Department of Computer Science and Engineering

Combining User and Context: Living Labs Innovation in Digital Services

Tingan Tang

Aalto University

DOCTORAL DISSERTATIONS

Aalto University publication series
DOCTORAL DISSERTATIONS 91/2014

Combining User and Context: Living Labs Innovation in Digital Services

Tingan Tang

A doctoral dissertation completed for the degree of Doctor of Science (Technology) to be defended, with the permission of the Aalto University School of Science, at a public examination held at the lecture hall T2 of the school on August 15th 2014 at 12 noon.

Aalto University
School of Science
Department of Computer Science and Engineering
Information Systems and Service Engineering Group

Supervising professor
Professor Matti Hämäläinen

Thesis advisor
Professor Matti Hämäläinen

Preliminary examiners
Professor Christer Carlsson, Åbo Akademi University, Finland
Professor Jayanta Chatterjee, Indian Institute of Technology, India

Opponent
Associate Professor Zhangxi Lin, Texas Tech University, USA

Aalto University publication series
DOCTORAL DISSERTATIONS 91/2014

ISBN 978-952-60-5740-8
ISBN 978-952-60-5741-5 (pdf)
ISSN-L 1799-4934
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)
http://urn.fi/URN:ISBN:978-952-60-5741-5

Unigrafia Oy
Helsinki 2014

Finland

Publication orders (printed book):
tingan.tang@aalto.fi

NORDIC ECOLABEL
441 697
Printed matter

Aalto University

Aalto University, P.O. Box 11000, FI-00076 Aalto www.aalto.fi

Abstract

Author
Tingan Tang

Name of the doctoral dissertation
Combining User and Context: Living Labs Innovation in Digital Services

Publisher School of Science

Unit Department of Computer Science and Engineering

Series Aalto University publication series DOCTORAL DISSERTATIONS 91/2014

Field of research Information Technology and Services

Manuscript submitted 13 November 2013 **Date of the defence** 15 August 2014

Permission to publish granted (date) 11 April 2014 **Language** English

☐ **Monograph** ☒ **Article dissertation (summary + original articles)**

Abstract

With the continuous advances of Information and Communication Technology (ICT) such as Ubiquitous Computing, Mobile Computing and the Internet of Things (IoT), users' living contexts and daily life activities are increasingly digitalized. Based on these developments and other enabling factors, an emerging user- and context-driven open innovation approach called "Living Lab" has recently gained rising popularity and momentum in both academia and industry.

As an emerging and promising innovation approach, many theoretical and empirical insights are needed to understand the dynamics of Living Labs. This thesis focuses on Living Labs innovation in the digital services domain and it addresses three aspects of Living Labs: Concept, Architecture and Methods.

The relative paucity of research on Living Labs advocates an exploratory approach that augments the research status quo with qualitative and quantitative empirical insights. The insights are gained from both a literature review and many years of Living Lab practice experiences from several Living Lab project cases in both academia and industry. The first aspect explores the Living Lab concept. A Living Lab concept framework is proposed by studying the key innovation principles of Living Lab and comparing the Living Lab principles with the corresponding Web 2.0 principles. The second aspect deals with the technical architecture of the Living Lab infrastructure. A ubiquitous Living Lab services platform is proposed and implemented by combining social media and the Web of Things. A common Living Lab technical architecture is generalized based on several Living Lab projects implementation experiences. A Web-based two-layered integration technical framework is proposed to integrate heterogeneous smart devices into business processes, and this framework is evaluated in a real-life elderly care case. The third aspect studies the methods used in Living Lab. A Living Lab process model and methods taxonomy are proposed and evaluated. Two case studies by different Living Lab methods are presented. Finally, a comparison of different Living Lab methods is summarized. The three studied Living Lab aspects are not separated from each other but intertwined in the whole Living Lab context for digital services innovation.

Overall, this thesis advances a better understanding of the Living Labs innovation paradigm.

Keywords Living Labs, Web 2.0, Innovation, Digital Services

ISBN (printed) 978-952-60-5740-8 **ISBN (pdf)** 978-952-60-5741-5

ISSN-L 1799-4934 **ISSN (printed)** 1799-4934 **ISSN (pdf)** 1799-4942

Location of publisher Helsinki **Location of printing** Espoo **Year** 2014

Pages 195 **urn** http://urn.fi/URN:ISBN:978-952-60-5741-5

Preface

This thesis would not be possible without the help and contribution of many people during my journey pursuing a Ph.D.

First of all, I want to thank my supervisor, Prof. Matti Hämäläinen, who kindly offered me the opportunity to pursue my Ph.D. degree in this interesting and exciting Living Labs research area. Prof. Matti has helped me not only with academic guidance but also in many daily life needs.

Secondly, I want to thank my colleagues in the ISSEG group and ACIO group: Kimmo Karhu, Timo Itälä, Mikko Heiskala, Junying Zhong, Yong Han, Ilkka Melleri, Mika Helenius, Kari Hiekkanen, Janne Korhonen and Patricio Elisabete for many constructive discussions. Special thanks to Kimmo Karhu for collaborating on my first publication and many other joint papers. I am grateful to him for sharing ideas with me and helping with many problems in daily life.

Thirdly, I want to thank Dr. Zhengyu Wu for collaborating many joint papers. Thanks to Prof. Yang Ji at the Beijing University of Posts and Telecommunications and Prof. Jianbing Liu at the Beijing Research Center of Urban Systems Engineering, and many other colleagues for helping with the Living Lab experiments and data collection. Thanks to Prof. Xiaofeng Ma at the Tongji University for commenting on the draft of this thesis.

Fourthly, I want to thank my pre-examiners, Prof. Christer Carlsson at the Åbo Akademi University and Prof. Jayanta Chatterjee at the Indian Institute of Technology for giving the valuable comments to improve the quality of the thesis. I am honored to have Prof. Zhangxi Lin at the Texas Tech University as my dissertation opponent.

This thesis has been funded by the OtaSizzle, T3RC, MobiMe, MMEA, UBISERVE, and Actage research projects. I would like to thank the funding agencies for these research projects, such as TEKES and the Aalto

University's MIDE program, and the management and the colleagues of these research projects.

Finally, I express my greatest gratitude to my parents and my elderly brother Tingbin Tang for their selfless love. Last but not least, I thank my wife Hong Wang and my son Weichu Tang for their love and patient support during this long Ph.D. study journey and continuing life.

Espoo, June 15, 2014,

Tingan Tang

Contents

List of Publications

This thesis consists of an overview and of the following publications which are referred to in the text by their Roman numerals.

I Tang, T., Wu, Z., Hämäläinen, M. and Ji, Y.. From Web 2.0 to Living Lab: an Exploration of the Evolved Innovation Principles. *Journal of Emerging Technologies in Web Intelligence*, VOL. 4, NO. 4, pages 379 – 385, November 2012.

II Tang, T., Wu, Z., Karhu, K., Hämäläinen, M. and Ji, Y.. Internationally Distributed Living Labs and Digital Ecosystems for Fostering Local Innovations in Everyday Life. *Journal of Emerging Technologies in Web Intelligence*, VOL. 4, NO. 1, pages 106 – 115, February 2012.

III Tang, T., Wu, Z., Hämäläinen, M. and Ji, Y.. Internationally Distributed Digital Ecosystems Infrastructure and Networked Living Labs Approach for Everyday Life Innovation. *International Journal of Social Computing and Cyber-Physical Systems*, Submitted, 15 pages, 2014.

IV Wu, Z., Itälä, T., Tang, T., Zhang, C., Ji, Y., Hämäläinen, M. and Liu, Y.. A Web-based two-layered Integration Framework for Smart Devices. *EURASIP Journal on Wireless Communications and Networking*, VOL. 2012, NO. 1, pages 1 – 12, April 2012.

V Tang, T. and Hämäläinen, M.. Beyond Open Innovation: the Living Labs way of ICT Innovation. *Interdisciplinary Studies Journal*, VOL. 3, NO. 4, pages 15 – 23, March 2014.

VI Tang, T. and Hämäläinen, M.. Comparison of two local social media services in Finland and China by social network analysis. *International Journal of Social Network Mining*, VOL. 1, NO. 2, pages 209 – 224, December 2012.

VII Tang, T., Cheng, C. and Hämäläinen, M.. Everyday Life Sensing by Living Lab approach. *Journal of Software*, VOL. 9, NO. 6, pages 1545 – 1552, June 2014.

Author's Contribution

Publication I: "From Web 2.0 to Living Lab: an Exploration of the Evolved Innovation Principles"

The author of this thesis was the primary author of this paper. He explored the key innovation principles of Living Lab by conceptual analysis approaches and compared the Living Lab innovation principles with corresponding Web 2.0 principles. This paper contributes by providing a holistic view towards the Living Lab concept.

Publication II: "Internationally Distributed Living Labs and Digital Ecosystems for Fostering Local Innovations in Everyday Life"

The author of this thesis was the primary author of this paper. He proposed a ubiquitous Living Lab architecture by combining social media and Web of Things. This paper contributes to the creation of a ubiquitous Living Lab services platform architecture and the exploration of the core components in the Living Lab infrastructure architecture.

Publication III: "Internationally Distributed Digital Ecosystems Infrastructure and Networked Living Labs Approach for Everyday Life Innovation"

The author of this thesis was the primary author of this paper. He proposed a common Living Lab infrastructure architecture based on several Living Lab project infrastructure implementation experiences. This paper contributes to the generalization of a common Living Lab technical architecture and the implementation of the core elements in the architecture.

Publication IV: "A Web-based two-layered Integration Framework for Smart Devices"

The author of this thesis was the third author of this paper. The paper proposed a Web-based two-layered integration framework that enables smart devices to integrate with each other via lightweight RESTful interfaces and other back-end applications into agile business processes. The proposed framework was validated by a real-life elderly care Living Lab use case.

Publication V: "Beyond Open Innovation: the Living Labs way of ICT Innovation"

The author of this thesis was the primary author of this paper. Based on several international Living Lab project practice experiences, he proposed a Living Lab activity process model and a taxonomy of Living Lab methods. This paper contributes to the understanding of the processes of Living Lab activities and future development trends of Living Lab methods.

Publication VI: "Comparison of two local social media services in Finland and China by social network analysis"

The author of this thesis was the primary author of this paper. He used social network analysis, text mining and correlation analysis to compare the user behavior in two similar local campus-based social media services in Finland and China from a long-term international Living Lab social media research project. This paper contributes to the understanding of the features of digital services in the Living Lab context.

Publication VII: "Everyday Life Sensing by Living Lab approach"

The author of this thesis was the primary author of this paper. He presented a study of everyday lives of Chinese university students by mobile sensing based Living Lab methods. This paper contributes to the demonstration of the advantages of ICT-embedded real context methods in understanding users' everyday life experiences and activities.

List of Abbreviations

Ajax	Asynchronous Javascript and XML
API	Application Programming Interface
BPM	Business Process Management
BUPT	Beijing University of Posts and Telecommunications
CMS	Content Management System
CRM	Customer Relationship Management
DBE	Digital Business Ecosystem
DE	Digital Ecosystem

ENoLL	European Network of Living Labs
ERP	Enterprise Resource Planning
GPS	Global Positioning System
ICT	Information and Communication Technology
ICTA	Internet Community Text Analyzer
IoT	Internet of Things
IT	Information Technology
ITU	International Telecommunication Union
IS	Information Systems
LL	Living Lab
MMEA	Measurement, Monitoring and Environmental Assessment
MNE	Multinational Enterprise

PC	Personal Computer
PD	Participatory Design
PPPP	Public Private People Partnerships
QAP	Quadratic Assignment Procedure
REST	Representational State Transfer
RFID	Radio Frequency Identification
RSS	Really Simple Syndicate
SaaS	Software as a Service
SME	Small and Medium Enterprise
SNA	Social Network Analysis
SNS	Social Networking Sites
SOAP	Simple Object Access Protocol
UCD	User-Centered Design

WoT	Web of Things
XML	Extensible Markup Language

List of Figures

List of Tables

1. Introduction

1.1 The evolution of innovation paradigm

The great dynamic effect of innovation on the economy has been recognized by scholars for quite a long time [45, 108]. Innovation has been the main source of competitive advantage for companies since the 1990s [117].

Four historical periods for the development of the innovation paradigm have been identified in the literature [95]. The post-war period to the mid-1960s is indicated as the era of technology or science push. The disadvantage of this approach is that little attention is paid to the entire process or the role of the market place [95]. Innovation relying exclusively on technology push can lead to low user acceptance [114].

From the mid-1960s to the late 1970s, the innovation paradigm shifted from technology push to market pull. The downside of the market pull approach is that it can only cater to explicit user needs or incremental innovations rather than breakthroughs [95, 114].

From the late 1970s to the early 1990s, a combined innovation approach by both market pull and technology push became prevalent. This approach has two main drawbacks. First, it focuses on product and process innovations rather than market and organizational innovations. Second, it focuses on the creation of innovations rather than exploitation [95]. During this period, Von Hippel identified the change in the user role from traditional passive respondents to active innovation co-creators [128, 126]. Different user involvement approaches emerged during this period, for example, participatory design (PD) [87] and user-centered design (UCD) [29].

From the early 1990s to the early 2000s, the fourth innovation paradigm is characterized by more extensive alliances, partnerships and collaborations between different partners. The phenomena of Web 2.0 [94], Crowdsourcing [56], and Open Innovation [25] emerged during this period. Both radical innovation and incremental innovation are emphasized [50, 11]. For example, Web 2.0 is not much radical technical innovation but new way of using existing technologies [94]. Market and organizational innovations are focal points in this period [61, 51]. For example, the Open Innovation model is a new organizational innovation model for companies, in which there is more internal and external cooperation [24]. One challenge of the fourth innovation paradigm is that innovation processes are becoming more complex for coordination and system integration of different partners and components in innovation networks [95].

1.2 Transformation and expansion of user and context

With the fourth innovation paradigm represented by the Open Innovation model becoming more and more popular, companies are increasingly interested in involving users in innovation, especially in the ICT innovation and Information Systems (IS) [44]. However, involving users in the innovation processes is still considered to be complex [22, 80, 62, 113]. Many reasons concerned for this are related with the transformation and expansion of the concepts of context and user in the innovation process. For example, traditional IT systems focus on supporting organizational processes and work practices such as the Enterprise Resource Planning (ERP) systems and the Customer Relationship Management (CRM) systems. While the organizational context still prevails for the usage of ICT technologies and systems, with the popularity and pervasion of ICT technologies such as home PCs, the Internet, and mobile phones, ICT becomes more and more popular in private contexts as well (e.g., for supporting social contacts and interactions in people's everyday lives) [65, 134, 113, 137].

Users usually interact with innovation applications (e.g., products or services) in continuous frames of different contexts such as space, time, actors, and artifacts, as shown in Figure 1.1 [137]. Hence, the process of exploring user requirements and needs related to innovations is a complex technical, social, and psychological process that is bound to the actual contexts [113].

However, many traditional user involvement approaches, such as UCD

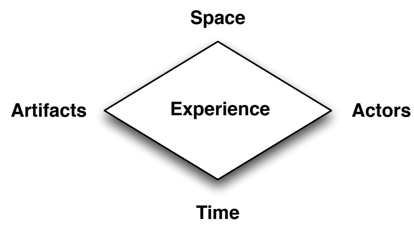


Figure 1.1. Schematic framework of the user experience (from [137]).

[49] and PD [86], come more from the background of workplace context (e.g., workshop or laboratory) than users' real-life contexts. Therefore, they usually have some limitations in the continuity of interaction of different contexts (e.g., time, space, actors, and events) [40]. For example, traditional user involvement approaches might ignore how innovations are used with an array of other artifacts [53] or neglect the collective or social aspect of innovation utilization [37, 62] or limit interaction to single events for short-term participation [71, 100]. Therefore, recent research on user involvement in innovation advocates understanding users in more mundane contexts that stretch from workplaces and organizations into everyday life [16, 110] and public spheres [10, 59, 15].

On the other hand, the concept of users is also transformed and expanded in innovation. First, the user's role has transformed and expanded during the evolution of the innovation paradigm. Users' role has changed from passive content consumers to content producers (e.g., Wikipedia) to active innovation co-creators (e.g., New Product Development) [57, 129, 128, 130]. Second, the user's scope is expanded. In the early period of user innovation, "Lead users", who are ahead of a trend and encounter needs, are the main source for user innovation [129, 128, 127]. Many user innovation examples (e.g., Open source software) stem from professional or hobbyist communities instead of average consumers [55]. Many traditional user involvement approaches, such as UCD and PD, limit the involvement of a small group of users and are more based on the assumption that user needs are something given or pre-existing, which can be answered by users or elicited by researchers. However, with the development of ICT technologies, more and more ordinary people (e.g., the real end-users) are empowered by ICTs (e.g., PCs and Smartphones) and have the potential as a new innovation source. ICTs facilitate more genuine and large-scale democratic engagement of innovation by citizens [10]. "Lead users"-based user innovation and a small group of user-oriented traditional user-involvement approaches are not capable of addressing the needs and dreams of the majority of “normal" users and lay citizens [100, 40]. For average users, they articulate their needs only gradually by interacting with the applications in the real-life contexts because user needs might not be well known (e.g., implicit needs) or even not yet existing at the time of involving them (e.g., future needs) [62]. They often prefer familiar products and incremental improvements (e.g., the common products in their real-life contexts) [30, 119]. For normal users, the “user-developer culture gap" [37] is even bigger than lead users as there are less mutual contexts between ordinary users and developers or designers (e.g., the laboratory context vs. the real-life social context and the unfamiliar technological solutions and modeling languages vs. familiar daily life products and languages) [125, 100].

1.3 The emergence of Living Lab innovation approach

Under the background of the fourth innovation paradigm characterized by the extensive collaboration and partnerships and the transformation and expansion of user and context in innovation, one emerging Open Innovation approach called “Living Lab" (LL), which employs the advantages of both users and their real-life contexts, has recently gained increasing interest and momentum in both industry and academia [32, 31, 120, 5]. The initial concept of LL was introduced in 1995 by Professor William Mitchell from the MIT MediaLab and School of Architecture and city planning [33]. The original idea of LL was to construct a home-like living environment by ambient intelligence and ubiquitous computing technologies (such as wireless and sensor technologies) to sense, prototype, and validate complex ICT solutions [113]. Examples of this kind of LLs include the Aware Home at the Georgia Institute of Technology [70] and the PlaceLab at MIT [63], which simulate users' real-life contexts (e.g., the home) in the laboratory. Later, the concept has been extended to more general open innovation environments in real-life contexts, in which user-driven innovation is fully integrated within the co-creation process by the close collaboration between users and other stakeholders such as business, research institutes, and government in Public-Private-People Partnerships (PPPP) [33, 103]. Many examples of this kind of LLs are listed in the European Network of Living Labs (ENoLL, www.openlivinglabs.eu), which transform users' real-life contexts (e.g., community and city) into a big social

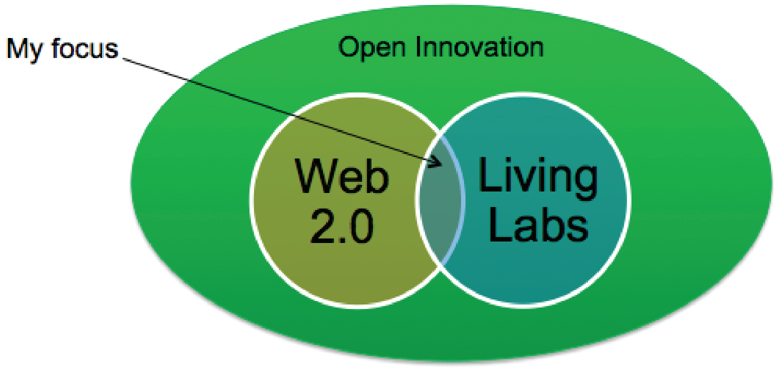


Figure 1.2. Research focus

innovation laboratory [59].

The advantages and benefits of the LL approach have been recognized in many studies. For example, LL can provide structure and governance for companies to involve users [3, 113], understand user needs in the real-life contexts [63], and reduce market-based risk [4]. However, as a relatively young and evolving innovation approach and research field, more theoretical and empirical research is needed to gain deeper insights into the different aspects of the dynamic LL domain, such as user involvement, service creation, infrastructure, methodology, and innovation outcomes [104, 28, 38, 113, 85].

