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Mervi Hämäläinen

Organizations' Digital Transformation

Toward a Systematic Approach to Organizations' Digital Transformation

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF INFORMATION TECHNOLOGY

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ABSTRACT

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Rapidly evolving, emerging digital technologies create opportunities for organizations, but simultaneously, organizations are hesitant to embed and deploy novel digital technologies in their activities. Organizations consider that novel digital technologies contain uncertainties and that the process of digital transformation is multifaceted and complex. This dissertation investigates organizations' digital transformation (ODT) and examines the elements that improve robust deployment of novel digital technologies within organizations. This dissertation based on qualitative research methods contributes to the literature on ODT and draws on findings from selected research papers. This dissertation presents a proposed framework for ODT formulated around four main dimensions: strategy, technology, governance, and stakeholders, each complemented by sub-elements. The ODT framework's dimensions and sub-elements have interlinked relationships, and the objective of the framework is to provide a systematic approach to carrying out ODT in an effective way. The strategy dimension highlights top management's long-term commitment and involvement in creating digital leadership and cultures that increase organizations' digital maturity to deliver digital transformation. The strategy dimension acknowledges digital technologies' impacts on organizations' processes and structures and evaluates the investment needs, risks, and disruptiveness caused by novel technologies in business models and value networks. The technology dimension focuses on digital technologies and the creation of technology experimental practices embedded in either organizations' current activities or separate business units. The technology dimension supports organizations in discovering testable business cases and considering vertical and horizontal scopes and data collection. The governance dimension refers to the robust deployment of novel digital technologies by setting measurable indicators to monitor the outcomes of digital transformation. Finally, the stakeholder dimension encompasses the relevant stakeholders, business models, and value propositions of ODT.

Keywords: Digital technology, Digital transformation, Digitalization, Organization

TIIVISTELMÄ (ABSTRACT IN FINNISH)

Hämäläinen, Mervi
Organisaation digitaalinen transformaatio – systemaattinen toimintatapa organisaation digitaalisen transformaation toteuttamiseksi
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Nopeasti kehittyvät digitaaliset ratkaisut avaavat uusia mahdollisuuksia organisaatioiden toiminnan tehostamiseksi ja kehittämiseksi. Uudet digitaaliset palvelut ja alustat mahdollistavat esim. uusien liiketoimintamallien ja arvonluontimahdollisuuksien kehittämisen globaalilla tasolla. Kuitenkin monissa organisaatioissa uudet digitaaliset innovaatiot herättävät epäilyksiä. Nopean kehityssyklin johdosta uusiin digitaalisiin innovaatioihin kohdistuu paljon epävarmuustekijöitä ja organisaatiot kokevat uuden teknologian integroimisen organisaation toimintaan, sen rakenteisiin ja prosesseihin monimutkaiseksi.

Väitöskirjassa esitetään toimintamalli organisaation kokonaisvaltaisen digitaalisen transformaation toteuttamiseksi. Toimintamallin tarkoituksena on tuoda esiin näkökulmia, jotka edistävät organisaation digitaalista muutosprosessia ja madaltavat uusien digitaalisten innovaatioiden käyttöönottoa. Toimintamallin avulla organisaatio voi uudistaa toimintaansa systemaattisesti epävarmuustekijät huomioiden ja riskejä minimoiden.

Organisaation digitaalinen transformaatio -toimintamalli koostuu neljästä keskeisestä osa-alueesta strategia, teknologia, johtaminen ja hallinta sekä sidosryhmäyhteistyö. Toimintamallin keskeisiä osa-alueita on täydennetty kuhunkin teemaan oleellisesti liittyvillä osatekijöillä. Strategia osa-alue painottaa mm. organisaation ylimmän johdon osallisuutta ja sitoutumista pitkäaikaisen digitaalisen transformaation läpiviemiseksi. Organisaation ylin johto on myös keskeisessä roolissa organisaation digitaalisen kyvykkyyden sekä organisaatiokulttuurin kehittämisessä, jotka tukevat organisaation digitaalista uudistamista. Teknologia osa-alue arvioi olemassa olevia sekä uusia nousevia digitaalisia innovaatioita sekä niiden mahdollisia vaikutuksia organisaation toiminaan. Teknologia teema ottaa myös kantaa digitaalisten ratkaisujen testaus- ja kokeilukäytänteiden kehittämisestä sekä teknologiakokeilujen ja niiden tulosten jalkauttamisesta organisaation varsinaisiin toimintoihin. Toimintamallin johtaminen ja hallinta osa-alue vastaa organisaation digitaalisen uudistamisen systemaattisesta toteuttamisesta, käytännön toimeenpanemisesta ja hallinnasta sekä avaintulosmittareiden kehittämisestä. Johtaminen ja hallinta osa-alue johtaa ja hallinnoi digitaalisen uudistamisen sidosryhmäyhteistyötä sekä valvoo yhteisten tavoitteiden ja tulosten toteutumista. Sidosryhmä osa-alue tarkastelee digitaalisen transformaation vaikutuksia olemassa oleviin sidosryhmiin, mutta arvioi myös uusia toimijoita sekä sidosryhmiä digitaalisesti uudistuvassa toimintaympäristössä. Sidosryhmä osa-alue arvioi uusia liiketoiminta- sekä arvonluontimahdollisuuksia sekä perinteisessä että digitaalisessa toimintaympäristössä.

Väitöskirja on toteutettu laadullisen tutkimusmenetelmän periaatteita noudattaen. Tutkimus lisää teoreettista ymmärrystä organisaation monimutkaisesta digitaalisesta transformaatiosta sekä antaa käytännönläheisen ja systemaattisen näkökulman organisaation uudistamiseen digitaalisten työkalujen avulla.

Avainsanat: Digitaalinen teknologia, Digitaalinen transformaatio, Digitalisaatio, Organisaatio

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It always seems impossible until it is done. —Nelson Mandela

Writing a dissertation is like running a marathon. The first thought is that the journey is impossible to accomplish, but gradually, the vision gets brighter, and the motivation becomes strong enough to set off on the journey and think, "Yes, I can do it." Between practice and hard work, frustration and uncertainty, the bright vision and passion provide fuel to continue the long, sometimes lonely ride, but ultimately, it is the guidance of peers and support of loved ones that give one the wings to accomplish this mission that seems impossible until it is done.

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Helsinki, November 3, 2019 Mervi Hämäläinen

LIST OF INCLUDED ARTICLES

1. Hämäläinen, M., & Ojala, A. (2015). Additive manufacturing technology: identifying value potential in additive manufacturing stakeholder groups and business networks. In *AMCIS 2015: Proceedings of the Twenty-First Americas Conference on Information Systems*.
2. Hämäläinen, M., & Ojala, A. (2017). 3D printing: challenging existing business models. In A. Khare, B. Stewart, & R. Schatz (Eds.), *Phantom ex machina: digital disruption's role in business model transformation* (pp. 163–174). Springer Cham.
3. Manikas, K., Hämäläinen, M., & Tyrväinen, P. (2016). Designing, developing, and implementing software ecosystems: towards a step-wise guide. In S. Jansen, C. Alves, & J. Bosch (Eds.), *IWSECO 2016: Proceedings of the 8th International Workshop on Software Ecosystems* (pp. 70-79).
4. Hämäläinen, M., & Tyrväinen, P. (2016). A framework for IoT service experiment platforms in smart-city environments. In *ISC2 2016: IEEE Second International Smart Cities Conference. Improving the citizens' quality of life. Proceedings* (pp. 664–671). IEEE.
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FIGURE

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1 INTRODUCTION

When digital transformation is done right, it's like a caterpillar turning into a butterfly, but when done wrong, all you have is a really fast caterpillar.[1]

Ubiquitous digital infrastructures and novel digital technologies have integral roles in modern societies. On the societal level, for instance, the European Union (EU) has identified several policy areas to foster digital transformation in member countries. The aims of the EU's digital transformation policies are to strengthen traditional industries in Europe and to create digital capabilities to seize opportunities and innovations that advanced digital technologies enable for organizations and individuals. EU has paid special attention to European cities, which are seen as enablers of digital transformation on local levels. European cities are encouraged to support local businesses, public organizations, and administrations in the digital transformation process by providing funding for so-called smart city development. (European Commission, 2018.)

In the private sector, pervasive digital infrastructures and technologies have enabled the emergence of new digital platforms and ecosystems with new business models, customer experiences, and value creation possibilities. Companies such as Trivago, Spotify, and Netflix are examples of companies that operate purely in digital environments and offer digital services globally through digital platforms. These companies, along with other digital players, have drastically changed business models, for example, in the tourism, music, and entertainment industries.

Rapid digital evolution and new digital innovations have also challenged the status quo of strong incumbents. Nearly a decade ago, players in telecommunication industry witnessed how competitors' unorthodox, out-of-box thinking proved to be fatal for the giant mobile phone manufacturer Nokia Corporation. Rival companies Apple and Google challenged Nokia by revolutionizing user expectations with the new iPhone mobile phone and the Android operating system. By taking user experiences to a completely new level and introducing new business models with digital ecosystem platforms, Apple

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1 George Westerman, 2014.

and Google both displaced Nokia from its market-leading position in a relatively short period of time. (Siilasmaa, 2018; Vuori & Huy, 2018.) Nokia's myopic, arrogant approach, combined with path-dependent strategic choices, ended its saga as a world-leading mobile phone manufacturer (Siilasmaa, 2018).

Information systems have become integral parts of modern societies, and digital solutions are increasingly embedded in organizations' daily operations and activities, so the phenomenon of digital transformation has been perceived as a paradigm shift (Berman & Marshall, 2014). Digital transformation can be understood *"as the changes that the digital technology causes or influences in all aspects of human life"* (Stolterman & Fors, 2004, p. 689). It should be further noted that novel digital technologies and innovations may contain radical and disruptive features (Morakanyane, Grace, & O'Reilly, 2017) that have potential to generate systemic impacts, change the trajectories of technologies and user preferences, and revolutionize the status quo of established businesses, value networks, and even whole industries (Au, Tan, Leong, & Ge, 2018; Carlo, Lyytinen, & Rose, 2011; Gimpel et al., 2018; Skog, Wimelius, & Sandberg, 2018; Weill & Woerner, 2015).

It has also been perceived organizations' digital transformation (ODT) is not a trivial procedure. Digital transformation is recognized to be multifaceted, complex, and uncertain (Davenport & Westerman, 2018; Hess et al., 2016; Sahu, Deng, & Mollah, 2018; Tabrizi et al., 2019). It can have influences on organizations' resources, capabilities, processes, structures, and investment needs, for example. Furthermore, it has been found that organizations' digital transformation affects their cultures, digital maturity, users, value creation, business models, and stakeholders in their value networks. (Chanias & Hess, 2016a and 2016b; Morakanyane, Grace, & O'Reilly, 2017.) With multifaceted digital transformation subjected to uncertainties, a more holistic, systematic overview of ODT is needed (Kutzner, Schoormann, & Knackstedt, 2018).

This dissertation is positioned to respond to this call and consider the phenomenon of digital transformation from socio-technical perspectives. This research examines the interplay of novel digital technologies and organizations. The research aims are to extend knowledge of ODT and to provide a systematic approach to conduct digital transformation in organizations. The dissertation research identifies elements relevant to ODT and means to systematically carry out digital transformation within organizations. Digital transformation is seen as a paradigm shift, and digital innovations may generate systemic, disruptive impacts, so this dissertation also considers the disruptiveness of digital transformation within organizations' business models, value creation, and value networks.

This research centers on the concepts of digital technologies, digitalization, and digital transformation. This dissertation also provides an overview of technology discontinuities, digital innovations, and the theory of disruptive innovations. It also discusses technology testing and experimental practices and smart cities based on research conducted in so-called smart city contexts and private organizations operating in heavy industry. The concept of the smart city is used to illustrate how the conventional city can transform its organization into a smart city by utilizing novel digital technologies and solutions. The research was partly performed in Finnish smart cities. The rest of the research was conducted in companies operating in the Finnish heavy metal industry and focused on three-dimensional (3D) printing technology's influences on companies' business models, value creation, and stakeholders.

The next Chapter 1.1 presents the identified challenges organizations face when confronting novel digital technologies in the market. The phenomenon of digital transformation in information systems research is discussed in Chapter 1.2. A presentation of the research objectives and the organization of the dissertation conclude Chapter 1.

1.1 Challenges of organizations' digital transformation

Digital infrastructures and technologies are widely diffused through our societies and are distinct parts of organizations' activities (Deloitte, 2019; Fitzgerald et al., 2014). However, organizations seem to have challenges confronting new, emerging digital technologies and game-changing innovations such as big data, data analytics, machine learning, and embedded sensor technologies (Sebastian et al., 2017; Singh & Hess, 2017). Identified challenges concern, for example, governance and leadership issues and, alternatively, organizations' digital maturity levels and cultures that do not support implementation of novel digital technologies (Berghaus & Back, 2016; Grover, Kohli, & Ramanlal, 2018).

Recent studies have revealed executives' major concerns associated with rapidly advancing digital technologies and the threat of new, "born-digital" competitors in the market. Chief executive officers (CEOs) are concerned about their organizations' agility and ability to adopt new digital technologies such as big data and data analytics in a timely manner to gain competitive advantages, for example, compared nimble digital native ventures. CEOs also worry about meeting performance expectations for existing operations and legacy information technology (IT) infrastructure, as well as attracting and retaining top talents. (Kappelman et al., 2018; North Caroline State University & Protiviti, 2018.)

Deloitte's (2019) *Industry 4.0 Paradox* report showed that digital transformation is organizations' top strategic priority despite certain paradoxes involving, for example, organizations' strategy, culture, and resources such as talents. For example, companies might believe they have right skills and talents in place to support digital transformation, but simultaneously, they consider finding and engaging the right talents to be challenging. Additionally, due to organizational inertia and defensive mindsets, digital transformation is regarded as a matter of improving and maintaining current processes, offerings, and profitability rather than discovering new possibilities for innovations and business models. (Deloitte Review, 2019.)

As in smart cities, public organizations' digital initiatives face not only technical but also political, organizational and managerial obstacles (Nam &

Pardo, 2011; Naphade et al., 2011). Weak management, a lack of technical skills to govern digital initiatives, and insufficient models for sustainable value creation for stakeholders in smart city ecosystems have been identified as reasons preventing city organizations from fully implementing and achieving the benefits emerging digital technologies produce (Scuotto, Ferraris, & Bresciani, 2016; Vilajosana et al., 2013; Veeckman & van der Graaf, 2015). Digital-technology-infused cities also face certain risks, particularly related to security and privacy, and if not well managed, these risks may materialize and result in severe consequences for city operations (Naphade et al., 2011).

1.2 Organizations' digital transformation in Information Systems (IS) research

Sidorova et al. (2008) identified five significant research areas in information systems sciences: IT and organizations, IS development, IT and individuals, IT and markets, and IT and groups. Over the decades, IS research has evolved from focusing on technology to exploring the relationships and influences of IT on organizations' elements (e.g., structures, processes, performance, and culture; Melville, Kraemer, & Gurbaxani, 2004; Raymond, 2011) and organizations' internal and external value networks (e.g., users, suppliers, and customers; Davis, 2000). IT and organizational change have been compelling research topics in the IS research field (Raymond, 2011) because information systems form interdependencies between technology and human agencies (Picot & Baumann, 2009). According to Orlikowski and Baroudi (1991), the major goal of information systems research is to improve the development and use of information systems within organizations. Moreover, the fundamental knowledge of interest in IS research is how information systems as "semiotic and sociotechnical systems can be effectively deployed in the human enterprise" (Grover & Lyytinen, 2015, p. 272). However, it has been stated that the major challenge of IS research is to study the overall effects of the digital transformation occurring in our societies (Stolterman & Fors, 2004).

The concept of digital transformation has technology, organization, and social dimensions (Reis et al., 2018), so digital transformation appears to be an emerging, attractive phenomenon in IS research and among IS scholars. As an illustration of the evolution of the concept, the AIS eLibrary database provides hints of this upward trend. Searching for the key word "digital transformation" returns 37 search results for the years 2010–2012 but 87 results for 2013–2015. The search results increase drastically during 2016–2018, reaching 594 for the term "digital transformation." IS publications such as *MIS Quarterly Executive*, *Business & Information Systems Engineering*, and *Communications of the Association for Information Systems* are the leading publishers of digital-transformation-related articles. Digital transformation seems to be a rising phenomenon in IS research, providing motivation to observe the phenomenon in greater detail and depth.

1.3 Research objectives

Considering the challenges presented in section 1.1 and the pervasiveness of digital transformation, this dissertation is positioned to explore digital transformation in organizations operating in the private and public sectors. This dissertation is aimed at developing a systematic approach to ODT through the following research objectives:

RO1. Which elements form the foundation of ODT?
RO2. How can organizations take control of their digital transformation?

The aim of RO1 is to identify the elements that influence ODT. RO2 investigates the ways in which organizations systematically address and carry out digital transformation. Both research objectives are intended, first, to improve organizations' ability to effectively adopt and implement novel digital technologies and, second, to help organizations achieve the set objectives of digital transformation. This dissertation is intended to achieve these research objectives, as well as present the prior theoretical literature and selected research papers.

1.4 Organization of the dissertation

This dissertation and its chapters center on six research articles. The dissertation is structured into five main chapters. Chapter 1 provides the background for the dissertation. Chapter 2 outlines the theoretical background of the concepts of digital technologies, digitalization, digital transformation, and technology discontinuities. A discussion on disruptive innovation theory, disruptive digital innovation, technology testing and experimental practices, and smart cities as platforms for digital technology experiments concludes chapter 2. Chapter 3 presents the research objectives, methodology, and data analysis. Chapter 4 provides an overview of the six research articles. Chapter 5 presents the results and contributions to theory and practice, along with the research limitations and recommendations for future studies.

2 THEORETICAL BACKGROUND

The body of knowledge of this dissertation is derived from the literature. This chapter commences by briefly introducing concepts of digital technologies and digitalization. Section 2.3 explores the digital transformation phenomenon from the perspectives of organizations and businesses. The rationale of technology discontinuities and digital innovations is presented in sections 2.4 and 2.5. The theory of disruptive innovation extends the perspective of disruptive innovation and considers its influences on organizations' critical functions such as strategic choices, business models, and stakeholders, including customers and suppliers. A discussion on technology testing and experimental practices and smart cities as platforms for technology experiments concludes the chapter.

2.1 Digital technologies

The transition from analog to digital technologies laid the foundation for novel digital technologies. The ability to convert analog signals into digital formats allowed the emergence of more powerful, less costly networks and devices, which accelerated innovations in the areas of digital technologies, devices, and infrastructures. (Tilson, Lyytinen, & Sørensen, 2010.) The emergence of a ubiquitous digital infrastructure has supported the development of fashionable, nascent digital technologies and services. Wang (2010) defined fashionable IT as a transitory, collective belief that IT is new, efficient, and at the forefront of practice. However, not all emerging digital technologies are beneficial and provide long-lasting value. Over time, nascent digital technology is either diffused and adopted in a market or wiped out if its utility and value expectations are not met (Wang, 2010). International consulting companies such as Deloitte and Gartner prepare yearly forecasts for technology trends. Digital technologies such as 3D and four-dimensional (4D) printing, augmented and virtual reality, machine learning, autonomous vehicles, smart robots, cloud computing, sensor technologies, and big data have dominated the lists of digital technology trends

(Deloitte, 2019; Gartner, 2018a, 2018b). Acronyms such as SMAC and SMACIT (social, mobile, analytics, cloud, and the Internet of Things) have been used to refer the latest novel digital technologies (Berman & Marshall, 2014; Gimpel et al., 2018; Sebastian et al., 2017).

Moreover, 3D printing technology is based on digital computer-aided design (Liu & Zhou, 2010), which allows producing unique, complex 3D physical objects by adding materials with layer-by-layer technique (Petrick & Simpson, 2013). Similarly, 4D printing follows 3D printing procedures, but so-called smart materials are used in the 4D printing process. Smart materials have the ability to change the geometry, functions, and properties of 3D printed objects when affected by external stimuli such as temperature, water, and light (Choi et al., 2015; Khoo et al., 2015). The use of smart materials in 4D printing remains in its infancy, but interest and efforts to develop programmable and self-assembly smart materials for industrial use exist (Massachusetts Institute of Technology (MIT) Self-Assembly Lab, 2018). Cloud-based technologies, for example, enable sharing on-demand computing capabilities for multiple users over the Internet (Mell & Grance, 2011). The Internet of Things (IoT) refers to sensor technologies such as tags, sensors, and actuators that form a pervasive network of Internet-connected devices collecting data from our surroundings (Atzori, Iera, & Morabito, 2010). Data, indeed, are raw materials for data analytics and are needed to develop machine learning and artificial intelligence practices.

