Product-Service Systems: A new role for strategic design for sustainability. Politecnico di Milano.

Ceschin, F. (2014). Sustainable Product-Service Systems: Between Strategic Design and Transition Studies. https://doi.org/10.1007/978-3-319-03795-0

Ceschin, F., & Gaziulusoy, I. (2016). Evolution of design for sustainability: From product design to design for system innovations and transitions. Design Studies, 47, 118–163. https://doi.org/10.1016/j.destud.2016.09.002

Charnley, F., Lemon, M., & Evans, S. (2011). Exploring the process of whole system design. Design Studies, 32(2), 156–179. https://doi.org/10.1016/j.destud.2010.08.002

Chavan, A. L., Gorney, D., Prabhu, B., & Arora, S. (2009). The washing machine that ate my sari-mistakes in cross-cultural design. Interactions, 16(1), 26. https://doi.org/10.1145/1456202.1456209

Checkland, P. (1978). The origins and nature of "hard" systems thinking. Journal of Applied Systems Analysis, 5(2), 99–110.

Checkland, P. (1981). Systems thinking, systems practice. Wiley.

Checkland, P. (1985). From Optimizing to Learning: A Development of Systems Thinking for the 1990s. Journal of the Operational Research Society, 36(S9), 757–767. https://doi.org/10.1057/jors.1985.141

Checkland, P. (2000). Soft Systems Methodology: A Thirty-Year Retrospective. Systems Research and Behavioral Science, 17(S1), 11–58.

Churchman, C. W. (1957). Introduction to Operations Research. New York: John Wiley.

Churchman, C. W. (1971). The Design of Inquiring Systems. New York: Basic Books.

Clarkson, J., Simons, C., & Eckert, C. (2001). Predicting Change Propagation in Complex Design. 1–10. https://doi.org/10.1115/1.1765117

Cleff, T., & Rennings, K. (1999). Determinants of environmental product and process innovation. European Environment, 9(5), 191–201. https://doi.org/10.1002/(SICI)1099-0976(199909/10)9:5<191::AID-EET201>3.0.CO;2-M

Clegg, C. W. (2000). Sociotechnical principles for system design. Applied Ergonomics, 31(5), 463–477.

COELBA. (2015). Coelba - Companhia de Eletricidade do Estado da Bahia [Website]. Retrieved August 2, 2015, from http://www.coelba.com.br/

COELCE. (2015a). Coelce - Companhia Energética do Ceará [Website]. Retrieved August 2, 2015, from https://www.coelce.com.br/

COELCE. (2015b). Program Ecoelce [Website]. Retrieved August 2, 2015, from https://www.coelce.com.br/coelcesociedade/programas-e-projetos/ecoelce.aspx

Coley, F. J. S., & Lemon, M. (2009). Exploring the design and perceived benefit of sustainable solutions: a review. Journal of Engineering Design, 20(6), 543–554. https://doi.org/10.1080/09544820802001276

Conklin, J., Basadur, M., & Vanpatter, G. K. (2007a). Rethinking Wicked Problems (Part 1). Next Design Leadership Institute Journal, 10(10.3), 31.

Conklin, J., Basadur, M., & Vanpatter, G. K. (2007b). Rethinking Wicked Problems (Part 2). Next Design Leadership Institute Journal, 10(10.3), 31.

Conley, C. (2004). Leveraging Design's Core Competencies. Design Management Review, 15(3), 45–51. https://doi.org/10.1111/j.1948-7169.2004.tb00171.x

Costa Junior, J. da, & Diehl, J. C. (2013). Product-Service System Design Approach for the Base of the Pyramid Markets: Practical Evidence from the Energy Sector in the Brazilian Context. In M. Schaefer, N. Kebir, & D. Philipp (Eds.), Proceeding of International Conference on Micro Perspectives for Decentralized Energy Supply (pp. 48–51). Berlin: Technische Universität Berlin.

Costa Junior, J. da, Diehl, J. C., & Secomandi, F. (2018). Educating for a systems design approach to complex societal problems. Journal of Engineering Design, 29(3), 65–86. https://doi.org/10.1080/09544828.2018.1436162

Costa Junior, J. da, Pereira, J. V. I., Zacar, C. H., Enriconi, A., Gomes, N. S., & Santos, A. (2010). Sistema Produto+Serviço para o cozinhar sustentável: Estudo de Caso Projeto Monno. Projetica, 1(1), 146–161. https://doi.org/10.5433/2236-2207.2010v1n1p162

Costa Junior, J. Da, Santos, A. L. R. dos, & Diehl, J. C. (2017). Introducing systems oriented design for complex societal contexts in design engineering education. FormAkademisk - Forskningstidsskrift for Design Og Designdidaktikk, 10(1), 1–20. https://doi.org/10.7577/formakademisk.1460

Cozzens, S. E. (2012). Social cohesion at the global level: The roles of science and technology. Science and Public Policy, 39(5), 557–561. https://doi.org/10.1093/scipol/scs067

Cross, N. (2001). Design thinking: Understand how designers think and work. Oxford: Berg Publishers.

Crul, M. M. R., & Diehl, J. C. (2006). Design for Sustainability a practical approach for Developing Economies.

da Costa Junior, J., Diehl, J. C., & Snelders, D. (2019). A framework for a systems design approach to complex societal problems. Design Science, 5, e2. https://doi.org/10.1017/dsj.2018.16

Daellenbach, H. (2001). Hard OR, soft OR, problem structuring methods, critical systems thinking: a primer. Proceedings of the ORSNZ Conference.

den Uijl, S., & Bahlmann, T. (2002). A complex societal problem: Reintegration of partially disabled people in the workforce in the Netherlands. European Journal of Operational Research, 140(2), 413–426. https://doi.org/10.1016/S0377-2217(02)00079-6

DeTombe, D. (2013). Societal Complexity. In S. I. Gass & M. C. Fu (Eds.), Encyclopedia of Operations Research and Management Science (3rd ed., pp. 1425–1430). Springer.

DeTombe, D. (2015a). Complex Societal Problems. In Handling Societal Complexity (pp. 35–79). https://doi.org/10.1007/978-3-662-43917-3_3

DeTombe, D. (2015b). Human Problem Handling. In Handling Societal Complexity (pp. 81–154). https://doi.org/10.1007/978-3-662-43917-3_4

Diehl, J. C. (2009). Designing sustainable solutions for the "Base-of-the Pyramid." Proceedings of the 2nd International Symposium on Sustainable Design, (Rocchi 2006), 31–41. Retrieved from http://portal.anhembi.br/sbds/anais/ISSD2009-P-31.pdf

Diehl, J. C., & Christiaans, H. H. C. M. (2015). Sustainable Product Service Systems: The future for designers? Proceeding of the International Design Congress. Gwangju.

Dobers, P., & Wolff, R. (1999). Eco-efficiency and dematerialization: Scenarios for new industrial logics in recycling industries, automobile and household appliances. Business Strategy and the Environment, 8(1), 31–45. https://doi.org/10.1002/(SICI)1099-0836(199901/02)8:1<31::AID-BSE178>3.0.CO;2-2

Donaldson, K. (2002). Recommendations for Improved Development by Design. Development by Design (Dyd02) Conference. Bangalore.

Duflo, E., Greenstone, M., & Hanna, R. (2012). Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves. Dicussion Paper 2012-41, p. 73. Cambridge.

Dzombak, R., Mehta, C., Mehta, K., & Bilén, S. G. (2014). The Relevance of Systems Thinking in the Quest for Multifinal Social Enterprises. Systemic Practice and Action Research, 27(6), 593–606. https://doi.org/10.1007/s11213-013-9313-9

Elzen, B., Geels, F. W., & Green, K. (2004). System Innovation and the Transition to Sustainability. https://doi.org/10.4337/9781845423421

Emili, S. (2017). Designing Product-Service Systems applied to Distributed Renewable Energy in low-income and developing contexts: a strategic design toolkit. Brunel University London.

Emili, S., Ceschin, F., & Harrison, D. (2016). Energy for Sustainable Development Product – Service System applied to Distributed Renewable Energy: A classification system, 15 archetypal models and a strategic design tool. Energy for Sustainable Development, 32(1), 71–98. https://doi.org/10.1016/j.esd.2016.03.004

Espinosa, A., Harnden, R., & Walker, J. (2008). A complexity approach to sustainability – Stafford Beer revisited. European Journal of Operational Research, 187(2), 636–651. https://doi.org/10.1016/j.ejor.2007.03.023

Filippo Filho, G., Marotta Cassula, A., & Roberts, J. J. (2014). Non-technical Losses in Brazil: Subsidies for Implementation of Smart-Grid. Journal of Energy and Power Engineering, 8(7), 1301–1308. https://doi.org/10.17265/1934-8975/2014.07.018

Flood, R. L. (2010). The relationship of "systems thinking" to action research. Systemic Practice and Action Research, 23(4), 269–284. https://doi.org/10.1007/s11213-010-9169-1

Forlizzi, J. (2012). The Product Service Ecology: Using a Systems Approach in Design. Proceedings of the 2nd Conference on Relating Systems Thinking and Design (RSD2). Oslo, Norway, 1–27.

Forrester, J. W. (1971). World Dynamics. Wright & Allen.

Francois, P. (2002). Social Capital and Economic Development. Taylor & Francis.