1.4 Scope of research

LL has its origin as an extension to the testbed for ICT technologies and services. Currently, LL is also mainly used on ICT development and innovation [38, 60]. For this reason, this thesis mainly focuses on LL research and practices in the digital services domain. In digital services, Web 2.0 has enabled a dramatically large user population to become involved in digital services innovation (e.g., social media) as active producers instead of passive consumers by lowering the barriers for users to contribute. Currently, Web 2.0 technologies have been widely used in many LL domains, such as healthcare, communities, and smart cities [68, 105, 106]. Therefore, more specifically, the research focus is on the intersection between Web 2.0 and LL for digital services, as shown in Figure 1.2.

1.5 Motivations and research questions

Two research questions and their respective motivations are as follows:

ICT infrastructure is an important means in many LL innovation activities, such as context research and stakeholders' collaboration and co-creation processes [38, 85]. Infrastructure does not refer to the services and technologies per se under control of the LL, but to illustrate how different services, technologies, and stakeholders are connected to open networks or architectures[85]. LL has been defined as a platform [7, 92], an ecosystem [97, 31], a system [28], and an organization [83]. These perspectives of definitions emphasize the infrastructure functions of LL (platform) and how different components or resources are connected and organized (Ecosystem, system, and organization). For the important roles of ICT infrastructure, the first objective is to provide empirical experiences and insights into the ICT infrastructure architecture aspect from many years of international LL project practice experiences in different domains. Although Web 2.0 technologies have been widely used in many LL domains [68, 105, 106], the research to form a holistic LL infrastructure architecture by using Web 2.0 technologies is still scarce. For this reason, the first research question is as follows:

- RQ1: Can Web 2.0 elements be used in the LL infrastructure as a part of the LL architecture?

Suitable processes and methods are needed for LL to understand users' behavior and to facilitate user involvement and stakeholders' collaboration in the innovation and development process. LL has also been defined as a methodology [84], and an approach [34]. However, as LL is a rather new area, there is a remarkable lack of in-depth descriptions and discussions of LL processes and methods in current LL literature [38, 113]. Therefore, more empirical experiences are needed in the LL processes and methods aspects [33, 38]. The second research objective is to provide empirical experiences in the LL processes and methods based on many years of international LL project practice experiences. The second research question is as follows:

- RQ2: What are proper methods for implementing an LL?

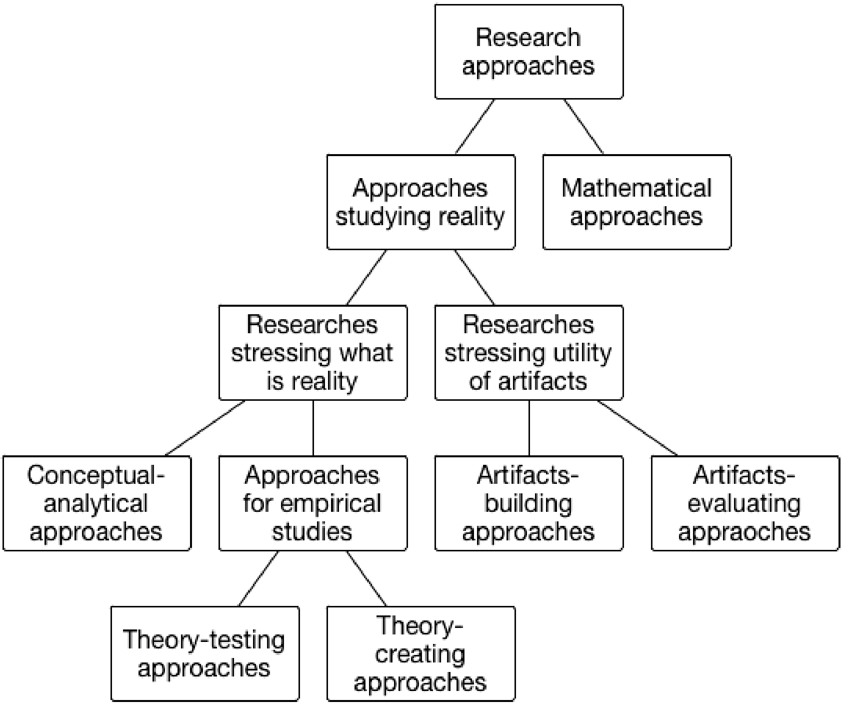


Figure 1.3. Taxonomy of research approaches (from [67]).

1.6 Research approach

LL by nature is multi-disciplinary [13]. Therefore, different research approaches are used for different research questions and different aspects of LL. There are different taxonomies of research approaches in the IS research area [41, 93, 82, 67, 58]. The research approach taxonomy proposed by Järvinen (Figure 1.3) is selected to illustrate the research approaches used in this thesis [67]. Overall, the research approaches in this thesis belong to *approaches studying reality* because LL is related to real users and real-life contexts. Specifically, research approaches for RQ1 (LL architecture) belong to *researches stressing utility of artifacts* as LL infrastructure artifacts are built and evaluated by design science methods. Design science methods are mainly used to assess the quality and effectiveness of artifacts [58]. Research approaches for RQ2 (LL methods) belong to *researches stressing what is reality*. Research approaches for RQ2 (LL methods) can be subdivided into *approaches for empirical studies*, where raw data are collected from reality. Further, research approaches for RQ2 (LL methods) belong to *theory-testing approaches* through case studies.

1.7 Structure of the thesis

The structure of the thesis is organized according to the research questions shown in Figure 1.4.

Chapter 1 presents the background, motivation, research scope, research questions,research approach, thesis structure, and a summary of research contributions.

Chapter 2 proposes a conceptual framework of LL (Publication I) by conceptual-analytical approaches. *Conceptual-analytical approaches* are used by a literature review, which does not require empirical research to be conducted but relies more on existing theories, models, and frameworks in the literature and logical reasoning to integrate them [67]. The conceptual framework proposes a set of core principles of LL, which is juxtaposed against the corresponding Web 2.0 principles for comparison.

Chapter 3 addresses the RQ1 (Publication II & Publication III & Publication IV). Publication II proposes and implements a ubiquitous LL services platform architecture by combining social media and Web of Things (WoT). Publication III generalizes a common LL infrastructure architecture from the implementation experiences in several different LL projects. Publication IV studies how to integrate the heterogeneous smart devices into business processes by a Web-based two-layered integration technical framework.

Chapter 4 addresses the RQ2 (Publication V & Publication VI & Publication VII). A LL activity process model and a LL methods taxonomy are proposed and evaluated (Publication V) . Publication VI and Publication VII present the application of different LL methods in two LL projects. Publication VI presents a study of two campus-based social media services by social network analysis, while Publication VII presents a study of everyday lives of Chinese university students by mobile sensing. A comparison of different LL methods is summarized.

Chapter 5 discusses and concludes the thesis.

1.8 Key contributions of the thesis

The key contributions of the thesis are as follows:

- Although many definitions of LL from different perspectives have been proposed in the LL literature, a holistic view towards LL is still form-

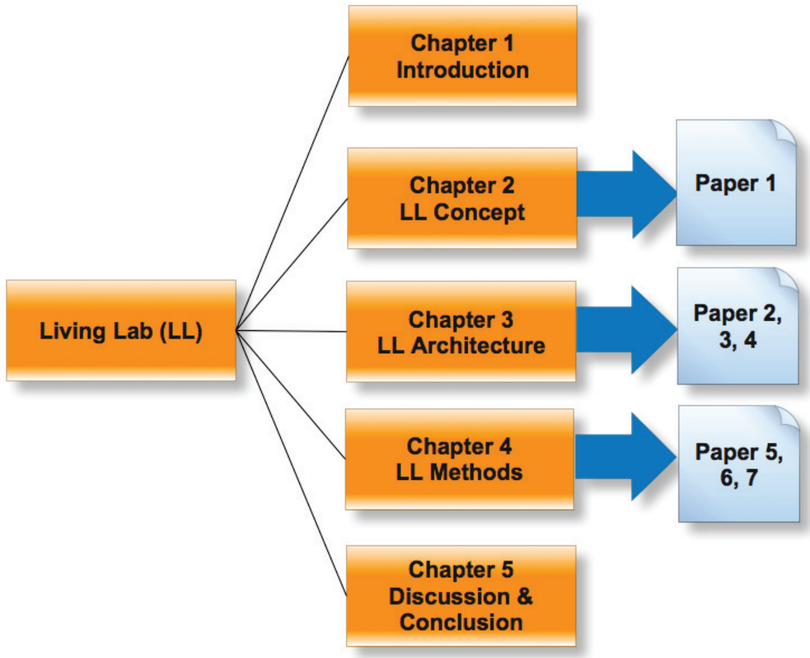


Figure 1.4. Thesis structure

ing. This thesis proposes an LL conceptual framework to organize fragmented views towards LL into a holistic view (Publication I). The conceptual framework proposes a set of core principles of LL, which is juxtaposed against the corresponding set of Web 2.0 principles for comparison. The conceptual framework is from the perspective of digital services of how LL innovation principles have changed or expanded from Web 2.0 principles for digital services in different dimensions.

- A ubiquitous LL services platform is proposed and implemented by combining the social media and Web of Things (Publication II), which provides smart innovation spaces in the real-life contexts and user behavior sensing capabilities. The platform artifacts are tested and improved in different projects. A common ICT infrastructure architecture model (Publication III) is generalized from different LL projects implementation experiences. A two-layered Web-based technical framework to integrate heterogeneous smart devices and business processes into the LL infrastructure (Publication IV) is proposed. The feasibility and effectiveness of the technical framework are evaluated in a real-life elderly care LL case and compared with other alternative integration solutions by different criteria.

- An LL activity process model and and a taxonomy of LL methods (Publication V) are developed and evaluated in different LL projects for better understanding of LL activity processes and methods classification. A comparison of different LL methods is summarized from the application of LL methods in several LL project cases (Publication VI, Publication VII).

2. Living Lab Concept

This chapter proposes an LL conceptual framework by conceptual analysis approaches. The core innovation principles of LL are proposed and compared with corresponding Web 2.0 principles. The purpose of this chapter is to provide a holistic view towards LL from the perspective of digital services.

2.1 The fragmented views towards Living Lab Concept

With the development of LL, it has been defined as a methodology, approach, environment, platform, ecosystem, and organization, as shown in Table 2.1. There is no universally accepted definition for LL yet. The current situation towards the LL view is similar to "the blind men and the elephant" story. Different definitions view LL from different perspectives. These definitions are not contradictory but are complementary to each other. There are also some attempts to identify the key principles and characteristics of LL, such as openness, empowerment of users, and realism [33, 28, 13, 12]. However, a holistic view towards LL is still forming [9].

2.2 The connections between Web 2.0 and Living Lab

An innovation paradigm is a process of development and evolution. Although LL and Web 2.0 seem to belong to different domains, there are many similarities and connections between Web 2.0 and LL. For example, Web 2.0 and LL share many common characteristics, as follows [97, 38]:

- Empower users and involve them as active co-creators.

Table 2.1. Living Lab definitions from different perspectives

Perspective	Definition
Environment	environments for innovation and development where users are exposed to new ICT solutions in (semi) realistic contexts, as part of medium- or long-term studies targeting an evaluation of new ICT solutions and discovery of innovation opportunities [38].
	a user-centric innovation milieu built on everyday practice and research, with an approach that facilitates user influence in open and distributed innovation processes engaging all relevant partners in real-life contexts, aiming to create sustainable values [13].
Methodology	a user-centric research methodology for sensing, prototyping, validating, and refining complex solutions in multiple and evolving real-life contexts [33].
	a methodology to deal with user-driven open innovation as well as a way to organize the collaborative experimentation and co-creation with real users in a real-life environment [84].
Approach	a systemic innovation approach in which all stakeholders in a product, service, or application participate directly in the development process [34].
	a human-centric research and development approach whereby ICT innovations are co-created, tested, and evaluated in open, collaborative, multi-contextual real-world settings [12].
Platform	an experimental platform where the users are studied in their everyday habitat [92].
	an open innovation platform aims at reconstructing the natural user environment as much as possible [7].
Ecosystem	an open research and innovation ecosystem involving user communities (application pull), solution developers (technology push), research labs, local authorities, and policy makers, as well as investors [97].
	a user-driven open innovation ecosystem based on a business – citizens – government partnership which enables users to take an active part in the research, development, and innovation process [31].
System	a system enabling people, users/consumers of services and products, to take active roles as contributors and co-creators in the research, development, and innovation process [28].
Organization	a "service providing organization in the topic of R&D and innovation" with a set of resources including: areas of competency, local partners and stakeholders, ICT infrastructure, operational methodology, and administrative resources [83].

- Evaluate or validate new ICT solutions with users.

- Gain insight into unexpected ICT uses and new service opportunities. For example, Web 2.0 services can gain insight from users' online behavior by Web analytics tools (e.g., Google Analytics). LL can gain insight from users' everyday life activities and experiences by different kinds of sensors.

- Medium- or long-term studies with users by ICT mediation.

Web 2.0 technologies have been widely used in many LL domains such as healthcare [68] , communities [105], and smart cities [106].

2.3 From Web 2.0 to Living Lab: a comparison of the core innovation principles

Historically, there are also fragmented views towards Web 2.0, which has been seen as Web technologies [72], software applications [122], syndication of contents [26], services [2], community, and business models [66]. However, the seven principles of Web 2.0 proposed by O'Reilly are still the best way to comprehensively understand it and show how Web 2.0 has evolved from Web 1.0 [94, 88]. We argue that similar to Web 2.0, in order to get a holistic view of LL , it is important to understand the key principles of LL. Due to the similarities and connections between Web 2.0 and LL and the scope of this thesis in digital services, it is interesting to juxtapose LL principles against Web 2.0 principles for comparison from the perspective of digital services.

The following subsections will detail the comparison between the seven widely accepted Web 2.0 principles by O'Reilly [94] and our summarized key principles of LL. The key principles of LL are mainly based on existing theories, models, and frameworks in the literature and logical reasoning to integrate them.

2.3.1 Principle 1: Web as a platform vs. Living Lab as an innovation ecosystem

A Web 2.0 service is a combination of software and data or Software as a Service (SaaS) [94]. In SaaS mode, the software is no longer traditional packaged software, but exists as web services. From the perspective of innovation, Web 2.0 is not much of a technical innovation but rather a new way of using existing technologies. For example, a key component of Web 2.0 “Ajax" (Asynchronous Javascript and XML) is built on existing Web technology (Javascript) and standard (XML). Many Web 2.0 services are web mashups which are innovative ways of integrating existing web services and data sources [36], as shown in Figure 2.1 (a). In Web 2.0, the Web becomes a programmable innovation platform (cf. www.programmableweb.com) instead of a passive data repository as in Web 1.0 .

The innovation vortex of LL is shown in Figure 2.1 (b). LL innovation expands the first Web 2.0 principle in several ways. First, although both Web 2.0 and LL are networked innovations, the network boundary of LL has expanded from the Web to real-life contexts by using enabling technologies such as ubiquitous computing and WoT. Therefore, the services and data sources for innovation have expanded. Second, the stakeholders in innovation have expanded. Web 2.0 is a grassroots (community) innovation, while LL is a more complex innovation ecosystem involving many different stakeholders such as business, research institutes, developers, government, and end-users or Public-Private-People Partnerships (PPPP) [33]. Third, the complexity of innovation has increased because of the artifacts network expansion (e.g., more devices and sensors) and the actors network expansion (e.g., more stakeholders), the complexity of innovation also increased in LL innovation because of the increasing efforts to integrate more heterogeneous devices and to coordinate the collaboration between more different stakeholders. The ecosystem perspective of LL corresponds to the openness principles of LL, as digital innovations are created and validated in open collaborative multi-contextual empirical real-life contexts [13, 12].

2.3.2 Principle 2: Harnessing collective intelligence vs. combining user and context

Harnessing collective intelligence is the main principle of Web 2.0 [94]. Other similar phrases for collective intelligence are the “wisdom of crowds" and the “long tail" effect. Examples of this principle include Google PageRank, Flickr tagging, and Amazon reviews. Essentially, it means utilizing the network effects from user contributions or user-added values. Specifically, Web 2.0 services are designed to utilize the implicit contributions from a large number of ordinary users as opposed to explicit contributions

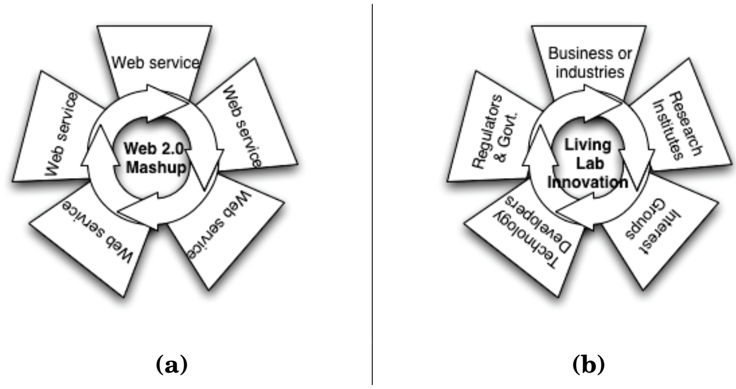


Figure 2.1. Innovation vortex: (a) Web 2.0 (b) Living Lab .

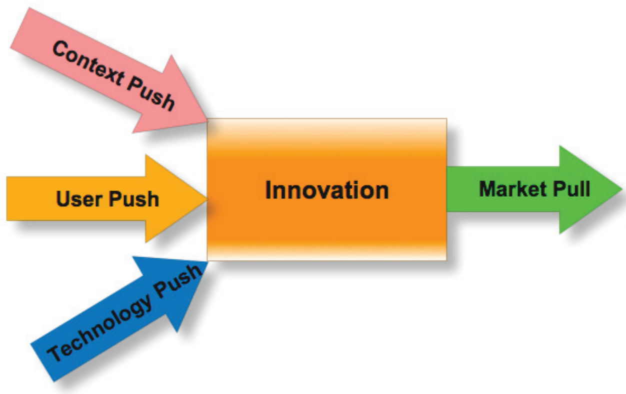


Figure 2.2. Innovation forces (adapted from [114]).

from a small number of leader users or experts [66].

On the one hand, the scope of users in innovation has expanded in LL. With the development of ICT technologies, more and more ordinary people (e.g., elderly people and lay citizens) are empowered by ICTs (e.g., Smartphones) and have the potential, as a new innovation source, for a wider range of collective intelligence [10]. On the other hand, although users are still in the central position in LL innovation, the drivers of innovation in LL innovation have expanded by adding a new innovation force — the “Context Push", as shown in Figure 2.2 [114]. Traditional innovation forces include technology push and market pull. The rise of user-driven innovation and community innovation (e.g., Web 2.0) adds a new innovation force — user push. The key difference between LL and other user-driven innovation approaches is that LL emphasizes the innovation from context push in users’ real-life contexts, which can discover hidden user needs and unexpected user behavior patterns [99, 39].

2.3.3 Principle 3: Data is the next Intel Inside vs. Experience is the next key aspect

In Web 2.0, the companies who control the data can gain key advantages in the market, which also reflects that data is one of the main purposes of computing in Web 2.0.

In LL, the main purpose of computing is experience rather than data. Early LL research built a home-like experiential environment by using sensors and intelligent devices. With the further development of ICT technologies such as WoT and mobile computing, the four dimensions of people's everyday life experiences (time, space, actors, and artifacts) have been increasingly digitalized [137]. The focus of LL is to obtain ICT innovation sources from people's everyday experiences in real-life contexts and innovate ICT solutions to make better life experiences for people. Many scholars argue that the computing paradigm is shifting from data to experience [65, 137].

2.3.4 Principle 4: End of the software release cycle vs. End of the innovation cycle

In Web 2.0, software shifts from artifact to services that need to be maintained continuously. For example, Google must continuously crawl the Web to update its indices. Thus, there are no traditional software release cycles for Web 2.0 services. Users are treated as co-developers. New features are quickly added to or removed from services by real time monitoring of user online behavior. Web 2.0 services often exist in "the perpetual beta" development status [94].