Recently, blockchain and 5G technologies have attracted interest in diverse industries. Blockchain technology was primarily introduced in the context of cryptocurrencies but recently has been proven to streamline real-time payment transactions and improve transparency and cost savings, especially in the banking sector (Glaser, 2017; Guo & Liang, 2016). Using high-carrier frequencies, 5G cellular networks are promised to enhance digital services' quality and device density and connectivity. In particular, 5G networks can support the deployment and diffusion of IoT and sensor technologies. However, 5G technology is still evolving, and its diffusion has been delayed by technology restrictions, along with energy efficiency, regulation, and standardization issues. (Andrews et al., 2014; Boccardi et al., 2014.)

2.2 Digitalization

Digitalization refers to encoding analog information into digital formats (Yoo, 2012) and is defined as a sociotechnical process that considers the adoption of digitized or digital technologies and innovations in individual, organizational, and societal contexts (Legner et al., 2017; Tilson, Lyytinen, & Sørensen, 2010). Digitalization also reflects socioeconomic perspectives on digital technologies and the ways in which their use results in the growth of industries, global economies, employment, and overall human well-being (Katz, 2017). Cheaper, smaller, more powerful digital devices, along with general-purpose digital networks, underlie the phenomenon of digitalization. It has been argued that properties such as the pervasiveness, scalability, and flexibility of digital infrastructures are fundamental to perceiving the impacts of digitalization (Tilson, Lyytinen, & Sørensen, 2010). Pervasive, scalable, flexible digital infrastructures enable individuals and organizations of all sizes and from all backgrounds to develop new business models and deliver digital offerings through global digital platforms and channels more quickly and cheaply than ever before. Simultaneously, pervasive digital infrastructures have accelerated adoption of new digital technologies, services, and applications at a speed that never seen before. (El Sawy et al., 2016; Gimpel et al., 2018; Tilson, Lyytinen, & Sørensen, 2010.)

Digitalization increases the connectedness among diverse entities. Cyber-physical systems allow imperceptible connections and communication among individuals, organizations, and objects. These interconnected entities generate data perceived to be a source of new knowledge extending understanding of living conditions, surroundings, behavior, and preferences. Data are seen valuable for new value propositions and business model design and allow organizations to make more far-reaching estimations and predictions. Digital technologies thus are excellent means for generating, collecting, storing, processing, and analyzing data to benefit individuals and organizations. (Davis et al., 2017; Gimpel et al., 2018.)

2.3 Digital transformation—dimensions and elements

The concept of digital transformation frequently appears as an equivalent concept as the notion of digitalization (Henriette, Feki, & Boughzala, 2016; Reis et al., 2018). Transformation is characterized by the magnitude of change as a radical shift from a dominant position to another state of being. Transformation has been found to result in significant changes in cultures, behaviors, and mindsets because it influences individuals and organizations and alters how they see themselves and other actors in business networks and the world as a whole. (Anderson & Anderson, 2002; Manzoni et al., 2017.)

Digital transformation is perceived as a paradigm shift (Berman & Marshall, 2014) resulting in "the changes that the digital technology causes or influences in all aspects of human life" (Stolterman & Fors, 2004, p. 689). The evolution of digital technologies has become increasingly embedded in social areas (Legner et al., 2017; Tilson, Lyytinen, & Sørensen, 2010) and may also be driven by individual persons (Legner et al., 2017). Digital transformation is also understood to be "technology-induced change" (Legner et al., 2017, p. 306) with potentially radical and disruptive features (Morakanyane, Grace, & O'Reilly, 2017) that revolutionize prevailing practices by disrupting the trajectories of established businesses and changing the structures of industries and value networks (Au et al., 2018; Gimpel et al., 2018; Weill & Woerner, 2015). Digital transformation offers a way to change traditional business activities (Davenport & Westerman, 2018). Characteristically, the process of digital transformation and implementation of digital technologies is multifaceted, complex, and uncertain (Davenport & Westerman, 2018; Hess et al., 2016; Sahu, Deng, & Mollah, 2018; Tabrizi et al., 2019).

Prior literature reviews conducted by on the concept of digital transformation have focused on certain central attributes like strategy, operational processes, skills, capabilities, culture, and information and digital technologies. These attributes represent organizational perspectives on digital transformation. Other elements such as customers, user experiences, value creation, and business models encompass the business aspects of digital transformation. The disruption and disruptiveness of digital innovations have also been covered in literature reviews on digital transformation. (Gerster, 2017; Henriette, Feki, & Boughzala, 2016; Morakanyane, Grace, & O'Reilly, 2017; Kutzner, Schoormann, & Knackstedt, 2018.)

In the following section, the prior literature is extended, and the elements that influence ODT are summarized and categorized into the organizational and business dimensions. The two dimensions are presented, and their elements are more closely described.

2.3.1 Organizational dimensions and elements

It has been argued strategy, not technology, drives digital transformation (Kane et al., 2015; Tabrizi et al., 2019). This argument has been justified by the reality that digitalization and digital transformation have ubiquitous impacts on industries' and organizations' structures, internal, and external functions and value networks. It, therefore, has been emphasized that organizations should have a strategic focus on how to carry out long-term digital transformation within themselves. (Chanias & Hess, 2016a; Henriette, Feki, & Boughzala, 2016; Hess et al., 2016; Kane et al., 2015; Legner et al., 2017; Matt, Hess, & Benlian, 2015; Ross, Beath, & Sebastian, 2017; Sebastian et al., 2017; Tabrizi et al., 2019.) Traditionally, organizations have developed IT strategies to manage IT infrastructures, tools, applications, and services (Gerster, 2017; Hess et al., 2016) that support organizations' functions and processes (Teubner, 2013).

Differentiated from IT strategy, notions of digital business strategy, digital transformation strategy, and digital strategy are used to refer to organizations' strategic focus on how to implement digital technologies and transformation within themselves and their value networks (Bharadwaj et al., 2013; Kane et al., 2015; Matt, Hess, & Benlian, 2015; Mithas, Tafti, & Mitchell, 2013; Pagani, 2013; Ross et al., 2016). Digital business and transformation strategies reflect businesses' perspectives on digital transformation and consider the technical and human resources and capabilities required to digitalize organizations' structures, products, services, processes, and business models (Table 1). Digital business and transformation strategies take into account how organizations create and deliver differential value for vital stakeholders such as customers and actors in their value networks. (Bharadwaj et al., 2013; Matt, Hess, & Benlian, 2015; Pagani, 2013; Ross et al., 2016.)

Table 1 Digital transformation: organizational elements

Organizational elements	**Authors**
Change management and governance	Chanias (2017); Chanias and Hess (2016); Haffke, Kalgovas, and Benlian (2017); Matt, Hess, and Benlian (2015); Tabrizi et al. (2019); Wulf, Mettler and Brenner (2017)
Culture	Alfaro et al. (2019); Chanias (2017); Dery, Sebastian, and van der Meulen (2017); Eden et al. (2019); Gust et al. (2017); Haffke, Kalgovas, and Benlian (2017); Kane et al. (2015); Kutzner, Schoormann, and Knackstedt (2018); Morakanyane, Grace, and O'Reilly (2017); Singh and Hess (2017); Tabrizi et al. (2019); Tumbas, Berente, and vom Brocke (2017)
Data	Alfaro et al. (2019); Berman and Marshall (2014); Davenport and Westerman (2018); Goul (2018); Gust et al. (2017); Legner et al. (2017); Ross, Beath, and Sebastian (2017); Sahu, Deng and Mollah (2018); Sebastian et al. (2017); Tabrizi et al. (2019); Westerman, Bonnet, and McAffee (2014); Westerman and Bonnet (2015)
Digital maturity	Davenport and Westerman (2018); Fitzgerald et al. (2014); Haffke, Kalgovas, and Benlian (2017); Hess et al. (2016); Kane et al. (2015); Kutzner, Schoormann, and Knackstedt (2018); Matt, Hess, and Benlian (2015); Morakanyane, Grace, and O'Reilly (2017); Remane et al. (2017); Singh and Hess (2017); Westerman, Bonnet, and McAffee (2014)
Digital strategy (strategy)	Dery, Sebastian, and van der Meulen (2017); Gerster (2017); Gimbel et al. (2018); Goul (2018); Haffke, Kalgovas, and Benlian (2017); Hess et al. (2016); Kutzner, Schoormann, and Knackstedt (2018); Legner et al. (2017); Matt, Hess, and Benlian (2015); Morakanyane, Grace, and O'Reilly (2017); Ross, Beath, and Sebastian (2017); Sebastian et al. (2017); Tabrizi et al. (2019); Tumbas, Berente, and vom Brocke (2017); Wulf, Mettler, and Brenner (2017)
Digital technologies	Alfaro et al. (2019); Henriette, Feki, and Boughzala (2016); Goul (2018); Gust et al. (2017); Hess et al. (2016); Kane et al. (2015); Kutzner, Schoormann, and Knackstedt (2018); Matt, Hess, and Benlian (2015); Morakanyane, Grace, and O'Reilly (2017); Sahu, Deng, and Mollah (2018); Singh and Hess (2017); Tumbas, Berente, and vom Brocke (2017); Westerman and Bonnet (2015)
Disruptiveness	Berman and Marshall (2014); Chanias (2017); Dery, Sebastian, and van der Meulen (2017); Gerster (2017); Gimbel et al. (2018); Gust et al. (2017); Henriette, Feki, and Boughzala (2016); Legner et al. (2017); Morakanyane, Grace, and O'Reilly (2017); Pagani (2013); Remane et al. (2017); Sahu, Deng, and Mollah (2018); Sebastian et al. (2017); Singh and Hess (2017); Skog et al. (2018); Weill and Woerner (2015); Wessel (2017); Westerman, Bonnet, and McAffee (2014)
Finance, investments, investors	Berman and Marshall (2014); Chanias (2017); Chanias and Hess (2016); Davenport and Westerman (2018); Dery, Sebastian, and van der Meulen (2017); Goul (2018); Gust et al. (2017); Hess et al. (2016); Matt, Hess, and Benlian (2015); Ross, Beath, and Sebastian (2017); Sebastian et al. (2017); Tabrizi et al. (2019); Tumbas, Berente, and vom Brocke (2017); Weill and Woerner (2015)

Leadership and top management involvement, right mindset	Alfaro et al. (2019); Chanias (2017); Chanias and Hess (2016); Dery, Sebastian, and van der Meulen (2017); Eden et al. (2019); El Sawy et al. (2016); Fitzgerald et al. (2014); Gust et al. (2017); Kane et al. (2015); Legner et al. (2017); Matt, Hess, and Benlian (2015); Sebastian et al. (2017); Singh and Hess (2017); Sebastian et al. (2017); Tabrizi et al. (2019); Tumbas, Berente, and vom Brocke (2017); Westerman, Bonnet, and McAffee (2014); Westerman and Bonnet (2015); Wulf, Mettler, and Brenner (2017)
Monitoring, performance indicators	Alfaro et al. (2019); Chanias (2017); Chanias and Hess (2016); Haffke, Kalgovas, and Benlian (2017); Fitzgerald et al. (2014); Matt, Hess, and Benlian (2015); Weill and Woerner (2015); Wulf, Mettler, and Brenner (2017
Risks	Gust et al. (2017); Kane et al. (2015); Singh and Hess (2017); Tabrizi et al. (2019)
Process	Alfaro et al. (2019); Chanias (2017); Davenport and Westerman (2018); Eden et al. (2019); Henriette, Feki, and Boughzala (2016); Kane et al. (2015); Kutzner, Schoormann, and Knackstedt (2018); Legner et al. (2017); Matt, Hess, and Benlian (2015); Morakanyane, Grace, and O'Reilly (2017); Sahu, Deng, and Mollah (2018); Tumbas, Berente, and vom Brocke (2017); Westerman, Bonnet, and McAffee (2014); Westerman and Bonnet (2015)
Skills and capabilities	Alfaro et al. (2019); Berman and Marshall (2014); Chanias (2017); Chanias and Hess (2016); Davenport and Westerman (2018); Dery, Sebastian, and van der Meulen (2017); Eden et al. (2019); El Sawy et al. (2016); Gimpel et al. (2018); Gust et al. (2017); Haffke, Kalgovas, and Benlian (2017); Henriette, Feki, and Boughzala (2016); Hess et al. (2016); Kane et al. (2015); Legner et al. (2017); Matt, Hess, and Benlian (2015); Morakanyane, Grace, and O'Reilly (2017); Ross, Beath and Sebastian (2017); Sebastian et al. (2017); Singh and Hess (2017); Tabrizi et al. (2019); Tumbas, Berente, and vom Brocke (2017); Weill and Woerner (2015); Wulf, Mettler, and Brenner (2017)
Structure	Hess et al. (2016); Matt, Hess, and Benlian (2015); Legner et al. (2017); Westerman and Bonnet (2015)

To simplify the concepts of digital business and transformation strategies, the notion of digital strategy is applied in the dissertation to describe the strategic measures organizations need to consider when deploying novel digital technologies in their structures and activities. A digital strategy thus is the holistic view top management adopts to evaluate, manage, and govern the digital transformation journey (Chanias & Hess, 2016a). More specifically, a digital strategy helps organizations consider the use of digital technologies and reflect on the pervasive changes and potential disruption that implementation of digital technologies can cause for organizations (Chanias & Hess, 2016a; Gimbel et al., 2018; Matt, Hess, & Benlian, 2015). The purpose of a digital strategy is to enable organizations to systematically address the directions of digital transformation and to improve themselves to lead and set measurable objectives for digital transformation (Chanias & Hess, 2016a; Kane et al., 2015; Ross, Beath, & Sebastian, 2017). A digital strategy helps management evaluate organizations' digital maturity and the progress of digital transformation (Kane et al., 2015; Matt, Hess, & Benlian, 2015). A digital strategy also enables organizations to prioritize and coordinate alternative digital pathways for digital technologies' implementation (Matt, Hess, & Benlian, 2015).

A digital strategy also considers the influences of digital transformation on organizations' structures, processes, stakeholders, value networks, sales channels, value creation, business models (Hess et al., 2016; Legner et al., 2017; Matt, Hess, & Benlian, 2015; Morakanyane, Grace, & O'Reilly, 2017; Prince, 2017; Rauch, Wenzel, & Wagner, 2016; Sebastian et al., 2017; Singh & Hess, 2017), and customer and user experiences (Henriette, Feki, & Boughzala, 2016; Sahu, Deng, & Mollah, 2018; Singh & Hess, 2017; Weill & Woerner, 2015). A digital strategy identifies the capabilities and resources such as leadership and management skills needed to carry out the changes digital transformation requires (Hess et al., 2016; Matt, Hess, & Benlian, 2015; Ross, Beath, & Sebastian, 2017; Singh & Hess, 2017; Sebastian et al., 2017). A digital strategy assesses the need for separate business units to experiment with digital technologies and digital transformation implementation. A digital strategy reviews the financial and investment needs and sets indicators to measure the performance and outcomes of digital transformation. (Chanias, 2017; Tabrizi et. al., 2019; Wulf, Mettler & Brenner, 2017.)

Prior research has determined that executives' roles and support are critical for the success of organizations' IT implementation (Järvenpää & Ives, 1991). Digital transformation demands visionary leadership with fresh mindsets and skills (Chanias & Hess, 2016a; El Sawy et al., 2016; Fitzgerald et al., 2014; Kane et al., 2015; Westerman, Bonnet, & McAffee, 2014). El Sawy et al. (2016, p. 141) defined digital leadership as "doing the right things for the strategic success of digitalization for the enterprise and its business ecosystem." Digital leadership considers upgrading organizations' digital skills (El Sawy et al., 2016; Legner et al., 2017), which, together with technology and business capabilities, form the operational backbone for efficient digital transformation and digital strategy implementation within organizations (Sebastian et al., 2017). Strong digital leadership fosters an organization-wide culture that supports the digital transformation process and reduces internal resistance and barriers to organizations' digitalization efforts (Gimpel et al., 2018; Kane et al., 2017; Singh & Hess, 2017; Tabrizi et al., 2019). Strong digital leadership also clarifies the governance of digital transformation and supports change management within the organization (Chanias, 2017; Gimpel et al., 2018).

Traditionally, the chief information officer (CIO) has been responsible for organizations' IT infrastructures, architectures, and internal business processes. The rapid diffusion of new digital technologies and their pervasive use in organizations' activities have extended the CIO's role to consider business perspectives on digital transformation such as the customer experience and new business model innovation. (El Sawy et al., 2016; Gimpel et al., 2018; Hess et al., 2016; Matt, Hess, & Benlian, 2015; Singh & Hess, 2017.) Some organizations, however, have separated the CIO's role from business issues and established a new position: the chief digital or transformation officer (CDO/CTO), who addresses business perspectives and supports top management in digital strategy and transformation (El Sawy et al., 2016; Hess et al., 2016; Gimpel et al., 2018; Legner et al., 2018; Singh & Hess, 2017). The CDO/CTO's role is to design a holistic, integrated vision for digital transformation, orchestrate digital initiatives, and enhance cross-functional collaboration with organizations' stakeholders (Gimpel et al., 2018; Singh & Hess, 2017). The CDO/CTO has a central role in developing digital capabilities, delivering new digital customer experiences, and discovering new business and value creation opportunities. The CDO/CTO and the CIO closely collaborate to achieve the targets set for digital transformation. (Gimpel et al., 2018; Singh & Hess, 2017; Weill & Woerner, 2015.)

Sing and Hess (2017) identified evaluating ODT maturity as one part of the CDO's role. Digital maturity reflects "the status of the company's digital transformation," particularly the achievements of the organization's digital transformation efforts (Chanias & Hess, 2016b, p. 4). Remane et al. (2017) argued that digital transformation is context- and organization-specific, and organizations' digital maturity should not be evaluated linearly. Instead, they suggested evaluating how digital transformation affects organizations' functions and estimating organizations' readiness to manage digital transformation and change (Remane et al., 2017). Davenport and Westerman (2018) even emphasized evaluating the readiness of the entire industry, customers, and competitors. Digital maturity enables organizations to reassess their digital strategy and set measurable indicators for digital transformation (Chanias, 2018; Matt, Hess, & Benlian, 2015). Setting specific key indicators to measure digital transformation improves top management's ability to assess investment needs and make correct investment decisions. Key performance indicators also help organizations obtain the highest value from their investments and digital strategy. (Chanias, 2017; Ross, Beath, & Sebastian, 2017; Sebastian et al., 2017.)

Structural changes refer to how digital technologies and activities influence and alter firms' organizational arrangements and how changes influence organization´s internal and external processes. The structural aspect includes personnel who drive and administer digital transformation and evaluates the extent and leverage of digital transformation within organizations. (Hess et al., 2016; Legner et al., 2017; Matt, Hess, & Benlian, 2015; Tabrizi et al., 2019.) From the perspective of organizational processes, novel digital technologies and services automate and streamline internal and external processes such as human resources, accounting, sales, and customer and supplier procedures. Automating processes enables organizations to restructure and refocus personnel on more valuable tasks. Furthermore, digital technologies provide real-time, 24/7 support and services, increasing transparency and trust among organizations' primary stakeholders such as customers. (Davenport & Westerman, 2018; Sahu, Deng, & Mollah, 2018; Westerman, Bonnet, & McAffee, 2014.)

2.3.2 Business dimensions and elements

Chanias and Hess (2016b) have identified some external triggering events that push organizations to transform their business activities into digital forms. Changes in customer behavior and demands for digital offerings propel organizations to digitalize customer processes and develop systems that enhance customer and user experiences. It has been emphasized that customers should be placed at the heart of digitalizing customer processes to optimize the user experience and satisfaction. Customer and user experiences are highlighted as the primary targets of ODT initiatives. (Chanias, 2017; Chanias & Hess, 2016b; Fitzgerald et al., 2014; Henriette, Feki, & Boughzala, 2016; Sahu, Deng, & Mollah, 2018; Westerman, Bonnet, & McAfee, 2014.)

Other factors that influence organizations' digitalization decisions relate to competitors' digital actions and the emergence of new entrants outside the industry. Competitors that adopt modern digital technologies and digitalize their services and processes earlier than other players experience improved competitive advantages such as growth of revenue and profit margins. By investing in novel digital technologies and developing digital capabilities well before rival companies, early adopters gain first-mover advantages in their industries. Early adopters may influence reference companies and force them to monitor digital technologies and encourages organizations to take steps toward digital transformation. (Chanias, 2017; Chanias & Hess, 2016b; Fitzgerald et al., 2014; Weill & Woerner, 2015.)