Friebe, C. A., Flotow, P. Von, & Täube, F. A. (2013). Exploring the link between products and services in low-income markets—Evidence from solar home systems. Energy Policy, 52, 760–769. https://doi.org/10.1016/j.enpol.2012.10.038

Gaziulusoy, A. İ. (2010). System innovation for sustainability: a scenario method and a workshop process for product development teams. Retrieved from https://researchspace.auckland.ac.nz/handle/2292/6106

Gaziulusoy, A. İ. (2015). A critical review of approaches available for design and innovation teams through the perspective of sustainability science and system innovation theories. Journal of Cleaner Production, 107, 366–377. https://doi.org/10.1016/j.jclepro.2015.01.012

Gaziulusoy, A. İ., & Boyle, C. (2013). Proposing a heuristic reflective tool for reviewing literature in transdisciplinary research for sustainability. Journal of Cleaner Production, 48, 139–147. https://doi.org/10.1016/j.jclepro.2012.04.013

Gaziulusoy, A. İ., & Brezet, H. (2015). Design for system innovations and transitions: A conceptual framework integrating insights from sustainability science and theories of system innovations and transitions. Journal of Cleaner Production, 108, 1–11. https://doi.org/10.1016/j.jclepro.2015.06.066

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy, 31(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W. (2004). Understanding System Innovations: A Critical Literature Review and a Conceptual Synthesis. In System Innovation and the Transition to Sustainability (pp. 19–47). https://doi.org/10.4337/9781845423421.00012

Geels, F. W. (2005). Technological transitions and system innovations: a co-evolutionary and socio-technical analysis. Cheltenham, UK: Edward Elgar Publishing.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environmental Innovation and Societal Transitions, 1(1), 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Geller, H., Schaeffer, R., Szklo, A., & Tolmasquim, M. (2004). Policies for advancing energy efficiency and renewable energy use in Brazil. Energy Policy, 32(12), 1437–1450. https://doi.org/10.1016/S0301-4215(03)00122-8

Gershenson, C., & Heylighen, F. (2004). How can we think the complex? Managing the Complex Vol.1: Philosophy, Theory and Application., 47–62.

Geum, Y., & Park, Y. (2011). Designing the sustainable product-service integration: a product-service blueprint approach. Journal of Cleaner Production, 19(14), 1601–1614. https://doi.org/10.1016/j.jclepro.2011.05.017

Gharajedaghi, J. (2011). Systems thinking: managing chaos and complexity: a platform for designing business architecture (3rd ed.). Burlington: Elsevier.

Ghisi, E., Gosch, S., & Lamberts, R. (2007). Electricity end-uses in the residential sector of Brazil. Energy Policy, 35(8), 4107–4120. https://doi.org/10.1016/j.enpol.2007.02.020

Giannini Pereira, M., Camacho, C. F., Vasconcelos Freitas, M. A., & da Silva, N. F. (2012). The renewable energy market in Brazil: Current status and potential. Renewable and Sustainable Energy Reviews, 16(6), 3786–3802. https://doi.org/10.1016/j.rser.2012.03.024

Giannini Pereira, M., Sena, J. A., Vasconcelos Freitas, M. A., & da Silva, N. F. (2011). Evaluation of the impact of access to electricity: A comparative analysis of South Africa, China, India and Brazil. Renewable and Sustainable Energy Reviews, 15(3), 1427–1441. https://doi.org/10.1016/j.rser.2010.11.005

Giannini Pereira, M., Vasconcelos Freitas, M. A., & da Silva, N. F. (2011). The challenge of energy poverty: Brazilian case study. Energy Policy, 39(1), 167–175. https://doi.org/10.1016/j.enpol.2010.09.025

GLOBALDATA. (2017). GlobalData. Retrieved September 1, 2018, from https://www.globaldata.com/

Goedkoop, M., Halen, C. Van, Riele, H. Te, & Rommens, P. (1999). Product service systems, ecological and economic basics.

Gradl, C., & Knobloch, C. (2011). Energize the BoP! Energy Business Model Generator for Low-Income Markets.

Greening, L. A., Greene, D. L., & Difiglio, C. (2000). Energy efficiency and consumption — the rebound effect — a survey. Energy Policy, 28(6–7), 389–401. https://doi.org/10.1016/S0301-4215(00)00021-5

Günther, J., Frankenberger, E., & Auer, P. (1996). Investigation of individual and team design processes. In N. Cross, H. Christiaans, & K. Dorst (Eds.), Analysing design activity (pp. 112–117). John Wiley & Sons.

Habermas, J. (1972). Knowledge and human interests. London: Heineman.

Halen, C. van, Vezzoli, C., & Wimmer, R. (2005). Methodology for Product Service System Innovation: How to implement clean, clever and competitive strategies in European industries. Assen, Netherlands: Royal Van Gorcum.

Hall, A. D. (1962). A methodology for systems engineering. Van Nostrand Reinhold.

Halme, M., Jasch, C., & Scharp, M. (2004). Sustainable home services? Toward household services that enhance ecological, social and economic sustainability. Ecological Economics, 51(1–2), 125–138. https://doi.org/10.1016/j.ecolecon.2004.04.007

Hamari, J., Sjöklint, M., & Ukkonen, A. (2016). The sharing economy: Why people participate in collaborative consumption. Journal of the Association for Information Science and Technology, 67(9), 2047–2059. https://doi.org/10.1002/asi.23552

Hammersley, M. (2017). On the Role of Values in Social Research: Weber Vindicated? Sociological Research Online, 22(1), 1–12. https://doi.org/10.5153/sro.4197

Hammond, A. L., Kramer, W. J., Katz, R. S., Tran, J. T., & Walker, C. (2007). The Next 4 Billion: Market size and business strategy at the base of the pyramid. Retrieved from http://www.wri.org/publication/the-next-4-billion

Hart, S. L., & Prahalad, C. K. (2002). The Fortune at the Bottom of the Pyramid. Strategy+Business, 1(26).

Hart, S. L., & Sharma, S. (2004). Engaging fringe stakeholders for competitive imagination. The Academy of Management Executive, 18(1), 7–18. https://doi.org/10.5465/AME.2004.12691227

Hekkert, M. P., Pas, F. van der, & Treffers, D. J. (2001). “Dematerialization and sustainable product service systems”, Sustainable Services and Systems: Transition towards Sustainability? Towards Sustainable Product Design. Proceedings of the 6th International Conference, 29-30 October. Amsterdam: The Center for Sustainable Design.

IEA. (2012). World energy outlook 2012. Paris: OECD/IEA.

IEA. (2016). International Energy Outlook 2016. Retrieved from www.eia.gov/forecasts/ieo

ISO. (2006). ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework (Vol. 3). Vol. 3. international Organization For Standarization.

ISO. (2010). ISO 9241-210: Ergonomics of human-system interaction - Human-centred design for interactive systems. 9241-210. International Standards Organization.

Ison, R. L. (1993). Changing community attitudes. Rangelands Journal, 15, 154–166.

Ison, R. L., Maiteny, P. T., & Carr, S. (1997). Systems methodologies for sustainable natural resources research and development. Agricultural Systems, 55(2), 257–272. https://doi.org/10.1016/S0308-521X(97)00010-3

Jackson, M. C. (1982). The Nature of Soft Systems Thinking: the Work of Churchman, Ackoff and Checkland. Journal of Applied Systems Analysis, 9, 17–29.

Jackson, M. C. (1985). Social systems theory and practice: the need for a critical approach. International Journal of General Systems, 10, 135–151.

Jackson, M. C. (1991). The origins and nature of critical systems thinking. Systems Practice, 4(2), 131–149. https://doi.org/10.1007/BF01068246

Jackson, M. C. (2001). Critical systems thinking and practice. European Journal of Operational Research, 128(2), 233–244. https://doi.org/10.1016/S0377-2217(00)00067-9

Jackson, M. C. (2003). Systems thinking: Creative holism for managers. John Wiley & Sons.

Jackson, M. C., & Keys, P. (1984). Towards a system of systems methodologies. Journal of the Operational Research Society, 35(6), 473–486.

Jannuzzi, G. de M. (2007). Energy Efficiency Programs for Low-income Household Consumers in Brazil: Considerations for a Refrigerator-Replacement Program.

Johnson, J. (2005). Complexity science in collaborative design. CoDesign, 1(4), 223–242. https://doi.org/10.1080/15710880500478346

Jones, P. H. (2014). Systemic Design Principles for Complex Social Systems. In G. S. Metcalf (Ed.), Social Systems and Design (pp. 91–128). https://doi.org/10.1007/978-4-431-54478-4_4

Joore, P. (2008). The V-Cycle for system innovation translating a broad societal need into concrete product service solutions: the multifunctional centre Apeldoorn case. Journal of Cleaner Production, 16(11), 1153–1162. https://doi.org/10.1016/j.jclepro.2007.08.007

Joore, P. (2010). New to Improve-The Mutual Influence between New Products and Societal Change Processes. Delft University of Technology.

Joore, P., & Brezet, H. (2015). A Multilevel Design Model: the mutual relationship between product-service system development and societal change processes. Journal of Cleaner Production, 97(1), 92–105. https://doi.org/10.1016/j.jclepro.2014.06.043

Kaygusuz, K. (2007). Energy for Sustainable Development: Key Issues and Challenges. Energy Sources, Part B: Economics, Planning, and Policy, 2(1), 73–83. https://doi.org/10.1080/15567240500402560

Koffka, K. (1935). Principles of Gestalt Psychology. In The Philosophical Review. New York: Hardcourt, Brace and Company.

Koh, E. C. Y., Förg, A., Kreimeyer, M., & Lienkamp, M. (2015). Using engineering change forecast to prioritise component modularisation. Research in Engineering Design, 26(4), 337–353. https://doi.org/10.1007/s00163-015-0200-5

Kumar, R., & Kumar, U. (2004). Service Delivery Strategy: Trends in Mining Industries. International Journal of Surface Mining, Reclamation and Environment, 18(4), 299–307. https://doi.org/10.1080/1389526042000274926

Laszlo, A., Laszlo, K. C., & Dunsky, H. (2009). Redefining success: designing systemic sustainable strategies. Systems Research and Behavioral Science, 8(3). https://doi.org/10.1002/sres.982

Lebel, L., & Lorek, S. (2008). Enabling Sustainable Production-Consumption Systems. Annual Review of Environment and Resources, 33(1), 241–275. https://doi.org/10.1146/annurev.environ.33.022007.145734

Lee, S., Geum, Y., Lee, H., & Park, Y. (2012). Dynamic and multidimensional measurement of product-service system (PSS) sustainability: a triple bottom line (TBL)-based system dynamics approach. Journal of Cleaner Production, 32, 173–182. https://doi.org/10.1016/j.jclepro.2012.03.032

Lemons, G., Carberry, A., Swan, C., Jarvin, L., & Rogers, C. (2010). The benefits of model building in teaching engineering design. Design Studies, 31(3), 288–309. https://doi.org/10.1016/j.destud.2010.02.001

Lilienfeld, R. (1985). The Rise of Systems Theory. Krieger Pub Co.