With the increase in the ubiquity and pervasiveness of ICT technologies (such as ubiquitous computing and mobile handset-based monitoring), the real time and large-scale monitoring of user behavior in real-life contexts becomes feasible and affordable. Users' living contexts become ubiquitous living "laboratories". LL research is conducted by continuously monitoring users' behavior in their daily life activities and experiences in different contexts (e.g., online and offline) over a medium or long period [38]. Users are treated as co-partners (e.g., co-developers and co-researchers), as shown in Figure 2.3. Empowered by ICT tools such as self-monitoring tools, visualization, and statistics tools, users can do some kinds of research work (e.g., collecting and analyzing data), which have been the privileges of researchers in the past [100]. Users are viewed as active

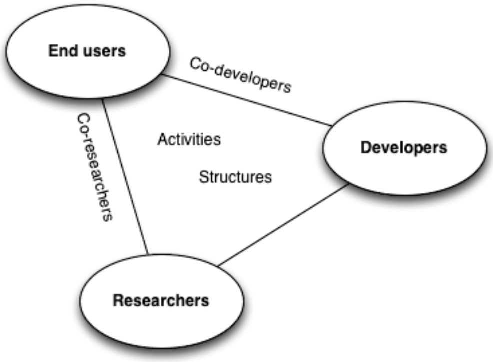


Figure 2.3. The model of Living Lab approach (adapted from [77]).

and competent co-partners and domain experts in LL, which stresses the active roles of users, such as decision-makers and co-creators, instead of passive roles such as participants [13, 12]. In addition to the meaning of research in real-life contexts, LL also suggests that innovation often exists in a continuously ongoing status. Innovations (e.g., new products or services) emerge from the continuous interaction between the stakeholders, such as users, developers, and researchers, and the interaction between users and innovations in real-life contexts [77]. Continuity is an important principle of LL [12].

2.3.5 Principle 5: Lightweight programming models vs. Dual innovation models

Web 2.0 services are web services built on top of lightweight programming models (such as RSS (Really Simple Syndicate), REST (Representational State Transfer), and Ajax) instead of more complex corporate web services models such as SOAP (Simple Object Access Protocol). This benefits the reuse of services and boosts grassroots innovation for low technical barriers [94].

From innovation's perspective, Web 2.0 is a bottom-up grassroots or community innovation model. There are also top-down innovation models, such as the classical manufacturer-centric closed models and Chesbrough's open innovation models [25]. In closed models, innovations are created in an R&D (Research and Development) unit or its equivalent [18]. In Chesbrough's open innovation models, companies harness both external ideas and internal R&D [25]. The closed innovation models and open innovation models are both company-leading top-down models.

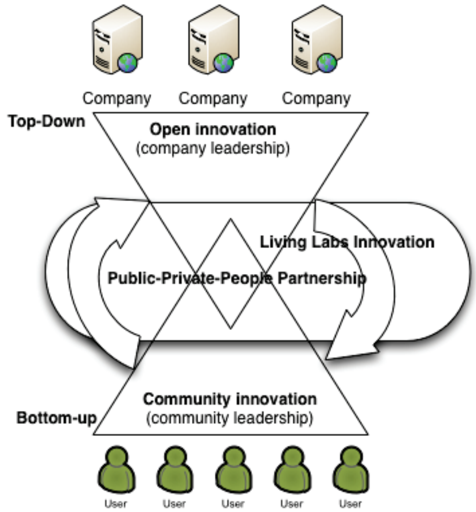


Figure 2.4. Dual model for Living Lab by combining top-down and bottom-up.

In general, LLs have an important role as bridges. LLs are bridges or intermediaries between open innovation and community innovation [9]. LLs are commonly known as Public Private People Partnerships which integrate concurrent research and innovation processes [14]. Based on this and the idea of a dual model that integrates business and grassroots into an enterprise architecture design [132, 52], the dual model is proposed to illustrate the intermediary role of LL between open innovation and community innovation as shown in Figure 2.4. The combination of top-down and bottom-up is an important principle of LLs [75, 79]. With top-down, LLs provide structure and governance to user participation for companies [3] and manage innovation development networks [76] and technology adaptions in an organizational setting [20]. With bottom-up, LL provides user needs, requirements, and unanticipated innovation ideas and innovation development to companies [98, 118, 79].

2.3.6 Principle 6: Software above the level of a single device vs. Experience above the level of a single context

Web 2.0 services are no longer limited to the PC platform. They can be accessed by heterogeneous devices such as PCs, mobile phones, and tablets. The Web functions as a virtual single device for users, providing them with seamless access to services [94].

However, in Web 2.0, computing is still separated from users' other daily activities and experiences, while in LL, it is seamlessly embedded in ev-

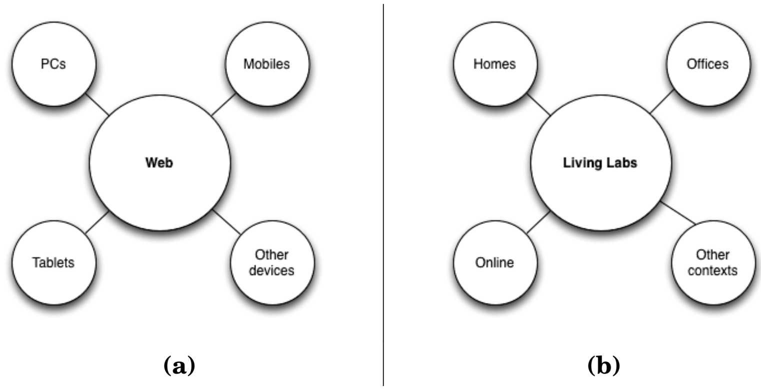


Figure 2.5. Connection: (a) Web as a single device (b) Living Lab as a single context .

eryday life experiences and contexts. Therefore, LLs act as a single context for users, which provide users with seamless experiences in different contexts. The comparison between Web 2.0 and LL is illustrated in Figure 2.5. Figure 2.5 shows that Web provides a uniform access interface to heterogeneous devices, while LL offers a consistent experience for different contexts. Essentially, Web 2.0 connects people no matter what devices they use or where their physical contexts are. Web 2.0 functions as a big virtual device for running Web applications and services . For LL, it connects both people and contexts, including online context and different offline physical contexts for seamless user experiences in different contexts.

2.3.7 Principle 7: Rich user experiences vs. Real user experiences

Web 2.0 services provide users with richer service experiences by using technologies such as Ajax [94]. However, Web 2.0 service experience is still separated from other forms of human daily experiences such as shopping and traveling. For LL, the core is to provide users with seamless real-life experiences in different contexts. The principle of realism (real users in real life situations) is also what distinguishes LL from other kinds of user-centric innovation approaches [12].

2.4 Chapter summary

We summarize the comparison between Web 2.0 and LL in Table 2.2.

In Table 2.2, we can see that LL innovation expands from Web 2.0 inno-

Table 2.2. The core innovation principles comparison between Web 2.0 and Living Lab

Principle	Dimension	Web 2.0	Living Lab
P1	Network boundary	Web	Real-life contexts
P2	Innovation drivers	Users	Users & contexts
P3	Computing paradigm	Data	Experience
P4	User roles	Co-developers	Co-partners
P5	Innovation model	Bottom-up	Bottom-up & top-down
P6	Connection	People	People & contexts
P7	Feature	Rich experiences	Real experiences

vation in many different dimensions, such as network boundary and user roles. Compared with Web 2.0, LL is a wider and deeper level of innovation approach which integrates more devices, stakeholders, and disciplines. This also makes it more difficult to scale up LL to the macrolevel [3]. The challenges are not only technical; they can also be commercial, legal, political, and cultural.

Web 2.0 and LL are similar in that they both take advantage of the active and centric roles of users and their communities. The relationship between Open Innovation and LL is that LL is a user- and context-driven Open Innovation. LL is a combination of company-led Open Innovation and user-led community innovation. The key difference between LL and Open Innovation and other user-driven innovation approaches is that LL emphasizes the importance of real-life contexts in innovation.

In this chapter, we propose a conceptual framework for LL by studying the key innovation principles of LL and comparing the LL principles with corresponding Web 2.0 principles. This chapter contributes to a holistic view towards LL.

3. Living Lab Architecture

3.1 The importance of ICT infrastructure in Living Lab

As a general user-centric innovation approach and milieu in real-life contexts, LL does not limit itself to ICT innovation. It can be used for non-ICT areas such as rural development and non-ICT products and services innovation [13]. However, from LL literature and many European Commission (EC) reports such as recent LL reports [31, 32], we can see that ICT has increasing importance in LL development and innovation, either as a means or an end. For example, ICT technologies such as ubiquitous computing and mobile technologies have been used to measure user daily activities. Web-based tools have been used for LL stakeholder communication and collaboration. The development of networking of LLs has higher demands for ICT technologies such as reusable, interoperable, adaptive, and scalable ICT infrastructure architectures and tools. This chapter addresses the RQ1: Can Web 2.0 elements be used in the LL infrastructure as a part of the LL architecture?

3.2 Background theory

With the rapid development of ICT technologies, digitization has entered into nearly every aspect of people's lives, such as entertainment, business, education, government, and health. There is an increasing number of information sources and services around us enabling new ways of interacting with our everyday environment in work, at home, and in leisure activities. Examples include intelligent devices, sensors embedded in the environment and the emerging Internet-of-Things (IoT). Simultaneously users are becoming increasingly involved as information providers and consumers by means of Web 2.0 and social media. Around these phenomena, some related emerging research concepts and research fields have become popular, such as Digital Ecosystem (DE), LL, and experiential computing. In order to better understand the digital aspect of LL, we first clarify the relationships between DE, LL, and experiential computing.

3.2.1 Digital Ecosystem

The origin of the DE concept is related to the concept of the Digital Business Ecosystem (DBE) , which was first proposed in Europe as a response to how the European Union could assist SMEs (Small and Medium Enterprises) in adopting ICT technologies more effectively in order to improve productivity [89]. Nachira defines DBE as " a 'digital environment' populated by 'digital species', which could be software components, applications, services, knowledge, business models, training modules, contractual frameworks, laws, . . . " [89]. The DBE is the combination of the technical or digital part (Digital Ecosystem) and the business part (Business Ecosystem) [90]. The DBE definition emphasizes the business perspective.

There are many different emerging definitions for DE. For example, Briscoe and Wilde define DE as "the digital counterparts of biological ecosystems, which are self-organizing and scalable architectures that can automatically solve complex, dynamic problems" [19]. This definition views DE from the architecture perspective. Chang and West define DE as "an open, loosely coupled, domain-clustered, demand-driven, self-organizing agents' environment, where each species is proactive and responsive for its own benefit or profit" [23]. This definition views DE from the environment perspective. For the purpose of this chapter, we view DE as a technical architecture.

3.2.2 Experiential computing

Traditionally, computing is separated from other forms of human activities and focuses on organizations and business [65, 112, 137]. With the ubiquity and pervasion of ICT and digitization by sensors, embedded computing, mobile computing, and social computing, a new computing paradigm called "experiential computing" has emerged [65]. Experiential computing is defined as "digitally mediated embodied experiences in everyday activities through everyday artifacts with embedded computing capabilities" [137].

3.2.3 The relationships between Digital Ecosystem, Living Lab, and Experiential computing

The relationships between DE, LL, and experiential computing are shown in Figure 3.1.

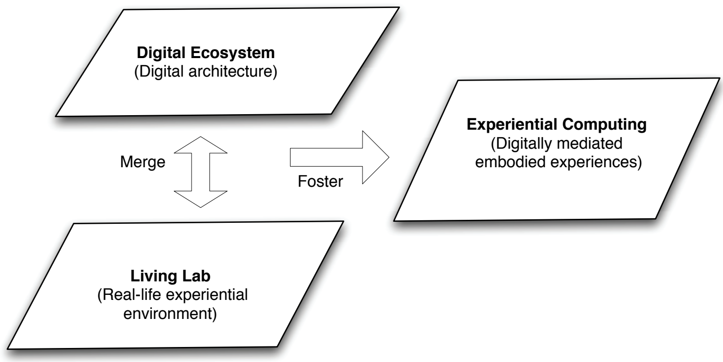


Figure 3.1. The relationships between Digital Ecosystem, Living Lab, and Experiential computing.

DE provides a scalable and self-organizing ICT technical architecture [19], while LL provides a rich experiential environment for data, information, and innovation sources [33]. The combination of DE and LL will foster experiential computing and innovations in everyday life experiences.

The four dimensions of user everyday life experience (time, space, artifacts, and actors) are digitalized in experiential computing [137]. For example, the space context is digitalized by context-aware computing such as ambient intelligence, ubiquitous computing, and IoT. The digitalization of time can take the forms of a digital timestamp and a time line (e.g., real-time, historical user behavior data and future prediction of user behavior). The digitalization of artifacts can take the form of different kinds of sensors, such as tagging (e.g., RFID chips), location (e.g., GPS), environment (e.g., temperature), and movement (e.g., accelerator) [21, 101]. The digitalization of actors has been partly accomplished by Social Networking Sites (SNS) and Social media [137], mobile computing (e.g., smartphones), and wearable computing (e.g., smart wrist watch) [102]. Figure 3.2 shows the ICT-enabled LL experiential computing by combining digitalized LL environment, actors, and artifacts in everyday life.

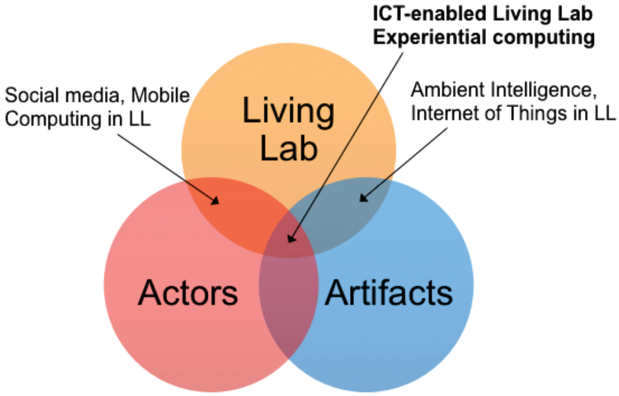


Figure 3.2. ICT-enabled Living Lab experiential computing.

3.3 Living Lab and social media

One essential component in an ICT-enabled LL experiential computing infrastructure is the digitalized actors in LL. The digitization of actors in the LL environment has been accomplished in part by social media and mobile computing, as shown in Figure 3.2.

3.3.1 OtaSizzle project

OtaSizzle is a long-term LL mobile social media research project at Aalto University. According to the project Wiki, "OtaSizzle will develop an open experimentation environment for testing mobile social media services. It will be a 'living lab' for thousands of users in Otaniemi, with extensions in greater Helsinki. The project will create prototype mobile social media service platforms and study them with extensive field tests, coupled with quantitative measurements and qualitative analysis. The outcome will be a "packaged" experimentation environment, the "SizzleLab" concept" [96].

The OtaSizzle platform includes core services and end-user services. The core services provide some common services such as user profiles, user groups, session management, location information, and social networks that are shared by all end-user services. On top of the core and enabling services, end-user can create many kinds of mobile and Web-based social media services [81]. The communication between the core services and the end-user services is based on RESTful (REpresentational State Transfer) HTTP request and response [35]. The overview of the OtaSizzle project architecture is shown in Figure 3.3.

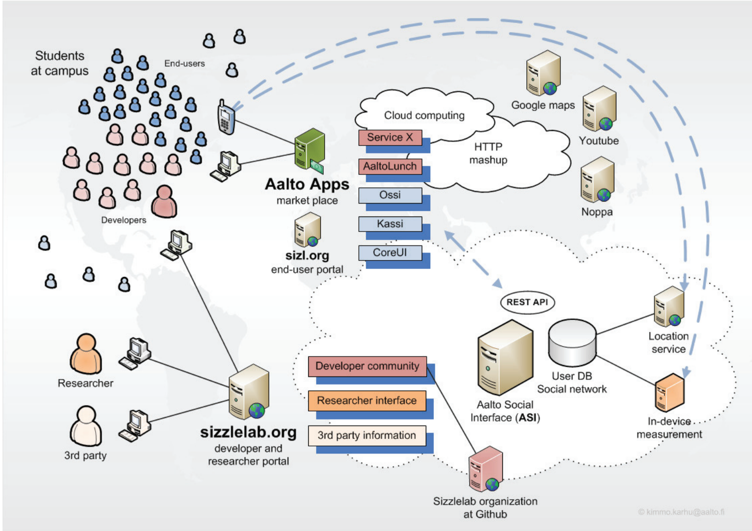


Figure 3.3. OtaSizzle architecture (adapted from [81])

Most core services and end-user services developed in the OtaSizzle architecture have been open-sourced under the MIT open source license. The services themselves are just seeds for further social media service development and innovation. The source codes are hosted in Github (`https://github.com/sizzlelab`). For the details on the OtaSizzle architecture implementation, see Publication II and Publication III.

The OtaSizzle environment and experiments (e.g., mobile handset-based user social media interaction behavior experiments) are being partially replicated in China (Beijing University of Posts and Telecommunications), in the U.S. (UC Berkeley), and in Africa (University of Nairobi) for carrying out comparative studies on the development and use of target services.

3.4 Living Lab and the Internet of Things

Other essential components in ICT-enabled LL experiential computing infrastructure are the digitalized context and artifacts by Ambient Intelligence, IoT, and smart devices, as shown in Figure 3.2.

3.4.1 Smart BUPT project

The Smart BUPT project, focusing on IoT research, aims at creating an open campus based innovation platform by combining IoT and LL approaches to facilitate user-driven creation of useful and intelligent ser-

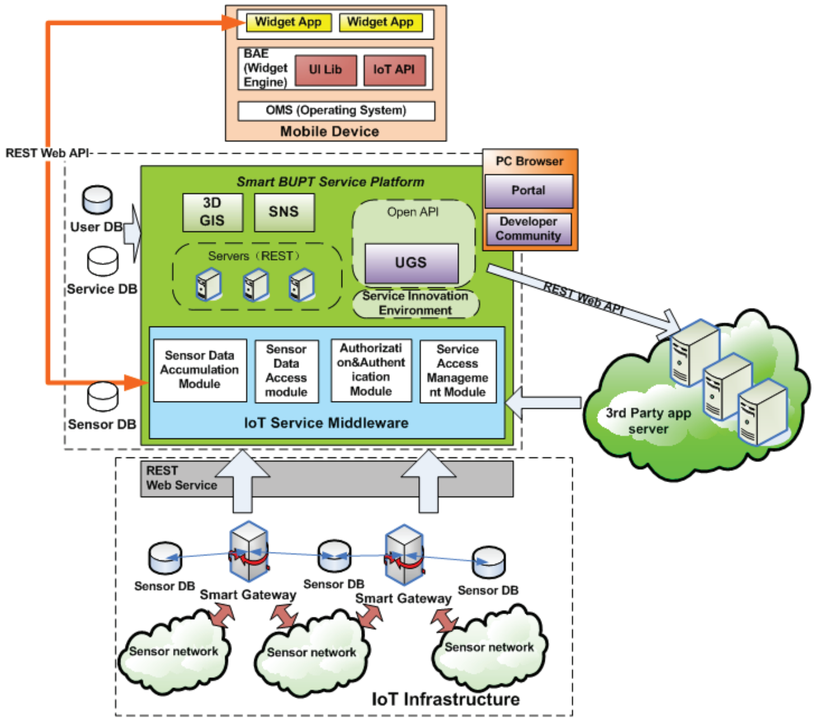


Figure 3.4. Smart BUPT architecture

vices related to the user's daily activities. In order to lower the technical threshold for users to create mobile ubiquitous services, Smart BUPT project architecture is based more on the concept of WoT. Similar to the concept of IoT, WoT is based on the vision that everyday devices and objects are connected and fully integrated into the Web by using existing well-accepted Web standards such as HTTP and REST [115]. The Smart BUPT project architecture is shown in Figure 3.4.

For the details on the Smart BUPT architecture implementation, see Publication II and Publication III. Again, the Smart BUPT WoT services are meant as seeds and examples, and the key area of the activity is to develop the infrastructures and environment for long-term research in real-life settings with support for situationally and locally relevant services, as in the case of the OtaSizzle counterpart, but with special emphasis on enabling the use of sensor-based information sources and the IoT approach.