The motivation to implement digital technologies is to improve businesses (Fitzgerald et al., 2014). Digital transformation contains uncertainties and may even disrupt existing business models, so organizations observe relevant business cases to implement digital technologies and evaluate the potential benefits of novel digital technologies (Fitzgerald et al., 2014; Tabrizi et al., 2019). Conducting technology experiments in specific business cases helps organizations learn and test digital solutions in practice before final implementation. Some organizations even establish external business units for technology experiments. External business units allow organizations to experiment with new digital solutions in a flexible manner and pivot if solutions are not feasible. Experiments with digital solutions external to normal business procedures enable organizations to adjust and renew value propositions and business models and even discover completely new business models. (Berman & Marshall, 2014; Davenport & Westerman, 2018; Chanias, 2017; Chanias & Hess, 2016b; El Sawy et al., 2016; Fitzgerald et al., 2014;Tabrizi et al., 2019.)

When designing digital strategy and transformation processes, organizations should also consider both digital technologies' influence on existing value networks and new digitally enabled value networks (Pagani, 2013). It has been argued that digital technologies make value networks more transparent but may also simultaneously fragment and even disrupt businesses in existing value networks (Berman & Marshall, 2014; Pagani, 2013). Novel digital innovations may provide specific functions that serve traditional value networks but also value creation and capture points in cross-boundary value networks (Berman & Marshall, 2014; Pagani, 2013).

Table 2 Digital transformation: business elements

Business elements	**Authors**
Business models, value creation and proposition	Alfaro et al. (2019); Berman and Marshall (2014); Chanias (2017); Davenport and Westerman (2018); Dery, Sebastian, and van der Meulen (2017); El Sawy et al. (2016); Fitzgerald et al. (2014); Gerster (2017); Gimpel et al. (2018); Goul (2018); Gust et al. (2017); Haffke, Kalgovas, and Benlian (2017); Henriette, Feki, and Boughzala (2016); Hess et al. (2016); Kane et al. (2015); Legner et al. (2017); Matt, Hess, and Benlian (2015); Morakanyane, Grace, and O'Reilly (2017); Ross, Beath, and Sebastian (2017); Sahu, Deng, and Mollah (2018); Sebastian et al. (2017); Singh and Hess (2017); Tabrizi et al. (2019); Tumbas, Berente, and vom Brocke (2017); Weill and Woerner (2015); Westerman, Bonnet, and McAffee (2014); Westerman and Bonnet (2015); Wulf, Mettler, and Brenner (2017)
Business/use case	Haffke, Kalgovas and Benlian (2017); Fitzgerald et al. (2014); Gust et al. (2017); Tabrizi et al. (2019)
Customer and user experiences, needs and process, engagement	Alfaro et al. (2019); Berman and Marshall (2014); Chanias (2017); Chanias and Hess (2016); Dery, Sebastian, and van der Meulen (2017); Fitzgerald et al. (2014); Gerster (2017); Goul (2018); Gust et al. (2017); Henriette, Feki, and Boughzala (2016); Legner et al. (2017); Matt, Hess, and Benlian (2015); Morakanyane, Grace, and O'Reilly (2017); Ross, Beath, and Sebastian (2017); Sahu, Deng, and Mollah (2018); Sebastian et al. (2017); Singh and Hess (2017); Tabrizi et al. (2019); Weill and Woerner (2015); Westerman, Bonnet, and McAffee (2014); Westerman and Bonnet (2015); Wulf, Mettler, and Brenner (2017)
Competitors, entrants, competitive advantages	Berman and Marshall (2014); Chanias and Hess (2016); Davenport and Westerman (2018); Morakanyane, Grace, and O'Reilly (2017); Singh and Hess (2017); Westerman and Bonnet (2015)
Experiments	Berman and Marshall (2014); Haffke, Kalgovas, and Benlian (2017); Tabrizi et al. (2019); Westerman, Bonnet, and McAffee (2014); Wulf, Mettler, and Brenner (2017)
Separate business units	Chanias (2017); Chanias and Hess (2016); Hess et al. (2016); Matt, Hess, and Benlian (2015); Tabrizi et al. (2019)
Value chains and networks, digital business ecosystems	Berman and Marshall (2014); Gimpel et al. (2018); Gust et al. (2017); Matt, Hess, and Benlian (2015); Morakanyane, Grace, and O'Reilly (2017); Pagani (2013); Weill and Woerner (2015)

Weill and Woerner (2015) found that companies that obtain 50% or more of their revenue from digital business ecosystems have higher revenue growth and profit margins. Digital business ecosystems are formed around digital platforms, which are meeting places and markets for individuals and organizations of all sizes to conduct business (Weill & Woerner, 2015; Pagani, 2013). Digital platforms represent a new form of market structure with new service and business models

(Pagani, 2013; Sebastian et al., 2017). Digital platforms open global horizons to offer products and services to customers worldwide (Gimpel et al., 2018) and simultaneously collect valuable data from actors in digital business ecosystems. With efficient use of analyzed data, digital ecosystem actors can evaluate and predict changes in customer behavior well before their competitors and justify their business according to market needs (Sahu, Deng, & Mollah, 2018).

2.4 Technology discontinuities

The trajectories of some new innovations and technologies are extensive enough to change the business procedures and even transform the existing conditions and structures of whole industries, economies, and societies. The challenges of new technologies and innovations concern their predictability and the ways in which they influence businesses, industries, and societies over the time. Foster (1986) claimed that we live in an age of discontinuity, where technology discontinuities occur periodically with increasing frequency. Well-known economist Joseph Schumpeter (2010) explained the source of technology discontinuities: “the process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one.”

Over time, mechanisms to analyze technology discontinuities have been created to allow businesses to evaluate technology trajectories and related potential threats. The technology S-curve presented by Foster (1986) has been used to monitor the processes and performance of novel innovations and analyze their effects. The technology S-curve traces technology discontinuities and new, emerging technologies by identifying certain product user groups’ present and past performance parameters and then calculating limits for each performance parameter (Foster, 1986). Based on the S-curve model, a new technology progresses relatively slowly in its initial phase, but as it evolves over time, its performance improves at an increasing rate. In the final stage, the technology matures, reaching its performance limits in a market. (Christensen, 1992.) The S-curve is aimed at reconstructing the past and predicting future technology performance trajectories valuable to individual firms and industry (Christensen, 1992; Foster, 1986). However, defining technologies and their precise trajectories with the S-curve is difficult and may not provide accurate information to management (Christensen, 1992; Foster, 1986).

Anderson and Tushman (1990) argued that technological change is cyclical, and technology discontinuities occur in areas of ferment where new innovation is emerging and challenging current innovations and technologies in a market. A dominant design ends the ferment and leads new technology development toward incremental evolution. Breakthrough innovation occurs in areas of ferment and differs “dramatically from the norm of continuous incremental innovation”. (Anderson & Tushman, 1990, p. 606.) Incrementally evolving, dominant innovation is classified as innovation that reinforces and enhances competences and capabilities within organizations, whereas innovation that requires fundamentally new skills and capabilities and employs new approaches for problem solving is identified as competence-destroying innovations (Henderson & Clark, 1990; Tushman & Anderson, 1986).

The idea of cyclical process was also presented by Nieto, Lopéz, and Cruz (1998), who described technology change as a diffusion process. Typical of technological evolution, the diffusion process has three phases: introduction, growth, and maturity. In the introduction phase, the diffusion process is slow as the new technology contains uncertainties, and organizations have limited possibilities to evaluate it. However, organizations begin to obtain information and develop internal competences to assess the utility and risks of the new technology. In the second growth phase, if the new technology proves its usefulness and is widely accepted by the customer and stakeholder base, technology diffusion begins to accelerate. In the third phase, when the technology reaches its performance limits, diffusion begins to mature and decline. (Nieto, Lopéz, & Cruz 1998.)

Technology is considered to be a partly socially driven phenomenon (Anderson & Tushman, 1990), so the diffusion of innovation model understands technology diffusion as a social process in which new technology and innovation are communicated through certain channels among people and in their social systems. The diffusion rate of the new innovation depends on whether people accept or reject it over time. If the new innovation is experienced as complex and incompatible with existing user values and needs, the diffusion rate may remain slow. (Rogers, 2002.) Alternatively, if users perceive that the new innovation provides improved advantages relative to existing offerings, its acceptance likely will accelerate faster (Rogers, 2002), displacing existing technologies from the market over time.

2.5 Digital innovation

IT innovation is defined as "the creation and new organizational application of digital computer and communication technologies" (Lyytinen & Rose, 2003, p. 557), which has vital impacts on social and economic developments (Latzer, 2009). Digital innovation is distinguished from IT innovation and defined as innovation that "carries out new combinations of digital and physical components to produce novel products" (Yoo, Henfridsson, & Lyytinen, 2010, p. 725). Fichman, Dos Santos, and Zheng (2014) viewed digital innovation as a fundamental and powerful concept consisting of new products, processes, and business model elements enabled by IT. Skog, Wimelius, and Sandberg (2018) described digital innovation as

> the process of combining digital and physical components to create novel devices, services and business models, bundling them to constitute and enable market offerings, and

embedding them in wider sociotechnical environments to enable their diffusion, operation and use.[2]

The evolution of information and digital technologies has been phenomenal. Short life cycles and rapid changes are characteristic features of information and digital technologies (Latzer, 2009; Skog, Wimelius, & Sandberg, 2018). New IT and digital innovations emerge frequently, but only some radically change technological, economic, and social trajectories. In IS research, digital disruption is framed as "digital technology-induced environmental turbulence capable of producing industry-level upheaval" (Skog, Wimelius, & Sandberg, 2018, p. 432). Radical, disruptive digital innovation is characterized as unique, original, and risky during the time of breakthrough. Disruptive digital innovation is also rapidly adopted by numerous end users, resulting in a positive network effect. Over time, radical, disruptive digital innovation may evolve and generate systemic and transformative impacts and have seminal influences on future IT innovation trajectories. (Carlo, Lyytinen, & Rose, 2011; Skog, Wimelius, & Sandberg, 2018.)

The disruptive information technology innovation model (DITIM) identifies three IT innovation types: IT base innovation, system development processes, and IS services innovations (Carlo, Lyytinen, & Rose, 2011; Lyytinen & Rose, 2003). The development of Internet technology can be considered to be a fundamental digital innovation that has transformed the trajectories of IT and digital innovation. Internet computing relies on heterogeneous, distributed digital infrastructures that provide ubiquitous network connectivity and services, processing power, and possibilities for application and service development. (Brancheau, Janz, & Wetherbe, 1996; Carlo, Lyytinen, & Rose, 2011; Fichman, Dos Santos, & Zheng, 2014; March, Hevner, & Ram, 2000.) System development process innovation refers to changes in development tools, methods, teams, and structure. The innovation of digital IS services refers to organizations' effective utilization of digital tools and innovation of new applications and digital services. (Carlo, Lyytinen, & Rose, 2011; Lyytinen & Rose, 2003.)

If digital base innovation is transformative and affects all digital innovation types (base, system development process, and IS services), the three innovation types together have disruptive impacts and consequences (Carlo, Lyytinen, & Rose, 2011). The DITIM suggests that transformative base digital innovation is adopted before or simultaneously with the emergence of digital service innovation. Digital base innovation enables the emergence of digital service innovation, so radical process innovation can emerge simultaneously with or after digital service innovation. (Carlo, Lyytinen, & Rose, 2011.)

It is worth noting that the Internet alone is not disruptive but, rather, it is enabling technology (Latzer, 2009). Since the development of the World Wide Web by Tim Berners-Lee (Berners-Lee & Cailliau, 1992), interconnected computer networks have allowed the emergence of new, relatively cheap, easy-to-use online digital services, processes, and business models that reach customers

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[2] Skog, Wimelius & Sandberg, 2018, p. 433

globally (Fichman, Dos Santos, & Zheng, 2014). This ubiquitous digital infrastructure has fostered the emergence of the digital economy and allowed digital platform businesses to blossom globally. Digital platforms are virtual meeting points that enable (re)using and (re)sharing tangible and intangible assets (Baldwin & Woodard, 2009) among, for example, platform owners, content providers, and end users (Tiwana, 2014). Digital platforms also foster innovation with external parties (Evans & Gawer, 2016).

Digital infrastructure and platforms have transformed, for example, our consumption, shopping, and payment payments and travelling and entertainment practices and have even engendered new industries such as online games and e-sport. Incumbents such as Amazon, Google, and Uber are examples of platform businesses that have grown from tiny digital enthusiasts into globally operating giants. These giants serve their global customers through online platforms, but simultaneously, they provide platform partnership programs for external developers to create new digital services and applications for global audiences (Evans & Gawer, 2016). For individuals, digital platforms offer possibilities to optimize use of their physical assets such as apartments and cars (Evans & Gawer, 2016) and enable conducting online micro-businesses requiring low levels of skills, effort, and financial investments.

2.6 Disruptive innovation theory

The past is good predictor of the future only when conditions in the future resemble conditions in the past.[3]

Analyzing new emerging technologies has proven to be challenging (Christensen, 1992; Foster, 1986) because prior data and experiences of new innovation are limited or do not exist at all (Christensen, Anthony, & Roth, 2004). In the previous Chapter 2.5, it was mentioned that digital technologies are subjected to rapid changes and are characterized as unique and risky with short life cycles. It has also been noted that novel digital innovation may evolve and generate systemic impacts and changes in technologies, industries, and even societies (Carlo, Lyytinen, & Rose, 2011; Skog, Wimelius, & Sandberg, 2018; Wessel, 2017). Novel digital technologies and innovations have potential to spur transformations and disrupt the status quo of organizations' operational environment, so it is worth examining the foundations of disruptive innovation theory. The theory of disruptive innovation has influenced and inspired organizations of all sizes in both the private and the public sectors (Christensen, Raynor, & McDonald, 2015; King & Baatartogtokh, 2015) and has achieved considerable recognition since it was introduced more than two decades ago (Danneels, 2004; Henderson, 2006; Schmidt & Druehl, 2008; Tellis, 2006). The theory of disruptive innovation recognizes the characteristics of disruptive innovation and the reasons why some

3 Christensen, Anthony & Roth, 2004, p. xxi,

organizations survive or die in the face of novel disruptive innovation. The theory views disruptive innovation from the perspectives of incumbents and small ventures and proposes solutions for organization to cope with groundbreaking innovations.

2.6.1 Principles of disruptive innovation

Disruptive innovation originates from the perception that some well-managed established companies tend to face difficulties to keep their leading positions when confronting technological discontinues (Christensen, 1997), especially when technology discontinuities and disruptions are caused by smaller companies with more limited resources than the incumbents (Christensen, 1997; Christensen, Raynor, & McDonald, 2015). The new, emerging innovation that has the potential to disrupt the status quo is technologically more straightforward, simpler, and easier to use (Christensen, 1997; Roger, 2002), providing relative advantages for its users (Roger, 2002). The new innovation may also be based on different knowledge and present new, testable processes and offerings (Ballon, Pierson, & Delaere, 2005; Roger, 2002). In most cases, disruptive innovation is low performing and inferior to dominant solutions and is initially introduced in small, niche market unattractive to incumbents (Christensen, 1997) or markets with no consumption. Over time, the low-performing, emerging solution evolves and fulfills the demands of mainstream customers (Christensen & Bower, 1996).

Disruption occurs when the trajectory of the low-performing, new, emerging innovation intersects with the demands of mainstream customers in established markets. The performance of the emerging innovation is good enough to meet mainstream customers' value expectations for affordability and convenience in the market. When the disruptive innovation is still in its infancy stage, established companies focus on evolving their dominant solutions and providing their most valuable customers with high-performing solutions they do not necessarily need. Focusing too much on the most profitable customers and ignoring the emergence of the nascent innovation in a timely manner might prove to be fatal for incumbents. Ignorance may result in the loss of customers and leading positions in the market. (Christensen, 1997; Christensen, Raynor, & McDonald, 2015.)

In the following sections, the viewpoints on disruptive innovation in incumbents' and small ventures' activities are considered. Specific foci identified by the theory of disruptive innovation concern customers, resources, business operations, and value networks.

2.6.2 Disruptive innovation and incumbents

Strategies that were superior in the past may not be relevant and valid in the future. It has been argued that myopic, arrogant, ill-equipped management without a vision of future performance trajectories is one reason why incumbents disregard new, emerging innovations outside mainstream markets (Christensen & Bower, 1996; Henderson & Clark, 1990; Henderson, 2006; King &

Baatartogtokh, 2015; Tellis, 2006). Charitou and Markides (2003) asserted that the size of the potential disruption and organizations' motivation to respond to conflicts influence incumbents' abilities to navigate and survive in the changing technological landscape. If the new innovation is strategically significant to incumbents' existing business, they have greater motivation to follow and respond to the new innovation trajectories (Charitou & Markides, 2003). Pérez, Dos Santos Paulino, and Cambra-Fierro (2017) highlighted middle management's role in communicating novel ideas developed either internally or externally to senior-level managers. Middle managers have the power to influence top-level decision makers; views on the salience of new innovation and simultaneously enhance the innovation culture within organizations (Pérez, Dos Santos Paulino & Cambra-Fierro, 2017).

According to the theory of disruptive innovation, high-end, profitable customers ultimately prevent incumbents from reacting to technology discontinuities sufficiently early (Bower & Christensen, 1995; Christensen, 1997; Christensen & Bower, 1996). This claim is justified by the reality that the most profitable customers influence organizations' strategic choices such as investment decisions. Managers prefer to prioritize investments that support profit generation (Christensen, 2006), thereby giving the most profitable customers the power to determine how intangible and tangible resources are allocated within organizations and their value chains (Christensen, 2006; Christensen & Bower, 1996; Henderson, 2006). Incumbents thus allocate their resources and lock in the use of dominant technology (Ballon, Pierson, & Delaere, 2005; Christensen & Bower, 1996) to produce products and services that satisfy existing customers' needs and expectations (Christensen, 1997; Christensen & Bower, 1996; Christensen, Raynor, & McDonald, 2015). Exclusive product portfolios for high-end customers provide higher profit margins for organizations and management. Management's incentives such as performance rewards thus influence and even direct management to prioritize and focus on serving high-end, mainstream customers. (Christensen & Bower, 1996.)

It has also been found that investors constitute another stakeholder group that may determine and even prevent firms from succeeding with new innovation. In the context of digital innovation, it has been found that if investors highly value target companies' growth potential and expect to obtain higher market valuations, they are likely to invest in start-ups. In contrast, if investors value current-period profits and expect lower market valuations from industry incumbents, they are less likely to invest in digital innovation. (Bharadwaj, Mani, & Nandkumar, 2018.)

Organizations' strategic choices regarding resources, processes, and value indeed influence how successful they are when confronting technological discontinuities (Christensen, 1997; Christensen, Anthony, & Roth, 2004; Christensen & Bower, 1996). Organizational resources are considered to be more flexible to change than organizational processes and values, which are characterized as robust and not easily subject to rapid changes within organizations (Christensen, 2001). Organizational resources such as human capital, technologies, and financial resources are assets that are the lifeblood of firm performance and existence. Processes are series of activities that turn resources into offerings (products and services), and firm values are criteria that prioritize and determine decision making and resource allocation within companies. (Christensen, Anthony, & Roth, 2004.)

The value network is the context in which stakeholders exchange intangible and tangible goods to receive benefits (Allee, 2008). Stakeholders in the value networks of dominant innovation are likely to develop and establish their resources, capabilities, processes, and structures according to the requirements that serve existing mainstream customers. Dominant innovation and mainstream customers thus influence strategic choices and guide investments decisions by companies in value networks. (Christensen, 1997; Christensen & Rosenbloom, 1995.) It has been highlighted that when confronting new, emerging innovations, organization should evaluate how fundamentally novel innovation challenges existing value network (Ansari & Krop, 2012) because novel innovations may have broad implications for the diverse stakeholder groups in value networks. Depending on its novelty and depth of disruptiveness, new innovation may diminish or even destroy the value of existing stakeholders and generate totally new value networks (Christensen & Raynor, 2003; Hall & Martin, 2005). Christensen (2016) emphasized the need to analyze the performance attributes of new innovation and evaluate its attractiveness to current value networks and whether it generates new value networks.

Hall and Martin (2005) argued that the complexity and ambiguity of the primary and secondary stakeholders in value networks influence how stakeholders view new innovation, particularly its organizational, technological, commercial, and social uncertainties. If stakeholder complexity and ambiguity in value networks is high, it may hinder acceptance of new disruptive innovation and even generate conflicting demands. Ethical, social, and regulatory aspects are reasons that may prevent the diffusion of a prominent innovation in the value network even if it provides lucrative technological and commercial opportunities. (Hall & Martin, 2005.) Pérez, Dos Santos Paulino, and Cambra-Fierro (2017) found that innovators should extend collaboration from industry-specific value chains to external industries' value networks to enhance synergies and innovations. This claim is justified by the observation that industries such as the space industry cooperate with external industries such as the telecommunication, meteorology, and land monitoring industries, which may accelerate the emergence of inter-industry innovation (Pérez, Dos Santos Paulino & Cambra-Fierro, 2017). Obal (2013) recommended creating interorganizational trust among value networks' stakeholders when confronting disruptive innovation. Interorganizational trust may have positive impacts on how stakeholders in value networks adopt new innovation and perceive its usefulness and value. Consequently, it is vital that the disrupter create trustful relationships with stakeholders in old and new value networks. Incumbents may gain competitive advantages by introducing the entrant's disruptive innovation to their existing stakeholders in their value networks and simultaneously lowering the barriers to innovation acceptance and raising awareness of the disruptive innovation among their stakeholder groups. (Obal, 2013.)