Lima, C. A. F., Gradvohl, A. B., Carvalho, T., Ricardo, J., Navas, P., & Arruda, O. S. (2009). Programa Ecoelce de Troca de Resíduos por Bônus na Conta de Energia. Anais Do V Congresso de Inovação Tecnológica Em Energia Elétrica - V CITENEL, 1–8. Belém.

Lindahl, M., & Ölundh., G. (2001). The Meaning of Functional Sales in Life Cycle Engineering: Challenges and Opportunities. 8th International Seminar on Life Cycle Engineering.

Lindahl, M., Sundin, E., Sakao, T., & Shimomura, Y. (2007). Integrated Product and Service Engineering versus Design for Environment — A Comparison and Evaluation of Advantages and Disadvantages. In Y. Takata, S and Umeda (Ed.), Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses (pp. 137–142). https://doi.org/10.1007/978-1-84628-935-4_24

London, T., & Hart, S. L. (2004). Reinventing strategies for emerging markets: beyond the transnational model. Journal of International Business Studies, 35(5), 350–370.

London, T., & Hart, S. L. (2011). Next Generation Business Strategies for the Base of the Pyramid. In ptgmedia.pearsoncmg.com. New Jersey: FT Press.

Lopes, A. M., Fam, D., & Williams, J. (2012). Designing sustainable sanitation: Involving design in innovative, transdisciplinary research. Design Studies, 33(3), 298–317. https://doi.org/10.1016/j.destud.2011.08.005

Luomi, M. (2014). Sustainable Energy in Brazil: Reversing Past Achievements or Realizing Future Potential. University of Oxford.

Mahajan, V., & Banga, K. (2005). The 86 Percent Solution: How to Succeed in the Biggest Market Opportunity of the Next 50 Years. New Jersey: Prentice Hall.

Manzini, E. (2006). Design, ethics and sustainability: guidelines for a transition phase. Nantes - Cumulus Working Papers, June, 9–15.

Manzini, E., & Vezzoli, C. (2003). A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize. Journal of Cleaner Production, 11(8), 851–857. https://doi.org/10.1016/S0959-6526(02)00153-1

Margolin, V. (1995). The Politics of the Artificial. Leonardo, 28(5), 349. https://doi.org/10.2307/1576217

Matos, S., & Silvestre, B. S. (2013). Managing stakeholder relations when developing sustainable business models: the case of the Brazilian energy sector. Journal of Cleaner Production, 45, 61–73. https://doi.org/10.1016/j.jclepro.2012.04.023

Mays, R. E., Racadio, R., & Gugerty, M. K. (2012). Competing constraints: The operational mismatch between business logistics and humanitarian effectiveness. Proceedings - 2012 IEEE Global Humanitarian Technology Conference, GHTC 2012, 132–137. https://doi.org/10.1109/GHTC.2012.29

Meadows, D. H. (1999). Leverage points: Places to Intervene in a system. Hartland: The Sustainability Institute.

Meadows, D. H. (2008). Thinking in Systems: a Primer. Chelsea Green Publishing.

Meadows, D. H., Meadows, D. L., Randers, J., & Behren, W. W. (1972). The Limits to Growth: a Report for the Club of Rome's Project on the Predicament of Mankind. New York: Universe Books.

Meier, H., Völker, O., & Funke, B. (2011). Industrial Product-Service Systems (IPS2): Paradigm shift by mutually determined products and services. The International Journal of Advanced Manufacturing Technology, 52(9–12), 1175–1191. https://doi.org/10.1007/s00170-010-2764-6

Melles, G., de Vere, I., Misic, V., Vere, I. De, & Misic, V. (2011). Socially responsible design: thinking beyond the triple bottom line to socially responsive and sustainable product design. CoDesign, 7(3), 143–154. https://doi.org/10.1080/15710882.2011.630473

Metcalf, G. S. (Ed.). (2014). Social Systems and Design. Springer.

Mink, A. (2016). Design for Well-Being: An Approach for Understanding Users' Lives in Design for Development. Delft University of Technology.

Mink, A., Diehl, J. C., & Kandachar, P. (2018). Comprehensive user insight to improve technologies for development. International Development Planning Review, 40(3), 299–328. https://doi.org/10.3828/idpr.2018.13

Misra, K. B. (2008). Engineering Design: A Systems Approach. In Handbook of Performability Engineering (pp. 13–24). https://doi.org/10.1007/978-1-84800-131-2_2

MMA. (2008). Plano Nacional sobre Mudança do Clima - PNMC. Brasilia.

MME. (2007). National Plan of Energy 2030. Brasília.

Modi, V., McDade, S., Lallement, D., & Saghir, J. (2005). Energy services for the Millennium Development Goals: Achieving the Millennium Development Goals. New York.

Mont, O. (2002a). Clarifying the concept of product–service system. Journal of Cleaner Production, 10(3), 237–245. https://doi.org/http://dx.doi.org/10.1016/S0959-6526(01)00039-7

Mont, O. (2002b). Drivers and barriers for shifting towards more service-oriented businesses: Analysis of the PSS field and contributions from Sweden. The Journal of Sustainable Product Design, 2(3/4), 89–103. https://doi.org/10.1023/B:JSPD.0000031027.49545.2b

Morelli, N., & Tollestrup, C. (2006). New representations techniques for Designing. Proceedings of the Engineering and Product Design Education Conference, (September), 6. SALZBURG: Salzburg University of Applied Sciences.

Morgan, P. (2006). Ways of Thinking About Capacity Issue. Maastrich.

Moser, B. R., & Wood, R. T. (2015). Complex Engineering Programs as Sociotechnical Systems. In Concurrent Engineering in the 21st Century: Foundations, Developments and Challenges (pp. 51–65).

Mukaze, S., & Velásquez, D. C. V. (2012). Product Service System: Co-Designing for Social Impact. Institute of Technology.

Mulder, K. F., Segalàs, J., & Ferrer-Balas, D. (2012). How to educate engineers for/in sustainable development. International Journal of Sustainability in Higher Education, 13(3), 211–218. https://doi.org/10.1108/14676371211242535

Murthy, P. N. (2000). Complex societal problem solving: a possible set of methodological criteria. Systems Research and Behavioral Science, 17(1), 73–101.

Nelson, H. G. (2004). A whole systems design approach to decentralized governance for human development. United Nations Development Programme.

Nelson, H. G. (2005). The design of design learning: The graduate programs in whole systems design- a reflective case study. Doctoral Education in Design Conference, (June).

Nelson, H. G. (2008a). Design Communication: Systems, Service, Conspiracy, and Leaderships. In Dialogue as a Collective Means of Design Conversation (pp. 39–49). https://doi.org/10.1007/978-0-387-75843-5_3

Nelson, H. G. (2008b). Simply Complex by Design. Performance Improvement Quarterly, 20(2), 97–115. https://doi.org/10.1111/j.1937-8327.2007.tb00443.x

Nelson, H. G., & Stolterman, E. (2012). The Design Way: Intentional change in an unpredictable world. Cambridge, UK: MIT PRESS.

Nelson, H. G., & Vanpatter, G. K. (2004). Patterns in Motion: Examining Design's Reconstruction. NextD Journal, 12.

Nielsen, B., & Santos, A. L. R. (2013). Key challenges of product development for humanitarian markets. Proceedings of the 3rd IEEE Global Humanitarian Technology Conference, GHTC 2013, 411–415. https://doi.org/10.1109/GHTC.2013.6713721

Nissing, C., & von Blottnitz, H. (2010). Renewable energy for sustainable urban development: Redefining the concept of energisation. Energy Policy, 38(5), 2179–2187. https://doi.org/10.1016/j.enpol.2009.12.004

Nussbaum, M., & Sen, A. (1993). The Quality of Life. Clarendon Press.

O'Rafferty, S., Curtis, H., & O'Connor, F. (2014). Mainstreaming sustainability in design education – a capacity building framework. International Journal of Sustainability in Higher Education, 15(2), 169–187. https://doi.org/10.1108/IJSHE-05-2012-0044

Oliga, J. C. (1988). Methodological foundations of systems methodologies. Systems Practice, 1(1), 87–112. https://doi.org/10.1007/BF01059890

Oosterlaken, I. (2009). Design for Development: A Capability Approach. Design Issues, 25(4), 91–102. https://doi.org/10.1162/desi.2009.25.4.91

Optner, S. L. (ed. . (1973). Systems Analysis. Penguin: Harmondsworth.

Papanek, V. J. (1972). Design for the real world: Human ecology and social change. Thames & Hudson Publishers.

Park, H., & Benson, E. (2013). Systems thinking and connecting the silos of design education. Proceedings of International Conference on Engineering and Product Design Education.

Passos, L., Cardemil, J. M., & Colle, S. (2014). Feasibility study of using domestic solar hot water systems as alternative to reduce the electricity peak demand in Brazil. Energy Procedia, 57, 2487–2495. https://doi.org/10.1016/j.egypro.2014.10.258

Patrzyk, F. (2014). Desenvolvimento de Metodologia Educacional de Eficiência Energética aplicada ao Ensino Infantil. Instituto de Tecnologia para o Desenvolvimento - Institutos Lactec.

Patrzyk, F., & Medeiros, L. De. (2015). Desenvolvimento de metodologia educacional de eficiência energética aplicada ao ensino infantil. EDUCERE - XIII Congresso Nacional de Educação. Curitiba, Brazil: Pontifícia Universidade Católica do Paraná (PUCPR).

Penin, L. (2006). Strategic design for social sustainability in emerging contexts. Politecnico di Milano.

Phelan, S. (1999). A Note on the Correspondence Between Complexity and Systems Theory. Systemic Practice and Action Research, 12(3), 237–246.

Pittman, J. (2004). Living sustainably through higher education: a whole systems design approach to organizational change. Higher Education and the Challenge of Sustainability. Problematics, Promise, and Practice, 199–212.

Prahalad, C. K. (2005). The Fortune at the Bottom of the Pyramid: Eradicating poverty through profits. New Jersey: Wharton School Publishing.

Prahalad, C. K., & Ramaswamy, V. (2000). Co-opting customer competence. Harvard Business Review.

Prahalad, C. K., & Ramaswamy, V. (2004). Co-creation experiences: The next practice in value creation. Journal of Interactive Marketing, 18(3), 5–14. https://doi.org/10.1002/dir.20015

Raduma, W. (2011). Occupy Reimagining Design. The ReReThinking Series.