3.5 Ubiquitous Living Lab services platform

3.5.1 UBISERVE project

The UBISERVE project (Research on Future Ubiquitous Services and Applications) is “a joint research effort funded by Finland Tekes (the Finnish Funding Agency for Technology and Innovation), which is dedicated to advance research in the field of Future Ubiquitous Services (FUS). The project will strengthen the collaboration between Finland and China in the ICT alliance through constructing service-enabling environments, developing test environments for FUS in real-life settings. The activities include Living-Labs based research on ubiquitous innovation and constructive research on transmission algorithms and service overlay architectures” [121].

3.5.2 Ubiquitous Living Lab services platform architecture

People’s everyday experiences can be conceptualized as the interactions with four dimensions: time, space, actors, and artifacts [137]. From its own perspective, experiential computing is enabled by the mediation of all or part of the dimensions of the aforementioned four dimensions of human experiences through digital technology [137]. From the perspective of DE, Nachira et al. believe that DE is made possible by the convergence of three networks: ICT networks, social networks, and knowledge networks [90].

Based on these perspectives, we believe that the combination of the mobile social media and IoT is important for the ubiquitous LL services architecture. The complementary relationship between the OtaSizzle project and the Smart BUPT project is shown in Figure 3.5. From Figure 3.5, we can see that the OtaSizzle project focuses on the combination of LL and social media (the network of people), while Smart BUPT project focuses on the combination of LL and the Internet of Things (the network of things). The combination of these three parts is the ubiquitous LL services platform—UBISERVE.

The similarities between the OtaSizzle project and the Smart BUPT project are as follows:

- Living Lab approach

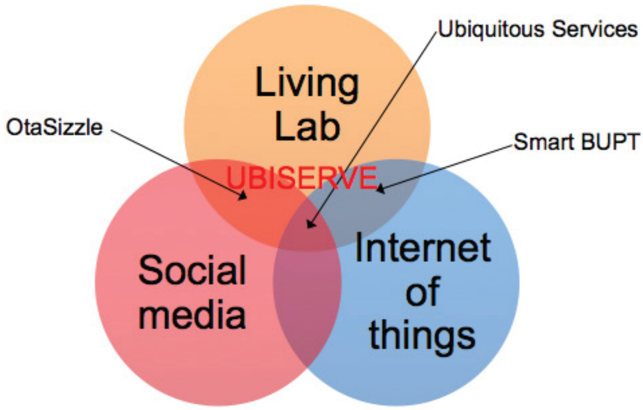


Figure 3.5. Complementary relationship between the projects

  - Both are based on the LL idea and mobile services platform.
  - Both are first deployed in a campus environment.
- Technical similarities
  - Their architectures are similar (layered and modular). There are core services libraries and different end-user services.
  - The core services libraries of the OtaSizzle and the Smart BUPT sensor libraries are both written in Ruby on Rails.
  - The calls between end-user services and core services is by RESTful APIs.
  - Both have location-based services.
- Ecosystem thinking
  - Both are open platforms which provide open APIs to third-party developers.
  - Both are supported by partnering with third-party companies.

Based on the similarities and complementary relationship between the OtaSizzle and the Smart BUPT, we propose a ubiquitous LL innovation

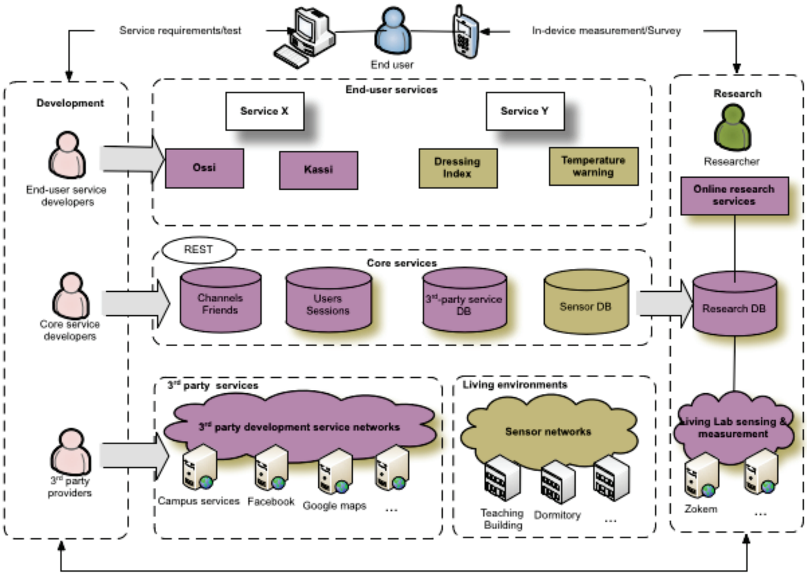


Figure 3.6. A ubiquitous Living Lab services platform

platform architecture as shown in Figure 3.6. We divide the architecture into two parts: an LL actors part and an LL infrastructure part. In the LL actors part, we focus on the main actors, such as end-users and developers and their roles in the ecosystem. In the infrastructure part, we focus on the digital species and technical architecture that combine the social media and sensor-based services from the original OtaSizzle and the Smart BUPT architectures. The architecture is described in three blocks. The leftmost block is the development block. The rightmost block is the research block. The middle block is the LL infrastructure. Above these three blocks, the topmost part is the end-users.

Living Lab actors

Depending on the nature of different LLs, there are different types of actors or stakeholders in the LLs (e.g., users, companies, governments, and research institutes, etc.). They are self-organizing and related to each other and maintain the ecosystem collaboratively. The essential actors in the LL ecosystem are end-users, developers, and researchers [77].

End-users End-users are not only services consumers and testers; they can also act as innovation co-creators. Their needs and requirements in their daily activities and experiences are sources for new services and innovations.

Developers Developers develop tools, services, and applications for end-users, other developers, and researchers.

Researchers Researchers carry out different theoretical and empirical research such as service design, service usage, service adoption, and user behavior in the real-life contexts.

Living Lab infrastructure

The middle block is the LL infrastructure block. In order to illustrate the combination of the OtaSizzle (social media part) and the Smart BUPT (IoT part), we use different colors to represent components from the OtaSizzle and the Smart BUPT, respectively. Specifically, in the architecture, the components related to the OtaSizzle social media are filled in red, while the components related to the Smart BUPT WoT are filled in yellow. If a component is filled in red with a yellow shadow, this means that both the OtaSizzle and the Smart BUPT architectures contain this component. Examples include the third-party services or the components based on the combination of components from both projects, such as the new end-user services built on top of both the OtaSizzle and the Smart BUPT core services.

The infrastructure block contains three sub-blocks or layers. The bottom layer consists of third-party services networks and sensor networks. The sensor networks include smart objects and wired/wireless networks. Different services and data sources (such as sensor data) can be combined to create a new service by a Web mashup — a Web application that integrates services and data from multiple sources to provide a unique service [138].

The middle layer is the core services layer. The core services include the social network service, the sensor-based services, and third-party core services.

The top layer is the end-user services layer. The end-user services can be built on top of core services and third-party services. The communication between the end-user services layer and the core serves layer is by RESTful Web services APIs. Some end-user services also provide web services APIs for further mashups.

3.6 A common Living Lab infrastructure architecture

Based on many LL infrastructure implementation experiences in different projects, such as the OtaSizzle, the Smart BUPT projects (LLs for Smart campuses), the T3RC responsive city project (an LL project for a smart and sustainable city), the Measurement, Monitoring and Environmental Assessment (MMEA) project (an LL project for citizen-driven environmental measurement and monitoring), and the Actage project (an LL project for smart elderly care) [118, 136], we find that although different projects are in different application domains, they share many similarities, as follows:

Stakeholders Although some projects (e.g., the Actage project, an international LL project with a wider selection of stakeholders from governments, industries, and research institutes in both Finland and China) have been involved with more different stakeholders than other projects (e.g., the T3RC project, a Finnish local academic project with less stakeholders), the common stakeholders by roles in all projects are end-users, developers, and researchers.

Technology Although different projects have used different technologies (e.g., the social media in the OtaSizzle and WoT in the Smart BUPT), from the technical architecture's perspective, they can be divided into network layer, service platform layer, and application layer.

Artifacts Different projects have some common needs for LL infrastructure artifacts, such as mobile handset-based measurement tools for monitoring user behaviors in real-life contexts and an LL researchers platform for project management, research data collection, and user-panel management because many LL researchers come from non-IT backgrounds (e.g., economics and arts). Therefore, many LL infrastructure artifacts have been developed, used, tested, and improved in different LL projects and experiments.

Based on the aforementioned LL projects infrastructure implementation experiences and similarities, a common or general LL infrastructure architecture is proposed, as shown in Figure 3.7.

The common technical architecture includes three blocks. The left-most block is the service developers and providers block, which includes the end-user application and service developers, core service providers, and third-parties service providers. The middle block includes three layers.

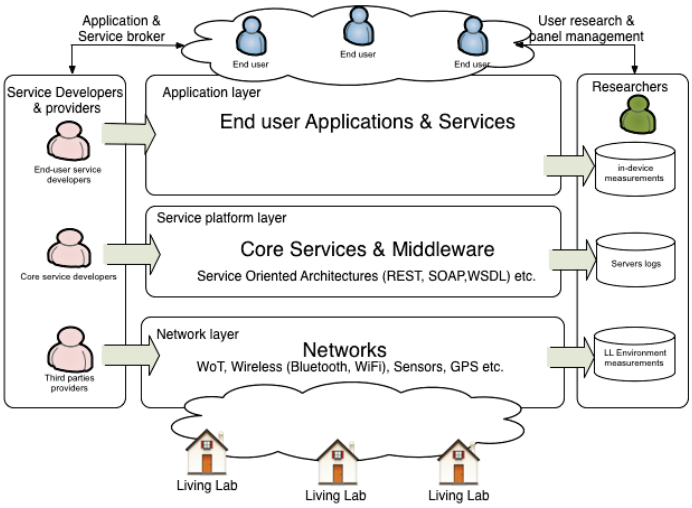


Figure 3.7. A common Living Lab technical architecture

The bottom layer is the network layer, which contains the networks such as WoT, wireless, and sensors. The middle layer is the service platform layer, which contains the core services and middleware. The top layer contains the end-user applications and services. The right-most block is the researchers block, which contains the tools for collecting research data such as in-device (e.g., mobile handset-based) measurement tools. There are two clouds in the architecture. The top cloud is the collection of end-users. The bottom cloud is the collection of LLs, namely the real-life contexts. Between the end-users and service providers, there is a application & service broker or repository to help end-users find the applications and services. Between the end-users and researchers, there are tools for user research and user panel management.

Many core components or elements in the common LL infrastructure have been developed and improved in different LL projects as open-sourced LL tools (`https://github.com/sizzlelab`). For example, rePortal (`https://github.com/t3rc/rePortal`) is an LL experiment project management platform (e.g., user panel recruitment and tools management). ContextLogger3 (`https://github.com/apps8os/contextlogger3`) is a mobile handset-based sensing and logging tool. AaltoApps (`https://github.com/sizzlelab/aaltoapps`) is a developer applications and services marketing platform. Publication II & Publication III elaborate the implementation of different components and tools in the common LL architecture.

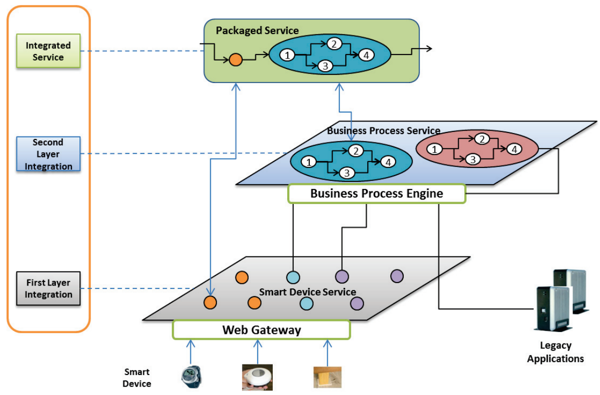


Figure 3.8. A Web-based two-layered integration technical framework

3.7 A Web-based two-layered integration technical framework

In LL ICT architecture, how to integrate heterogeneous smart devices from different manufacturers and more importantly how to integrate these devices into complex business environment are two important challenges. For the first challenge, RESTful WoT provides a lightweight, efficient, and scalable solution for integrating heterogeneous smart devices such as the physical Mashup [47, 48]. For the second challenge, a Web-based two-layered integration framework is proposed, as shown in Figure 3.8 [136]. The device layer integration (integrating heterogeneous smart devices) is by RESTful WoT gateway, while the business process layer integration (integrating devices into business processes) is by BPM (Business Process Management) middleware [136, 135]. Publication IV elaborates the design and implementation of the Web-based two-layered integration technical framework in more detail. The proposed solution is evaluated by a real-life elderly care LL use case and is compared with other solutions by different criteria such as interoperability, complexity, flexibility, compatibility, and agility.

3.8 Chapter summary

In this chapter, a ubiquitous LL services platform combining social media and WoT is proposed and implemented. A common LL technical architecture is proposed by the experiences from many LL projects, which has been implemented and evaluated in different LL projects. A Web-based two-layered integration technical framework is proposed for integrating heterogeneous smart devices into business processes, which is evaluated in a real-life elderly care case.

4. Living Lab Methods

Suitable processes and methods are needed for LL to understand users' behavior and facilitate user involvement and stakeholder collaboration in the innovation and development process. However, there is a remarkable lack of in-depth descriptions and discussions of LL processes and methods in current LL literature [38]. More empirical experiences are needed in the LL processes and methods aspects [38]. Therefore, this chapter will explore the LL methods.

4.1 Living Lab process

Several LL methodology models on LL activity processes have been proposed in the LL literature. For example, the FormIT model is the spiral LL methodology model through the iteration of three stages: the design of concepts, the design of prototypes, and the design of the final system [12]. The FormIT model is from the perspective of the design of the product or service. The iLabo LL methodology model uses the iteration of four phases: contextualization, concretization, implementation, and feedback [8]. The iLabo model emphasizes the importance of context. The Helsinki LL methodology is a three-phase spiral methodology. The first phase is Grounding, in which stakeholders are identified and users are selected. The second phase is the interactive and iterative Co-design phase, in which prototypes are co-designed with users. The third phase is appropriation and implementation, in which the final innovation outcome is tested and feedback is gathered [6]. The Catalan LL methodology is also a three-phase spiral methodology. The first phase is group selection. The second phase is the creation of an innovation arena, which often involves the use of advanced ICT infrastructure. The final phase is the context development or experimentation in the real-life contexts [6].

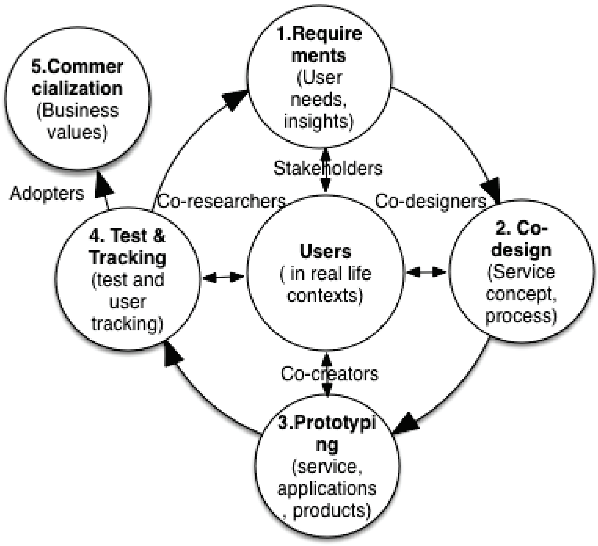


Figure 4.1. Living Lab process

By synthesizing the existing LL literature [12, 8, 5, 6] and many years of international LL practices, we propose an LL process model as shown in Figure 4.1. In this model, users and their real-life contexts are in the centric positions. The model has four iterative phases: Requirements, Co-design, Prototyping, and Test & Tracking, plus an iteration exit phase: Commercialization.

The first phase is requirements in which the real-life contexts, users (groups), and issues to be solved are preliminarily identified. For the features of LL, the issues are usually closely related with users' real-life needs, such as healthcare and traffic.

The second phase is co-design. Based on the input from the requirement analysis phase, designers (e.g., service designers) involve users and other stakeholders to co-design some LL products or services to solve users' requirements.

The third phase is prototyping. Developers co-develop LL innovation prototypes with users. The co-creation of ICT solutions is one of the core advantages of LL over traditional user-centric methodologies [84].

The fourth phase is Test & Tracking, in which the prototypes are tested (e.g., functions and usability) and users' interactions with prototypes are tracked in real-life contexts. Users' feedback is collected.

Two additional cycles are included in Figure 4.1: the user cycle and the commercialization cycle. As a user-centric and context-centric open innovation approach, users and their real-life contexts are the core of LL methodology. The iterative phases are not in linear sequence but can take place concurrently. They interact with each other in the LL context. With the innovation vortex of the iteration, some innovation outcomes might be commercialized.

The proposed LL process model has been tested and validated in many LL projects cases, such as the OtaSizzle project and the Actage project. In the OtaSizzle project, the users are targeted to Aalto University students and staff. The requirements from students, such as exchanging goods and services are the sources for developing different OtaSizzle services. The services are co-designed by the collaborations among different players such as users, designers, and developers. Many rounds of user studies by both interviews [73, 116] and mobile handset-based methods [69] were conducted to improve the OtaSizzle services. In OtaSizzle, the Kassi service (a campus-based social media service for exchanging goods and services) has been successfully commercialized. In the Actage project, the users are elderly people. The requirements of elderly people in their daily lives are the sources for innovation. Many elderly-caring products and services are co-designed and developed by involving elderly people in both the laboratory and their real-life contexts (e.g., homes). Several tests and experiments by case study and a mobile handset-based user behavior measurement method have been conducted in the Actage project. Some elderly-caring products and services have been commercialized in both the Finland and China markets. Publication V elaborates more on the process-model evaluation.

4.2 Living Lab methods

Although many different types of methods are reported in LL studies, such as interviews and ICT-enabled methods, the current LL literature lacks a framework or taxonomy to classify different LL methods [84]. Therefore, we propose an LL methods taxonomy to categorize different types of LL methods, as shown in Figure 4.2. LL is a mixed or multidisciplinary approach, which combines the researcher-mediated research methods and the ICT-enabled research methods. LL is a new methodological approach that combines the features of Lab research (user labs) and Action research (real-world settings) [59]. Therefore, the horizontal axis is the two components of LL, namely the *laboratory* part (more control)

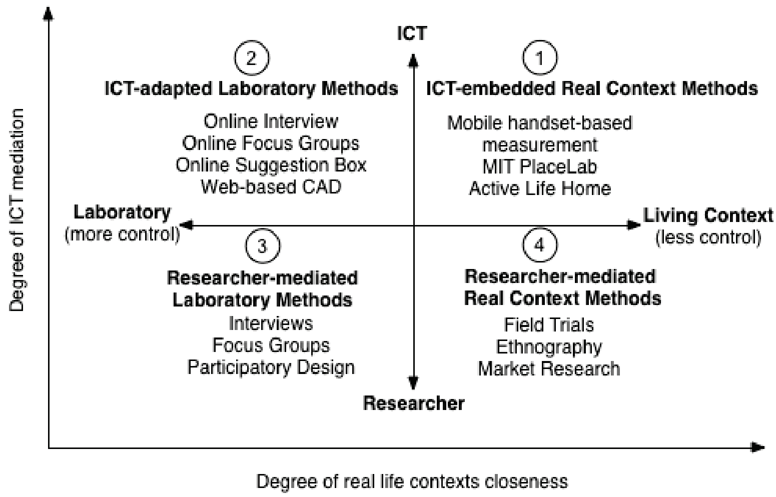


Figure 4.2. Living Lab methods

and the *living* part (less control). The vertical axis is the mediation, by ICT or by researchers. There are four quadrants in Figure 4.2, namely the ICT-embedded real context methods, ICT-adapted laboratory methods, researcher-mediated laboratory methods, and researcher-mediated real context methods.