2.6.3 Disruptive innovation and small ventures

Small ventures with different knowledge, skills, and capabilities have been identified as initiators of disruptive innovation (Ballon, Pierson, & Delaere, 2005; Christensen & Bower, 1996; Henderson & Clark, 1990; Tushman & Anderson, 1986). Disruptive innovation presents opportunities for entrants but also threats for incumbents (Christensen & Raynor, 2003). Characteristically, entrants (also called small ventures or start-ups) are more agile at adopting new innovation (Christensen, 1997) and exploiting and adjusting their limited resources to match the demands of new innovation in a timely manner (Henderson & Clark, 1990). Small ventures thus are more loosely, if at all, engaged with dominant technologies, resources, and value networks and can more nimbly make adequate changes with stakeholders. In contrast, incumbents are path dependent and locked in to current organizational, technological, and commercial structures. (Macher & Richman, 2004; Obal, 2013; Pérez, Dos Santos Paulino & Cambra-Fierro, 2017.)

Typically, new innovation follows a non-linear process (Ballon, Pierson, & Delaere, 2005; Hirooka, 2005) and may emerge randomly without a specific customer problem or need. Customers may not even know what they want until they see and experience the new solution in their context (Rasool et al., 2018). Small ventures often unintentionally build new innovation (Ries, 2011), which materialize from trial-and error processes (Christensen, 2016) without specific customer needs (Ries, 2011). Alternatively, new innovation may be commercialized in small, specialized niches (Adner & Zemsky, 2005). In challenges for small ventures, they have fewer assets, resources, and capabilities than incumbents (Govindarajan, 2016) to find suitable users and markets where new innovative solutions can be tested and experimented without competition (Christensen, 2001). Disruptive innovation may initially even compete against non-consumption; in other words, there is not necessarily demand or market for innovation, or the solution is beyond the reach of users (Christensen, Johnson, & Rigby, 2002; Christensen, Anthony, & Roth, 2004). However, regarding advantages, game-changing innovation has different performance attributes (low costs, low performance, and greater convenience of use) that are lucrative for small emerging markets but are not attractive for customers in established markets during the outset of new, game-changing innovation (Bower & Christensen, 1995). For innovators and small entrants, isolated, niche, low-end and non-consumption markets are excellent environments (Christensen & Raynor, 2003) to apply low-price and high-volume strategies (Adner & Zemsky, 2005; Christensen, Johnson, & Rigby, 2002) and experiment with "not good enough" solutions (Christensen, Johnson, & Rigby, 2002) with lower costs, less money, and fewer risks (Bower & Christensen, 1995; Christensen & Raynor, 2003).

2.6.4 Solutions to encounter and succeed with disruptive innovation

Growth is fuel that keeps a business's engine fresh and working. Every company needs growth to maintain competitiveness and keep up with the market. However, many organizations tend to become complacent when business is growing steadily, and no threats exist on the horizon. (Christensen, Johnson, & Rigby, 2002.) As mentioned, management's myopia and ignorance of technology discontinuities and inability to evaluate the value of emerging innovation (Ballon, Pierson, & Delaere, 2005; Hendersson, 2006; King & Baatartogtokh, 2015) diminish companies' ability to identify threats in a timely manner and cause organizations to lose their strong market positions.

Disruption is a serial process, not a specific event; therefore, disruptive innovation evolves over time (Christensen, 2006; Christensen, Raynor, & McDonald, 2015; Rafii & Kampas, 2002). To keep organizations' constantly aware of nascent innovations, one solution based on the theory of disruptive innovation is to create specific disruptive strategies to improve organizations' abilities to perceive new emerging solutions and evaluate their possibilities for growth in existing businesses and new markets (Christensen, Johnson, & Rigby, 2002; Christensen & Raynor, 2003). Specific disruptive strategies require commitment from management to allocate enough resources and to create practices that increase the probability of generating new ideas and new disruptive growth business within organizations. A disruptive strategy enables organizations to create the processes and value networks needed to conduct new growth opportunities while sustaining business activities. (Christensen, Johnson, & Rigby, 2002.) The aim of a disruptive strategy is to help organizations seek information, notice threats, evaluate disruptive innovation trajectories, and consider whether a disruptive innovation has the potential to evolve to a point where it can transform conventional industry structures and irreparably alter the competence and capability requirements and demands within the industry (Christensen & Raynor, 2003; King & Baatartogtokh, 2015). A disruptive strategy also helps organizations consider markets outside the main market and discover new, testable solutions with disruptive attributes for small and non-consumption markets (Christensen, Johnson, & Rigby, 2002; Christensen & Raynor, 2003).

Nearly all innovations start from small-scale experiments, and the beginning of every disruptive business has not been straightforward, clear, or predictable. The markets in which new emerging innovations are initially presented are small, low-profit, and undervalued by incumbents. (Christensen, Johnson, & Rigby, 2002; Christensen, Anthony, & Roth, 2004; Christensen, Raynor, & McDonald, 2015.) To solve the innovator's dilemma, the theory of disruption emphasizes that incumbents should establish a parallel, autonomous business unit separate from the parent organization (Christensen, 2001; Christensen & Raynor, 2003; Christensen, Raynor, & McDonald, 2015; Macher & Richman, 2004; Markides, 2006). Establishing an external business unit approved by senior management is justified by the reality that existing resources, processes, and values serve mainstream customers, but novel innovation has different value propositions and business models and thus initially serves customers in different market segments (Christensen, 2001, 2006; 2016; Christensen, Raynor, & McDonald, 2015). An external business unit allows management to strategically manage and evaluate emerging disruptive solutions and their threats and opportunities within the organization and iteratively develop and experiment with future-growth businesses (Bower & Christensen, 1996; Christensen, Johnson, & Rigby, 2002; Christensen & Raynor, 2003).

Other alternatives suggested for incumbents to succeed with new innovations and in new disruptive markets are to form strategic alliances with those developing new, emerging technologies (King & Baatartogtokh, 2015; Markides, 2006; Obal, 2013), as well as to acquire entrants, establish joint ventures, license new technologies (Christensen, Raynor, & McDonald, 2015; Danneels, 2004), and carry out technology and innovation pilots with start-ups (Schrage, 2018). Markides (2006) proposed that incumbents should not even try to develop disruptive innovations but should instead support the emergence of new, innovative, small entrants and nurture them to use their specific capabilities and fresh energy to launch new technologies to niche markets. Later, incumbents may engage with disruptive entrants and bridge the gap between old and new competences and capabilities (Danneels, 2004; Markides, 2006) by investing in new entrants' businesses. Incumbents, for example, may provide established distribution channels, resources, and strong branding for entrants' benefit and turn matured, disruptive innovations from niche markets into mass markets (Markides, 2006; Obal, 2013).

Chen, Zhang, and Guo (2016) also recommended developing proper tools for analyzing technology disruption and timing. Regularly analyzing emerging technology trends and studying hidden, weak signals of potential disruptive innovation enable organizations to conceive ideas of future technology trajectories and develop idea matrices corresponding to latent and actual customer needs. By identifying new, emerging markets and studying potential users and customers, organizations prepare themselves for the design of new growth strategies and value proposition scenarios. (Chen, Zhang, & Guo, 2016; Rasool et al., 2018.) Another suggestion is to analyze organizations' motivational asymmetries related to markets, market segments, capabilities, and business models. Asymmetries may reveal anomalies in businesses and provide hints of trajectory discontinuities that may later disrupt markets. (Adner & Zemsky, 2005; Christensen, Anthony, & Roth, 2004.) It has also been emphasized that companies' current customers, revenue, and cost structures should be considered when evaluating new innovation. If disruptive innovation's performance attributes evolve and intersect with the needs of high-end customers in mainstream markets, incumbents' revenue and cost structures are not competitive in contrast to companies with disruptive solutions. (Adner & Zemsky, 2005; Bower & Christensen, 1995.)

2.6.5 Criticism and trajectories of disruptive innovation theory

Technology change and discontinuities seem to emerge unsystematically and unexpectedly (Tellis, 2006). The theory of disruptive innovation is aimed at finding explanations for perceptions on why some well-managed, established companies fail when confronting technology and market discontinuities and changes (Christensen, 1997, 2016). In recent decades, the disruptive technology theory has evolved and has been refined into the theory of disruptive innovation (Christensen, 2001, 2006; Christensen et al. 2016). The reason for this is that disruption is not seen as a technology problem per se but instead as a business model problem (Christensen, 2006). Markides (2006) offered a dissenting opinion and argued that disruptive technology innovation is a fundamentally different phenomenon from disruptive business model innovation. He explained that business model innovation does not develop new products or services but redefines them and discovers how to deliver them to customers. Furthermore, the emergence of business model innovation generates different competitive effects and patterns than technology innovation (Markides, 2006). Danneels (2004) argued that the concept of disruptive innovation has potential to broaden the theory's applicability, but along with other scholars, he also criticized the deficiencies of the precision of the theory's concepts and definitions (Markides, 2006; Tellis, 2006). Even Christensen (2001, 2006) himself acknowledged that the concept of disruption has other connotations, so another concept might have served the theory better.

Christensen (2001, 2006) stated that disruptive innovation is not an absolute phenomenon and called disruptive innovation a theory of relativity. For some organizations, disruptive innovation may have positive implications, but simultaneously, the same innovation may possess destructive elements that destroy other organizations' performance and business models (Christensen, 2001, 2006; Christensen, Raynor, & McDonald, 2015). It has been shown that disruptive innovation is relative to organizations' resources, values, and processes (Christensen, 2006). Disruptive innovation, in particular, may be either enhance or destroy competences (Danneels, 2004; Charitou & Markides, 2003; Christensen, 2006; Tushman & Anderson, 1986). Adner (2002) emphasized that novel technology's performance trajectories may also be relative to price and substitute products and services. The theory of disruptive innovation has been found to not similarly concern all organizations at the same points in time (Christensen, 2001, 2006) and is applicable only when certain conditions are met (King & Baatartogtokh, 2015).

Scholars have also criticized the validity and generalizability of the disruptive innovation theory (King & Baatartogtokh, 2015). It has been argued that the disruptive innovation cases presented by Christensen and his colleagues are based on ex-post analysis (Danneels, 2004; King & Baatartogtokh, 2015; Tellis, 2006) and have little predictive power for ex-ante technology evaluations (Adner, 2002). Danneels (2004) indicated that ex-ante predictions consist of predicting the dimensions of performance demands and levels of technology performance in specific markets. However, at the same time, it has commonly been recognized that ex-ante predictions of disruptive innovation trajectories are challenging and difficult, and academia should develop analytical tools to better identify disruptive innovations (Danneels, 2004; Tellis, 2006).

In response to these criticisms, it has been explained the theory of disruptive innovation is a simple, affordable way to evaluate organizations, technologies, and markets and thus predict potential discontinuities in innovations, businesses, and markets (Christensen 2006; Christensen, Anthony, & Roth, 2004). Analyzing incumbents' and entrants' resources, processes, and values may reveal certain asymmetries in current businesses and value networks that give hints of changes in business environments (Christensen, Anthony, & Roth, 2004). Christensen (2006) considered the detection of anomalies by scholars to have been valuable, triggering a cycle of developments that improved the theory of disruptive innovation.

2.7 Technology testing and experimental practices

The real measure of success is the number of experiments that can be crowded into twenty-four hours.[4]

Creating regular, continuous experimental practices within organizations has been argued to create knowledge and activate constant learning processes resulting in the discovery of new innovations (Ries, 2011; Schrage, 2018; Thomke, 2001, 2003). Organized experimental practices, or minimum viable pilots as called by Schrage (2018), allow organizations to learn from positive and negative experimental outcomes, which help organizations to develop their current product portfolios and improve internal and external processes. It has been argued the more failed experiments organizations generate, the sooner successful outcomes will emerge. (Thomke, 2001, 2003.) Learning from both negative and positive experiments and pilot results increases the probability of discovering new ideas and innovations, enhancing the potential for new value creation within organizations' value networks (Schrage, 2018; Thomke, 2003).

Organizations have been found to face certain barriers that prevent extensive implementation of technology experiments. Cultural and organizational perspectives such as insufficient skills and financial resources hinder organizations from fully benefitting from technology practices. Internal inertia such as reluctance to present prototypes and minimum viable products to customers prevents organizations from initiating experimental practices even though evidence of positive experimental outcomes may exist. (Kirsner, 2018; Schrage, 2018.) Other reasons for internal inertia relate to the idea that experiments are perceived expensive and time consuming and require building appropriate competences and capabilities. Perceptions of negative experimental

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4 Thomas Edison, (Kelly & Kelly, 2013)

outcomes as mistakes and inability to coordinate experimental practices between internal units hinder the development of full-scale experimental practices. (Kirsner, 2018; Thomke, 2001, 2003.)

To unlock these barriers, it has been suggested that from the very outset, organizations should adopt the iterative experimental design methodology and learn how it works (Kirsner, 2018; Kohavi & Thomke, 2017; Ries, 2011; Schrage, 2018). Another vital recommendation is to allocate sufficient technical and human resources to experimental activities and increase the quality of skills and capabilities to gain optimal results and value from experimental practices. Unlike conventional, expensive, time-consuming experimental practices, widespread digital infrastructures and novel digital technologies accelerate experimental processes and allow more effective and economic testing of new, emerging technologies. (Kohavi & Thomke, 2017; Thomke, 2001, 2003.) It has even been suggested that regular online experiments should be standard operating procedure for companies (Kohavi & Thomke, 2017). Using modern digital technologies allows performing parallel experiments in simulated and real-world experimental environments, resulting in faster experimental cycles and thus accelerated learning experiences at lower cost (Ries, 2011; Thomke, 2001, 2003). Experimenting with new, emerging technologies and integrating them into experimental processes early enough also benefits organizations' research and development (R&D) and innovation activities and helps organizations assess strategies and existing business operations. Utilizing novel digital technologies and online experiments helps organizations recognize new value creation and business model possibilities for customers and supply chain actors. (Kohavi & Thomke, 2017; Thomke, 2003.)

Systemic, rapid, iterative experiments lower the threshold for new innovation introduction (Thomke, 2001) and accelerate adoption of new innovation. As a result of early innovation experimental activities, organizations may increase their competitiveness and strengthen their leading position in the market by adapting new innovation earlier than their rivals and, alternatively, abandoning innovation based on the experiment results. Recognizing failures early enough is necessary to eliminate options not beneficial for organizations' purposes. Frequent, rapid, early-stage experiments also strengthen organizations' internal innovation capacity and increase the probability of successful innovation outcomes. (Thomke, 1998, 2001; Ries, 2011.)

As mentioned, it has been emphasized that organized experimental activities should follow iterative cyclic patterns (Kirsner, 2018; Schrage, 2018; Thomke, 1998, 2003). The agile iterative development approach has become a well-accepted methodology in the lean business development and the software development industry (Abrahamsson et al., 2002; Ries, 2011). Originally, the lean methodology was applied in start-ups and new business ventures (Ries, 2011), but incumbents have also adopted the lean approach to iteratively test and experiment with new innovation and business models (Bussgang & Clemens, 2018). The lean methodology and cyclic experiments have certain experimental stages such as designing, building, and executing experiments, followed by analyzing/measuring, and learning. These stages allow developers to create hypotheses and visions of potential solutions and systematically progress through trials until satisfactory solutions are found. (Ries, 2011; Thomke, 2003.) Rapid, systematic experiments allow organizations to immediately introduce prototypes or minimum viable products to potential users and receive valuable feedback from end users. Clear key performance indicators assist organizations in analyzing and measuring experimental outcomes. The analysis and measurement stage helps organizations learn from experiments and draw conclusions for the next step. (Kisner, 2018; Ries, 2011; Thomke, 2001.)

The agile software development methodology was developed in the rapidly changing digital technology industry. Agile software development allows companies to execute faster and nimbler software development procedures, reducing risks related to incorrect software, project deadlines, and budgeting, for example. The agile development methodology requires continuously testing and evaluating software and frequently releasing new software versions at intervals agreed upon by the software developer team. Incremental testing periods vary from daily to monthly cycles, which allow quick repair of software. (Abrahamsson et al., 2002.)

As in the lean methodology, customers and end users are integrated into the agile software development process from the beginning of projects. Close collaboration with customers and users during the entire software development life cycle enhances communication and possibilities to adjust to customer needs and make relevant changes during the iterations. (Abrahamsson et al., 2002.)

2.7.1 Technology testing and experimental facilities to support digital innovation

Joint technology testing and experimental facilities are established to support digital innovation expansion. The purpose of testing and experimental facilities is to support non-linear innovation development and enhance understanding of the socio-economic changes new, innovative digital technologies produce. Joint technology testing and experimental facilities further reduce the uncertainties and risks (e.g., technology and investment) linked to immature digital technology development. Previous research on European broadband open-innovation platforms distinguished six types of technology testing and experimental platforms (TEP) for digital and information and communication technologies (ICT) development: testbeds, field trials, prototyping platforms, living lab environments, societal pilots, and market pilots. (Ballon, Pierson, & Delaere, 2005.) Testbeds are described as scalable, semi-open, standardized laboratory environments for commercially immature technologies, products and services (Ballon, Pierson, & Delaere, 2005; Baran & Steurer, 2010; Wang et al., 2008).

Field trials are flexible, temporary, small-scale experiments that test technical and other attributes in limited but real-world environments with real users (Ballon, Pierson, & Delaere, 2005; Vines et al., 2017). Prototyping platforms are closed or partly open in-house technology design and development facilities, which are mostly driven by established companies. Prototyping platforms are primarily used for testing proofs of concept for mass production and markets. (Ballon, Pierson, & Delaere, 2005; Chtourou et al., 2017; Kästner et al., 2017; Leber & Madrid, 2018.)

2.7.2 Real-life technology experiments

Living labs are characterized as real-life experimental environments in which users are seen as co-designers of new innovations (Nesti, 2017). Leminen, Westerlund, and Nyström (2014) identified four significant user roles in living lab environments: informants, testers, contributors, and co-creators. In living labs, users are integrated into innovation development processes to gain information about technology acceptance in certain contexts and to understand the socio-technical impacts of new innovations. Living lab experiments make new innovations more visible and embedded in real-world environments. (Ballon, Pierson, & Delaere, 2005; Dutilleul, Birrer & Mensink, 2010; Leminen, Westerlund, & Nyström, 2014.) Living labs are desirable environments for developing and testing digital solutions and services in smart cities. Semi-open market pilots serve the best innovations that have already been matured and released to a limited number of end users to gain marketing data before final commercial launch. Finally, societal pilots are intended for rather mature technologies and are seen as tools for the inclusion of societal goals in innovation processes. Limited scalability and scope are characteristic attributes of societal pilots. (Ballon, Pierson, & Delaere, 2005.)

2.8 Smart cities as platforms for digital technology experiments

2.8.1 Smart cities

The smart city has been a popular phenomenon in urban development settings, but in the academic literature, the concept of the smart city has not been consistently defined. The concept of the smart city was introduced in the mid-1990s by Tokmakoff and Billington (1994) and Shetty (1997) in the contexts of Adelaide, Australia, and Singapore. Both cities considered building a widespread high-speed broadband network infrastructure as a fundamental issue for future smart city development. It was envisioned that the broadband network would accelerate the emergence of new content providers and the development of digital applications and services for citizens. The rationale behind strengthening the cities' information infrastructure was also that it would attract ICT companies and stimulate their knowledge-based economies. (Shetty, 1997; Tokmakoff & Billington, 1994.)

ICT and modern digital technologies are closely associated with the smart city concept. Batty et al. (2012, p.481) called the smart city is a laboratory for innovation and defined it as "a city in which ICT is merged with traditional infrastructures, coordinated and integrated using new digital technologies." Caragliu, Del Bo, and Nijkamp (2011, p. 70) stated that a city is smart "when investments in human and social capital and traditional (transport) and modern ICT communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory government." Public organizations such as the EU, International telecommunication standardization sector (ITU-T) Focus Group, and International Organization for Standardization (ISO) have followed earlier definitions of smart cities. EU (2018) defined a smart city as "a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business." The ITU-T Focus Group (2015) and ISO (2013) described the smart city as an innovative city using ICT to improve the quality of life, enhance the efficiency of urban operations and services, and support sustainable socio-economic and environmental outcomes by responding to the challenges urbanization creates.