Ramalingam, B., Scriven, K., & Foley, C. (2009). Innovations in international humanitarian action. In 8th Review of Humanitarian Actions: Performance, Impact and Innovation (pp. 1–88).

Reinders, A., Diehl, J. C., & Brezet, H. (2012). The Power of Design: Product Innovation in Sustainable Energy Technologies. Wiley.

REN21. (2016). Renewables 2016 Global Status Report. In Global Status Report.

Reubens, R. (2016). To Craft, By Design, for Sustainability: Towards holistic sustainability design for developing-country enterprises. Delft University of Technology.

Rocchi, S. (2005). Enhancing Sustainable Innovation by Design: An Approach to the Co-creation of Economic, Social and Environmental Value. Duurzame. Erasmus University Rotterdam.

Ryan, A. J. (2014). A Framework for Systemic Design. FORMakademisk, 7(4), 1–14.

Ryan, C., Gaziulusoy, I., Mccormick, K., Trudgeon, M., McKormick, K., Trudgeon, M., … Trudgeon, M. (2016). Virtual City Experimentation: A Critical Role for Design Visioning. In J. Evans, A. Karvonen, & R. Raven (Eds.), The Experimental City (pp. 1–18). Routledge.

Sadorsky, P. (2009). Renewable energy consumption and income in emerging economies. Energy Policy, 37(10), 4021–4028. https://doi.org/10.1016/j.enpol.2009.05.003

Salim, R. A., & Rafiq, S. (2012). Why do some emerging economies proactively accelerate the adoption of renewable energy? Energy Economics, 34(4), 1051–1057. https://doi.org/10.1016/j.eneco.2011.08.015

Santos, A., Krämer, A., & Vezzoli, C. (2009). Design Brings Innovation to the Base of the Pyramid. Design Management Review, 20(2), 78–85. https://doi.org/10.1111/j.1948-7169.2009.00010.x

Santos, A. L. R. (2015). Mind the gap: Designing Sustainable Healthcare In Humanitarian Aid Proefschrift. Delft University of Technology.

Schaeffer, R., Szklo, A. S., Cima, F. M., & Machado, G. (2005). Indicators for sustainable energy development: Brazil's case study. Natural Resources Forum, 29(4), 284–297. https://doi.org/10.1111/j.1477-8947.2005.00141.x

Schäfer, M., Jaeger-Erben, M., & Santos, A. (2011). Leapfrogging to Sustainable Consumption? An Explorative Survey of Consumption Habits and Orientations in Southern Brazil. Journal of Consumer Policy, 34(1), 175–196. https://doi.org/10.1007/s10603-010-9150-5

Segalàs, J., Ferrer-Balas, D., & Mulder, K. F. (2010). What do engineering students learn in sustainability courses? The effect of the pedagogical approach. Journal of Cleaner Production, 18(3), 275–284. https://doi.org/10.1016/j.jclepro.2009.09.012

Sevaldson, B. (2008). A system approach to design learning. In A. Menges (Ed.), System thinking and Integral Design. Offenbach: Hochschulverlag HFG Offenbach.

Sevaldson, B. (2009). Why should we and how can we make the design process more complex ? In M. L. Berg (Ed.), Shaping Futures (pp. 274–281). Oslo: Oslo School of Architecture.

Sevaldson, B. (2010). Discussions & Movements in Design Research: A systems approach to practice research in design. FORMakademisk, 3(1), 8–35.

Sevaldson, B. (2011). GIGA-mapping: Visualisation for complexity and systems thinking in design. Nordes '11: The 4th Nordic Design Research Conference, 137–156.

Sevaldson, B. (2013). Systems Oriented Design: The emergence and development of a designerly approach to address complexity. 2nd International Conference for Design Education Researchers, (May), 1–22. https://doi.org/ISBN 978-82-93298-00-7

Sevaldson, B. (2014a). Holistic and dynamic concepts in design: What design brings to systems thinking. Relating Systems Thinking and Design 2014, 1–16. Oslo.

Sevaldson, B. (2014b). System Oriented Design (Webpage). Retrieved January 1, 2014, from http://www.systemsorienteddesign.net/

Sevaldson, B. (2015). GIGAmaps: Their role as bridging artefacts and a new Sense Sharing Model. Relating Systems Thinking and Design 4, 1–11. Canada.

Sevaldson, B., Hensel, M. U., & Frostell, B. (2010). Systems-oriented design and sustainability. In F. Ceschin, C. Vezzoli, & J. Zhang (Eds.), Sustainability in Design - Now! Challenges and Opportunities for Design Research, Education and Practice in the XXI Century (pp. 465–474). Bangalore: Greenleave Publishers.

Shrimali, G., Slaski, X., Thurber, M. C., & Zerriffi, H. (2011). Improved stoves in India: A study of sustainable business models. Energy Policy, 39(12), 7543–7556. https://doi.org/10.1016/j.enpol.2011.07.031

Siddiqi, A., Clewlow, R. R., & Sussman, J. M. (2014). Complex Socio-Technical Problems for Engineers: Pedagogical Motivation and Experience at the Undergraduate Level. In A. V. Gheorghe, M. Masera, & P. F. Katina (Eds.), Infranomics: Sustainability, Engineering Design and Governance (Vol. 24, pp. 195–211). https://doi.org/10.1007/978-3-319-02493-6_13

Sklar, A., & Madsen, S. (2010). Global Ergonomics: Design for Social Impact. Ergonomics in Design: The Quarterly of Human Factors Applications, 18(2), 4–31. https://doi.org/10.1518/106480410X12737888532921

Skyttner, L. (2006). General Systems Theory - Problems, Perspectives, Practice (2nd ed.). https://doi.org/10.1142/9789812774750

Sleeswijk Visser, F., Stappers, P. J., van der Lugt, R., & Sanders, E. B.-N. (2005). Contextmapping: experiences from practice. CoDesign, 1(2), 119–149. https://doi.org/10.1080/15710880500135987

Smith, C. E. (2011). Design for the other 90%. Editions Assouline.

Stahel, W. R. (1997). The functional economy: cultural and organisational change. In The industrial green game (pp. 91–100). Washington: National Academy Press.

Stahel, W. R., & Reday-Mulvey, G. (1981). Jobs for Tomorrow: The Potential for Substituting Manpower for Energy. New York: Vantage Press.

Stasinopoulos, P., Smith, M. H., Hargroves, K. C., & Desha, C. (2009). Whole System Design: An Integrated Approach to Sustainable Engineering (Taylor & F). London.

Sterman, J. D. (2000). Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw-Hil Higher Education.

Stjepandić, J., Wognum, N., & Verhagen, W. J. C. (2015). Concurrent Engineering in the 21st Century. In J. Stjepandić, N. Wognum, & W. J.C. Verhagen (Eds.), Concurrent Engineering in the 21st Century: Foundations, Developments and Challenges. https://doi.org/10.1007/978-3-319-13776-6

Taket, A. (1992). Creative Problem Solving: Total Systems Intervention. Journal of the Operational Research Society, 43(10), 1013–1016. https://doi.org/10.1057/jors.1992.153

Tatham, P., & Houghton, L. (2011). The wicked problem of humanitarian logistics and disaster relief aid. Journal of Humanitarian Logistics and Supply Chain Management, 1(1), 15–31. https://doi.org/10.1108/20426741111122394

The World Bank. (2014). World Development Indicators. Retrieved from http://data.worldbank.org/data-catalog/world-development-indicators/wdi-2011

Thompson, B. S. (1999). Environmentally-sensitive design: Leonardo WAS right! Materials & Design, 20(1), 23–30. https://doi.org/10.1016/S0261-3069(98)00046-6

Tischner, U., & Verkuijl, M. (2006). Design for (Social) Sustainability and Radical Change. Perspectives on Radical Changes to Sustain- Able Consumption and Production, 199–215. Copenhagen.

Tukker, A. (2004). Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Business Strategy and the Environment, 13(4), 246–260. https://doi.org/10.1002/bse.414

Tukker, A., & Tischner, U. (2006). Product-services as a research field: past, present and future. Reflections from a decade of research. Journal of Cleaner Production, 14(17), 1552–1556. https://doi.org/10.1016/j.jclepro.2006.01.022

Ulrich, W. (1983). Critical Heuristics of Social Planning: A New Approach to Practical Philosophy. Wiley.

Ulrich, W. (2013). Critical Systems Thinking. In S. I. Gass & M. C. Fu (Eds.), Encyclopedia of Operations Research and Management Science (pp. 314–326). Springer.

UNEP. (2001). The Role Of Product Service Systems in a Sustainable Society. Paris.

UNEP. (2002). Product-Service Systems and Sustainability: Opportunities for sustainable solutions. Paris.

United Nations. (2010). Sustainable Energy for All Initiative. Retrieved December 10, 2015, from http://www.se4all.org/

Valckenaers, P., & Van Brussel, H. (2016). On the Design of Complex Systems. In Design for the Unexpected (pp. 9–18). https://doi.org/10.1016/B978-0-12-803662-4.00002-3

Vandermerwe, S., & Rada, J. (1988). Servitization of business: Adding value by adding services. European Management Journal, 6(4), 314–324. https://doi.org/10.1016/0263-2373(88)90033-3

Vanpatter, G. K. (2014). Making Sense of Next Design Frontiers. Humantific, 1–13.

Vanpatter, G. K., & Jones, P. (2009). Design 1.0, 2.0, 3.0, 4.0; The Rise of Visual SenseMaking. NextD Journal, 1(March), 1–12.

Vasantha, G. V. A., Roy, R., Lelah, A., & Brissaud, D. (2012). A review of product–service systems design methodologies. Journal of Engineering Design, 23(9), 635–659. https://doi.org/10.1080/09544828.2011.639712

Vezzoli, C. (2010). System Design for Sustainability: Theory, Methods and Tools for a Sustainable “satisfaction-system” Design (2nd ed.). Maggioli Editore.