The first quadrant is the ICT-embedded real context methods. These methods are the core or essence of the LL approach, which manifest the advantages and innovativeness of the LL approach. Examples include the smart homes and mobile handset-based measurement. In these methods, the ICT is embedded in the users' real-life contexts. The advantages of the methods in this quadrant are that they are non-obtrusive or less obtrusive (embedded in the real-life contexts) and suitable for collecting big data from large user bases continuously with less human efforts. The disadvantages include unfamiliarity to many researchers and user privacy issues.

The second quadrant is the ICT-adapted laboratory methods, which are the adapted versions (by ICT technologies) of traditional researcher-mediated laboratory methods (in the third quadrant). Examples include the online interview and the online focus group. Compared with the methods in the first quadrant, they are more familiar to researchers.

The third and fourth quadrants are the researcher-mediated laboratory methods (e.g., interviews and surveys) and researcher-mediated real context methods (e.g., field trials and ethnography) respectively. They are well-established methods and very familiar to researchers.

In the following two sections, we present two case studies by different LL methods. The first case is to study users' online activities in two campus-based LL social media services by social network analysis. The second case is to study everyday life activities of Chinese university students by mobile sensing.

4.3 Case study: Campus-based social media services

The background of the campus-based social media case originates from the LL social media research project "OtaSizzle" at Aalto University in Finland, which we have introduced in Chapter 3. OtaSizzle focuses on social media services especially the mobile ones and their creation, usage, research, and innovation [81]. One social media service developed in OtaSizzle is Kassi, which is a social media platform for facilitating students and staff at the Aalto campus to exchange goods and services. The difference between LL social media and traditional online social media is that in LL social media, the online and offline interactions are tightly intertwined in the LL environment and most of the exchanges require face-to-face interaction to be completed [116]. Kassi has been developed since the summer of 2008 and was publicly released in the fall of 2009. The registered users are more than 2,500 in September of 2010. The core service of Kassi is exchanging goods and services (requesting something and offering something). Besides the core service, Kassi also provides social networking functionalities such as user profiles, friends, and groups. Figure 4.3 shows the interface of Kassi.

During the international collaboration of the OtaSizzle project, the OtaSizzle core services and end-user services have partly been replicated and adapted at Nairobi University, Kenya, in Africa, Beijing University of Posts and Telecommunications (BUPT) in China, and the University of California, Berkeley, in the U.S. [118]. Among these expansions, the Kassi service has been adapted and deployed in BUPT with a new name, "YOU". In August 2010, the localized YOU service (e.g., Chinese translation and user interface changes) was finished. In January 2011, the registered users in YOU is a little more than 1,000. Figure 4.4 shows the interface of YOU.

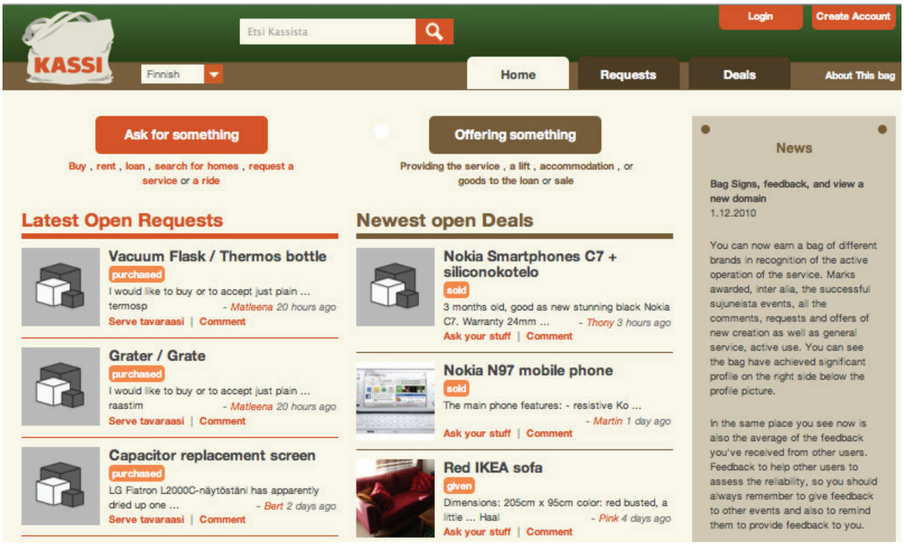


Figure 4.3. Kassi

4.3.1 Research methods

We use Social Network Analysis (SNA) to analyze different user behaviors such as exchanging, friending, and grouping. SNA studies the social relationships (ties) such as friendships and communications among social actors such as individuals or organizations (nodes) and the patterns and implications of these relationships [133]. The three most popular individual or actor centralities to measure the relative importance of an actor in a network are as follows [133]:

- Degree Centrality: Degree centrality is the number of ties a node has. For example, in an undirected friendship network, the friendship degree of an individual is the total number of friends he or she has. For directed networks, degree centrality divides into in-degree (the number of ties connected to a node) and out-degree (the number of ties connected from a node). For example, in a personal email communication network, the in-degree is the number of emails received, and the out-degree is the number of emails sent.

- Betweenness Centrality: Betweenness centrality measures the importance of a node as a “bridge" or “middleman" role in a network.

Figure 4.4. YOU

- Closeness Centrality: Closeness centrality measures the closeness by geodesic distances of a node to other nodes in a network.

Except for the aforementioned three node or actor centralities, these are also corresponding network or group degrees, betweenness and closeness centralities. From Freeman's group centrality computation formulas [133], we know that group centrality equals 0 when all actors have exactly the same centrality index (degree, betweenness, or closeness centrality), and equals 1 if one actor "completely dominates or overshadows" the other actors (the star shape of the network structure). In order words, if group centralities decrease, this means that group members' positions or behaviors become more similar or "democratic" in the network. On the contrary, if group centralities increase, this means that group members' behaviors become more differentiated or "hierarchical", as few core or leader players dominate the network.

The SNA data come from the two social media database records, which include different social network relationships such as friendships, groups, and conversations. The main SNA tool is Condor [43]. Besides SNA, Internet Community Text Analyzer (ICTA)[54, 46] was used for categorizing social media topics to understand the service usages. QAP (Quadratic Assignment Procedure) correlation analysis by UCINET 6 [17] and Pearson correlation analysis by SAS were used to understand the correlations between different social relationships (e.g., the friend relation and exchanging relation) and different user behaviors (e.g., the requesting and offering

Table 4.1. Statistics of goods and services in Kassi and YOU

	Kassi	YOU
Goods Offers	802	704
Goods Requests	261	103
Services Offers	221	76
Services Requests	119	8
Total	1403	891

Figure 4.5. Top 30 terms in Kassi

behaviors), respectively.

4.3.2 Results

Exchanging behavior

The Kassi dataset is from September 2009 to September 2010 (1 year), while the YOU dataset is from August 2010 to January 2011 (half a year). Table 4.1 shows the statistics of goods and services usage in Kassi and YOU.

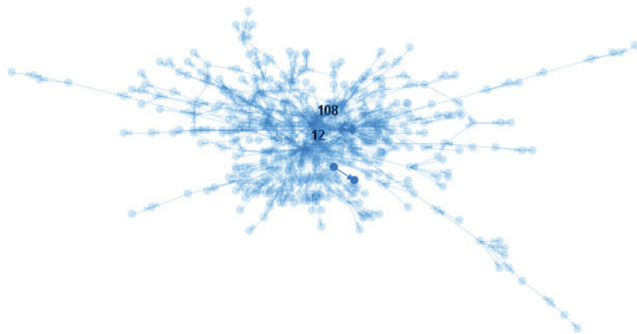
Although the time spans of data records for Kassi and YOU are different, we can still see some usage patterns from Table 4.1. For similarities, both Kassi and YOU have far more goods than services. Both Kassi and YOU have far more offers than requests. For differences, the ratio between services and goods in Kassi is much higher than that in YOU. The ratio between requests and offers in Kassi is also much higher than that in YOU.

Figures 4.5 and 4.6 show the top 30 terms discussed in Kassi and YOU by the ICTA text analyzer. From Figures 4.5 and 4.6, we can also see that both Kassi and YOU terms are closely related to the students' campus life, such as studying, living, and entertainment. However, we can also see the differences. For example, the top two terms in Kassi are "asking price" and "apartments", while in YOU, they are "information" and "book".

To understand the evolution of exchanging behavior, we use Condor to

Figure 4.6. Top 30 terms in YOU

Figure 4.7. Kassi conversation network



analyze the exchanging communication or conversation data. The conversation network is a directed network.

Figures 4.7 and 4.8 illustrate the conversation networks of Kassi and YOU, respectively. From these two figures, we find that both Kassi and YOU conversation networks are sparse (low network densities). Both networks have a few leader users with high-degree centralities; they are mainly the project members of the social media services.

Figure 4.9 also shows that both Kassi and YOU conversation network densities are low (sparse). For Kassi, at the beginning of the Kassi public release, a few users act as leaders by overshadowing other users by their

Figure 4.8. YOU conversation network

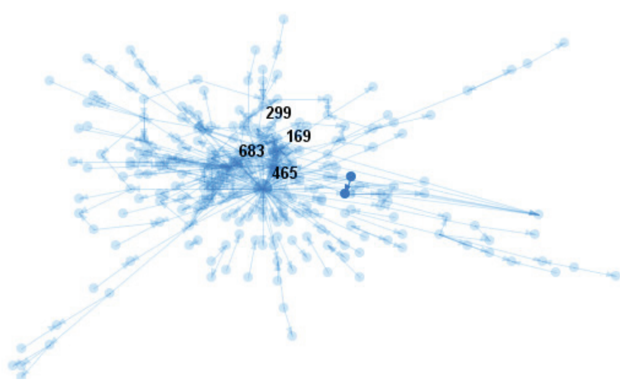


Figure 4.9. Comparison of betweenness(red), degree(blue) and density(green) in Kassi and YOU conversation networks (left: Kassi, right: YOU)

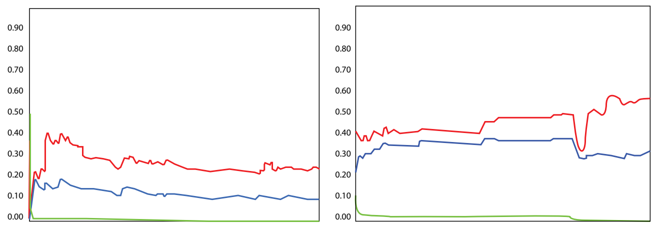
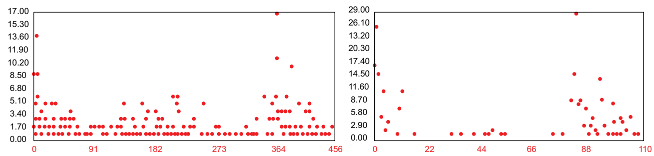


Figure 4.10. Comparison of daily new conversations in Kassi and YOU (left: Kassi, right: YOU)



higher degree of centrality and betweenness centrality because of promotion activities. When the time went by, the behavior of users in the Kassi network became more similar after that. For YOU, the group degree and betweenness centralities are almost horizontal, which means the conversation activities are inactive. Later, the degree and betweenness centralities of YOU go up slightly. It relates to new rounds of promotion activities.

Both the Aalto and BUPT universities have made several rounds of promotional activities for Kassi and YOU, respectively. Figure 4.10 shows that during promotion periods (at the beginning of semesters), conversation activity surges; and between the promotion periods, daily conversations are quite steady in Kassi. Comparatively, the daily conversations are even less, and intermittent, in YOU.

Friending behavior

A friendship network is a one-mode network (which means the subjects of social network analysis belong to a single set), and an undirected network (which means that if actor A is a friend of actor B, then actor B is also a friend of actor A [133]).

Figures 4.11 and 4.12 show the Kassi and YOU friendship networks, respectively. We can see that only a few lead users are active (with high-degree centrality), while most users in both Kassi and YOU are not active in making friends. However, we can also see the differences between Kassi and YOU friendship networks. In Kassi, the whole friendship network is connected, while in YOU, there are several isolated sub-groups or sub-

Figure 4.11. Kassi friendship network

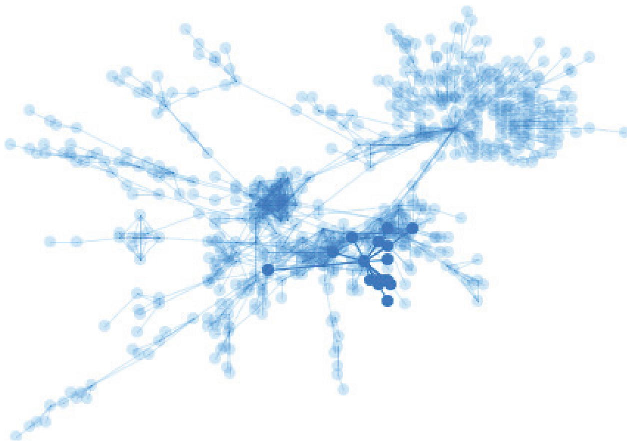
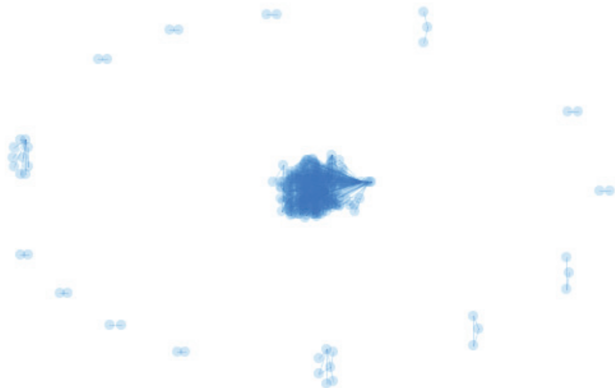


Figure 4.12. YOU friendship network



networks around the central network. The reason might relate to the comparative short time of operation of the YOU service.

Figure 4.13 shows a comparison of betweenness, degree, and density in the Kassi and YOU friendship networks. We can see that both friending activities become inactive or stagnant after public release of the services.

Figure 4.14 shows the comparison of daily new friendships in Kassi and YOU. It further confirms that the friending activities are inactive after the promotions. Comparatively, the friending behavior in YOU is even less and intermittent.

Grouping behavior

In Kassi and YOU, registered users can create their own groups or join existing groups. The group network is a two-mode network because the relationship is between two sets, namely the users and the groups [133].

Figure 4.13. Comparison of betweenness(red), degree(blue) and density(green) in Kassi and YOU friendship networks (left: Kassi, right: YOU)

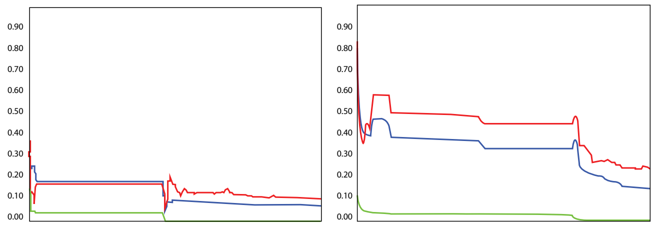
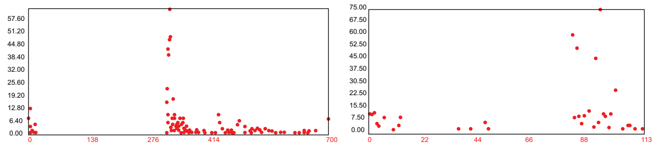


Figure 4.14. Comparison of daily new friendships in Kassi and YOU (left: Kassi, right: YOU)



Figures 4.15 and 4.16 show the group networks of Kassi and YOU, respectively. Kassi has 58 groups, while YOU has 35 groups. The phenomenon of users' co-presence in multiple groups, which is popular in Facebook [74], is not common in Kassi and YOU. Most users are only in one or two groups.

Figure 4.17 shows that the grouping activities are inactive or stagnant in both Kassi and YOU after their public release.

Figure 4.18 shows that there are some group activity surges around each round of promotion periods. However, between promotion periods, the grouping activities are quite inactive.

Correlation analysis

To better understand the correlation between different behaviors such as conversation, friending, and grouping, we use SAS for the correlation analysis.

Reciprocity Reciprocity or mutualism is a phenomenon which has been observed in many online communities [64, 131]. In order to measure reciprocity, we make Pearson correlation analyses between the offers and requests and between the conversation in-degrees and out-degrees by SAS.

Table 4.2 shows that there are moderate positive correlations between offers and requests and between conversation in-degrees and out-degrees. Earlier Kassi user studies also found out that reciprocity is a key factor in user's participation motivation [73, 116].

Figure 4.15. Kassi group network

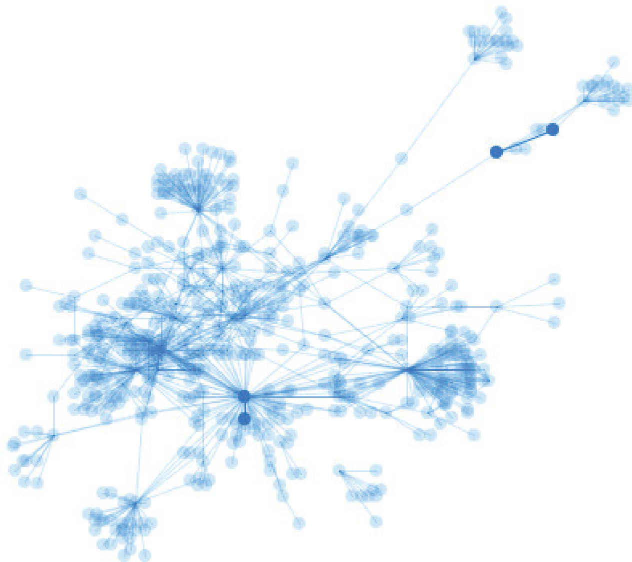


Figure 4.16. YOU group network

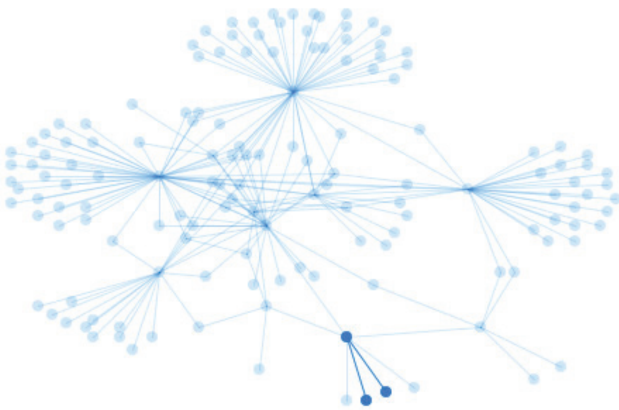


Figure 4.17. Comparison of betweenness(red), degree(blue) and density(green) in Kassi and YOU group networks (left: Kassi, right: YOU)

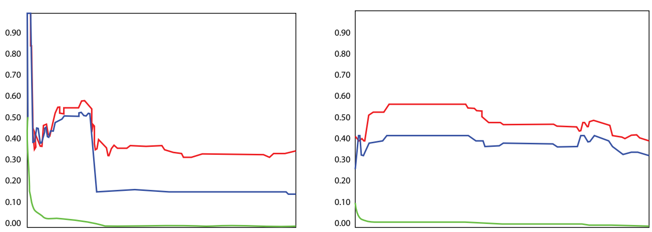


Figure 4.18. Comparison of daily new grouping activities in Kassi and YOU (left: Kassi, right: YOU)

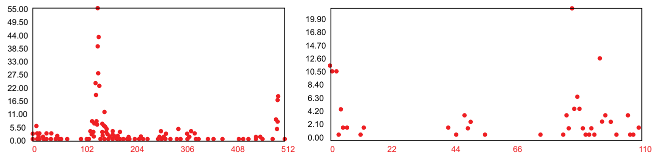


Table 4.2. Correlation analysis for reciprocity

	Coefficient	Significance
Kassi offers & requests	0.511	< 0.0001
Kassi in-degrees & out-degrees	0.552	< 0.0001
YOU offers & requests	0.436	< 0.0001
YOU in-degrees & out-degrees	0.502	< 0.0001

Social networking and exchanging activities As we introduced in the Section 4.3, Kassi and YOU support social networking functionalities, except for the core exchanging service. So one interesting question is whether the social networks such as friends and groups correlate with the exchanging activities: for example, whether the friendship and group relationship will help or contribute exchanging relationship or behavior. As the "relationship" data per se are the data about "correlation" which violates the rule of "collinearity", many traditional statistics techniques (e.g., the Ordinary Least Squares) can not be used. A randomization test method called the "Quadratic Assignment Procedure" (QAP) was widely used in SNA for this situation [111].