Urban areas are complex, constantly changing ecosystems (Jabareen, 2013; Ren & Sanz, 2011; Schaffers, Ratti, & Komninos, 2012) vulnerable to natural crises and discontinuities in technologies and global and national economies (Baccarne, Mechant, & Schuurman, 2014). Investment in ICT and digital technologies cities is intended to improve the performance of soft domains such as education and healthcare (Petersen, Concilio, & Oliveira, 2015), but digital technologies are also used to upgrade hard infrastructures such as energy, sewer, and traffic. Investing in digital technologies and infrastructures cities is aimed at, for example, synchronizing city processes, improving monitoring of cities' critical functions, increasing resource efficiency and, moreover, lowering the costs of city services and the threshold of service availability. Through digitalization of city activities and services, the smart city is aimed at improving citizen participation and making the city more transparent and less bureaucratic. The ultimate goal is to improve the city's functionality and the quality of life for all stakeholders. (Gabrys, 2014; Olivares, Royo, & Ortiz, 2013; Lea et al., 2015; Sánchez et al., 2013; Zanella et al., 2014.)

2.8.2 Smart city technology testing and experimental platforms—a platform for digital technology and service experiments

It has been argued that smart cities are significant settings to introduce and experiment with new technologies in niche, multifaceted city domains (Carvalho, 2014) such as education, healthcare, tourism, transportation, energy, and waste management. One reason for this statement is that smart cities are invaluable sources of challenging functional and nonfunctional requirements and application domains in which to test novel technologies and thus facilitate socio-technical changes (Carvalho, 2014; Lanza et al., 2015; Sánchez et al., 2013). However, a prerequisite for reliable technology experiments in smart city settings is adequate ICT infrastructure (Olivares, Royo, & Ortiz, 2013; Sanchez et al., 2014; Struye, Braem, Latré, & Marquez-Barja et al., 2018). Decent ICT and smart city

TEP infrastructure allow collecting (real-time) data from diverse city verticals through heterogeneous devices such as sensors, video surveillance cameras, and wearable devices. Data, whether real time or historical, are regarded as a significant outcome of smart city TEP activity (Benabbas et al., 2017). Data generated through heterogeneous networks of digital devices are fuel for diverse smart city TEP stakeholders such as research communities, city authorities, and technology developers, allowing them to detect real-life incidents and extend understanding and knowledge about human habitats and behaviors in cities. Based on the received data, actors in smart city TEP can develop, test, and validate smart city applications and services in real-life smart city domains that benefit all citizens in the smart city. (Benabbas et al., 2017; Juraschek et al., 2012; Lanza et al., 2015; Latre et al., 2016; Schaffers et al., 2011; Yokoyama et al., 2015.)

A previous chapter 2.7.1 presented six technology test and experiment platforms. In the smart city domain, testbeds and living labs have been the dominant TEPs for experimenting with and testing ICT network and digital technologies. Testbeds are used to experiment with wireless network infrastructures, sensor networks, and applications. (Juraschek et al., 2012; Lanza et al., 2015; Latre et al., 2016; Olivares, Royo, & Ortiz, 2013.) Smart city testbeds have operated under scalable laboratory conditions, which have allowed repeating experiments in simulated environments (Latre et al., 2016; Olivares, Royo, & Ortiz, 2013) and made it possible to validate R&D results in realistic environments (Struye et al., 2018).

User involvement and integration into smart city technology experiments have been strongly emphasized (Gabrys, 2014; Lanza et al., 2015; Latre et al., 2016; Sanchez et al., 2014; Yokoyama et al., 2015). Extending technology experiments from closed laboratory environments to real-world, living lab conditions enables integrating real users during an early stage of the smart city technology experimental process (Sánchez et al., 2013; Schaffers et al., 2011). User integration into smart city living labs allows testing both technical and social functionalities, which gives smart city TEP stakeholders valuable information about the socio-technical and socio-economic aspects of new digital innovation (Sánchez et al., 2013; Sanchez et al., 2014; Schaffers et al., 2011; Yokoyama et al., 2015). User integration also increases possibilities to discover barriers that may prevent diffusion and acceptance of new digital innovation (Benabbas et al., 2017; Schaffers et al., 2011; Yokoyama et al., 2015). In large, smart city experimental projects as in SmartSantander, Spain, a specific model called experimentation as a service has been developed to enable large-scale, multipurpose technology experiments in the smart city environment (Lanza et al., 2015; Sánchez et al., 2013; Yokoyama et al., 2015).

3 RESEARCH APPROACH AND METHODOLOGY

In this chapter, an overview of the research approach and methodology is presented. This research investigates ODT, and research´s main scope is providing a systematic approach for carrying out digital transformation and deploying novel digital technologies in organizations' activities. The research is positioned as investigating IT and organizations, and its aim is to increase knowledge and understanding of the elements that influence how novel digital technologies are deployed in organizations and their value networks.

3.1 The research approach

The research approach identifies philosophical worldview of the research and sets principles and steps for the research plans and procedures. The research approach guides the research design (also called the strategy) and methods for data collection, analysis, and interpretation. The discipline's orientation and prior research experiences influence the philosophical worldview in certain research domains. (Creswell, 2014; Grover, 2015.) The IS discipline contains positivist, interpretive, and critical research approaches. Traditionally, the positivist research approach has dominated the IS field, but the interpretive approach has gained increased popularity, especially in research on the relationships among IT, individuals, and organizations. The critical research approach constitutes a minor research philosophy in the IS research field. (Chen & Hirschheim, 2004; Orlikowski & Baroudi, 1991; Walsham, 2006.)

The differences between the positivist and interpretivist research approaches arise in the ontology of the research traditions. The positivist approach is seen as dualistic in nature, giving the researcher a passive, separate role from the research object. The interpretive research tradition, in contrast, considers the researcher and the research object to be in-separate. In the interpretive approach, the researcher is embedded in the social constructs of the research object. (Orlikowski & Baroudi, 1991; Weber, 2004.) In another perspective that differentiates these two approaches, the positivist tradition tends to generate and test hypotheses and theories, whereas the interpretivist researcher interprets and describes the research object's social world and meanings. Qualitative research designs are associated with the interpretive research tradition, whereas quantitative research designs have dominated the positivist research tradition. However, this distinction is not strict because both positivist and interpretivist approaches may apply mixed methods combining quantitative and qualitative research strategies. (Creswell, 2014; Orlikowski & Baroudi, 1991; Walsham, 2006; Weber, 2004.)

Orlikowski and Baroudi (1991) indicated that major goal of IS research is to have impacts on IS practices and the development and use of IS within organizations. They argued that the design and use of IS within organizations is embedded in social contexts influenced by time, culture, and politics (Orlikowski & Baroudi, 1991). The interpretive approach has gained a foothold in organizational research settings and affirmed its position in management and organization studies (Lee, 1991; Prasad & Prasad, 2002). In organizational and management studies, use of the interpretive approach is justified by the perception that certain research questions and problems may not be answered by applying only quantitative designs. Instead, applying qualitative and mixed-method research designs may result in the best research outcomes and knowledge of reality. The qualitative interpretive and mixed-method approaches are also well accepted research traditions in the IS discipline. (Orlikowski & Baroudi, 1991; Prasad & Prasad, 2002; Weber, 2004.) It has been argued that the interpretive research approach improves IS researchers' understanding of human thoughts and actions in social and organizational contexts and thus enhances understanding of IS and IS management within organizations (Klein & Myers, 1999).

3.2 Qualitative research approach

It has been emphasized that researchers should choose the interpretivist or the positivist research tradition based on the nature of the research phenomenon and research question (Orlikowski & Baroudi, 1991). Instead of developing specific technical IS artifacts or evaluating the utility of specific IS artifacts, this research considers organizational perspectives of IS. The interpretive qualitative research approach, therefore, best serves the research objectives.

Qualitative research focuses on social and cultural phenomena and explores the meanings individuals and groups associate with certain social and human problems (Creswell, 2014; Myers, 1997). Qualitative research is aimed at explaining contextual information and understanding actors' interpretations and perspectives (Hirsjärvi & Hurme, 2008). The qualitative research approach is flexible to changes and inductively forms general perspectives from complex particulars and individual meanings (Creswell, 2014). Saunders, Lewis, and

Thornhill (2009) argued that the qualitative interpretive strategy allows researchers to capture fundamental meanings attached to organizational life.

Creswell (2014) proposed that qualitative research is exploratory. The exploratory research strategy is preferred if the research questions and objectives are unclear, the variables are unknown, the theory base is inaccurate, the research concepts are immature, or the research phenomenon requires more explicit insights (Creswell, 2014; Saunders, Lewis, & Thornhill, 2009). Qualitative exploratory research strategies and sources include literature reviews, open-ended and semi-structured interviews, documents, notes, reports, press releases, workshops, and participant observation (Creswell, 2014; Myers, 1997; Ottmann & Crosbie, 2013; Saunders, Lewis, & Thornhill, 2009; Walsham, 2006). Articles (I–VI) in this dissertation are based on the foundation of qualitative research. Articles I and II utilize semi-structured interviews to explore and understand meanings and interpretations among interviewees. Article III uses prior research in digital ecosystems and presents two different approaches: actor-rooted and business-rooted ecosystem building. The exploratory research strategy is applied in Articles IV, V, and VI.

3.2.1 Interviews

Data collection for this study was conducted from November 2013 to February 2019. Empirical data were collected from semi-structured and open-ended interviews. The first interviews were conducted from mid-December 2013 to mid-January 2014, followed by the second interviews in October 2015. The first semi-structured interviews involved a total of eight participants from six companies in Finnish machine industry (Article I). The second interviews involved two interviewees, one at a metal 3D printing company and one representing the agriculture machine industry. An interviewee from the agriculture machine industry was also involved in the first interview round (Article II).

The third semi-structured and open-ended interviews involved 17 interview sessions. Data was also collected during smart city events like workshops. Data was collected during period of February 2016 to May 2017 as part of the 5K project, a joint smart city development project with universities, cities, and companies from the ICT industry. The interviewees involved in interview sessions represented different actors in the smart city context. The interviews were used as secondary data to support the work presented in Article III and the conceptual frameworks presented in Articles IV and V. The fourth interviews were conducted in May 2017 and March-April 2018. Additionally data was collected during three smart city related workshops arranged in Helsinki and Oulu during March-August, 2018. Altogether nine interviewees participated in the interviews. However, the results presented in Article VI contained interviews from seven interviewees. The data from two interviewees was used as background and secondary data in Article VI.

3.2.2 Secondary data

Secondary data are a useful source for finding answers to specific research questions. Secondary data include raw data and published summaries such as meeting minutes, interviews, annual reports, and newsletters (Saunders, Lewis, & Thornhill, 2009). The secondary data presented in this dissertation came from interviews and documents. The documentary secondary data consisted of meeting minutes, workshops, organizations' websites, and published city reports on city strategies, policies, and board meeting minutes. Additionally, the 5K project stakeholder interviews and interviews from two participants were utilized. Secondary data were used to support the research in Articles II, III, and IV and find answers to the research objectives in Article VI.

3.3 Conceptual research approach

Becker (1998, p. 110) declared that "without concepts, you don't know where to look, what to look for, or how to recognize what you were looking for." Concepts, therefore, are important to research and relevant in all research approaches, especially the interpretive tradition. Conceptual research systematically investigates the meanings of concepts, which are subject to change along with alterations in our experienced reality of the world (Dreher, 2018; Xin, Tribe, & Chambers, 2013). The hallmark of the conceptual research is that it does not necessarily require empirical data to create knowledge and support knowledge claims (Mora et al., 2008; Xin, Tribe, & Chambers, 2013). Conceptual research is not a standardized procedure; instead, it serves the aims to systematically clarify the logics and meanings of concepts and to encourage researchers to review relevant knowledge from prior research and the current uses of concepts in specific domains (Dreher, 2018; Xin, Tribe, & Chambers, 2013). In the IS discipline, conceptual research is one of the most applied methods, especially in conceptual behavior and design research (Mora et al., 2008). Conceptual research has been found to be valuable when little is known about the research area and when the aim is to examine possibilities for further studies in prior studies. Conceptual research is also aimed at advancing and extending current knowledge about specific research areas (Baiyere, 2016).

The goal of a conceptual framework is to identify and name the concepts relevant to the study, organize and categorize them, and, finally, integrate them and form meaningful relationships among them (Jabareen, 2009; Rocco & Plakhotnik, 2009). Articles IV, V, and VI are conceptual in nature. The conceptual frameworks presented in Articles IV and V are based on concepts that emerged in the research literature. The concepts were categorized, and meaningful relationships were identified. The aim of the conceptual frameworks was to increase knowledge about relatively unknown research contexts and phenomenon and to form the foundations for the further research. Article VI extends the conceptual papers with empirical research.

3.4 Data analysis

Qualitative content analysis is regarded as suitable for researchers employing explorative, relatively low levels of interpretation (Vaismoradi, Turunen & Bondas, 2013). Hsieh and Shannon (2005) classified qualitative content analysis into three categories: conventional, directed, and summative. Conventional content analysis is used when the researcher wishes to describe the study phenomenon, but the existing theory and literature is limited. Directed content analysis is aimed at validating and extending existing theory, whereas summative content analysis is applied to identify and quantify certain words in text material. Summative content analysis is used to analyze the words and content of manuscripts such as journals and books. (Hsieh & Shannon, 2005.)

Qualitative content analysis uses verbal and textual materials such as recorded and transcribed interviews, videos, written reports, documents, and peer-reviewed literature. Content analysis is a flexible method to analyze qualitative material but also forces the researcher to examine research materials in detail and systematically. Content analysis makes the researcher reflect on the study material in light of the research objectives. (Elo & Kyngäs, 2008; Flick, 2014.) Content analysis follows certain processes with preparation, organizing, and reporting phases. The preparation phase identifies the unit of analysis, such as the themes, content, and depth of the analysis. The organizing phase involves the use of either inductive or deductive analysis. Inductive analysis uses open coding such as writing notes and headings while reading the text material. During the open coding process, codes are sorted into meaningful categories and abstractions. The purpose of the categories and sub-categories is to form relationships among them. The categories and sub-categories thus provide a means to increase in-depth knowledge and understanding about the study phenomenon. Deductive content utilizes prior research material in new research contexts or tests earlier categories, theories, and research literature. In both approaches, the reporting phase involves creating meaningful categories that reflect the research objectives. (Hsieh & Shannon, 2005; Elo & Kyngäs, 2008.)

The analysis of the qualitative data in this dissertation was carried out using conventional content analysis. More precise details about the data analyses are presented in the following articles (Articles I, II, IV, V, and VI). In Articles I, II, and VI, the interviews and literature are the primary source for the analysis. Article III extends prior research on software ecosystem design. The proposed process in Article III utilizes secondary interview data collected during February–August 2016. Article IV follows the conventional content analysis process, and in Article V, the principles of grounded theory, combined with content analysis processes, are applied.

4 OVERVIEW OF THE ARTICLES

4.1 Article I: "Additive manufacturing technology: Identifying value potential in additive manufacturing stakeholder groups and business networks"

Hämäläinen, M., & Ojala, A. (2015). Additive manufacturing technology: identifying value potential in additive manufacturing stakeholder groups and business networks. In *AMCIS 2015: Proceedings of the Twenty-First Americas Conference on Information Systems*.

Research objectives

This paper examines additive manufacturing (AM) technology from the perspectives of value creation in business activities and business stakeholders. The research was conducted with companies operating in the Finnish metal industry. The aim was to determine AM technology usage in research companies and to answer two research questions: 1) Where and how value is created in companies' business relationships? 2) How does AM technology affect companies' value creation among their primary stakeholders?

Findings

The study results indicate that value is primarily created in customer, supplier, and employee relationships. AM technology is primarily used in product prototypes and R&D functions. Customer satisfaction is improved when companies use AM prototypes to illustrate the final products to customers in the early product-development phase. AM prototypes allow customers to examine products' forms, colors, and structures in real operational environments. For employees and customers, AM prototypes allow detecting product design errors in the early design phase. AM prototypes thus shorten product development cycles, reducing the time and costs of R&D activities. In this way, AM technology influences supplier relationships and produces new ecosystems. AM machines are considered to be relatively expensive, so companies prefer to acquire AM prototypes from external AM service companies. Additionally, AM service companies have specific knowledge of the materials used in the AM process and understand how to use AM machines.

Connection to the objectives of the dissertation

This article addresses the customer centricity, value creation, and value network perspectives when exploring new digital technology. Companies, both small and medium-sized enterprises (SME) and incumbents, consider value creation for customers and integration of customers and novel technology to be primary conditions when accessing new digital technology and innovation.

4.2 Article II: "3D printing: Challenging existing business models"

Hämäläinen, M., & Ojala, A. (2017). 3D printing: challenging existing business models. In A. Khare, B. Stewart, & R. Schatz (Eds.), *Phantom ex machina: digital disruption's role in business model transformation* (pp. 163–174). Springer, Cham.

Research objectives

Digitizing manufacturing has been viewed as transforming the ways in which goods are designed and made. Contemporary digital technologies such as 3D printing and AM offer potential to design and produce forms and structures impossible in traditional settings. However, little is known about how disruptive 3D printing is for companies' business models and value networks. The purpose of this research, therefore, was to explore how 3D printing influences and shapes existing business models and their components such as product offerings, value delivery, and revenue model.

Findings

The study results reveal that 3D printing allows designing and producing products challenging or even impossible with traditional production methods. For example, 3D printing enables making nested forms and internal tunnels in metal nozzles. 3D printing opens doors for new product innovation and extends the product range for existing and new customers. Moreover, 3D printing has disrupted traditional mold producers' businesses as the costs of 3D printed prototypes are fractions of the prices of traditional molds. In addition, 3D printing technology has created new value networks and ecosystems. The actors around 3D printing technology include 3D printer manufacturers, 3D printing service providers and sub-contractors, product designers, material experts, and end users. A need for external actors to deliver finishing services emerges from the interviews. The experienced value from 3D printing technology is perceived in the form of customized, unique products and possibilities to produce mini-series at affordable prices. Remarkable time and cost savings are attributed to 3D printing. It also enables iterative product design with customers, increasing communication and strengthening mutual understanding and trust with customers. Investors influence organizations' business models and digital technology implementation.

Connection to the objectives of the dissertation

This article considers the stakeholder dimension and business model perspectives in the context of novel technology, which influences the emergence of new stakeholders and business ecosystems. Ecosystems are formed around 3D printing technology and include 3D printing machine manufacturers, customers, service providers, product designers, and material experts. A future need for actors to provide finishing services exists. Investors have significant roles in organizations' possibilities to implement novel technologies and influence business model design.

4.3 Article III: "Designing, developing, and implementing software ecosystems: towards a step-wise guide"

Manikas, K., Hämäläinen, M., & Tyrväinen, P. (2016). Designing, developing, and implementing software ecosystems: towards a step-wise guide. In S. Jansen, C. Alves, & J. Bosch (Eds.), *IWSECO 2016: Proceedings of the 8th International Workshop on Software Ecosystems* (pp. 70-79).

Research objectives

This paper proposes a process for designing, developing, and establishing software ecosystems based on three steps: pre-analysis, design, and evaluation and monitoring. The proposed process is based on the prior literature on software ecosystems and the identified challenges in creating software ecosystems, which especially concern software ecosystems' survivability, productivity, and health. The interviews conducted during the 5K project influenced the emergence of the process description presented in the paper. A step-wise guide was applied in two ecosystems: a Danish telemedical ecosystem and a smart city ecosystem in Finland.

Findings

The proposed process for software ecosystem design is aimed at bringing focus to essential elements such as pre-analysis, design, evaluation, and monitoring. However, the method does not cover all elements relevant to software ecosystem design. It is identified orchestration of the software ecosystem is vital for the software ecosystem's health and evolution. Further, the interface between the technical and organizational dimensions should reflect the orchestration strategy of the ecosystem and thus respect domain, borders, and roles of the ecosystem and its actors.

Connection to the objectives of the dissertation

This paper addresses the governance dimension of the ODT framework. In building robust digital ecosystems, the pre-analysis, design, orchestration, and monitoring elements are essential for the survivability of the digital ecosystem. The governance and orchestration elements support organizations in setting measurable indicators for digital transformation. Governance thus helps organizations monitor and strengthen the outcomes of digital transformation.

4.4 Article IV: "A framework for IoT service experiment platforms in smart-city environments"

Hämäläinen, M., & Tyrväinen, P. (2016). A framework for IoT service experiment platforms in smart-city environments. In *ISC2 2016: IEEE Second International Smart Cities Conference. Improving citizens' quality of life. Proceedings* (pp. 664–671). IEEE.