Vezzoli, C., & Ceschin, F. (2011). The Learning Network on Sustainability: an e-mechanism for the development and diffusion of teaching materials and tools on design for sustainability in an open-source and copy left ethos. International Journal of Management in Education, 5(1), 22. https://doi.org/10.1504/IJMIE.2011.037753

Vezzoli, C., Ceschin, F., & Diehl, J. C. (2015). Sustainable Product-Service System Design applied to Distributed Renewable Energy fostering the goal of sustainable energy for all. Journal of Cleaner Production, 97, 134–136. https://doi.org/10.1016/j.jclepro.2015.02.069

Vezzoli, C., Ceschin, F., & Kemp, R. (2008). Designing transition paths for the diffusion of sustainable system innovations. A new potential role for design in transition management? Changing the Change. Design, Visions, Proposals and Tools, 1–14. Turin, Italy: Umberto Allemandi.

Vezzoli, C., Ceschin, F., Osanjo, L., Moalosi, R., Nakazibwe, V., & Diehl, J. C. (2015). An African European network of design universities fostering the goal of sustainable energy for all: An innovative teaching approach based on the combination of Distributed Renewable Energy and design for Sustainable Product-Service Systems. KIDEC 2015 Kampala International Design Conference.

Vezzoli, C., Ceschin, F., & Rithaa, M. M. (2007). LeNS_AFRICA An African Learning Network on Sustainability for the development and diffusion of teaching materials and tools on Design for Sustainability in an open-source and copyleft ethos. Design, 5(December), 22–43. https://doi.org/10.1504/IJMIE.2011.037753

Vezzoli, C., Delfino, E., & Ambole, L. A. (2014). System Design for Sustainable Energy for all. A new challenging role for design to foster sustainable development. FORMakademisk, 7(3), 1–27. https://doi.org/10.7577/formakademisk.791

Vezzoli, C., Kohtala, C., Srinivasan, A., Diehl, J. C., Fusakul, S. M., Xin, L., & Sateesh, D. (2014). Product-Service System Design for Sustainability. https://doi.org/http://dx.doi.org/10.9774/GLEAF.978-1-909493-69-8_8

Vezzoli, C., & Tischner, U. (2005). Sustainability design-orienting toolkit (SDO-MEPSS) (C. Vezzoli & U. Tischner, Eds.). Retrieved from http://www.mepss-sdo.polimi.it/mepss/website/mepss.html

Viswanathan, M., & Rosa, J. A. (2007). Product and Market Development for Subsistence Marketplaces: Consumption and Entrepreneurship beyond Literacy and Resource Barriers. Advances in International Management, 20(1), 1–17. https://doi.org/10.1016/S1571-5027(07)20001-4

Viswanathan, M., & Sridharan, S. (2012). Product Development for the BoP: Insights on Concept and Prototype Development from University-Based Student Projects in India. Journal of Product Innovation Management, 29(1), 52–69. https://doi.org/10.1111/j.1540-5885.2011.00878.x

Vogtländer, J. G., Bijma, A. S., Brezet, H., & Vogtländer, J. (2002). Communicating the eco-efficiency of products and services by means of the eco-costs/value model. Journal of Cleaner Production, 10(1), 57–67. https://doi.org/10.1016/S0959-6526(01)00013-0

Vogtländer, J. G., Brezet, H. C., & Hendriks, C. F. (2001). The virtual eco-costs '99 A single LCA-based indicator for sustainability and the eco-costs-value ratio (EVR) model for economic allocation. The International Journal of Life Cycle Assessment, 6(3), 157–166. https://doi.org/10.1007/BF02978734

Vredenburg, K., Isensee, S., & Righi, C. (2002). User-centered Design: An Integrated Approach. Upper Saddle River: Prentice Hall PTR.

Wakeford, N. (2004). Innovation through people-centred design: lessons from the USA. DIT Global Watch Mission Report.

WBCSD. (1998). World Business Council for Sustainable Development. Retrieved December 1, 2014, from http://www.wbcsd.org/

WCED. (1987). The Brundtland report: Our common future. In Oxford University Press. https://doi.org/10.1080/07488008808408783

Webb, J. W., Kistruck, G. M., Ireland, R. D., & Ketchen, Jr., D. J. (2010). The Entrepreneurship Process in Base of the Pyramid Markets: The Case of Multinational Enterprise/Nongovernment Organization Alliances. Entrepreneurship Theory and Practice, 34(3), 555–581. https://doi.org/10.1111/j.1540-6520.2009.00349.x

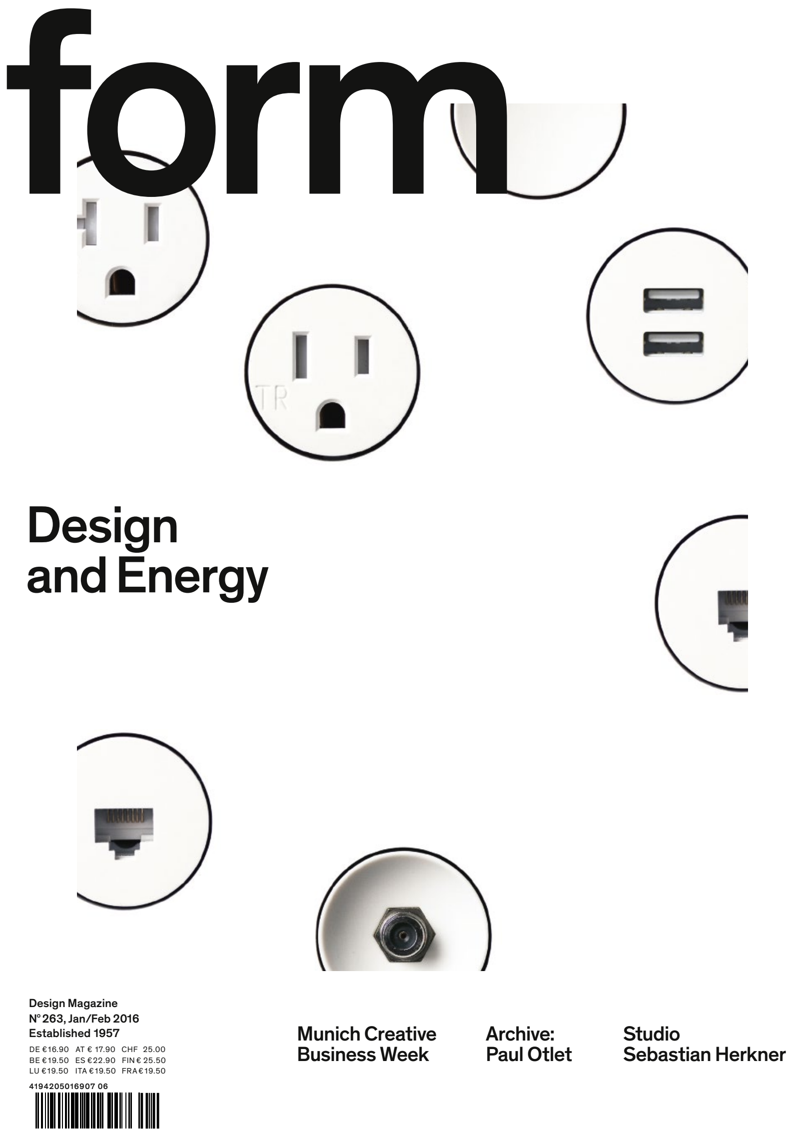
Whiteley, N. (1993). Design for Society. Reaktion Books.

Zheng, Y., & Stahl, B. C. (2011). Technology, capabilities and critical perspectives: what can critical theory contribute to Sen's capability approach? Ethics and Information Technology, 13(2), 69–80. https://doi.org/10.1007/s10676-011-9264-8

Zheng, Y., & Stahl, B. C. (2012). Evaluating Emerging ICTs: A Critical Capability Approach of Technology. In I. Oosterlaken & J. van den Hoven (Eds.), The Capability Approach, Technology and Design; Philosophy of Engineering and Technology (pp. 57–76). https://doi.org/10.1007/978-94-007-3879-9_4

Annexes

Annex 1 – Interview - Form Design Magazine



Editorial

Design Ein Software-Update soll die Marke VW retten. Ein Problem, das jahrelang nicht lösbar schien, wurde jetzt innerhalb eines guten Monats mit ein paar Programmierkniffen und einem sogenannten Strömungstransformator, dessen Kosten sich im Cent-Bereich bewegen dürften, behoben. Chapeau, aber mit Verlaub, das klingt zunächst, wie es jüngst Michael Müller auf Spiegel Online treffend bezeichnete, nach einem Fluxkompensator, dem „Zeitflussverdichter" aus „Back to the Future", jener Film-Trilogie, der wir auch die Existenz des Hoverboards (↗ S. 14) zu verdanken haben. Nun geht es aber weniger darum, an der Schnelligkeit der VW-Ingenieure zu zweifeln, sondern eher darum, die Langsamkeit des Managements zu hinterfragen. Immer wieder nämlich gibt es auch außerhalb des Films Menschen, die ihrer Zeit voraus sind, sei es durch Spekulation (↗ S. 57) oder durch stringentes Weiterverfolgen gegenwärtiger Möglichkeiten. Die Historie der Elektromobilität (↗ S. 82) oder Paul Otlets Erfindung des Internets avant la lettre (↗ S. 90) geben hiervon lehrreiche Beispiele. Entwicklungen scheitern oft nicht an den technischen Möglichkeiten oder den mangelnden Visionen Einzelner, sondern an der Bequemlichkeit und an wirtschaftspolitischen Interessen.

Kontext Es ist diese ungute Allianz aus Trägheit und Lobbyismus, die auch bei unserem Schwerpunktthema Energie (↗ S. 36) immer wieder mitschwingt. Anders wären jahrhundertelange unkontrollierte Waldrodungen zur Bauholz-, Brennholz- und Flächengewinnung, Umsiedlungen ganzer Ortschaften infolge des Kohleabbaus, kriegerische Konflikte um Öl und Gas und auch ein VW-Abgasskandal nicht zu verstehen. Design kann zu einem bewussteren Umgang mit Energie beitragen (↗ S. 38), kann von Suffizienz (↗ S. 54) über systemische Konzepte (↗ S. 65) bis hin zum schon erwähnten spekulativen Design unterschiedliche Aspekte einfließen lassen. Nicht zuletzt geben die Beispiele in unserem Design Guide to Energy (↗ S. 43) eine Vorstellung davon, dass es zu den oftmals als alternativlos bezeichneten fossilen oder nuklearen Technologien sehr wohl ressourcen- und umweltschonende Alternativen gibt.