We use UCINET 6 for the QAP analysis. The main results are shown in Table 4.3. From Table 4.3, we can see that friendships and groups are not correlated with current Kassi and YOU core service usage, namely the exchanging relationship. In fact, Figures 4.13 and 4.17 also suggest this result. Figures 4.13 and 4.17 show that degree and betweenness centrality lines are almost horizontal (unchanged) after the public release of Kassi and YOU.

4.3.3 Discussion

From exchanging behavior analysis, we see that the top discussion terms in Kassi and YOU show strong locality features (e.g., geographical local contexts features and culture features). For example, in Kassi, users tend to make transactions (asking prices) of items more, while in YOU , users

Table 4.3. Correlation analysis for social networks and exchanging behaviors

	Obs Value	Significance
Kassi friendship & exchanging	0.237	0.312
Kassi group & exchanging	0.285	0.084
YOU friendship & exchanging	0.476	0.261
YOU group & exchanging	0.583	0.121

tend to borrow items more. In Kassi, coffee is one top discussed term, which reflects the Finnish culture. In Kassi, another top discussed term is apartment (e.g., renting or sharing apartments), while in YOU, there are no such discussions. These differences might relate to the context differences. Many Aalto University students have to rent or share apartments because of the limited university accommodation resources, while in BUPT, almost all students live in university dormitories. Both Kassi and YOU top discussion terms show the close relationship with students' daily life activities and needs. Both Kassi and YOU have far more tangible items than intangible services, which suggests that utilitarian values instead of social values are the main motivations to use the social media services [73, 116]. The predominance of tangible goods than intangible services may due to the risk of exchange goods is less than services (e.g., goods usually have explicit value, while services do not) [27, 116] and the lack of social capital (e.g., trust, norms, obligations, and expectations) [91]. However, the ratio between services and goods in Kassi is much higher than that in YOU. This might reflect the social capital differences in the two campuses. Both Kassi and YOU have far more offers than requests, which suggests users are clearer about what they have than what they need.

From the conversation network SNA analysis, we can see that after the public release of Kassi, users' exchanging behavior becomes more similar as conversation network betweenness decreases. However, the conversation network betweenness curve of YOU goes up slightly during a half-year time span. This may relate to the promotion activities in which lead users dominate the network. From the correlation analysis, we know that users' conversations are moderate positively correlated with users' requests and offers, and there are reciprocal relationships between requests and offers.

From the friending behavior analysis and grouping behavior analysis, we know that friending and grouping behaviors become stagnant after the public release. The correlation analysis between social networks and conversations further confirms that currently there are not much correlations between social networks and users' exchanging behaviors.

As the LL social media services span the online and offline contexts, we acknowledge the limitation in studying users' interaction activities by online database logs.

We summarize the above findings as follows:

- LL social media usage shows close connections with the features of users and contexts (e.g., culture features and geographical local contexts features) and are closely connected with users' daily life activities and needs.

- Because users are clearer about what they have than what they need and the importance of reciprocity, it's important to find or elicit hidden user needs from their daily lives to promote the usage of LL innovation.

- The building of social capital (e.g. trust and norms) is important to escalate the LL innovation usage (e.g., from goods exchange to services exchange).

- The interaction with LL social media usually spans different contexts, such as online and offline contexts. Therefore, it's important to record user activities in different contexts of interaction to comprehensively understand user behaviors.

4.4 Case study: Everyday life sensing

In this section, we present an LL experiment on Chinese university students' everyday lives by mobile handset-based measurement.

4.4.1 Research methods

The mobile sensing tool is the MIT open source Android-based mobile sensing framework "Funf" (`www.funf.org`) [1]. The experiment was conducted in a laboratory at the Chinese University of Posts and Telecommunications from 16.10.2012 to 25.11.2012 (six weeks). In the experiment,

Table 4.4. Demographic information on the participants

ID	Gender	Mobile Device	Android version
1	male	Samsung GT-19100G	4.0.4
2	female	HTC Villec	4.0.3
3	female	ZTE U930	4.0.3
4	male	HTC Vivow	4.0.3
5	femae	Samsung GT-19108	2.3.6
6	male	HTC Espresso	4.0.3
7	female	HTC Marvel	2.3.5
8	female	Meizu M9	4.0.3
9	male	XiaoMi M1	2.3.5
10	female	ZTE V880	2.2.2
11	female	HTC Vivo	2.3.5
12	female	Samsung S5830	2.3.4
13	female	Samsung GT-19300	4.0.4
14	male	XiaoMi M1	4.0.4
15	female	Huawei iT9200	4.0.3
16	female	Vtion Vpad V7	2.2.2
17	male	XiaoMi M1	2.3.5
18	male	Motorola Titianium	2.1
19	male	Xiaomi M1	2.3.5

19 participants (11 females and 8 males) were recruited, as shown in Table 4.4.

Funf provides an abundance of built-in sensors or probes such as positioning, social, motion, environment, and device interaction [1]. The Funf mobile sensing client used in the experiment is "Funf in a box" (www.funf.org/inabox). By using Funf in a box, each experiment participant will have the same Funf probe configuration (e.g., the number of the enabled probes and their sampling frequencies). Table 4.5 shows the configuration parameters for some Funf probes. For the detailed meanings of the configuration parameters, please refer to the wiki pages of the Funf Developers website (`https://code.google.com/p/funf-open-sensing-framework`). The collected data will first be stored at the local storages of the participants' mobile devices and periodically upload to a configured Dropbox account storage. The data are stored in the SQLite database format. The data are protected by passwords and are anonymized. All the privacy

Table 4.5. Funf sensing configuration

Category	Probe name	sensing frequency
Device	Android info	604,800 seconds
	Battery Info	600 seconds
	Hardware Info	604,800 seconds
	Mobile Network Info	604,800 seconds
Device Interaction	Applications	36000 seconds
	Running Applications	30 seconds
Motion	Accelerometer	300 seconds for 30 seconds
	Activity	300 seconds for 15 seconds
	Orientation	180 seconds for 15 seconds
Positioning	Location	1,200 seconds for 120 seconds
	Cell Towers	600 seconds for 30 seconds
	Bluetooth	600 seconds for 30 seconds
	Wifi devices	600 seconds for 30 seconds
Social	Call Logs	36,000 seconds
	Contacts	36,000 seconds
	SMS Logs	36,000 seconds

parts of data (such as Call Logs and browsing URLs) are hash encrypted.

4.4.2 Results

Application usage

Funf application probes can measure what applications are installed on the device, what applications are uninstalled, and what applications are currently running.

There are 182 unique application packages (around 10 applications per person). We categorize all these installed applications into 19 categories. We first search the applications from the respective app stores (such as Google Play and Qihoo App Store) by their names. We then use the categories identified in the respective app stores. For the applications that we can't figure out, we will verify them by asking the participants. The application categories are shown in Table 4.6. The numbers of applications in each category are shown in Figure 4.19.

74% of the participants (all 8 male participants and 6 female participants) did not delete any applications during the experiment time span,

Table 4.6. Application categories

Category	Description
System	System-related applications such as control panel, settings, clipboard, input methods, etc.
Tools	Utilities for a wide range of tasks such as VPN client, FileTransferClient, Flashlight, etc.
SNS	Social network services such as Sina Weibo, and Renren, etc.
Productivity	Applications that enhance productivity, such as Office, calendar, contacts, clocks, etc.
Communication	Communication applications include Instant Messaging (e.g., WeChat), email, SMS (including Fetion and Youni SMS), etc.
Voice	Phone calls and other voice-related applications
Personalization	Ringtones, wallpapers, desktop themes
Photography	Photos and videos, camera
Education	Study-related applications, such as dictionary
Reader	eBook readers, Adobe PDF reader
Browsing	browsers
Entertainment	Applications for amusement or enjoyment such as PPS, joke books, Mediashub
Map	Maps, navigation
News and magazines	Sina news, Diangping, radio news
Gaming	Different types of games
Appstore	Google Play, Qihoo Appstore, Wandoujia, Samsung Apps
Commerce	Online shopping and ebusiness such as Taobao, Tao800, Dazhihui
Music	Musics, and music players
Security	Security applications such as Qihoo 360 Mobile Safe, Kingsoft Mobile Guard

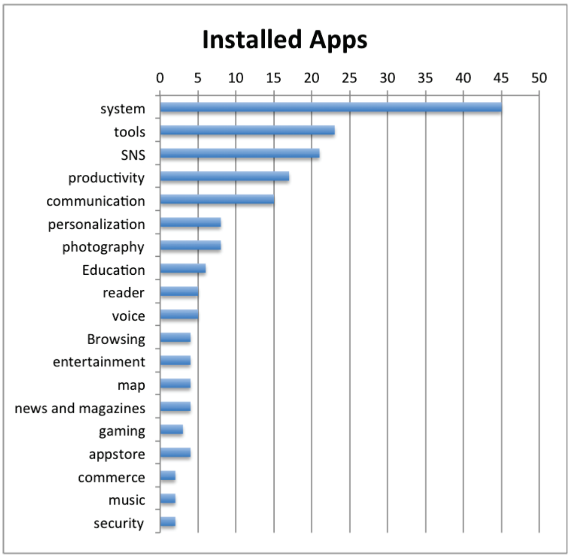


Figure 4.19. Installed applications

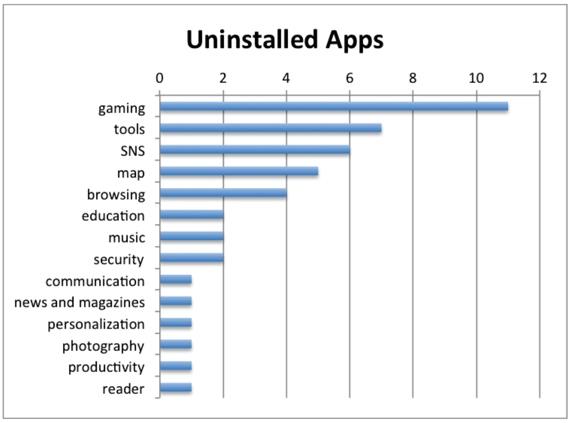


Figure 4.20. Uninstalled applications

while 5 female participants deleted 45 applications. Figure 4.20 shows the numbers of uninstalled applications.

From Funf's running applications probe data, we get all the running applications in each sampling session. The sampling frequency in this study is one-half minute. From all the running applications, we separate the top running applications (the applications that participants interact with) and background running applications (the applications running in the background). Figure 4.21 shows the top running applications by their frequencies. Many applications are shared among participants (e.g., Mobile QQ and Sina Weibo).

From all the top running applications data, we visualize the average

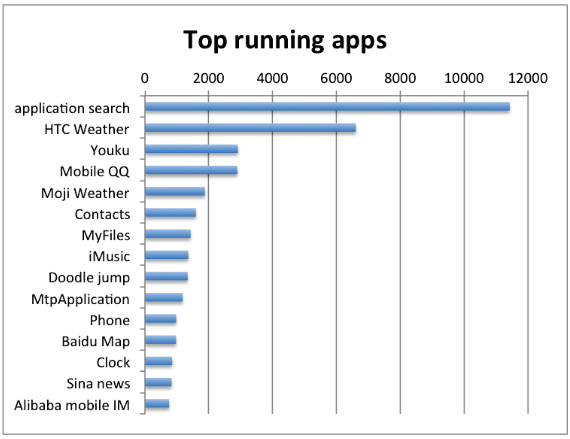


Figure 4.21. Top running applications by frequencies

activities of different categories of application usages in Figure 4.22. We also visualize the percentages of face time for each category of applications, their average used days used per week, and their percentage of usage in Figure 4.23 and Figure 4.24, respectively.

Mobility

Funf positioning probes use surrounding wireless signals to gather information about a device's absolute location and relative location to other devices by GPS, Cell ID, Bluetooth, and Wifi.

During the experiment, only one participant enabled GPS. For this reason, we used Cell ID probe as our positioning method. Although the accuracy of Cell ID positioning is not very high, however, it is enough to roughly show the students' daily mobility activities. There are 347 unique Cell IDs in all the Cell ID probes dataset. The original Cell ID numbers differ from each other very much. For example, one Cell ID is 7 and another Cell iD is 33271. To simplify the visualization, we renumber all the unique Cell IDs from 1 to 347. We then separate all the Cell ID probe data into weekday data and weekend data. Finally, we visualize all the weekday and weekend Cell ID distribution data in a single day's time span (24 hours), as shown in Figure 4.25 and Figure 4.26, respectively. Namely, we condense six weeks of data into one typical day's time span.

In Figure 4.25 and Figure 4.26, the red dots represent female students' mobilities, while the blue dots represent male students' mobilities. As in this experiment, we have more female students than male students, so there are more red dots than blue dots in both figures. The red and blue dotted lines, which are at the two ends of Figure 4.25 and Figure 4.26 dur-

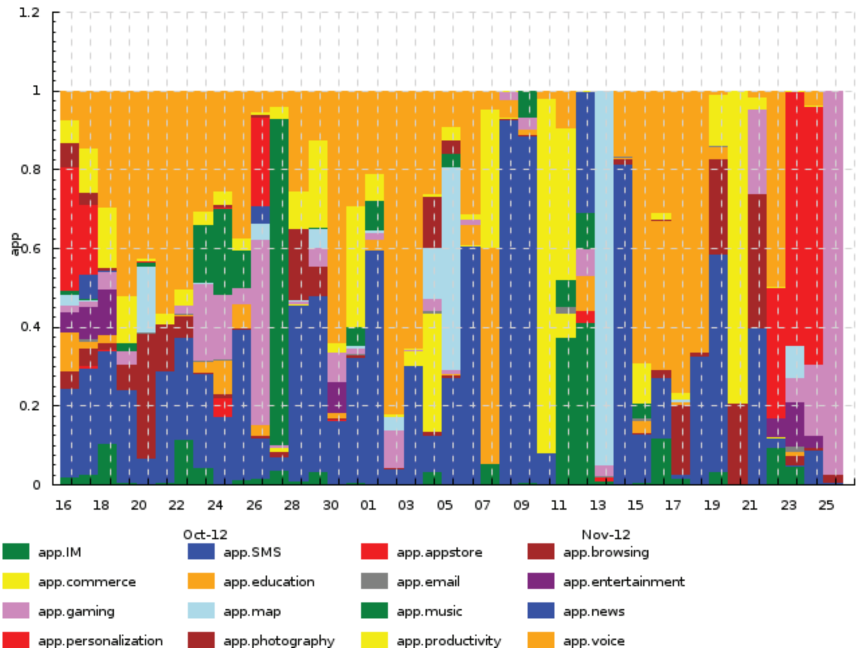


Figure 4.22. Average activities of running applications daily usage

ing the sleeping time (e.g., 10 PM to 6 AM), can be identified as the students' sleeping places (e.g., dormitories). The distribution of the dots in Figure 4.25 and Figure 4.26 shows the students' daily mobility patterns. For example, during the weekday working hours (8 AM to 5PM), the top of Figure 4.25 shows a mix of red dots and blue dots. This is because our participants are recruited from the same laboratory. In the middle of Figure 4.26, where the red dots and blue dots are mixed, is the campus dining places. Through the Cell IDs, LACs (Location Area Code), MCCs (Mobile Country Code), and MNCs (Mobile Network Code),we calculate mobility locations (latitude and longitude). We identified with participants that almost all the main activities (such as sleeping, eating, and studying) take place in the campus areas. The overlapping of many dots in Figure 4.25 and Figure 4.26 reflects the repeatability of everyday routine activities. Most dots are on the horizontal lines (the same locations), which reflects the comparatively small and simple range of student life activities (e.g., dormitories, laboratories, and campus).

4.4.3 Discussion

In this case study, we present a study of the everyday lives of Chinese university students by mobile sensing. The Funf tool used provides an

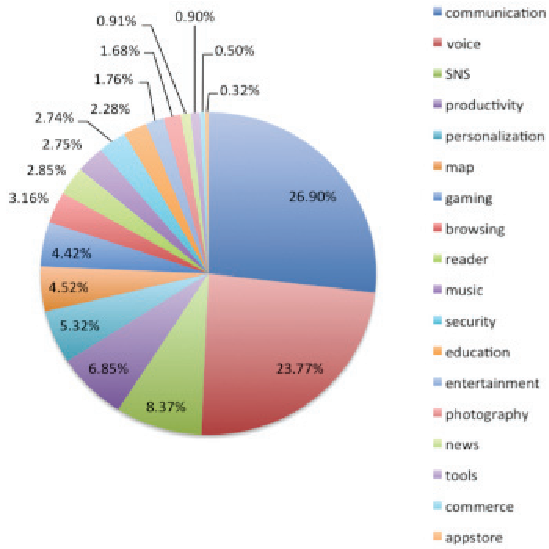


Figure 4.23. Running applications face time statistics

abundance of rich sensor data such as application usage, mobility, social (e.g., Call Logs), and device. In this study, we mainly present the results on application usage, and mobility patterns of the experiment.

From the application usage study, we find that the daily application used by students is small (averaging 10 applications per participant). For installed applications, different students share many common applications such as Sina Weibo, UCMobile, and Youdao Dictionary. Besides the system applications, the top three categories of applications installed are tools, SNS, and productivity. For uninstalled applications, the majority of students did not uninstall any applications during the study. So the daily used applications by students are quite steady. Among the uninstalled applications, gaming is the top category of uninstalled applications.

For the running applications, we find that the top three categories of running applications are SMS, voice and SNS (total accounts for 57% of face times). Therefore, we can say that students mainly use their smartphones for communication and social networking. SMS is used more often by students than phone calls. This is might because of the cheaper cost of SMS and the increase in other means of voice communication, such as the Wechat, an Instant Messaging tools with voice function.

From the mobility study by Cell IDs, we find that almost all the main activities such as sleeping, eating, and studying take place in the campus areas. The overlapping of many dots in Figure 4.25 and Figure 4.26 reflects the repeatability of everyday routine activities.

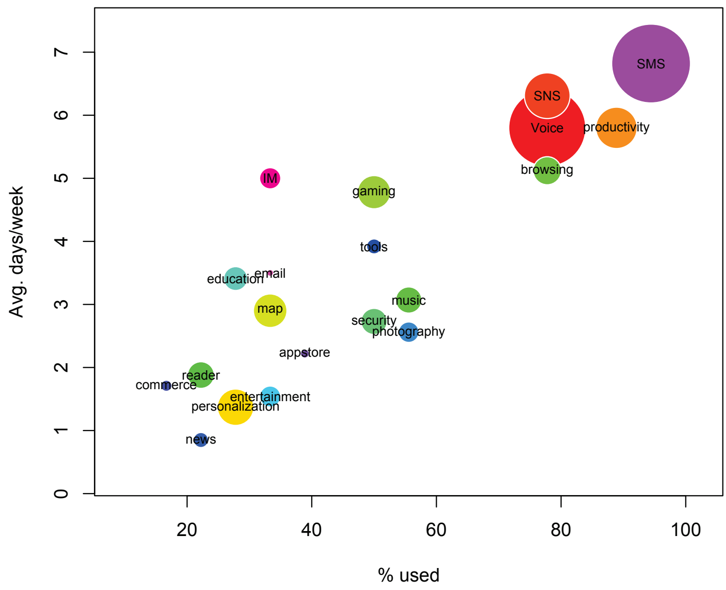


Figure 4.24. Running applications usage statistics

The ICT-embedded LL methods (e.g., the mobile sensing) provide an automatic and non-intrusive way of data collection during long periods compared to traditional user study methods (e.g., interviews). Through the combination of different LL methods (e.g., traditional researcher-mediated LL methods and ICT-enabled methods), we can get a comprehensive picture of the daily lives of users.

4.5 Chapter summary

Based on our experiences in using different LL methods in different projects and experiments (e.g., the aforementioned two case studies), we summarize the features of different LL methods. Different methods have their own advantages and disadvantages in different aspects, such as familiarity to researchers, obtrusiveness, data collection means, data richness, and application. Table 4.7 shows a comparison between the four types of LL methods.