Research objectives

Many TEP in smart city environments perish after the project funding is consumed due to e.g. the lack of a sustainable value creation model for the actors involved in TEP activities. Such a vision and instruments to construct robust IoT testing and experimental platforms are needed. This paper presents a framework for an IoT service experimental platform (IoT SEP), whose aim is to help TEP practitioners create a robust IoT SEP and increase its survivability and health. The IoT SEP framework was applied in two smart city projects: Smart Santander in Spain and Smart Kalasatama in Helsinki, Finland.

Findings

Altogether, eight factors significant for robust IoT SEP are identified: openness, real-world experiments, user/public involvement, vertical and horizontal scopes, scalability, sustainable value creation, continuity, IoT heterogeneity, and architecture design. These factors strengthen the IoT SEP's sustainability and survivability. Reaching critical mass in the IoT SEP results in a network effect, reinforcing the platform's health and thus the experienced value among the actors in the IoT SEP.

Connection to the objectives of the dissertation

This paper addresses the elements that support building robust platforms for IoT technology experiments. The findings reinforce ODT and help organizations consider the relevant dimensions when establishing environments for digital technology experiments.

4.5 Article V: "Improving smart city design: A conceptual model for governing complex smart city ecosystems"

Hämäläinen, M., & Tyrväinen, P. (2018). Improving smart city design: a conceptual model for governing complex smart city ecosystems. In A. Pucihar, M. Kljajić, P. Ravesteijn, J. Seitz, & R. Bons (Eds.), *Bled 2018: Proceedings of the 31st Bled eConference. Digital transformation: meeting the challenges* (pp. 263–278). Maribor, Slovenia: University of Maribor Press.

Research objectives

Growing smart city markets set high demands for smart city governance, ecosystem orchestration, and sustainability. Instead of short-term projects smart city development should be seen as a long-term commitment requiring multi-stakeholder collaboration. Very little is known about the elements that support robust smart city implementation and digital transformation within cities. This paper, therefore, explores the prior literature on smart city ecosystems and is aimed at identifying the main concepts relevant to sustainable, long-term smart city implementation.

Findings

Based on the literature, four main dimensions for robust smart city implantation are identified: strategy, technology, governance, and stakeholders. These dimensions, complemented with sub-dimensions, form the basis for a framework aimed helping smart city practitioners accomplish and govern long-term digital transformation within cities. The framework does not consider social and political elements. Further indicators to measure and analyze smart city initiatives could facilitate the health of digital transformation within cities.

Connection to the objectives of the dissertation

This conceptual study considers the dimensions of strategy, technology, governance, and stakeholder to be vital to digital transformation in smart cities. The framework presented in the article supports the formation and governance of complex, multifaceted stakeholder groups within smart cities. The framework extends the work presented in Article III and is aimed at improving the outcomes of digital transformation and the survivability of smart city ecosystems.

4.6 Article VI: "A framework for a smart city design—Digital transformation in the Helsinki smart city"

Hämäläinen, M. (2020). A framework for a smart city design: digital transformation in the Helsinki smart city. In V. Ratten (Ed.), *Entrepreneurship and the community. Contributions to management science.* (pp. 63–86). Springer, Cham.

Research objectives

This paper sets its foundation on the work presented in Article V and modifies the sub-dimensions of the proposed framework. The four main dimensions and sub-dimensions are applied to the Helsinki Smart City. The aim of the paper is, first, to analyze Helsinki Smart City through the presented dimensions and learn how Helsinki Smart City governs and implements its smart city initiatives. Second, the aim is to evaluate the framework's applicability in practice.

Findings

Digital technologies are at the center of the smart city phenomenon and initiatives. Helsinki has established a separate organization, Forum Virium (FV) Ltd, for innovation development. FV is funded by EU project funds, the city of Helsinki, and member companies. Many Helsinki smart city initiatives are project based and coordinated by FV. The dimensions presented in the smart city design framework reveal that Helsinki does not have specific digital or smart city strategies because digitalization is seen as the new normal. Deployment of ICT and digital technologies is embedded in Helsinki's city-level strategy. Helsinki has created strong technology experimental practices, which enable agile experiments with novel digital technologies. Quadruple helix collaboration is a common model to accomplish agile smart city pilots. Even though smart city initiatives are well established in Helsinki, many smart city initiatives are short term and project based. EU project funding is arbitrary, which prevents long-term, consistent smart city development. Furthermore, Helsinki does not have specific metrics to evaluate the outcomes of smart city initiatives. Based on the empirical results, specific digital strategy and indicators might improve the governance and health of smart city development in Helsinki. Adding political and social dimensions to the smart city conceptual framework might improve the framework's practical implications.

Connection to the objectives of the dissertation

This article presents empirical results from the framework presented in Article VI. This article considers the strategy, technology, governance, and stakeholder dimensions in the context of Helsinki Smart City and provides empirical perspectives for digital transformation in public organization.

4.7 Contributions to joint articles

The author of this dissertation wrote Article VI by herself. The author made the following contributions to the other articles. In Articles I and II, the author was responsible for developing the research idea, conducting the literature reviews and empirical studies, and writing the article. The co-author provided content, improved the manuscripts with constructive comments, and assisted with structuring the articles.

Article III was initiated by the first author and based on her prior work in software ecosystems. The other authors provided content and assisted with finalizing the paper.

Article IV was designed and written jointly with the authors. For Article V, the dissertation author was responsible for designing the research idea, conducting the literature review, designing the conceptual framework, and writing the article. The co-author provided content for the article, improved the manuscript with valuable, professional comments, and assisted with structuring the article.

5 RESULTS AND CONTRIBUTIONS

Organizations' digital transformation is a pervasive, multifaceted endeavor. This dissertation investigates ODT and the elements that influence how organizations may systemically and effectively deploy novel digital technologies into their activities. In this chapter, the results relevant to the two research objectives are addressed. The proposed ODT framework is presented, and the connections of the framework to the selected research papers are illustrated. Next, the solution to the second research objective is addressed, and finally, the contributions and implications for theory and practice are discussed. Research limitations and recommendations for future research conclude the chapter.

5.1 Proposed organizations' digital transformation framework and the research papers' connections

This section addresses solutions to the research objectives:

RO1. Which elements form the foundation of ODT?

RO2. How can organizations take control of their digital transformation?

5.1.1 Conceptualizing organizations' digital transformation—elements of organizations' digital transformation

A conceptual framework is defined as "a network of interlinked concepts that together provide a comprehensive understanding of phenomenon" (Jabareen, 2009, p. 51). This dissertation traces the major elements of digital transformation and proposes a conceptual framework for ODT. The proposed conceptual framework contributes to the literature on digital transformation and meets the aim to provide a systematic approach to carrying out ODT. The elements that emerged from the literature have features that make up the organization and business dimensions (Table 3).

Table 3 Conceptual foundations of organizations' digital transformation

Conceptualization of organizations' digital transformation	
Organizational dimension	**Business dimension**
Change management and governance	Business models, value creation and proposition
Culture	Business/use case
Data	Customer and user experiences, needs and process, engagement
Digital maturity	Competitors, entrants, competitive advantages
Digital strategy (strategy)	Experiments
Digital technologies	Separate business units
Disruptiveness	Value chains and networks, digital business ecosystems
Finance, investments, investors	
Leadership and top management involvement, right mindset	
Monitoring, performance indicators	
Risks	
Process	
Skills and capabilities	
Structure	

Synthetizing the elements from the organization and business dimensions give rise to four meaningful, interrelated categories: strategy, technology, governance, and stakeholders. The elements from the organizational and business dimensions are organized into four interrelated thematic groups (Table 4).

Table 4 Thematic orientation of organizations' digital transformation

Strategy	**Technology**	**Governance**	**Stakeholders**
Business models	Digital technologies and data	Business/use case	Business models, value creation and proposition
Change management and governance	Business/use case	Change management and governance	Customer and user experiences, needs and process, engagement
Culture	Experiments	Digital maturity	Value chain and networks, digital business ecosystems
Competitors, entrants, competitive advantages	Separate business units	Leadership and right mindset	
Digital maturity		Monitoring, performance indicators	
Digital strategy			
Disruptiveness			
Finance, investments, investors			
Leadership and top management involvement, right mindset			
Risks			
Processes and structure			
Separate business unit			
Skills and capabilities			

The synthesis from the prior literature discloses that certain elements receive more attention over the others (Table 1). In the organization dimension, skills and capabilities, leadership and management perspectives, the importance of digital strategy, and the disruptiveness of digital technologies are highlighted. The business dimension literature emphasizes the elements of customer and user experiences and the importance of value propositions and business model designs. All the elements in the four themes are more closely described in section 2.3. In the following section, the connections and relationships of the selected research papers to the ODT framework are presented.

5.1.2 Selected research papers' connections to the conceptualization of organizations' digital transformation

The selected papers form joint links to the ODT framework. The ODT framework comprises the organization and business dimensions (Table 3), which include the themes of strategy, technology, governance, and stakeholders and their sub-elements (Table 4). Figure 1 illustrates how the dissertation's research papers form connections to the ODT framework.

Figure 1 Proposed organizations' digital transformation framework and the connections of the research papers

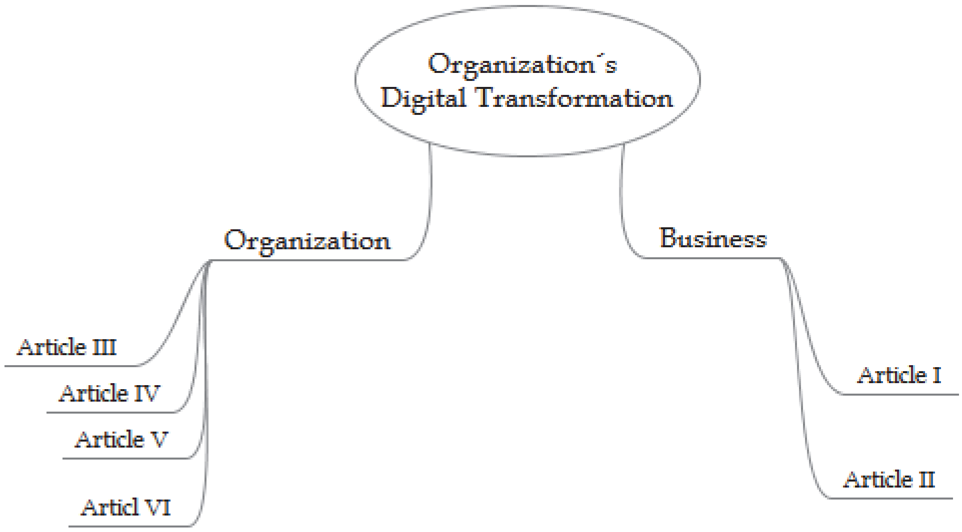

Table 5 compiles the ODT framework's thematic groups and elements and the findings from the selected research papers. The findings from the research papers are not fully comparable with the ODT framework because their contexts are different. The aim, though, is to find consistencies between theoretical knowledge and the research papers. The summary in Table 5 illustrates the research papers' similarities and differences with the ODT themes and elements. In public organizations such as smart cities, quadruple helix collaboration is emphasized. However, in the private sector, the roles of customer integration and experience, business models, and value propositions are pinpointed as the starting point elements for ODT. The research papers also highlight security and privacy issues and trace the vertical and horizontal scopes. In the following, the results from the research papers are presented in more detail.

Table 5 Organizations’ digital transformation framework and findings from the research papers

Strategy	**Technology**	**Governance**	**Stakeholders**
Business models	Business/use case	Business/use case	Customer and user experiences, needs and process, engagement
Change management and governance	Digital technologies and data	Change management and governance	Business models, value creation and propositions
Culture	Experiments	Digital maturity	Value chains and networks, digital business ecosystems
Competitors, entrants, competitive advantages	Separate business units	Leadership and right mindset	
Digital maturity		Monitoring, performance indicators	
Digital strategy			
Disruptiveness			
Finance, investments, investors			
Leadership and top management involvement, right mindset			
Risks			
Processes and structure			
Separate business unit			
Skills and capabilities			
	Findings from Articles (I–VI) included in the dissertation		
Strategy	**Technology**	**Governance**	**Stakeholder**
Capabilities	Architecture design	Orchestration	Customers
Vision and digital strategy	Data	Culture	Business models

	Digital technologies and infrastructure	Funding	Quadruple helix model
	Experimental facilities and experiments	Risk management	Value networks
	Security and privacy	Monitoring, performance indicators	Value proposition, value creation and capture
	Vertical and horizontal Scope	Experimental facilities and experiments	

Organization dimension

Articles III, IV, V, and VI provide conceptual and empirical perspectives on the ODT framework. Article III addresses the elements in the governance category. The article is based on prior studies on software ecosystems and focuses on improving the survivability, productivity, and health of software ecosystems. Similarly to the procedures of agile software development (Abrahamsson et al., 2002), Article III proposes that the design and development of software ecosystems is a continuous, iterative process. The article suggests conducting pre-analysis, design, and evaluation and monitoring phases when developing software ecosystems. The evaluation and monitoring phase is strongly emphasized because the software ecosystem is subject to constant changes. It is noted that systematically monitoring the software ecosystem's evolution improves its health, survivability, and productivity. The article III also highlights orchestration as a core element of the software ecosystem.

Article IV is conceptual in nature, and a framework for IoT SEP is formulated by exploring the literature on TEP in ICT and smart city environments. Article IV supports the findings in Article III and contributes to technology and stakeholder category in ODT framework. The IoT SEP presented in Article IV includes eight factors: openness, real-world experiments, user/public involvement, vertical and horizontal scopes, scalability, sustainable value creation, continuity, IoT heterogeneity, and architecture design. These eight factors support the health and sustainability of TEP and thus are significant when building a robust IoT SEP.

Article V is connected to the research because public organizations such as cities are undertaking digital transformation. The cities benefiting from digital technologies are labeled as smart cities. Article V is aimed at responding to challenges to the survivability and resilience of smart city ecosystems and presents a conceptual model for the governance of complex smart city ecosystems. The model is derived from the literature on smart city ecosystems and is aimed at improving the orchestration and governance of smart city ecosystems. The findings on the smart city ecosystem governance model accord with the categories and elements presented in the ODT framework. However, slight differences between the smart city ecosystem governance model and the ODT framework emerge in the elements in the strategy, technology, governance and stakeholder thematic groups. The sub-elements in the smart city ecosystem's conceptual model appear to be more limited than in the ODT framework, whereas elements such as security and privacy and vertical and horizontal scopes are emphasized in the smart city ecosystem model. The importance of these elements to the ODT model should be evaluated.

Article VI is founded on the conceptual model presented in Article V and provides empirical perspectives on the smart city's digital transformation. The results from the empirical research support the proposed conceptual model, but one anomaly emerges, indicating that forming a separate digital strategy is not a necessity in the smart city's digital transformation. A specific digital strategy is considered to be redundant because digital technologies are seen as the new normal in the smart city context. In other words, digital transformation is viewed as systemic change, and digital technologies and infrastructures are embedded in and integral to contemporary smart city development. The case smart city in Article VI, however, hired a CDO to support the smart city implementation. The CDO's purpose is to form a more holistic overview of the current status of the smart city's digital transformation.

The empirical findings in Article VI especially highlight the culture and external business unit sub-elements in the strategy category. Digital technologies, data, and technology experiments are emphasized in the technology category. The quadruple helix, user engagement, and value propositions sub-elements emerge in the stakeholder category.

Business dimension

It is evident that novel digital technologies influence organizations' businesses, and value is created through novel digital technologies. Connections of Articles I and II to the ODT framework appear through the sub-elements such as business models, value propositions and creation, customer engagement, and value network actors. Further sub-elements such as investments, disruptiveness, business and use cases, and technology experiments are covered in Articles I and II.

Articles I and II explore 3D printing technology in machine engineering and metal processing companies. The results in the articles show that the overall digitization of manufacturing has accelerated the diffusion of 3D printing technology. Moreover, 3D printing technology has influenced organizations' business model components such as products, value network actors, value delivery, and, in some research companies, revenue models. Some research companies' business models have evolved following the usage of 3D printing technology. One case company reported that it abandoned an initial business model because investors were uncertain about its relatively unknown technology and workability (see Article II). These findings support the idea that novel digital technologies influence business models. Business models are dynamic and subject to changes, and they evolve through certain phases including creation, reassessment, and development. Finally, business models are either abandoned or renewed and accepted as organizations' new business models (Ojala, 2016).

The research companies in Articles I and II highlight customers and customer integration as central elements when implementing 3D printing technology. Depending on actors' roles in value networks, their reasons for integrating customers into the 3D printing process vary. Customer integration is related, for example, to technology investment risks, improved quality, opportunities to produce a wide variety of tailored, customer-specific products, and possibilities to minimize design errors. Some companies also use 3D printing for marketing purposes. Value creation and delivery elements are related to cost and time savings in product design, testing, and modification activities and prototype production (see Articles I and II). Customer centricity and integration presented in Articles I and II support the findings from the ODT literature. Especially in private organizations, customer and user experiences are identified as primary targets of digital transformation initiatives (Alfaro et al., 2019; Chanias & Hess, 2016b). In public organizations such as smart cities, users' role is emphasized, but it appears that users are not the initial reason for digital transformation in smart cities (Article VI).

Moreover, 3D printing is proven to be an efficient technology for testing and experimenting with new prototypes and materials. In particular, 3D printed prototypes enable accomplishing several test rounds at affordable prices and reasonable time constraints compared to prototypes produced using traditional methods. The traditional method to produce prototypes is to sculpt molds from wood manually. Instead, 3D printed prototypes are designed by using 3D digital computer aided design tools. The digital prototypes are then 3D printed by cumulatively adding materials (Liu & Zhou, 2010). Compared to the traditional manual procedure, 3D printing streamlines and speeds up the overall design, production, and experiments with prototypes (Article I). Faster, easier, and cheaper than traditional mold technology, 3D printing has disrupted businesses in traditional mold manufacturing.

The characteristics of 3D printing technology relate to the features of disruptive innovation theory presented in Chapter 2.6.1. As 3D printed products are regarded faster, easier, and cheaper, 3D printing has met the demands of mainstream customers and replaced expensive, manually produced wooden prototypes. Product designers have also adopted lean and agile methods to 3D printing because the technology enables agile, cost-effective experimenting with new forms and structures. Using 3D printing technology allows designers to detect design errors and learn through trial and error. 3D printing technology allows designers more quickly determine what works and what does not.

The results in Articles I and II also support the idea of forming co-operation or strategic alliances with external companies (King & Baatartogtokh, 2015; Markides, 2006; Obal, 2013) and building business ecosystems around 3D printing technology. Large companies, in particular, prefer using sub-contractors because they have the best expertise in 3D printer use, materials, product finishing, and pricing. For smaller companies, belonging to the 3D printing ecosystem improves their overall knowledge of 3D printing technology and increases their new business opportunities.

5.1.3 Means to take control of digital transformation

Digital transformation is seen as a paradigm shift (Berman & Marshall, 2014), and ODT is characterized as multifaceted, complex, and uncertain (Davenport & Westerman, 2018; Hess et al., 2016; Sahu, Deng, & Mollah, 2018; Tabrizi et al., 2019). Digital transformation can emerge as radical and disruptive for some organizations and stakeholders in value networks (Au et al., 2018; Gimpel et al., 2018; Morakanyane, Grace, & O'Reilly, 2017; Weill & Woerner, 2015).

Technology discontinuities and disruption do not occur overnight but are serial processes that evolve over time, causing systemic impacts on industries and markets (Christensen, 2006; Christensen, Raynor, & McDonald, 2015; Rafii & Kampas, 2002; Skog, Wimelius, & Sandberg, 2018). Management, therefore, should create procedures that systemically identify and track potential and novel disruptive technologies (Bower & Christensen, 1995) and evaluate how serious the potential threats of new technology are (Weill & Woerner, 2015).

To address the second research objective on how organizations take control of ODT, this dissertation draws on the theoretical background material and the presented research papers. The observations on digital and disruptive innovations, technology testing and experimental practices, and smart city experimental platforms are intended to provide answers to the second research objective. The research papers with practical evidence complement the findings from the theoretical background material (Table 6).