Situation Gert Selle schreibt in seinem aktuellen Werk „Im Haus der Dinge" (↗ S. 102): „Dinge sind intelligenter geworden, Gebraucher dümmer. Das Subjekt/-Objekt-Verhältnis zwischen den beiden Aktanten scheint sich umzukehren – erstmals in der Geschichte des werkzeugführenden Menschen, als noch Klugheit und Kraft die Hand steuerten. […] Der Zauberlehrling wird heute damit belohnt, dass ihm eine Wischbewegung genügt, Gewünschtes herbeizuzitieren." Wir sollten dies nicht als Abgesang lesen, sondern als Aufforderung, den Dingen wachsam und nicht träge zu begegnen.

Mit dieser Ausgabe begrüßen wir sehr herzlich Sarah Schmitt bei uns im Team, die zukünftig zusammen mit Carolin Blöink und Susanne Heinlein die Gestaltung der form übernehmen wird. Am grundsätzlichen Layout werden wir festhalten, kleine Anpassungen haben wir jedoch vorgenommen und werden sie auch zukünftig nach Bedarf angehen.

Für die anstehenden Feiertage wünschen wir Ihnen Ruhe und Erholung. Wir freuen uns auf ein Wiedersehen 2016, bleiben Sie uns gewogen.

Stephan Ott, Chefredakteur

Design A software update is expected to save the VW brand. A problem that appeared impossible to solve for years has been rectified within a month with a couple of program adjustments and a flow transformer, which costs only a few cents. Kudos, but, if I may say so, and as recently aptly reported by Michael Müller on Spiegel Online, this sounds a bit like the "flux capacitor" from "Back to the Future", the film trilogy which also gave rise to the existence of hoverboards (↗ p. 14). But, the issue is less about doubting the speed of VW engineers and more about questioning the tardiness of management. Time and again we come across people, also outside of film, who are ahead of their time, whether this is due to speculation (↗ p. 57) or the rigorous pursuit of existing opportunities. The history of electro mobility (↗ p. 82) or Paul Otlet's invention of the Internet avant la lettre (↗ p. 90) are a couple of instructive examples. Developments often do not fail due to the technical possibilities or the lack of vision of individuals, but rather due to complacency and political or economic interests.

Context It is this disquieting alliance between indolence and lobbying that is also constantly at work in our focus topic on energy (↗ p. 36). Otherwise, hundreds of years of uncontrolled forest clearing for construction timber, firewood, and space, the resettlement of entire communities due to coal mining, military conflicts for oil and gas and even a VW exhaust scandal would be absolutely incomprehensible. Design can raise awareness of the use of energy (↗ p. 38) and can flow into various aspects, from sufficiency (↗ p. 54) and systemic concepts (↗ p. 65) to the already mentioned speculative design. Ultimately, the examples in our design guide to energy (↗ p. 43) also show that resource conserving and environmentally friendly alternatives are available to fossil or nuclear technologies, which are often described as having no alternatives.

Situation In his current work "Im Haus der Dinge" [In the House of Things] (↗ p. 102) Gert Selle writes: "Things have become more intelligent, users dumber. The subject/object relationship between the two actants appears to be reversing – for the first time in the history of tool-using people, when intelligence and strength still guided the hand. […] These days, the sorcerer's apprentice is rewarded with the idea that a swipe of the hand is enough to summon what is desired." We should not consider this a swansong, but rather a challenge to ensure that we respond with vigilance rather than idleness to the things.

With this issue, we would like to warmly welcome Sarah Schmitt to our team, who will take over the design of form, together with Carolin Blöink and Susanne Heinlein, in the future. We will stick with the basic layout, but we have made a few minor adjustments and will continue to do so in future wherever appropriate.

We wish you relaxing and restful holidays. We look forward to seeing you again in 2016 and hope that you will stay with us.

Stephan Ott, Editor-in-Chief

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Magazine

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↗ Seilbahnen/Ropeways
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Events

Besuchen Sie uns auf der Internationalen Möbelmesse in Köln vom 18. bis 24. Januar 2016 an Stand D 028 im Bereich Living Interiors in Halle 4.2. Am 18. Januar 2016 laden wir Sie herzlich zu einem Talk über die Neukonzeption der Autostadt Wolfsburg mit Konstantin Grcic und Friedrich von Borries ein. form wird außerdem vom 12. bis 16. Februar 2016 auf der Ambiente in Frankfurt am Main mit einem Stand (FOY 04 vor Halle 11) vertreten sein und auf der Munich Creative Business Week vom 20. bis 28. Februar 2016.
Visit us at the International Interiors Show in Cologne from 18 to 24 January 2016 at booth D 028 in the area living interiors in hall 4.2. You are warmly welcome to join a talk with Konstantin Grcic and Friedrich von Borries about the reconception of the Autostadt in Wolfsburg on 18 January 2016. form will also be present at Ambiente fair in Frankfurt/Main from 12 to 16 February 2016 (booth FOY 04 in front of hall 11) and at Munich Creative Business Week from 20 to 28 February 2016.

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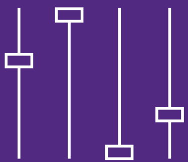
Focus

Files

Obwohl Strom kein menschliches Grundbedürfnis ist, kann damit doch der Lebensstandard von einkommensschwachen Bevölkerungsgruppen – und somit fast vier Milliarden Menschen weltweit – verbessert werden. Die Technologie dafür steht längst zur Verfügung. Warum aber haben immer noch so viele Menschen keinen Zugang zu einem verlässlichen, bezahlbaren Stromnetz? Jairo da Costa Junior, Industriedesigner und Doktorand an der Delft University of Technology, widmet sich in seiner Forschung dieser Fragestellung und sieht in der Anerkennung der Komplexität und der Integration in ein umfassendes System aus Produkten und Dienstleistungen die einzige Möglichkeit, einen funktionierenden Lösungsansatz zum Thema Energie und allen damit verbundenen Problematiken zu entwickeln.

Although not a basic human need, electricity can raise living standards for low-income populations worldwide, which after all account for some four billion people. The technology needed to accomplish this has long been available. So why are still so many people across the globe without a reliable, affordable power supply? Jairo da Costa Junior, industrial designer and doctoral candidate at Delft University of Technology, is currently engaged in a research project on questions such as these. He believes our only hope of developing a workable solution to the energy problem and related issues lies in our ability – and willingness – to acknowledge its complexity and to integrate the available products and services into an all-inclusive system.



Power to the People

Text: Jessica Sicking

Translation: Bronwen Saunders

Jairo, was ist Energie für Dich?
Jairo da Costa Junior Strom ist kein menschliches Grundbedürfnis im eigentlichen Sinne. Die Beziehung zwischen Strom und Bedürfnissen wie Licht, Nahrung, Wärme, Transport und selbst Kommunikation ist aber nicht zu leugnen. Wenn man sich allerdings ansieht, wie wir versuchen, bestehende soziale Differenzen und die Verbindung zwischen Armut und Umweltproblemen anzugehen, wird schnell deutlich, dass Strom immer noch ein unbekanntes Potenzial zur Steigerung der Lebensqualität bereithält – und das auf nachhaltige und ökonomisch verantwortungsvolle Art und Weise.

Du hast Dich mit einkommensschwachen Nutzern, die keinen oder nur eingeschränkten Zugang zu Strom haben, beschäftigt. Wie viele Menschen in Brasilien sind nicht an das örtliche Stromnetz angeschlossen?
Jairo da Costa Junior In Brasilien haben mittlerweile die meisten Menschen Zugang zu Strom; das Stromnetz erreicht inzwischen mehr als 95 Prozent der Bevölkerung. Das bedeutet allerdings nicht, dass diese

Jairo, how would you define energy?
Jairo da Costa Junior **The thing about electricity is that it is really not a basic need in the proper sense. But the relationship between electricity and other basic human needs like lighting, cooking, heating, transportation, and even communication is essential. Looking at how we overcome social challenges and indications of poverty in relation to environmental challenges made me realise that electricity really holds a big opportunity to contribute to the improvement of the quality of life of people – in a way that respects the boundaries of sustainability and is economically responsible.**

Your concern is with low-income users who have only limited access, or in some cases no access at all, to power supply. How many people in Brazil are not hooked up to the local grid?
Jairo da Costa Junior **In Brazil there aren't too many people without access to electricity; these days the grid reaches more than 95 per cent of the population. But this doesn't mean that these people do not have problems related to electricity. Even though they are technically connected to the grid, they still can't afford to pay for it. Many people are using electricity and not paying for it, because of, for example, requirements stated by the government concerning the lack of proper documentation to have access to economic instruments (like subsidiaries, reduced tariffs), high electricity consumption due to out-dated electronic devices, the lack of knowledge about energy efficiency or the lack of awareness regarding different electricity tariffs.**

All these aspects describe scenarios that are not factored into the government's own calculations. Thus the budget earmarked for electricity often falls far short of what is actually needed. Many projects in the past set out to solve problems at the local level only, often by implementing new technologies. Most were unsuccessful owing to their inadequate understanding of the circumstances on the ground, their failure to deliver a convincing value added for users, or their

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Menschen keine Probleme in Bezug auf Strom haben. Denn obwohl sie theoretisch Zugang zum Stromnetz haben, kann es immer noch vorkommen, dass sie sich eine offizielle Nutzung nicht leisten können. So nutzen viele Menschen zwar Strom, bezahlen aber nicht dafür aufgrund von Regierungsvorgaben bezüglich fehlender Dokumente für den Zugang zu ökonomischen Mitteln (wie Unterstützung, vergünstigte Tarife etc.), eines erhöhten Elektrizitätsverbrauchs durch veraltete Geräte, mangelnden Wissens zu Energieeffizienz oder fehlenden Bewusstseins für die Existenz verschiedener Stromtarife.