Depending on different LL cases situations, different combinations of methods in different quadrants can be used. However, through statistics, currently a predominant use of traditional researcher-mediated methods

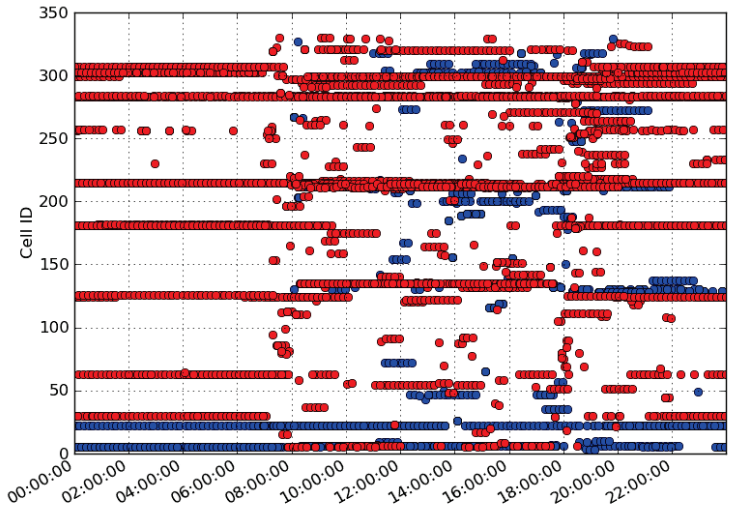


Figure 4.25. Mobility by Cell ID during weekdays

was observed in contrast to the rather limited usage of ICT-mediated methods [107]. The traditional researcher-mediated methods may be well-suited for some LL studies, but does not represent important methodological advances [38]. With the development of ICT technologies such as sensors, embedded computing, and mobile computing, users' daily life activities and experiences are increasingly digitalized. There is a trend for ICT-mediated methods, especially the ICT-embedded real context methods such as the smart-home type of environments like MIT PlaceLab [63] and mobile handset-based sensing and measurement methods [123].

This chapter proposes an LL process and LL methods taxonomy based on many years of international LL practice experiences. The LL process is a cyclic innovation process with the iterations of different phases, in which users are in the central position and have different roles in different phases. The proposed LL methods taxonomy shows that LL is a mixed or multidisciplinary approach. LL methods include both researcher-mediated and ICT-enabled methods. The ICT-embedded real context methods are the trends for future LL development, which represent important methodological advances of the LL approach. Different LL methods have their advantages and disadvantages and should be combined for a more comprehensive understanding of user behaviors from different sources.

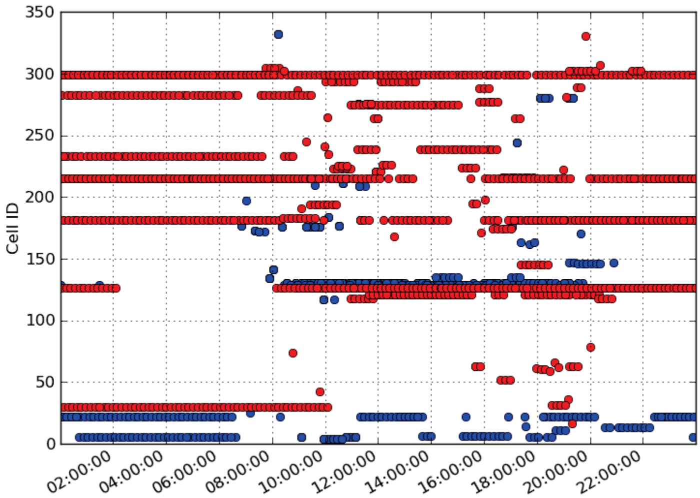


Figure 4.26. Mobility by Cell ID during weekends

Table 4.7. Comparison of different types of Living Lab methods

Dimension	Researcher-mediated real context methods	Researcher-mediated laboratory methods	ICT-adapted laboratory methods	ICT-embedded real context methods
Scalability	low	low	high	high
Real-life contexts	yes	no	no	yes
Obtrusiveness	high	high	middle	low
Time span	usually long	usually short	usually short	usually long
Data richness	high	low	low	high
Automatic data collection	no	no	partly	yes

5. Discussion & Conclusion

5.1 Answers to the research questions

- RQ1: Can Web 2.0 elements be used in the LL infrastructure as a part of the LL architecture?

ICT infrastructure is an important means in many LL innovation activities such as context research and stakeholders' collaboration and co-creation processes [38, 85]. The development of networking of LLs has higher demands for ICT technologies, such as reusable, interoperable, adaptive, and scalable ICT infrastructure architectures and tools. Although different ICT technologies (such as Web 2.0 [68, 105, 106], mobile technology [68, 109] and IoT [124, 106]) have been used in different LL domains (such as health care and smart cities) by many studies, infrastructure does not refer to the services and technologies per se under control of the LL, but illustrates how different services, technologies, and stakeholders are connected to open networks or architectures[85]. In the current LL literature, research combining different services, technologies, and stakeholders into architecture is scarce. In this thesis (Chapter 3), we propose and implement a ubiquitous LL services platform by combining social media and WoT (Publication II). People's daily experiences can be conceptualized as the interactions with four dimensions: time, space, actors, and artifacts [137]. The digitization of actors in an LL environment has been accomplished in part by social media, while the digitalized context and artifacts can be implemented by WoT. The combination of the social media and WoT provides users with ubiquitous services access and experiences in both an online context and offline physical contexts. A common LL technical architecture is proposed by the experiences from many LL projects, which has been implemented and evaluated in different LL projects (Publication III). A Web-based two-layered integration framework is proposed for integrating heterogeneous smart devices into business processes, which is evaluated in a real-life elderly-caring case and compared with other alternative solutions by different criteria (Publication IV).

- RQ2: What are proper methods for implementing an LL?

Suitable processes and methods are needed for LL to understand user behavior and facilitate user involvement and stakeholders' collaboration in innovation and development. However, as LL is a rather new area, there is a remarkable lack of in-depth descriptions and discussions of LL processes and methods in current LL literature [38, 113]. Therefore, more empirical experiences are needed in the LL processes and methods aspects [33, 38].

For the LL process, several LL process models have been proposed in the LL literature, such as the FormIT model [12], the iLabo model [8], the Helsinki LL model, and the Catalan LL model [6]. Different models are from different perspectives. For example, the FormIT model is from the perspective of the design of a product or service. The iLabo model emphasizes the importance of context [8]. By synthesizing the existing LL literature [12, 8, 5, 6] and many years of international LL practices, we propose an LL activity process model, which is a cyclic innovation process with iterations of different phases. The proposed model not only emphasizes the central position of users but also the central position of contexts, as LL is a combination of user push and context push. The key difference between LL and other user-driven innovation approaches is that it emphasizes the innovation from context push in users' real-life contexts, which can discover hidden user needs and unexpected user behavior patterns [99, 39]. The model also emphasizes the different roles of users (as co-partners) in different phases such as requirement analysis, co-design, co-creation and testing. The proposed LL process model corresponds to the several key innovation principles of LL in Chapter 2 (Publication I), such as the innovation drivers (users and contexts), user roles (co-partners), and the "end-of-innovation cycle" (the iterative innovation process with the continuous interaction between different stakeholders). The validity of the model has been verified by several LL project cases (Publication V).

For LL methods, although many different types of methods are reported in LL studies (such as interviews and ICT-enabled methods), the current LL literature lacks a framework or taxonomy to classify different LL methods [84]. Therefore, we propose an LL methods taxonomy to categorize different types of LL methods (Publication V). LL is a mixed or multidisciplinary approach, which combines the researcher-mediated research methods and the ICT-enabled research methods. LL is a new methodological approach which combines the features of Lab research (user labs) and Action research (real-world setting) [59]. Therefore, we divide LL methods into two dimensions. The horizontal dimension is the two components of LL, namely the *laboratory* part (more control) and the *living* part (less control). The vertical dimension is the mediation, by ICT or by researchers. LL methods are the continua of the two dimensions. There are four types of LL methods, namely the researcher-mediated real context methods, researcher-mediated laboratory methods, ICT-adapted laboratory methods, and ICT-embedded real context methods. The four types of LL methods have been used in different LL projects, such as the OtaSizzle project and the Actage project. Two LL user study cases are conducted by using different LL methods (Publication VI and Publication VII). The first case studies user behaviors in two local campus-based social media services by social network analysis. The results show that LL social media services have strong connections with the users and contexts under study. Also, the interaction with LL social media usually span different contexts, such as online and offline contexts. Therefore, it is important to record user activities in different contexts of interaction to comprehensively understand user behavior. The second case studies the daily life activities and experiences of 19 Chinese university students during one and a half months by mobile sensing. The results demonstrate that the ICT-embedded LL methods provide an automatic and non-intrusive way to collect data during long periods compared to traditional user study methods (e.g., interviews). Finally, a comparison of different LL methods are summarized. The ICT-embedded real context methods are the trends for future LL development, and they represent the important methodological advances of the LL approach. Different LL methods have their advantages and disadvantages and should be combined for a more comprehensive understanding of user behaviors from different sources.

5.2 Limitations of the study and future research directions

LL is a comparatively young innovation approach and research domain. The relative paucity of research on LL justifies the exploratory nature of this study of many research questions by empirical LL practice experiences and experiments. However, there are some limitations in the study. The research as a whole is based on many years of practice experience in several Sino-Finnish LL international collaboration projects. Hence, it may be problematic to generalize the findings (e.g., can the findings be transferred or adapted to the new LL contexts in other cultural backgrounds ?). Therefore, future research would need to validate the findings (e.g., LL methods and models) with more empirical evidences.

Specifically, for the LL concept, we propose an LL concept framework by conceptual analysis approaches that are based more on a literature review than an empirical basis. The proposed concept framework shows some interesting connections and similarities between LL and Web 2.0. Future research can be done to empirically study the relationships between LL and Web 2.0 and other innovation paradigms such as Open Innovation.

For LL ICT infrastructure research, the proposed infrastructure architecture and implementation are based more on the exploratory academic projects and proof-of-concept implementations. Future research can be done to apply and validate the infrastructure architecture and implementation in more serious real-life LL project cases. More automatic LL infrastructures are needed in the future for automatic data collection from different sources (e.g., sensors data and user feedback), data analysis, visualization and interpretation, and continuous experimentation in the LL context to discover hidden user needs and unexpected user behavior patterns.

For LL methods research, future research can be done to validate the proposed LL process model and methods taxonomy with more empirical evidence. Specifically, for the two campus-based social media services case study, as the LL social media services span the online and offline contexts, we acknowledge the limitation in studying users' interaction activities by online database logs. Therefore, for future research, the comparative study between the two social media services can be further extended through a theory of communication [78] and systems theory [42]. According to Luhmann's theory of communication, social systems are systems of communication. The unit of operation of social systems is the interactive construction of social meaning, which is generated as a consequence of communication and human interactions. The individual and his or her life are indispensable to the social system [78]. According to Luhmann's systems theory, it is important to understand how people traverse systems in the course of their daily life and people's relations to the wide range of incompatible systems they engage with on a daily basis [42]. Therefore, we believe that it is important to record users' activities in different contexts of interaction to comprehensively understand user behaviors and meaning in their daily life activities and experiences.

For a daily life sensing case study, we acknowledge three limitations. The first limitation is the limited numbers of experiment participants. The second limitation is the short time span of the experiment. The third limitation is that Funf in a box tool cannot provide user-input data. Therefore, in the future work, we plan to recruit more participants during a longer time period. With more participants over a longer time, we can study more detailed user behavior patterns and differences: for example, whether there are behavior differences between different genders or age groups. In future work, we will also analyze other sensor data collected by Funf, such as social activities (e.g., SMS Logs and Call Logs) and the Accelerometer sensor, which can detect the means of users' transportation (e.g., by foot or by car). To cope with the third limitation, we have also developed a new mobile sensing tool called "ContextLogger" , based on the Funf framework (`https://github.com/apps8os/contextlogger3`). The ContextLogger not only has all the Funf sensing capabilities but also provides an interface to let users mark or log an event such as shopping or driving. For example, users can start or stop activities by clicking different activity buttons. ContextLogger provides a list of common activities such as "at home" and "eating". Users can also add their own customized activities. Currently, ContextLogger also has the NFC (Near Field Communication) capability. Users can swipe their smartphones near the different NFC tags which represent different activities. In the future, we plan to add context-trigger functionalities to ContextLogger. For example, questionnaires can be sent to users when they are in specific contexts (e.g., time or place). With these kinds of real-time users' feedbacks in specific contexts, researchers can interpret the meanings of contexts more easily. In this study, we use the default sensing configurations for different sensors. However, we find that some sensors, such as the Accelerometer sensor and the Orientation sensor, will generate more data than other sensors, which will drain the storage rooms and batteries. However, when users are at home or at the office, some sensors can stop sensing (e.g., Accelerometer and Cell sensors). Therefore, it is important to have more intelligent or smart configurations for different sensors (e.g., sampling frequencies) in different contexts.

More research can be done on the combination application of different types of LL methods, such as traditional laboratory methods and ICT-embedded real context methods for different contexts (e.g., online social interaction and offline real-life interaction) integration in LL. As users' daily life activities include both indoor activities (e.g., cooking and sleeping) and mobile activities (e.g., traveling), it is reasonable to combine indoor sensing (e.g., Smart homes) with mobile sensing. By using these mixed LL methods, we would have a more comprehensive picture of people's daily life in real-world settings over long periods of time, providing a key element of the LL approach, i.e., a better understanding of user and user community needs, even beyond what they themselves have been able to explicitly identify because many of these needs and "service touchpoints" are unnoticed parts of daily life patterns and practices.

5.3 Concluding remarks

LL is an emerging and promising open innovation approach, which combines the innovation drivers of users and their real-life contexts. It provides a mechanism to further democratize innovation by engaging larger scale ordinary users and lay citizens in the innovation process over the medium or long term and connect different stakeholders. It has recently gained increasing interest and momentum in both academia and industry. It is an umbrella concept with multiple stakeholders, aspects, methods, and disciplines. Therefore, more cross-boundary, cross-domain and cross-disciplinary collaborations are needed to better understand it. This thesis endeavors to explore the three aspects of LL: concept, architecture, and methods. Hopefully, this thesis can help to better understand some parts of the LL innovation paradigm.

Bibliography

[1] Nadav Aharony. *Social fMRI: Measuring, Understanding, and Designing Social Mechanisms in the Real World*. PhD thesis, Massachusetts Institute of Technology, 2011.

[2] Bryan Alexander. Web 2.0: A new wave of innovation for teaching and learning? *Educause review*, 41(2):32, 2006.

[3] E. Almirall and J. Wareham. Living labs and open innovation: roles and applicability. *The Electronic Journal for Virtual Organizations and Networks*, 10(3):21–46, 2008.

[4] E. Almirall and J. Wareham. Contributions of living labs in reducing market based risk. In *Proceedings of the 15th International Conference on Concurrent Enterprising. Leiden, NL*, 2009.

[5] E. Almirall and J. Wareham. Innovation: A question of fit–the living labs approach. *Mobile Living Labs 09: Methods and Tools for Evaluation in the Wild*, 2009.

[6] Esteve Almirall, Melissa Lee, and Jonathan Wareham. Mapping living labs in the landscape of innovation methodologies. *Technology Innovation Management Review*, pages 12–18, 09/2012 2012.

[7] P. Ballon, J. Pierson, and S. Delaere. Test and experimentation platforms for broadband innovation: Examining european practice. In *Conference Proceedings of 16th European Regional Conference by the International Telecommunications Society (ITS), Porto, Portugal*, pages 4–6, 2005.

[8] Pieter Ballon, Jo Pierson, and Simon Delaere. Fostering innovation in networked communications: Test and experimentation. *Designing for Networked Communications: Strategies and Development*, page 137, 2007.

[9] G. Baltes and J. Gard. Living labs as intermediary in open innovation: On the role of entrepreneurial support. In *Proceedings of the 16th International Conference on Concurrent Enterprising, Lugano, Switzerland*, pages 21–23, 2010.

[10] Darin Barney. The morning after: citizen engagement in technological society. 2006.

[11] M.J. Benner and M.L. Tushman. Exploitation, exploration, and process management: The productivity dilemma revisited. *The Academy of Management Review*, pages 238–256, 2003.

[12] B. Bergvall-Kareborn, M. Hoist, and A. Stahlbrost. Concept design with a living lab approach. In *System Sciences, 2009. HICSS'09. 42nd Hawaii International Conference on*, pages 1–10. IEEE, 2009.

[13] B. Bergvall-Kåreborn, C. Ihlström Eriksson, A. Ståhlbröst, and J. Svensson. A milieu for innovation–defining living labs. In *2nd ISPIM Innovation Symposium, New York, December*, pages 6–9, 2009.

[14] V. Bilgram, A. Brem, and K.I. Voigt. User-centric innovations in new product development-systematic identification of lead users harnessing interactive and collaborative online-tools. *International Journal of Innovation Management*, 12(3):419–458, 2008.

[15] Erling Bjögvinsson, Pelle Ehn, and Per-Anders Hillgren. Design things and design thinking: Contemporary participatory design challenges. *Design Issues*, 28(3):101–116, 2012.

[16] S Bodker. Past experiences and recent challenges in participatory design research. *learning and expanding with activity theory*, pages 274–285, 2009.

[17] S.P. Borgatti, M.G. Everett, and L.C. Freeman. Ucinet for windows: Software for social network analysis. *Harvard Analytic Technologies,Harvard MA*, 2006, 2002.

[18] A. Botero, S. Vihavainen, and K. Karhu. From closed to open to what?: an exploration on community innovation principles. In *Proceedings of the 13th International MindTrek Conference: Everyday Life in the Ubiquitous Era*, pages 198–201. ACM, 2009.

[19] G. Briscoe and P. De Wilde. Digital ecosystems: Evolving service-orientated architectures. In *Bio-Inspired Models of Network, Information and Computing Systems, 2006. 1st*, pages 1–6. IEEE, 2007.

[20] Steffen Budweg, Hans Schaffers, Rudolf Ruland, Kjetil Kristensen, and Wolfgang Prinz. Enhancing collaboration in communities of professionals using a living lab approach. *Production Planning & Control*, 22(5-6):594–609, 2011.

[21] Francesco Calabrese, Kristian Kloeckl, and Carlo Ratti. Wikicity: Real-time location-sensitive tools for the city. *Handbook of research on urban informatics: The practice and promise of the real-time city*, pages 390–413, 2008.

[22] A.L.M. Cavaye. User participation in system development revisited. *Information & Management*, 28(5):311–323, 1995.

[23] E. Chang and M. West. Digital ecosystems a next generation of the collaborative environment. In *the Eight International Conference on Information Integration and Web-Based Applications & Services*, volume 214, pages 3–23, 2006.

[24] H. Chesbrough and K. Schwartz. Innovating business models with co-development partnerships. *Research-Technology Management*, 50(1):55–59, 2007.

[25] H.W. Chesbrough. *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business Press, 2003.

[26] Roger Clarke. Web 2.0 as syndication. *Journal of theoretical and applied electronic commerce research*, 3(2):30–43, 2008.

[27] Karen S Cook, Toshio Yamagishi, Coye Cheshire, Robin Cooper, Masafumi Matsuda, and Rie Mashima. Trust building via risk taking: A cross-societal experiment. *Social Psychology Quarterly*, 68(2):121–142, 2005.

[28] I. CoreLabs. Living labs roadmap 2007-2010:recommendations on networked systems for open user-driven research, development and innovation, in open document. *Luleå University of Technology-Centre for Distance-spanning Technology*, 2007.

[29] OMF De Troyer and C.J. Leune. Wsdm: a user centered design method for web sites. *Computer Networks and ISDN Systems*, 30(1):85–94, 1998.

[30] Charles R Duke. Understanding customer abilities in product concept tests. *Journal of Product & Brand Management*, 3(1):48–57, 1994.

[31] EC. Living labs for user-driven open innovation. [online]`http://ec.europa.eu/information_society/activities/livinglabs/docs/brochure_jan09_en.pdf`, January 2009. (Accessed December 14, 2011).