Table 6 Characteristic features of the theory of disruptive innovation and (disruptive) digital innovation

Theory of disruptive innovation		**(Disruptive) digital innovation**	
	Characteristic features		
Straightforward, inferior	Small, niche markets, new markets, low profit expectations	Short life cycles, rapid changes, high speed of adoption	Systemic impacts, unlimited network capabilities
Simple, easy to use	Markets without customers or demands	Risky, unique, original, fragile, unclear	Transformative, radical, disruptive
New architecture	No prior data, difficult to assess innovation and markets	Combination of digital and physical components	Pervasiveness, scalable, flexible
Different performance trajectories, low performing, low cost (cheaper)		Rapid and massive adoption, network effect	

Small entrants		Digital ecosystems, digital platform businesses, platform business models	
Revenue and cost structure			
Technology experiments; external business units; lean, iterative, agile pilots			

Characteristics of novel digital technologies and innovations

Disruptive and digital innovations are distinguished by certain characteristic attributes and principles. Disruptive innovation traditionally is identified as technologically more straightforward, simpler, and easier to use than dominant solutions (Bower & Christensen, 1995; Christensen, 1997; Roger, 2002). Disruptive innovation is low performing and even inferior compared to products targeted for high-end customers. Disruptive innovation is also initially introduced in small, niche markets and markets without customer demands (Bower & Christensen, 1995; Christensen, 1997).

Disruptive digital innovation has relatively a short life cycle and is considered to be risky during the time of breakthrough. As digital infrastructures mature and become pervasive, novel digital innovation has potential to be rapidly adopted by large numbers of end users. The diffusion of novel digital innovation occurs faster and has increasing potential to achieve critical mass, resulting in the network effect. IT base innovation also has established the ground for the emergence of online digital services, ecosystems, and platforms. Digital platforms and ecosystems offer easy plug-and-play solutions for third-party developers to design new and complementary digital services. Digital platforms are also low-threshold marketplaces for ecosystem actors to conduct businesses on a global scale at affordable prices and to more rapidly experiment with business models with low costs and efforts. (Carlo, Lyytinen, & Rose, 2011; Lyytinen & Rose, 2003; Weill & Woerner, 2015.) If disruptive digital innovation evolves, it may generate systemic impacts and seminal and transformative influences on future digital innovation trajectories (Carlo, Lyytinen, & Rose, 2011; Latzer, 2009; Skog, Wimelius, & Sandberg, 2018).

Technology testing and experimental practices

Nearly all innovation starts in small-scale experiments (Christensen, Raynor, & McDonald, 2015) whose outcomes are not straightforward or predictable. Creating a culture of systematic technology testing and experiments has been recognized to have positive influences on organizations' capacity to confront novel digital technologies (Article VI). Regular, continuous technology experiments also stimulate knowledge creation and activate constant learning processes (Ries, 2011; Schrage, 2018; Thomke, 2001, 2003), which improve organizations' possibilities to evaluate novel digital technologies and their fitness for organizations' and stakeholders' activities in value networks.

Ubiquitous digital infrastructures and services make testing new digital innovations and technologies more cost and time effective and accelerate the experimental processes (Kohavi & Thomke, 2017; Thomke, 2001, 2003). Providing evidence of faster product experimental cycles, Articles I and II show that 3D printing allows producing prototypes more quickly and at lower costs than manual prototypes. In addition, 3D printing speeds up overall product testing, shortening overall product lead times, and enables parallel, simultaneous product experiments with several different prototypes.

By developing a culture of systematic technology experimenting and investing in a digital online experimental environment and capabilities, organizations improve their capacity to explore novel technologies and their influences on organizations' current business model and value networks. Furthermore, establishing digital experimental practices improves organizations' ability to experiment with and create new business models in real-world settings. (Kohavi & Thomke, 2017; Thomke, 2003.) A lean technology experimental culture thus extends organizations' learning capabilities and learning from trial and error.

Article VI shows how a smart city successfully created a culture of novel digital technology experiments. A culture of agile pilots and technology experiments was developed over time as a result of the smart city's strategic decision to establish a separate business unit for smart city development and digital technology experiments. Developing a culture for agile pilots and technology experiments activated stakeholders throughout the smart city to develop and figure out how to benefit from novel digital technologies and conduct agile technology pilots on city-level strategic projects and procurements.

External business units

The literature on digital transformation and disruptive technology innovation has suggested establishing parallel, autonomous business units separate from parent organizations for agile technology experiments and innovation activities (Christensen, 2001; Christensen & Raynor, 2003; Christensen, Raynor, & McDonald, 2015; Macher & Richman, 2004; Markides, 2006). Among the benefits, external business units allow organizations to experiment with novel digital innovation and evaluate the risks, opportunities, and influences on organizations and their value networks without interfering current, matured business procedures. Further, in external experimental business units, organizations may iteratively innovate and experiment with new business models and value creation possibilities with new markets and new customers. (Bower & Christensen, 1996; Christensen, Johnson, & Rigby, 2002; Christensen & Raynor, 2003.) Alternatively, organizations may form strategic alliances, acquire entrants, establish joint ventures, license new technologies, and conduct accomplish technology and innovation pilots with start-ups (Christensen, Raynor, & McDonald, 2015; Danneels, 2004; King & Baatartogtokh, 2015; Markides, 2006; Obal, 2013; Schrage, 2018) to lower the risks and improve the opportunities with digital transformation.

As pointed out in Article VI, the smart city established a separate business unit to develop and experiment with new digital innovations and city services in collaboration with private companies, other public organizations, and citizens. The external business unit appeared to strengthen the organization's technology experimental culture and support agile technology experimental practices. The external technology experimental business unit even published a guidebook presenting the best practices and lessons from the agile pilots for the benefit of other cities and municipal organizations. The study results suggest that the external business unit enhanced the city's overall digital transformation process. Articles I and II provide evidence that incumbents are willing to build alliances and buy 3D printings as a service from 3D printing sub-contractors because incumbents are reluctant to invest in their own machines and knowledge creation. However, a tractor manufacturer (company H in Article I) stated in the second interview (Article II) that it had invested in its own 3D printer for R&D purposes. The aim with own 3D printer is to investigate the capabilities and restrictions of 3D printing technology and discover whether technology is usable for special accessory production in a new business unit.

Regarding how organizations may take control of ODT and systematically monitor novel digital technologies, it is suggested that they develop procedures for technology testing and experiments. By developing and creating a culture of agile and iterative technology experiments, organizations improve their possibilities to confront rapidly emerging and changing novel digital technologies. Investing resources in systematic technology experiments improves organizations' possibilities to analyze and evaluate the disruptiveness, risks, and opportunities related to emerging digital technologies. Furthermore, organizations increase their knowledge and understanding of digital technologies, thus improving their digital maturity and capabilities. Technology experiments further enable learning from trial and error and analyzing new business models based on experiments in real-world markets. Establishing external business units for technology experiments depends on organizations' strategic and investment choices. Separate business units may be a legitimate choice, especially if novel digital innovation is radical and may result in systemic impacts on industries and markets.

5.2 Contributions

This research addresses ODT and provides insights into the elements relevant to systematically designing and carrying out digital transformation. This dissertation also explores solutions for organizations to cope with and manage digital transformation. Table 7 summarizes the key findings and contributions.

Table 7 Summary of findings and contributions for research objectives

Research objective	Summary of the findings	Contributions
1. Which elements form the foundation of ODT?	The proposed ODT framework consists of four main themes: strategy, technology, governance, and stakeholders. Each theme contains sub-elements that complement the proposed framework. The research papers support the framework, but considering adding security and privacy and vertical and horizontal scopes under the technology theme is suggested.	The proposed framework is aimed at supporting and extending theoretical knowledge and design of the effective deployment of novel digital technologies in organizations' activities and value networks. The framework aids the systematic design of ODT (theory type V; Gregor, 2006).
2. How can organizations take control of their digital transformation?	Exploring the elements in the ODT framework and creating a culture of systematic, iterative technology testing and experimental practices help organizations evaluate and govern ODT. The characteristic features of disruptive and digital innovation constitute factors that help organizations evaluate the disruptiveness of novel digital technologies. Establishing external business units may strengthen analysis and deployment of novel technologies and help organizations explore new value propositions and business models without disturbing existing business operations.	The findings can influence IS practice, particularly the use, deployment, and management of novel digital technologies in organizations' activities. The study is also aimed at providing insights into technology adoption and business model research in the IS field.

5.3 Theoretical contributions

Orlikowski and Baroudi (1991) suggested that IT development and use within organizations is processual and contextual and that IS research's major goal is to have impacts on IS practice. Another fundamental goal of IS research is to find out how information systems can be effectively deployed in organizations and how well this research objective is addressed, particularly in terms of theory, empirical work and knowledge transfer (Grover & Lyytinen, 2015). Traditionally, IS research, including IT and organizations, has adapted theories from relevant disciplines such as psychology, economics, and sociology (Baskerville & Myers, 2002; Grover & Lyytinen, 2015; Picot & Baumann, 2009). Widely accepted theoretical frameworks applied in IS research include, for example, the technology acceptance model, resource-based view, and transaction and activity theories (Lim et al., 2013; Picot & Baumann, 2009). The phenomenon of ODT, though, provides a holistic approach to observe how organizations systematically and effectively implement novel digital technologies into their activities. Consequently, traditional theoretical approaches to investigating the phenomenon of digital transformation might not provide broad enough perspectives. Expanding knowledge about these factors that influence and are essential for ODT is needed.

Gregor (2006) identified five theory types in IS research: analysis, explanation, prediction, explanation and prediction, and design and action. Design and action theories are closely associated with design science. The objectives and content of this dissertation, therefore, address and explore the convergence and interplay of organizations and technology. This research thus is in line with and contributes to the design and action theories and reflects the design science approach, thereby positioning it to create and evaluate applicable IT artifacts for specific organizational problems. IT artifacts are defined as models, constructs, methods, and instantiations (Hevner et al., 2004; Peffers et al., 2007).

It has been emphasized that artifact development should be founded on existing theories and knowledge bases (Peffers et al., 2007) to better understand the problems and solutions artifacts address (Hevner et al., 2004). The proposed ODT framework primarily builds on the literature on digital transformation and is supported by the research papers and other theoretical background materials introduced in this dissertation. The dissertation is positioned to extend knowledge and understanding of ODT by providing a systematic approach to ODT and identifying means for organizations to take control of and manage the deployment of rapidly changing, novel digital technologies.

5.4 Practical implications

This dissertation provides several practical implications for organizations' decision makers and managers. First, management needs to have a strategic approach to creating a culture and capabilities for tracking novel digital technologies, the companies behind them, and the markets in which they operate. Second, management should have systematic procedures for the design and implementation of digital transformation. Third, an iterative, lean approach to experimenting with novel digital technologies, preferably in external business units, increases organizations' opportunities to learn about new digital technologies and how to align them to organizations' own structures and processes. Additionally, systematic technology experiments enable developing and renewing contemporary value propositions and business models in existing and new markets. Alternatively, strategic alliances and collaboration with digital start-up ecosystems may provide environments for learning and extending knowledge about new digital innovations. The ODT framework with its four themes of strategy, technology, governance, and stakeholders and their sub-elements is an instrument for organizations to use to systematically consider their digital transformation journey.

5.5 Limitations

Most of the dissertation is built on the foundation of the synthesis of the literature. The conceptual frameworks presented in dissertation itself and the selected articles provide little empirical evidence and thus should be subjected to more comprehensive, large-scale empirical testing and validation. Another limitation is the relatively small sample of companies, organizations, and interviewees in Articles I, II, and VI. Studying a broader set of similar novel digital technologies in more homogeneous organizations could provide deeper insights into the process, governance, and stakeholder dimensions of digital transformation within specific contexts. Additionally, the organizations are not comparable (e.g., in Articles I and II compared to Article VI), limiting comparisons of the study results between the articles. A more precise empirical research area could enable observing and comparing the obstacles and barriers that prevent digital transformation in a specific research context. The ODT framework presented in this dissertation, however, is applicable in diverse organizations because there is barely any industry or organization immune to the effects of digital transformation (Hess et al., 2016). The proposed ODT framework, therefore, is generalizable.

5.6 Recommendations for further studies

ODT is not trivial, and many historical incidents show how novel digital technologies and innovation have changed the course of many industries and even disrupted businesses. As an emerging research phenomenon, therefore, digital transformation provides several alternative paths in the IS research field. Considering organizational perspectives, the theory of the resource-based view of the firm could consider organizations' strategies, resources, and competitive advantages (Wade & Hulland, 2004), whereas organizational culture could investigate levels such as artifacts, values, and underlying assumptions (Schein, 1990). Another research approach could utilize unified theory of acceptance and use of technology (UTAUT) by Venkatesh et al. (2003, 2012) or alternatively diffusion of innovations theory. Exploring organization´s digital maturity and information asymmetry might provide new perspectives for organization´s digital transformation.

The conceptual frameworks presented in this dissertation encompass stakeholder, value creation, and business model perspectives, for example. The importance of customer experience, user integration, value propositions, and business elements is highlighted. Several IS researchers have investigated business models, for example, in software firms, cloud computing, and gaming and, alternatively, have explored how organizations' business models evolve in turbulent, uncertain markets (Luoma, 2013; Ojala, 2016; Ojala & Tyrväinen, 2011). Due to the rapid evolution and diffusion of novel digital technologies in global markets, future research could also investigate the interactions of ODT and business models. As evidence of the interplay of ODT and business models, it has been found that organizations' interactions with primary stakeholders such as customers and value network actors improve when organizations shift their activities from physical channels to digital platforms (Baber, Ojala, & Martinez, 2019). Stakeholder theory could offer insights into exploring how organizations create value for their current stakeholders (Freeman et al., 2010) and their new stakeholders in new market segments enabled by digital platforms (Baber, Ojala, & Martinez, 2019). Alternatively, in deregulated markets, observing digital transformation in new market conditions might provide interesting research subjects (Heikkilä & Heikkilä, 2019).

Novel digital technologies have relatively short life cycles and are subjected to rapid changes. Organizations may find it difficult to assess the disruptiveness of rapidly changing digital technologies for their activities. The theory of disruptive innovation and the DITIM presented in this dissertation provide perspectives for assessing technology discontinuities and disruptiveness. However, further research developing more unified theoretical foundations to address the disruptive elements of digital innovations and technologies and their impacts on organizations' diverse dimensions might also be fruitful for researchers in the IS field.

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ORIGINAL PAPERS

I

ADDITIVE MANUFACTURING TECHNOLOGY: IDENTIFYING VALUE POTENTIAL IN ADDITIVE MANUFACTURING STAKEHOLDER GROUPS AND BUSINESS NETWORK

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Additive manufacturing technology: Identifying Value Potential in Additive Manufacturing Stakeholder Groups and Business Networks

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Abstract

The development of additive manufacturing (AM) technology is expected to transform product design and manufacturing. It is predicted that the effects of AM on business will be diverse and extensive. It will be critical for business owners to observe how AM impacts on conventional supply chains and business networks, plus the effects on customers' value propositions and on value creation. Value creation and value capture are concepts strongly linked to business relations and to stakeholder management. However, the concept of value is inherently complex and multifaceted, and so are the structures within which value potential exists in business networks and business environments. The critical issue for business managers is to identify where and how value is created in business relations. In this study, the primary purpose was to observe how AM technology impacts on company value creation within complex business relations.

Keywords: 3D printing, additive manufacturing, stakeholder theory, value creation

Introduction

Technologies that have been labeled as "disruptive," such as the Internet and additive manufacturing (AM), have challenged conventional business procedures. The Economist business magazine estimated that the digitization of manufacturing would transform the way goods are made, and it referred to AM technology as the third industrial revolution. The effects of AM technology will not only change the way products are manufactured, but will also change how products are designed (The Economist 2012). AM technology accelerates product development cycles, shifts the profit structure of companies (Cohen et al. 2014), reduces the environmental load (Gilpin 2014), and can reshape future professions and jobs (The Economist, 2012). Altogether, AM technologies present an important strategic and competitive use of information technology.

Existing research on AM has provided a good understanding of the technical aspects of AM, and of how AM technology is implemented in various industries (e.g. Chimento et al. 2011; Michaleris 2014; Sanz-Izquierdo and Parker 2013). Nevertheless, the literature has not elaborated AM technology from the point of view of value creation for companies, or of business networks. This is important, as AM provides interesting perspectives for a company's value creation – involving delivery and capture among its current stakeholder groups – and there is a need to discover how AM technology could impact on future business relations and ecosystems. In this regard, one can draw on stakeholder theory (Freeman 1984) and research on value creation and value networks (e.g. Allee 2000; Ojala and Helander 2014), in order to understand how a company creates value for its stakeholders. This paper seeks to contribute to the literature on IS and value creation in the context of AM technology, by examining: 1) where and how value is created in company business relations and, 2) how AM technology impacts on a company's value creation among its primary stakeholders.

Stakeholder Theory

R.E. Freeman (1984) is regarded as the initiator of stakeholder theory. Freeman (1984) suggests that businesses should build their business strategy around relationships with key stakeholders, and that the focus should be on the jointness of the stakeholders' interests. Fundamentally, stakeholder theory is a theory concerning how business works and how it could work best in a turbulent global business environment. The purpose of the theory is to show how business can be described through stakeholder relationships, and how value is created for stakeholders in an effective way (Freeman et al. 2010). The importance of value creation for all stakeholders is underpinned by the assumption that people engaged in value creation will be more responsible to those individuals or groups whom they think they can affect, or whom they may be affected by.

If stakeholder theory provides answers to the problem of value creation, the essential question from a management perspective will be to determine which groups or individuals are stakeholders and which are not (Mitchell et al. 1997). Freeman (1984) defines a stakeholder as "any group or individual who can affect or is affected by the achievement of an organization's purpose" (Freeman 1984, 53). Friedman and Miles (2006) consider the organization itself to be a group of stakeholders; the purpose of the organization thus becomes that of managing the stakeholders' interests, needs, and viewpoints. By identifying a certain focal stakeholder group – such as top-management within an organization – it may be possible to manage other stakeholder groups (Friedman and Miles 2006).

Shareholders, customers, suppliers, distributors, employees, and local communities are considered to be the most common stakeholder groups of an organization (Friedman and Miles 2006). However, Freeman et al. (2010) determine customers, employees, financiers, communities, and suppliers as the primary stakeholder groups of the company (Figure 1). For Clarkson (1995) the primary stakeholders are those individuals or groups whose contribution to the organization is so important that without them the corporation could not survive.

Figure 1. Primary Stakeholder Groups (Freeman et al. 2010)

It is vital for organizations to consider other individuals and groups who can affect or be affected by the organization. Secondary stakeholders, such as the media, government, competitors, consumers and other special interest groups (for example environmental organizations) are examples of the stakeholders who may have an interest towards the organization and should thus not be ignored (Clarkson 1995; Freeman et al. 2010). This means that the stakeholders are multifaceted, forming dynamic cross connections and relationships among each other. The stakeholders thus form interfaces (Figure 1) at which value potential exists. The value potential is actualized when certain business activities occur between the stakeholders. By examining a company's ecosystem and stakeholder activities in the value creation process, it is possible to see where and how value is created and gained (Freeman et al. 2010).

Value Concept and Value Creation

Lepak et al. (2007) express the difficulty among scholars of defining what value creation is, the process in which value is created, and the mechanism that enables value creation in an organization and in business networks. Value originates from the assumption that a human is *a goal-oriented* organism seeking to achieve satisfaction and avoid dissatisfaction. Values are seen as qualitative, via the fact of being excellent, useful, or desirable (Rescher 1969). Values are beliefs and commitments that motivate a person to action to achieve desirable goals (Rescher 1969; Schwartz 2012). In the organizational context, Heinonen (2004, 2006) proposes that customer-perceived value can be conceptualized in four dimensions, involving *technical, functional, temporal*, and *spatial* dimensions in the service and product value context. The technical dimension consists of the technical elements included in the product or service. The functional dimension is related to the functional aspects of the service and product. The temporal dimension of value involves the benefits and sacrifices related to time, and includes the temporal aspects affecting perceptions of the value. The spatial dimension encompasses the benefits and sacrifices related to location (Heinonen 2004, 2006).

Ojala and Tyrväinen (2011) suggested that value occurs not only in customer-seller relationships but also among the other actors in business networks. Business networks may possess certain resources and qualities that the company is lacking. By belonging to the business networks, the company may benefit from the business network's resources and receive value directly or indirectly. Direct value may occur in a monetary form, but also in the form of critical resources. Indirect value may occur, for instance, in the form of improved market and networking potential (Ojala and Helander 2014).

Additive Manufacturing and Three-Dimensional Printing

Rapid manufacturing, rapid prototyping, or three-dimensional printing may be referred to when one is speaking of AM. AM includes materials adding methods such as stereo lithography, laser sintering, and three-dimensional printing. Various materials, including metal, composites, polymers, and ceramics are used in AM processes (Cotteleer et al. 2013). Petric and Simpson (2013) indicate that 3D printing and AM are perceived as synonyms, since both refer to a layer-by-layer production method.

AM technology is based on digital computer-aided design (CAD). It involves the creation of a series of digital images of an object, which are then transferred to an AM machine (Ford 2014). A physical model is formed from the digital image by adding materials cumulatively (Liu and Zhou 2010). The greatest advantages of AM are cost-effectiveness, reduced time to the market, a movement from mass production to more customized or tailor-made products, and environmental benefits. In addition, variety in materials, flexibility in design, and improved accuracy have been mentioned by AM technology users (Ford 2014; Cotteleer et al. 2013; Mertz 2013). Some authors (e.g. Petric and Simpson 2013) have even argued that AM provides the ability to produce almost anything that can be imagined.