All diese Aspekte beschreiben Szenarien, die nicht in die von der Regierung vorgenommene Berechnung eingeflossen sind. Der für den Strom vorgesehene Betrag stimmt also in vielen Fällen nicht mit der Realität überein. In der Vergangenheit haben sich viele Projekte damit beschäftigt, punktuell Lösungen, häufig in Form von neuen Technologien, zu implementieren – ohne Erfolg. In den meisten Fällen lässt sich das auf ein mangelndes tieferes Verständnis des lokalen Kontexts zurückführen: der Mehrwert für Nutzer war nicht überzeugend oder mit dem neuen Kontext (Infrastruktur, Technologie etc.) nicht kompatibel. Die Integration von Aspekten der Systemtheorie in den Designprozess scheint besonders vor dem Hintergrund, dass Bereiche wie Produkt- oder Grafikdesign von übergeordneten soziotechnischen Kontexten beeinflusst werden, sinnvoll. Der systemorientierte Ansatz beschreibt demnach selbst keine Designdisziplin, sondern eine bestimmte Denkweise, Orientierung oder Methode, die die Anwendung von bestehenden Werkzeugen oder Aktivitäten zur Beschreibung, Visualisierung, Entdeckung und Neuordnung von Akteuren, Aufgaben und Zielen ermöglicht. Gegenüber der klassischen Produktentwicklung spielt vor allem ein Mangel an bestehendem Wissen in Bezug auf den neuen, einkommensschwachen Kontext eine Rolle. Bestehendes Wissen und Methoden schränken eher ein, da Prozesse im Umgang mit neuen Technologien oder Produkten auf nicht vorhersehbaren örtlichen Normen, Überzeugungen und Gegebenheiten beruhen.

Bei Deiner Forschung bedienst Du Dich Ansätzen aus der Systemtheorie. Was sind die Vorteile gegenüber klassischer Produktentwicklung?
Jairo da Costa Junior Wenn man über Product-Service-Systems (PSS) spricht, geht es um einen größeren Maßstab, ein anderes Niveau von Komplexität und eine allumfassende Art der Integration. Systemorientierte Entwicklungen helfen den Geltungsbereich eines Konzepts zu erweitern. Wenn man über systemorientiertes Design spricht, muss zu allererst ein Perspektivenwechsel vorgenommen werden. Die Anwendung von partizipatorischen, generativen, nutzerzentrierten oder empathischen Methoden findet zu diesem Zweck statt und soll helfen, einen bestehenden Kontext neu zu betrachten. Heutzutage arbeiten die meisten Designer mit einem minimalistischeren Prozess, sodass man den neuen Kontext herstellt, das Problem analysiert und dann direkt nach konkreten Lösungen für das Problem sucht. In einkommensschwachen Gemeinden ist das nicht möglich. Man muss offen für Veränderungen bleiben und akzeptieren, dass Menschen anders als erwartet auf eine (für sie) neue Technologie reagieren. Die Lösung darf dann nur lauten, das Konzept für die neuen Nutzer anzupassen und nicht zu erwarten, dass die Nutzer sich der Technologie unterordnen.

Das Ziel der Forschungsarbeit von Jairo da Costa Junior ist die Beantwortung der Frage, inwieweit sich eine systemorientierte Designpraxis zur Entwicklung und Implementierung von neuen Produkten und Dienstleistungen eignet. Hierbei wird das gesamte, zugrundeliegende soziotechnische System einbezogen, denn nur so kann letztlich ein Product-Service-System entstehen, das eine erfolgreiche Beziehung zwischen allen Akteuren (dazu zählen unter anderen die einkommensschwachen Gemeinden, die Regierung, NGOs, Energieversorger, private Unternehmen, Bildungseinrichtungen wie Universitäten, aber auch Ingenieure, Designer, und Professoren) und Nutzern realisiert sowie gleichzeitig bezahlbare, nachhaltige Lösungen liefert. Erst wenn die soziokulturelle Basis definiert ist, können ein System und später einzelne Produkte entworfen werden, die tatsächlich Erfolg versprechend sind und sich in den bestehenden Kontext integrieren. Erkenntnisse, die sich vor diesem Hintergrund aus der Forschung ergeben, sind dementsprechend eher theoretischer Natur und in Bezug auf praktische Erkenntnisse sehr kontextbezogen. „Theorien mit Universalitätsanspruch sind also selbstreferentielle Theorien. Sie lernen an ihren Gegenständen auch immer etwas über sich selbst. Sie nötigen sich daher wie von selbst, sich selbst einen eingeschränkten Sinn zu geben – etwa Theorie als eine Art von Praxis, als eine Art von Struktur, als eine Art von Problemlösung, als eine Art von System, als eine Art von Entscheidungsprogramm zu begreifen.“[1] So muss also die Entwicklung des konkreten Systems oder Produkts immer innerhalb des vorher definierten Kontexts vorgenommen werden. Die Forschungsergebnisse dienen eher als Anleitung und Methodologie und können dementsprechend in jedem Kontext Anwendung finden.

incompatibility with the larger context (infrastructure, technology etc.). Integrating aspects of system theory into the design process seems an especially worthwhile avenue to pursue, bearing in mind how heavily influenced by overriding sociotechnical factors fields like product and graphic design are. The systems-oriented approach does not describe a design discipline per se; it is rather a certain way of thinking, an orientation or method, which enables the application of existing tools or activities to describe, visualise, discover, and reorganise all those involved, the task at hand and the objectives. One crucial factor here, unlike in classical product development, is our lack of knowledge of the new, low-income context. This makes existing know-how and methods more limiting than liberating, as processes involving the handling of new technologies or products are likely to run up against unforeseeable local norms, beliefs, and circumstances.

You make use of system theory in your work. What are the advantages of this compared with classical product development?
Jairo da Costa Junior **With product service systems (PSS) we are talking about a different kind of scale, a different kind of scope, a different kind of complexity, and also a different kind of integration. System-oriented developments help broaden the scope, so that first a change of perspective is needed. The application of participatory, generative, user-centred, or empathic methods help us to look at the context in a new way. Nowadays, most commonly we work with a more minimalist kind of approach, which means you go to a certain context, find the problem, narrow it down, and search for solutions to that specific problem. In the low-income context this is just not possible. You need to be open to change and accept that people react in a different way to what for them is a new technology. You are going to have to adapt the technology to the people and not force the people to adapt to the technology.**

The ultimate goal of Jairo da Costa Junior's research project was to answer the question of the extent to which system-oriented design practice lends itself to the development and implementation of new products and services. The underlying sociotechnical sys-tem must be included in the analysis as only then can a PSS based on the successful interaction of the supply side (including low-income municipalities, the government, NGOs, energy suppliers, private enterprises, schools and universities, as well as individual engineers, designers, professors, etc.) and the demand – for example users – be developed and an affordable, sustainable

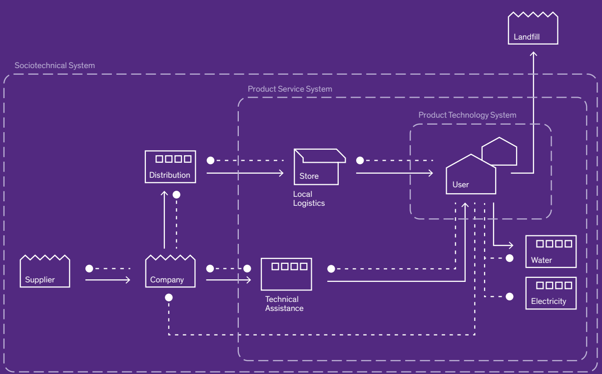
Inwieweit sind die Erkenntnisse und Ergebnisse, die Du bei Projekten in Brasilien gewinnst, auf andere Kontexte in Afrika oder sogar Europa übertragbar?
Jairo da Costa Junior In den meisten Fällen sind die Resultate und Erkenntnisse kontextspezifisch. Aus diesem Grund beschäftige ich mich weit weniger mit der Umsetzung von konkreten Projekten, sondern mehr mit Aspekten wie Bildung und Kontextualisierung. Mit meiner Forschung versuche ich im Bereich der Designausbildung ganz konkret Lernmittel zu schaffen, auf die Professoren und Designer zurückgreifen können, um von meinen Erkenntnissen zu profitieren. Zudem haben wir an Universitäten in Uganda und den Niederlanden Pilotprojekte durchgeführt, die mir geholfen haben herauszufinden, was nötig ist, um Studierende mit neuen Werkzeugen und Methoden zu besseren Ergebnissen zu verhelfen. Mit dem Fokus auf einkommensschwachen Gebieten in Schwellen- und Entwicklungsländern habe ich mich absichtlich einem extremen Kontext zugewandt, sodass ich im Endeffekt weiß, wie ich mit der Komplexität umgehen muss und meine Erkenntnisse auch in anders komplexen Kontexten wie Europa durchaus ihre Anwendung finden können. Das scheint im ersten Moment nichts zu sein, womit sich Designer auseinandersetzen müssen, hat aber einen großen Einfluss auf das Endresultat des Designprozesses. Das ist die Art von Komplexität, mit der sich Designer heute konfrontiert sehen. Die Frage für mich war also, wie ich mit der Komplexität arbeiten kann, anstatt zu versuchen, sie zu reduzieren oder zu vereinfachen.

1 Niklas Luhmann, *Soziale Systeme*, Frankfurt am Main: Suhrkamp, 1984, S. 9.

solution delivered. Only when the sociocultural basis has been defined one can design a system, and later individual products that really do promise success and that really can be integrated in the existing context. The research findings and insights obtained are likely to be more theoretical in nature and heavily context-dependent with regard to their practicability. "Theories that make a claim to universality are self-referential. At the same time, they always learn something about themselves from their objects. Therefore they are forced, as if by their own logic, to accept a limitation of their meaning, for example to understand theory as a kind of praxis, a structure, a problem solving, a kind of system, or a decisional program."[1] Thus the development of a concrete system or product must always be undertaken within the predefined context. The research findings thus serve more as instruction manual and methodology and hence can be applied in every context.