[32] EC. Advancing and applying living lab methodologies. [online]`http://ec.europa.eu/information_society/activities/livinglabs/docs/pdf/newwebpdf/living-lab-brochure2010_en.pdf`, July 2010. (Accessed December 14, 2011).

[33] M. Eriksson, V.P. Niitamo, and S. Kulkki. State-of-the-art in utilizing living labs approach to user-centric ict innovation–a european approach. *development*, 2005.

[34] K Feurstein, A Hesmer, KA Hribernik, KD Thoben, and J Schumacher. Living labs: a new development strategy. *Schumacher, J., Niitamo, V.-P. European Living Labs. A new approach for human centric regional innovation. Berlin*, pages 1–14, 2008.

[35] R.T. Fielding. *Architectural styles and the design of network-based software architectures*. PhD thesis, Citeseer, 2000.

[36] I.R. Floyd, M.C. Jones, D. Rathi, and M.B. Twidale. Web mash-ups and patchwork prototyping: User-driven technological innovation with web 2.0 and open source software. In *System Sciences, 2007. HICSS 2007. 40th Annual Hawaii International Conference on*, pages 86–86. Ieee, 2007.

[37] D.J. Flynn and M.D. Jazi. Constructing user requirements: a social process for a social context. *Information Systems Journal*, 8(1):53–83, 1998.

[38] A. Fölstad. Living labs for innovation and development of information and communication technology: a literature review. *The Electronic Journal for Virtual Organizations and Networks*, 10(August):99–131, 2008.

[39] A. Følstad. Towards a living lab for the development of online community services. *The Electronic Journal for Virtual Organizations and Networks*, 10:47–58, 2008.

[40] Pirjo Friedrich. *Web-based co-design: Social media tools to enhance user-centred design and innovation processes*. PhD thesis, Aalto University, 2013.

[41] Robert D Galliers. Choosing appropriate information systems research approaches: a revised taxonomy. 1992.

[42] Ilana Gershon. Seeing like a system luhmann for anthropologists. *Anthropological Theory*, 5(2):99–116, 2005.

[43] P.A. Gloor and Y. Zhao. Tecflow-a temporal communication flow visualizer for social networks analysis. In *ACM CSCW Workshop on Social Networks (ACM CSCW Conference, Chicago, 6*, 2004.

[44] Charles R Greer and David Lei. Collaborative innovation with customers: A review of the literature and suggestions for future research*. *International Journal of Management Reviews*, 14(1):63–84, 2012.

[45] G.M. Grossman and E. Helpman. *Innovation and growth in the global economy*. MIT press, 1992.

[46] A. Gruzd and C. Haythornthwaite. The analysis of online communities using interactive content-based social networks. In *Proceedings of the American Society for Information Science & Technology (ASIST) 2008 Conference*, 2008.

[47] Dominique Guinard, Vlad Trifa, Thomas Pham, and Olivier Liechti. Towards physical mashups in the web of things. In *Networked Sensing Systems (INSS), 2009 Sixth International Conference on*, pages 1–4. IEEE, 2009.

[48] Dominique Guinard, Vlad Trifa, and Erik Wilde. A resource oriented architecture for the web of things. In *Internet of Things (IOT), 2010*, pages 1–8. IEEE, 2010.

[49] Jan Gulliksen, Bengt Göransson, Inger Boivie, Stefan Blomkvist, Jenny Persson, and Åsa Cajander. Key principles for user-centred systems design. *Behaviour and Information Technology*, 22(6):397–409, 2003.

[50] A.K. Gupta, K.G. Smith, and C.E. Shalley. The interplay between exploration and exploitation. *Academy of Management Journal*, 49(4):693–706, 2006.

[51] J.K. Han, N. Kim, and R.K. Srivastava. Market orientation and organizational performance: is innovation a missing link? *The Journal of marketing*, pages 30–45, 1998.

[52] Yong Han. Development of a citizen-centric architecture approach and application to china regional healthcare platform proposal. Master's thesis, Helsinki University of Technology, 2009.

[53] M. Hasu. Critical transition from developers to users. *Activity-Theoretical Studies of Interaction and Learning in the Innovation Process. Academic Dissertation. Espoo: Otamedia Oy*, 2001.

[54] C. Haythornthwaite and A. Gruzd. A noun phrase analysis tool for mining online community conversations. *Communities and Technologies 2007*, pages 67–86, 2007.

[55] Eva Heiskanen, Sampsa Hyysalo, Tanja Kotro, and Petteri Repo. Constructing innovative users and user-inclusive innovation communities. *Technology Analysis & Strategic Management*, 22(4):495–511, 2010.

[56] J. Hempel. Tapping the wisdom of the crowd. *Business Week Online*, 27, 2007.

[57] Monika Hestad. Changing assumption for the design process–new roles of the active end user. *FORMakademisk*, 2(2), 2009.

[58] Alan R Hevner, Salvatore T March, Jinsoo Park, and Sudha Ram. Design science in information systems research. *MIS quarterly*, 28(1):75–105, 2004.

[59] Allen Higgins and Stefan Klein. Introduction to the living lab approach. In *Accelerating Global Supply Chains with IT-Innovation*, pages 31–36. Springer, 2011.

[60] M. Holst, A. Ståhlbröst, and B. Bergvall-Kåreborn. Openness in living labs: facilitating innovation. *Sort*, 20(50):100, 2010.

[61] Robert F Hurley and G Tomas M Hult. Innovation, market orientation, and organizational learning: an integration and empirical examination. *The Journal of Marketing*, pages 42–54, 1998.

[62] S. Hyysalo. Some problems in the traditional approaches to predicting the use of a technology-driven invention. *Innovation: The European Journal of Social Science Research*, 16(2):117–137, 2003.

[63] S.S. Intille, K. Larson, JS Beaudin, J. Nawyn, E.M. Tapia, and P. Kaushik. A living laboratory for the design and evaluation of ubiquitous computing technologies. In *CHI'05 extended abstracts on Human factors in computing systems*, pages 1941–1944. ACM, 2005.

[64] A. Iriberri and G. Leroy. A life-cycle perspective on online community success. *ACM Computing Surveys (CSUR)*, 41(2):1–29, 2009.

[65] R. Jain. Experiential computing. *Communications of the ACM*, 46(7):48–55, 2003.

[66] A. Jaokar and T. Fish. *Mobile Web 2.0: The innovator's guide to developing and marketing next generation wireless/mobile applications*. futuretext, 2006.

[67] Pertti Järvinen. Research questions guiding selection of an appropriate research method. In *ECIS*, pages 124–131, 2000.

[68] A.M. Kanstrup, K. Bjerge, and J.E. Kristensen. A living laboratory exploring mobile support for everyday life with diabetes. *Wireless personal communications*, 53(3):395–408, 2010.

[69] J. Karikoski and M. Nelimarkka. Measuring social relations with multiple datasets. *International Journal of Social Computing and Cyber-Physical Systems*, 1(1):98–113, 2011.

[70] C. Kidd, R. Orr, G. Abowd, C. Atkeson, I. Essa, B. MacIntyre, E. Mynatt, T. Starner, and W. Newstetter. The aware home: A living laboratory for ubiquitous computing research. *Cooperative Buildings. Integrating Information, Organizations and Architecture*, pages 191–198, 1999.

[71] JULIA KLAMMER, FRED VAN DEN ANKER, and MONIQUE JANNECK. Participatory service innovation in healthcare: the case of video consultation for paraplegics. In *ParticiPatory innovation conference*, page 285, 2011.

[72] MIYA Knights. Web 2.0 [web technologies]. *Communications Engineer*, 5(1):30–35, 2007.

[73] M. Kuikka, V.K. Tuunainen, and E. Suhonen. Motivations for and barriers to the use of social exchange in online communities: Case kassi. In *2nd Scandinavian Conference on IS & the 34th IRIS Seminar*, 2011.

[74] A. Lampinen, S. Tamminen, and A. Oulasvirta. All my people right here, right now: management of group co-presence on a social networking site. In *Proceedings of the ACM 2009 international conference on Supporting group work*, pages 281–290. ACM, 2009.

[75] Seppo Leminen. Coordination and participation in living lab networks. *Technology Innovation Management Review*, pages 5–14, 11/2013 2013.

[76] Seppo Leminen, Mika Westerlund, and Anna-Greta Nyström. Living labs as open-innovation networks. *Technology Innovation Management Review*, pages 6–11, 09/2012 2012.

[77] P. Levén and J. Holmström. Consumer co-creation and the ecology of innovation: A living lab approach. *Proceedings of IRIS31, August*, pages 10–13, 2008.

[78] Loet Leydesdorff. Luhmann, habermas, and the theory of communication. *Systems Research and Behavioral Science*, 17(3):273–288, 2000.

[79] Bram LIEVENS, Hans SCHAFFERS, Petra TURKAMA, Anna STÅHLBRÖST, and Pieter BALLON. Cross border living labs networks to support smes accessing new markets. In *eChallenges Conference Proceedings*, 2011.

[80] NAM Maiden and M. Hare. Problem domain categories in requirements engineering. *International Journal of Human-Computer Studies*, 49(3):281–304, 1998.

[81] M. Mäntylä, M. Hämäläinen, K. Karhu, A. Lampinen, K. Lehväslaiho, E. Nuutila, O. Oulasvirta, A. Pitkänen, R. Sarvas, E. Suhonen, J. Tuurunen, S. Törmä, and A. Virolainen. Sizzlelab: Building an experimentation platform for mobile social interaction. Bonn, Germany, September15-18 2009. MobileHCI'09.

[82] Salvatore T March and Gerald F Smith. Design and natural science research on information technology. *Decision support systems*, 15(4):251–266, 1995.

[83] F Molinari. Services for living labs. *Schumacher, Jens, Niitamo, Veli-Pekka (Ed.)*, 2008.

[84] I. Mulder and P.J. Stappers. Co-creating in practice: results and challenges. In *Collaborative Innovation: Emerging Technologies, Environments and Communities (Proceedings of the 15th International Conference on Concurrent Enterprising: ICE 2009, Leiden, The Netherlands, 22–24 June 2009). Centre for Concurrent Enterprise: Nottingham, UK*, 2009.

[85] I. Mulder, D. Velthausz, and M. Kriens. The living labs harmonization cube: Communicating living lab's essentials. *Ejov, The Electronic Journal for Virtual Organizations and Networks. Vol*, 10, 2008.

[86] Michael J Muller. Participatory design: the third space in hci. *Human-computer interaction: Development process*, pages 165–185, 2003.

[87] M.J. Muller and S. Kuhn. Participatory design. *Communications of the ACM*, 36(6):24–28, 1993.

[88] John Musser, Tim O'Reilly, et al. *Web 2.0: Principles and best practices*. O'Reilly Media Sebastopol, CA, 2007.

[89] F. Nachira. Towards a network of digital business ecosystems fostering the local development. 2002.

[90] F. Nachira, P. Dini, and A. Nicolai. A network of digital business ecosystems for europe: roots, processes and perspectives. *European Commission, Bruxelles, Introductory Paper*, 2007.

[91] Janine Nahapiet and Sumantra Ghoshal. Social capital, intellectual capital, and the organizational advantage. *Academy of management review*, pages 242–266, 1998.

[92] V.P. Niitamo, S. Kulkki, M. Eriksson, and K.A. Hribernik. State-of-the-art and good practice in the field of living labs. In *Proceedings of the 12th International Conference on Concurrent Enterprising: Innovative Products and Services through Collaborative Networks. Italy: Milan*, pages 26–28, 2006.

[93] Jay F Nunamaker Jr and Minder Chen. Systems development in information systems research. In *System Sciences, 1990., Proceedings of the Twenty-Third Annual Hawaii International Conference on*, volume 3, pages 631–640. IEEE, 1990.

[94] T. O reilly. What is web 2.0: Design patterns and business models for the next generation of software. *Communications and Strategies*, 65:17, 2007.

[95] J.R. Ortt and P.A. van der Duin. The evolution of innovation management towards contextual innovation. *European Journal of Innovation Management*, 11(4):522–538, 2008.

[96] OtaSizzle. Ubiquitous social media for urban communities. [online] `http://mide.tkk.fi/en/OtaSizzle`, 2011. (Accessed December 14, 2011).

[97] M. Pallot, B. Trousse, B. Senach, D. Scapin, et al. Living lab research landscape: From user centred design and user experience towards user cocreation. 2010.

[98] Corina Pascu and Marc van Lieshout. User-led, citizen innovation at the interface of services. *info*, 11(6):82–96, 2009.

[99] J. Pierson and B. Lievens. Configuring living labs for a 'thick' understanding of innovation. In *Ethnographic Praxis in Industry Conference Proceedings*, volume 2005, pages 114–127. Wiley Online Library, 2005.

[100] Maria C Powell and Mathilde Colin. Participatory paradoxes facilitating citizen engagement in science and technology from the top-down? *Bulletin of Science, Technology & Society*, 29(4):325–342, 2009.

[101] Oriana Riva and Cristian Borcea. The urbanet revolution: Sensor power to the people! *Pervasive Computing, IEEE*, 6(2):41–49, 2007.

[102] Daniel Roggen, Stephane Magnenat, Markus Waibel, and Gerhard Troster. Wearable computing. *Robotics & Automation Magazine, IEEE*, 18(2):83–95, 2011.

[103] R. Santoro and M. Conte. Living labs in open innovation functional regions. In *15th International Conference on Concurrent Enterprising. Leiden, NL*, 2009.

[104] H Schaffers and S Kulkki. Living labs: a strategy for open innovation fostering rural development. *Asia-Pacific Tech Monitor, Special Issue on Open Innovation: A New Paradigm in Innovation Management*, 2007.

[105] Hans Schaffers, Steffen Budweg, Rudolf Ruland, and Kjetil Kristensen. Collaborative environments to support professional communities: a living lab approach. In *Leveraging knowledge for innovation in collaborative networks*, pages 635–642. Springer, 2009.

[106] Hans Schaffers, Nicos Komninos, Marc Pallot, Brigitte Trousse, Michael Nilsson, and Alvaro Oliveira. Smart cities and the future internet: towards cooperation frameworks for open innovation. In *The future internet*, pages 431–446. Springer, 2011.

[107] J. Schumacher and K. Feurstein. Living labs–the user as co-creator. In *13th International Conference on Concurrent Enterprising*, pages 27–32, 2007.

[108] J. Schumpeter and U. Backhaus. The theory of economic development. *Joseph Alois Schumpeter*, pages 61–116, 2003.

[109] D. Schuurman, T. Evens, and L. De Marez. A living lab research approach for mobile tv. In *Proceedings of the seventh european conference on European interactive television conference*, pages 189–196. ACM, 2009.

[110] Jesper Simonsen and Toni Robertson. *Routledge handbook of participatory design*. Routledge, 2012.

[111] W. Simpson. The quadratic assignment procedure (qap). In *North American Stata Users' Group Meetings 2001*. Stata Users Group, 2001.

[112] R. Singh and R. Jain. From information-centric to experiential environments. *Interactive Computation*, pages 323–351, 2006.

[113] A. Ståhlbröst. *Forming future IT: the living lab way of user involvement*. PhD thesis, Luleå tekniska universitet, 2008.

[114] PJ Stappers, H. van Rijn, SC Kistemaker, AE Hennink, and F. Sleeswijk Visser. Designing for other people's strengths and motivations: Three cases using context, visions, and experiential prototypes. *Advanced Engineering Informatics*, 23(2):174–183, 2009.

[115] V. Stirbu. Towards a restful plug and play experience in the web of things. In *The IEEE International Conference on Semantic Computing*, pages 512–517. IEEE, 2008.

[116] E. Suhonen, A. Lampinen, C. Cheshire, and J. Antin. Everyday favors: a case study of a local online gift exchange system. In *Proceedings of the 16th ACM international conference on Supporting group work*, pages 11–20. ACM, 2010.

[117] J. Swan and H. Scarbrough. Knowledge, purpose and process: Linking knowledge management and innovation. In *System Sciences, 2001. Proceedings of the 34th Annual Hawaii International Conference on*, pages 10–pp. IEEE, 2001.

[118] T. Tang, Z. Wu, K. Karhu, M. Hämäläinen, and Y. Ji. An internationally distributed ubiquitous living lab innovation platform for digital ecosystem research. In *Proceedings of the International Conference on Management of Emergent Digital EcoSystems*, pages 159–165. ACM, 2010.

[119] Paul Trott. The role of market research in the development of discontinuous new products. *European Journal of Innovation Management*, 4(3):117–126, 2001.

[120] Petra Turkama. Enoll - nordic network of user-driven innovation and livinglabbing. [online]`http://www.nordicinnovation.net/_img/enoll_final_report.pdf`, August 2010. (Accessed December 14, 2011).

[121] UBISERVE. Ubiserve. [online] `http://jimup.cs.hut.fi/ubiserve`, 2011. (Accessed December 14, 2011).

[122] Carsten Ullrich, Kerstin Borau, Heng Luo, Xiaohong Tan, Liping Shen, and Ruimin Shen. Why web 2.0 is good for learning and for research: principles and prototypes. In *Proceedings of the 17th international conference on World Wide Web*, pages 705–714. ACM, 2008.

[123] H. Verkasalo. Handset-based analysis of mobile service usage. *doctoral dissertation, Helsinki University of Technology, Finland*, 2009.

[124] Sauro Vicini, Alberto Sanna, and Sara Bellini. A living lab for internet of things vending machines. In *The impact of virtual, remote, and real logistics labs*, pages 35–43. Springer, 2012.

[125] Richard Vidgen. *Developing web information systems: from strategy to implementation*. Butterworth-Heinemann, 2002.

[126] E. Von Hippel. The dominant role of users in the scientific instrument innovation process. *Research policy*, 5(3):212–239, 1976.

[127] E. Von Hippel. Lead users: a source of novel product concepts. *Management science*, pages 791–805, 1986.

[128] E. Von Hippel. *The sources of innovation*, volume 132. Oxford University Press New York, 1988.

[129] E. Von Hippel. *Democratizing innovation*. the MIT Press, 2005.

[130] E. Von Hippel and S. Thomke. Customers as innovators: A new way to create value. *Harvard Business Review*, 80(4):74–81, 2002.

[131] Y. Wang and D.R. Fesenmaier. Towards understanding members' general participation in and active contribution to an online travel community. *Tourism Management*, 25(6):709–722, 2004.

[132] Z. Wang, H. Matti, and Z. Lin. An open community approach to emergency information services during a disaster. In *2008 International Symposium on Information Science and Engieering*, pages 649–654. IEEE, 2008.

[133] S. Wasserman and K. Faust. *Social network analysis: Methods and applications*. Cambridge university press, New York, 1995.

[134] Mikael Wiberg. *The Interaction Society [: Practice, Theories and Supportive Technologies*. IGI Global, 2005.

[135] Zhenyu Wu, Timo Itala, Tingan Tang, Chunhong Zhang, Yang Ji, M Hamalainen, and Yunjie Liu. Gateway as a service: A cloud computing framework for web of things. In *Telecommunications (ICT), 2012 19th International Conference on*, pages 1–6. IEEE, 2012.

[136] Zhenyu Wu, Timo Itälä, Tingan Tang, Chunhong Zhang, Yang Ji, Matti Hämäläinen, and Yunjie Liu. A web-based two-layered integration framework for smart devices. *EURASIP Journal on Wireless Communications and Networking*, 2012(1):1–12, 2012.

[137] Y. Yoo. Computing in everyday life: A call for research on experiential computing. *MIS Quarterly*, 34(2):213–231, 2010.

[138] J. Yu, B. Benatallah, F. Casati, and F. Daniel. Understanding mashup development. *IEEE Internet Computing*, pages 44–52, 2008.

Aalto-DD 91/2014

ISBN 978-952-60-5740-8
ISBN 978-952-60-5741-5 (pdf)
ISSN-L 1799-4934
ISSN 1799-4934
ISSN 1799-4942 (pdf)

Aalto University
School of Science
Department of Computer Science and Engineering
www.aalto.fi

BUSINESS +
ECONOMY

ART +
DESIGN +
ARCHITECTURE

SCIENCE +
TECHNOLOGY

CROSSOVER

DOCTORAL
DISSERTATIONS