To what extent are the findings obtained from your projects in Brazil applicable to other contexts in Africa – or even Europe, for that matter?
Jairo da Costa Junior **Most of the time the insights and outcomes are really context-specific. Because of this, I am working much less with the implementation of distinctive projects and much more with the education and the contextualisation part. With my research I am trying to contribute to design education and create learning resources that will enable teachers and designers to benefit from my knowledge. Moreover, we conducted pilot projects at universities in the Netherlands and Uganda to better understand what students need to deliver better outcomes with a given set of new tools and methods. With a focus on emerging countries, I went to an extreme context, so in the end I know how to deal with complexity and will be able to apply this knowledge also in contexts with a different kind of complexity, like in Europe, for example. First this looks like something a designer should not even need to do, but it is something that really influences the design outcome. This is the complexity designers are facing today. The question for me, therefore, was how can I work with the complexity instead of reducing and simplifying it.**

1 Niklas Luhmann, *Social Systems*, Stanford: Stanford University Press, 1995, p. 11.



Product Service System, System Map, visualisation stakeholders

“ I am very grateful for all
the people who have helped me
to achieve this dream. ”

Acknowledgements

My ambitions to contribute to design theory, education, and practice by developing a systems design approach to handle complex societal problems have often been challenged by another complex task: carrying out a successful PhD research. It was a long journey that took over seven years of ups and downs, joyful and challenging moments. I am very grateful to all the people who have helped me achieve this dream. I was fortunate to interact with many new people, make many friends, and find some extraordinary ones during my PhD journey. All of them have contributed to making this thesis possible, and I am very grateful to every single one of them. Regardless of the names written in this acknowledgement section, the names and/or faces of all people that joined and supported me on this journey are engraved in my heart. Many times, simple gestures or small contributions from strangers have helped me to go through hard times and to make this accomplishment possible (more than they will ever imagine or I can even express to them).

First of all, I would like to thank my Master's degree supervisor, who prepared me for this challenging journey and whose help, above all, was crucial in giving me this opportunity. Prof. Dr. Aguinaldo, you believed in my capabilities before I could even find confidence in myself; my sincere thanks. I also want to thank my first promotor, Prof Han, for his early support of my research. Prof Han's unique supervision style and passion for music enriched my first years in the Netherlands. I want to express my sincere gratitude to my daily supervisor and promotor, Dr. Jan Carel, for his unique role and continuous support of my PhD throughout all these years. In particular, for JC's remarkable patience, experience, and knowledge, thank you very much for not giving up on me. I really appreciate that you have never discouraged me, even though I have myself many times doubted that I could succeed in completing this PhD.

Also, very special gratitude goes to Prof Dirk for believing in my work and joining my supervision team as my promotor at a challenging moment of my PhD research. Prof Dirk's positive advice and empathy were critical in helping me to overcome challenges and create the mindset I needed to complete my PhD. Also, I extend my gratitude to Dr Fernando for joining my supervision team as co-promotor and providing his expertise to help me to achieve excellence in my work. His guidance helped me many times when I felt stuck in my writing. Thank you also to Linda O'Brien, for the support on the English editing and many writing lessons during the development of this thesis. I also want to thank the Design for Sustainability research group and other colleagues and friends at TU Delft and around: Ana Laura, Jotte, Uchechi, Ivo, Asli, Daphne, Wouter, Kasia, Ronise, Milene, Farzaneh, Agnieszka, and Nicolo (to cite a few of the many). It has been a unique experience to have the opportunity to work with top researchers and experts in the field of sustainability and related areas.

I would also like to thank my best friends who are like family to me: Eduardo and Rodrigo. Eduardo, I am very grateful for the amazing experiences we have shared during our PhD journeys. In such a short time, you became a friend for a lifetime. Rodrigo, you have been a person I always look up to. Thank you for inspiring me to be my best self. Thanks to all my friends in Delft (and from Brazil) who also have supported me along the way: Marcelo, Wesley, Fabrício, Daniel, Leandro, Alexandre (to cite some of the many). Also, I would like to thank Kasia and her family. Thank you for taking me in as part of your family and for supporting me at so many difficult times during my PhD.

I am also very grateful to my family members, especially my mother, my sister, and my wife, who have provided me with moral and emotional support throughout this challenging journey. *Mãe, você é minha maior fonte de inspiração. Por muitas vezes, eu tive dúvidas se eu conseguiria terminar o doutorado. Mas, eu nunca pensei em nenhum momento em desistir de tentar. Obrigado por tudo que você sacrificou para permitir que eu tivesse essa oportunidade. Rê, você é minha maior fonte de admiração. Sua dedicação e ética são impecáveis. Eu nunca esquecerei o quando você se dedicou e lutou pra conquistar seus sonhos. Mãe e Rê, muito obrigado por serem meus exemplos de vida.* To my wife, who has changed my values and taught me to look at life with a whole new perspective, I say, Steffie, thank you for teaching me how to seek happiness and remain grateful in any time, place, or situation. Also, I extend my gratitude to all of Family Vos who took me in as one of their own and made me finally feel at home in The Netherlands. Thank you all.

Finally, I gratefully acknowledge the funding received from CNPq. The work presented in this thesis was partly funded by the Brazilian National Council for Scientific and Technological Development (CNPq).

About the author

Jairo da Costa Junior was born on the 18th of August 1983 in Florianópolis, Brazil. He studied design at the University of the Vale do Itajaí (Brazil) and graduated in Industrial Design (2002-2006). After graduation, he decided to pursue a specialisation in Graphic Design and Corporate Strategy (2007-2008) at the same university. In 2008, he started a monography with the title “Design and Sustainability - from a market strategy to the key factor in the development of products and services” to complete a specialisation in Teaching for Higher Education (2008-2009). The interest in this area led to a Master’s in Design (2010-2012) undertaken at the Federal University of Paraná (Brazil) on the topic “Eco-efficient Services in Product-Service Systems”. To complete the Master’s research, he worked at the Design & Sustainability Research Centre (Núcleo de Design & Sustentabilidade) and collaborated with a major manufacturer of products for water management systems to design innovative and sustainable product-service solutions. The project resulted in three patents amongst eleven inventions.

In 2012, Jairo left Brazil to pursue a PhD at Delft University of Technology (TU Delft). Throughout his doctoral research, he worked in multicultural and multidisciplinary environments and engaged in teaching and learning activities in Brazil, Uganda, the Netherlands, China, and Australia. In the process, he cultivated a desire to inspire people to design products, services, and entire systems dedicated to improving lives, lowering negative environmental impacts, and contributing to design theory and practice. Ultimately, he sought to empower designers to take part in finding solutions to problems faced by individuals, communities, and organisations to which they relate, live, and work. While finishing his PhD, he worked as Assistant Professor in Product Design and Manufacture at The University of Nottingham Ningbo China (UNNC). At UNNC, he also was appointed Course Director of the BEng in Product Design and Manufacture.

Besides, by exploring his passion for design and dance, he co-founded two start-ups. Dance Nomads, a creative industry company with the mission to travel the world to tell amazing visual stories about design, fashion, culture and dance. Also, Global Dance Trips, an innovative online platform for dance experiences around the world. More recently, he co-founded the Bio-based Materials Design Lab. BBM Design Lab is an international network that aims to share better ways of selecting, designing and proposing new materials for a circular economy.

Author's publications

COSTA JUNIOR, J., Diehl, J. C., Secomandi, F. (2019). Towards systems-oriented energy solutions: A multilevel analysis of a low-income energy-efficiency programme in Brazil. **Sustainability, 11**(5799). doi: 10.3390/su11205799 ★★★

COSTA JUNIOR, J., Diehl, J. C., Snelders, D. (2018). A framework for a systems design approach to complex societal problems. **Design Science, 5**(e2), 1-32. doi: 10.1017/dsj.2018.16 ★★★

COSTA JUNIOR, J., Diehl, J. C., Secomandi, F. (2018). Educating for a systems design approach to complex societal problems. **Journal of Engineering Design, 29**(3), 65–86. doi: 10.1080/09544828.2018.1436162 ★★★

COSTA JUNIOR, J., Santos, A. L. R. and Diehl, J. C. (2017). Introducing systems oriented design for complex societal contexts in design engineering education. **FORMAkademisk - Special Issue Systemic Design III, 10**(1), 1–20. doi: https://doi.org/10.7577/formakademisk.1460

Santos, A. L. R., COSTA JUNIOR, J., and Wauben, L. Designing products and services for challenging societal contexts. **Proceedings of the Relating Systems Thinking & Design Symposium RSD3**: Oslo, Norway, 2014.

COSTA JUNIOR, J. and Diehl, J. C. Product-Service Systems design approach for the Base of the Pyramid Markets: Practical Evidence from the Energy Sector in the Brazilian Context. In M. Schaefer, N. Kebir, & D. Philipp (Eds.) **Proceeding of the International Conference on Micro Perspectives for Decentralized Energy Supply**, (pp. 48–51). Berlin: Technische Universität Berlin, 2013.

COSTA JUNIOR, J., Sicking, J. Power to the people. **Form Design Magazine - Special Edition Design and Energy**, Frankfurt, Germany. n 263 - Jan/Feb 2016, p. 65-67. (Interview)

See also:

Santos, A., Sampaio, C. P., Silva, J. S. G., & COSTA JUNIOR, J. (2014). Assessing the use of Product-Service Systems as a strategy to foster sustainability in an emerging context. **Product Management & Development, 12**(2), 99–113.

ISBN 978-94-6384-102-3

The societal and technical problems faced by low-income markets are increasingly seen as more complex due to environmental, social, and economic concerns. The enormous negative impacts of complex societal problems and the inability of designers to deal with complexity cannot be overcome without a paradigm shift in how we understand, engage with, and teach about such issues. In light of this challenge, one can pose the question, "What is the best approach to deal with a complex societal problem?".

A traditional approach to deal with a complex problem is to simplify it. Alternatively, as here, research may aim to provide a novel approach to handle complex societal problems, thereby embracing complexity. Thus, this book contends that embracing complexity represents a significant shift from the traditional design approach to a systems design approach for sustainable development. To help designers to bring about such a transition, the four main contributions provided in this doctoral research are:

- Exploring the integration of systems thinking into design, particularly by adopting a systems design approach to sustainable energy solutions for low-income markets.
- Extending the scope of product-service system design through the introduction of four major systems thinking tenets: a holistic perspective; a multilevel perspective; a pluralistic perspective; and complexity-handling capacity.
- Proposing heuristic tools for the integration of systems thinking into design, which allows for developing new and strengthening existing systems design approaches.
- Increasing capacity building for a systems design approach to address complex societal problems through design education.

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ISBN 978-94-6384-102-3