During recent years AM machines and materials have improved, as have AM software and digital platforms. AM-compatible 3D scanners and software solutions have been developed for a variety of applications. Platforms such as Autodesk and Spark offer 3D design services that are optimized for AM. Consumer and electronics, automotive, aerospace and medical instrument industries have been the main industries to benefit from 3D printing (Mertz 2013; Petric and Simpson 2013). For instance, the automotive industry has benefited from AM in terms of producing tool prototypes and small customized parts. For it part, the aerospace industry is using AM to produce more light-weight and stronger components, and to print small numbers of geometrically complex parts from materials such as titanium and plastic (Ford 2014). The medical industry has increasingly benefited from AM; thus medical instrument companies can often fabricate unique products and small runs of complex parts (Ford 2014; Mertz 2013; Petric and Simpson 2013).

The Effects of AM on Value Formation

Petric and Simpson (2013) describe AM technology as a disruptive technology. By this they mean that AM has impacts on how products are designed, built, and delivered. The economies of scale of conventional manufacturing are challenged by economies of one, which AM technology makes possible. Petric and Simpson (2013) have estimated and compared the principles of conventional and AM technology in respect of economies of scale and economies of one (Table 1). Traditional manufacturing enables high volumes, which leads to a low unit price. With AM technology it is possible to produce tailor-made products with variable costs. The roles and responsibilities in the traditional supply chain are clear and well-defined. By contrast, AM technology enables local production and collaboration with various stakeholders. There are reductions in product delivery time and in costs to end-user when an AM service provider produces and delivers the product locally (Petric and Simpson 2013). Cotteleer and Joyce (2014) note that AM technology makes it possible to set up small and flexible AM service centers in various places, with lower capital costs. This opens up opportunities for companies to design and produce products more cost effectively, and to create value for existing and new customer segments. AM also impacts on the supply chain process, and on how products are transported in the supply chain.

Conventional/Additive Manufacturing	**Economies of Scale**	**Economies of One**
Competitive advantage	Low cost high volume & variety	Tailor-made products
Supply Chain	Well-defined roles and responsibilities	Non-linear, vague roles & local collaboration
Distribution	High volumes cover transportation costs	Local Customer/producer
Economic model	Fixed & Variable costs	Nearly all costs variable
Design	Standard, with aim of simplicity	Complex and unique
Competition	Precise	Continuous change

Table 1. Economies of Scale and Economies of One (Petric and Simpson 2013)

It is clear that AM technology impacts on supply chain activities, and also on the business partners and stakeholders involved in the supply chain. Companies have started to talk about moving from mass production to mass customization (Ford 2014). In particular, middle and small-sized manufacturers in the supply chain have the opportunity to take advantage of AM technology. Flexibility and cost savings are the aspects mentioned most often, with AM making it possible to respond quickly to changes and to produce (perhaps temporarily) components in house. In addition, AM technology allows production of critical components on demand, or spare parts for final use, reducing the overall risks in the supply chain, for example in terms of materials, tooling, storing, and transportation costs (Ford 2014).

Research Method

This study applied a qualitative research method, as the aim was to explain contextual information, and to understand the interpretations and perspectives of the actors. A qualitative study allows actors to articulate their perceptions of situations in the past, and to evaluate the elements effecting their development in the future. In addition, a qualitative research method examines the study phenomenon with a view to understanding the people operating within a certain social context (Myers and Avison 2007).

The companies selected for this study included six SMEs (small and medium-sized enterprises) and two large companies (see Table 2) from the Finnish machine industry. An SME is defined as a company having less than 250 employees (Statistics Finland 2014). In addition to size, the companies were categorized on the basis of their expertise in AM technology, into those of *beginner, experienced*, and *professional* level. A beginner-level company possesses some AM knowledge but lacks knowledge of AM materials, methods, and machines. Experienced-level companies utilize AM in R&D functions and are acquainted with AM design, materials, and methods. Experienced companies do not print AM products themselves, and instead utilize subcontracting. Professional-level companies provide AM end products, and services as subcontracting.

Altogether, eight semi-structured interviews were conducted (one per case company) as the means of data collection. The semi-structured interview procedure is flexible, enabling in-depth data collection and understanding of the research phenomenon (Gillham, 2005.) The themes and structure of the interviews were pre-planned, and the same questions were asked of all the interviewees. The interview questionnaire was divided into four themes: 1) a company's background, 2) AM benefits and value-adding elements, 3) a business development, and 4) resources and skills needed to implement AM technology. Finally, all the interviewees were able to make free comments and give feedback. In the SMEs, the interviewee was the owner or business manager, while in large companies the project manager or design engineer took on the role of interviewee. The interviews were recorded by using a voice recorder, and were transcribed verbatim. The average interview length was approximately 60 minutes.

Company	**Business description**	**Knowledge level**	**Company size**	**AM for prototype use**	**AM for final production**	**Own printer/ Subcontracting**
A	3D engineering design for the metal industry	Experienced	SME	Yes	No	Yes/No
B	Machine engineering	Beginner	SME	No	No	No/No
C	Metal processing and life-cycle solution provider	Beginner	SME	No	No	No/No
D	A subcontractor in machine engineering	Beginner	SME	No	No	No/No
E	AM service provider	Professional	SME	Yes	Yes	Yes/No
F	Machine engineering and design services	Experienced	SME	Yes	No	No/Yes
G	Optical devices, maintenance and product life cycle support.	Experienced	Large	Yes	No	No/Yes
H	Agricultural machines	Experienced	Large	Yes	No	No/Yes

Table 2. Overview of the Case Companies

Findings

The empirical study indicated that five companies (A, E, F, G, and H) utilized AM for prototypes and for miniature models production. Company E, an AM service provider, offered AM services for prototype use, but also for printing end-use products. The remaining three companies (B, C, and D) did not benefit from AM in their current business, but indicated an interest in learning more about AM technology and metal 3D printing. Two companies (A and E) owned printers suitable for AM, while three companies (F, G, and H) utilized subcontracting. Companies B, C, and D observed AM benefits between subcontracting and acquiring one's own printer. AM service provider (E) possessed professional-level knowledge, while the companies utilizing AM in prototype and in miniature products (A, F, G, and H) showed experienced-level knowledge. The others (B, C, and D) were regarded as being at beginner-level, with little knowledge of AM technology.

The Benefits of AM Technology, and Value-Adding Elements for a Company

The AM technology benefits noted varied among the case companies. Table 3 shows the benefits that interviewees expressed as being the most valuable for the company. The beginner-level companies (B, C, and D) indicated that AM technology would accelerate the company's development and generation of new products. AM technology might provide the opportunity to acquire a leading position and to achieve a competitive advantage over competitors. In addition, AM would make it possible to design more tailor-made products and to produce end-use products immediately, and further, to produce and deliver spare parts more rapidly, minimizing the stock requirements. Furthermore, one beginner-level company put forward the idea that current low-pressure molds could be replaced by AM molds, or else new stainless steel products could be designed and printed directly for the function required. In general, beginner-level companies assumed that AM technology would allow more flexible and faster service, and a better product offering.

Category	**Company benefits**
Beginner (B,C , and D)	New and tailored products, production to function, spare part delivery, minimizing of stock rate, AM molds, environmental issues
Experienced (A, F, G, and H)	3D designed, realistic prototypes, early human error detection, cost and time savings in product design, accelerating product testing and modification, marketing purposes, environmental issues
Professional (E)	Expanding AM services to new customers

Table 3. AM Company Benefits

The experienced-level companies (A, F, G, and H) benefited from AM in new product design and in all product R&D phases. AM made it possible to produce prototypes and miniatures precisely as they were 3D designed. In addition, human design errors could be detected at the early product design phase, and corrections for the second prototype version could be implemented easily. In particular, if molds are needed for industrial product manufacturing, AM streamlines mold design and production processes. Traditional expensive work phases such as tooling or manual work are absent in AM. This leads to cost and time savings in product design and manufacturing. The cost savings with AM technology were seen as substantial. The Design Engineer of Company H expressed this as follows:

> *Production molds are really expensive. If there is human error in the prototype design, it is preferable to detect and repair the error in an AM printed prototype, which costs around 1000 Euros. That is cheap compared to what happens if the error occurs in the final production mold. To repair the error in the final production mold is expensive and sometimes even impossible.*

Other benefits mentioned by the experienced-level users were related to new product design and product testing. As AM technology makes it possible to produce realistic prototypes and parts quickly and cost-effectively, new forms and structures can be produced. AM also accelerates functional and field tests, making it possible to perform modifications in the early phase, and to shorten product development time. This improves product quality. The Product Manager of Company G explained this as follows:

> *It is possible to present AM printed prototypes to customers, since they look like properly made final products. AM printed prototype products stand up to all kinds of scrutiny. In our case, an AM prototype printed with current plastic material stands up to normal product usage, but is not as durable as the final product under extreme conditions.*

Three experienced-level companies (A, G, and H) utilized AM prototypes for marketing purposes. The companies mentioned the ease of demonstrating sketched products to the customer, due to the fact that an AM prototype allows a genuine feeling for the product, including its form, structure, color, and usage. The experienced-level companies were of the opinion that AM technology can reduce the company's pollutant load and address environmental issues. One professional-level company (E) indicated that AM can facilitate new customer segments.

The Benefits of AM for Customers, and Value-Adding Elements

The noted customer benefits of AM and its value creation potential varied between beginner, experienced and professional levels. Table 4 illustrates AM customer benefits according to the companies researched.

Category	**Customer benefits**
Beginner (B, C, D)	New product solutions with savings in energy consumption, improved machine durability and lifetime, accelerated investment payback time.
Experienced (A, F, G, H)	Cost and timesaving in product concept design, realistic prototypes, reduced mold costs, ease of illustrating the final product or solution.
Professional (E)	Materials information and printing for function or prototype use.

Table 4. AM Customer Benefits

The value-adding elements for customers varied individually among the companies studied. The beginner-level companies' (B, C, and D) noted the potential to produce lighter products, leading to savings in the customer's energy consumption, and improving machine durability for the customer. This would accelerate the customer's investment payback time. AM may also widen the product offering, and enable faster spare part delivery, if spare parts are 3D designed and printed.

The experienced-level companies (A, F, G, and H) indicated cost efficiency and time-saving as the most valued advantages of AM. The design time for a new product concept had been reduced from months to a few weeks, since the prototypes and even molds could be produced directly, moving from 3D images to a final prototype or product part. AM technology allows customers to receive a genuine hands-on feeling for the product, as the AM prototype strongly resembles the final product in form, structure, and texture. In addition, AM makes it possible to produce immaculate prototypes prior to the final production mold. Company H also mentioned the ability to observe the entire interior design including ergonomic aspects, when all the parts are 3D printed, finalized, and assembled as in the final outcome. All these elements improve the quality, and reduce the time and costs for new product development. The Design Engineer of company H explained this as follows:

> *By utilizing AM in product design, we are able to examine the various product design aspects simultaneously. Firstly, the prototype can be installed in its final position with the right size, color, and surface structure. Secondly, we are able to explore and test the functionality of the prototype. In my case it means I am able to test how the armrest affects the seat's rotation and the ergonomics in general. Thirdly, we are able to execute collision tests.*

Impacts of AM on Value Creation

The empirical study indicated that the beginner-level companies (B, C, and D) based their business on one or a few long-term customer relationships (usually with large companies) and that they adapted their business to meet the customer's needs. There was less long-term business planning among these companies than among the larger companies (G and H). However the findings showed beginner-level companies to be interested in exploring AM and its impacts on business and customer value creation. For instance, Company C indicated that it would integrate its customers within the AM development and implementation process if AM technology were to become part of the company's service and life cycle management. By integrating customers within the AM process, the aim would be to share and minimize financial risks, and to explore mutual value possibilities with customers.

The beginner-level companies appreciated the fact that AM opens up the potential to design complicated product forms and to develop customer-tailored products in collaboration with the customers. If AM machines and materials were developed sufficiently, tailored materials could be used in certain machine parts, and it would be possible to offer customer-centric maintenance services irrespective of the manufacturer. In addition AM has the potential to improve the manufacturing process, making it possible to produce small product series or spare parts on demand.

The large companies (G and H) estimated that the utilization of the AM technology would increase within the next five years. They took the view that if AM technology allows the manufacture of products that are impossible with current methods and technologies, new value creation opportunities and new business models will arise. Such new products could be more complex in structure, as well as being lighter and extremely small. In addition, totally new product forms could be designed and produced. The Product Manager of Company G expressed this as follows:

> *In optronics, the aim is to have pieces that are as tiny as possible. In business terms it means we are able to design much more complex forms and structures. We can design and produce smaller and lighter pieces. Honeycomb and cavity structures cannot be produced with current methods. With AM technology this can be achievable.*

The interviewees noted that if various materials can be printed simultaneously, the final products could be produced for use immediately. The interviews also indicated that if there are improvements in AM materials and machine capacity, and if prices fall, AM will enable small-scale serial production and on-demand production. For one experienced-level company (A), AM technology has the potential to open up new customer relations at the global level.

Discussion

The findings in this study indicate that in the context of an AM business network, value exists primarily in customer relations, but additionally in supplier and employee relations. The companies indicated that AM increases company value, since AM prototypes realistically show the final product in terms of form, structure and usage. AM makes it possible to detect design errors at the early design phase; hence the product can be modified and AM prototype test cases run, prior to final production. The time saved with an AM prototype is substantial, and the costs are minute compared to conventional prototype methods. It was estimated that company value would emerge with new customer-tailored products, and by producing AM products for actual use. The companies also emphasized that AM widens the product offering to include both existing and new customer segments. The environmental benefits were also highly valued by the interviewees.

As Rescher (1969) emphasized, values originate from the assumption of a goal-oriented organism which attempts to achieve satisfaction. Customer satisfaction and value were improved when companies used an AM prototype to illustrate the final product to the customers. The AM prototype presents the final product in terms of form, structure and colors, and can withstand normal product use under normal conditions. The AM prototype improves trust and customer satisfaction, and it reduces misunderstandings during product development phases. Both time and costs are saved with AM prototypes, and this improves customer-perceived value. It was also estimated that AM reduces the customer's energy consumption and improves the durability and lifetime of the machines.

Heinonen (2004) proposed that customer value is conceptualized in terms of spatial and temporal values, in addition to technical and functional value elements. The large companies in this study emphasized an interest in acquiring AM services from external service providers, due to a reluctance to invest in their own machines and employees. If SMEs take the role of an AM service provider in an AM ecosystem, they may be able to offer local AM services on demand. For instance, an AM supplier could print a critical spare part locally in just a few hours instead of ordering the spare part through conventional channels. By forming joint ventures, SMEs could share their business risks, improve their AM knowledge, and gain benefits from Economies of One, as suggested by Petrick and Simpson (2013).

The study pointed to demands for additional AM materials, machines, and knowledge of processes. There is an essential role here for educational institutions in accelerating AM technology, given that AM requires totally new skills, with personnel such as digital product designers, materials specialists, and AM processing specialists. As Ojala and Tyrväinen (2011) have emphasized, value occurs not only in customer-seller relationships, but also in business networks. By forming and developing an AM ecosystem in the machine industry it may be possible to detect not only direct value but also indirect value, as noted by Ojala and Helander (2014). For SMEs in particular, belonging to AM ecosystem might provide an entry to new customer segments and markets. In this context, one can suggest that business owners in the machine industry have possibilities for redefining, reinterpreting, and re-describing their stakeholders' interests, and for discovering opportunities for direct and indirect value creation.

Conclusions

This study contributes to IS and value creation research in the context of AM technology in a number of ways. Firstly, although previous literature has examined AM from a technical perspective and in the context of a variety of industries, the present study focused on this topic from the perspective of value creation and networks. Secondly, the findings in this study provide detailed knowledge on how AM technology might increase perceived value via time and cost savings. All in all, it appears that AM shortens the time needed for conventional product design and production, enhancing the overall production cycle. Furthermore, AM has the potential for value creation, not only among current suppliers, but broadening outwards to new partners and customers. Here it is worth noting that although there has already been extensive discussion of value creation in the broader sense (Allee 2000; Ojala and Helander 2014; Walter et al. 2001) and of AM technology (Chimento et al. 2011; Michaleris 2014), value creation in the context of AM has been underrepresented in IS literature. Thirdly, this study incorporates stakeholder theory and the literature on value creation, seeking thus to extend IS research by conceptualizing value creation and value networks in the context of AM.

As a limitation, it will be noted that the case companies and the interviewees formed a somewhat heterogeneous group of AM adopters from a single country, i.e. Finland. The study included both SMEs and large companies, with considerable variation in the AM technology adoption and knowledge of those concerned. In addition, the interviewees' roles in the organizations varied, with resulting differences in viewpoints. These aspects should all be taken into the consideration in evaluating the results of this study. In further research, one could aim at more in-depth studies, observing and comparing companies that benefit from AM technology, and possible barriers of AM usage. This would provide fascinating insights on the differences in value creation and boundary spanning role of AM (Carlile 2002). It should also be noted that customers formed the main stakeholder group in this study, and that the role of other possible stakeholders was not so visible. Thus, the findings of this study would usefully be extended to cover the possible role of other stakeholder groups.

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II

3D PRINTING: CHALLENGING EXISTING BUSINESS MODELS

by

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3D printing: a challenge to existing business models

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Abstract

Technologies labelled as "disruptive" challenge conventional business procedures. The development of 3D printing technology and additive manufacturing (AM) is expected to transform product design and manufacturing. 3D printing technology makes it possible to produce complex and unique physical products from digitally designed CAD models. It is estimated that the effects of 3D printing on business will be diverse and far-reaching. Hence, it is vital for business owners to observe how 3D printing may impact on business models and business networks, considering also the effects on stakeholders' value propositions and on value creation. This paper reports on the potential impact of 3D printing technology on business models within the metal and machinery industries.

Key words: Business model, value delivery, value networks, 3D printing

1. Introduction

It is estimated that the digitization of manufacturing will transform the way goods are made. 3D printing has been referred as the third industrial revolution, involving not only the way products are manufactured, but also how they are designed (The Economist, 2012). 3D printing offers the potential to design forms and structures that are impossible with traditional methods. In addition, it is expected that 3D printing will accelerate product development cycles, shorten product delivery time, modify the profit structures of companies, and possibly reshape future professions and jobs (Cohen, Sargeant, & Somers,2014; The Economist, 2012). The diffusion of a new technology is a slow process, but it can ultimately have immense consequences (Davis and Venkatesh, 2000). It seems likely that business managers will have to re-evaluate their business models, here bearing in mind the circular process by which the reinvention of a business model can itself accelerate the adoption of a new technology (Ardilio and Seidenstricker, 2013). It appears that the overall digitization of manufacturing will be a factor accelerating the diffusion of 3D printing. Business managers would be well advised to understand the change-producing agents at work in 3D printing, and to anticipate how the technology may impact on business models. Due to a limited number of research on how 3D printing impacts business models (Rayna & Striukova, 2014), business network, and value creation, the aim of the study reported here was to determine how 3D printing influences and might shape an existing business model and its components, including the product, the value network, the value delivery, and the revenue model.

2. 3D printing

Three-dimensional printing can be taken to include rapid manufacturing, rapid prototyping, or additive manufacturing. It utilizes methods of adding materials, such as stereo lithography and laser sintering. Various materials – including metal, composites, polymers, and ceramics – are used in 3D printing processes (Cotteleer et al. 2013). The technology used with metal 3D printing follows laser sintering or laser melting principals. The laser beam melts thin metal powder layers and the product is produced by adding the material layer-by-layer. As a result durable and hard product is printed. (AM Finland, 2016.) Petric and Simpson (2013) note that 3D printing and additive manufacturing are perceived as synonyms, since both refer to a layer-by-layer production method.

Petric and Simpson (2013) describe 3D printing as a disruptive technology. By this they mean that 3D printing has impacts on how products are designed, built, and delivered. Also the traditional economies of scale of the conventional manufacturing are challenged by economies of one (Petric and Simpson, 2013). 3D printing technology is based on digital computer-aided design (CAD) (Liu and Zhou, 2010). It involves the creation of a series of digital images of an object, which are then transferred to a 3D printer (Ford 2014). A physical model is formed from the digital image by adding materials cumulatively (Liu and Zhou 2010). The greatest advantages of 3D printing are cost-effectiveness, reduced time to the market, a movement from mass production to more customized or tailor-made products, and environmental benefits. Users have also mentioned the features of variety in materials, flexibility in design, and improved accuracy (Cotteleer et al. 2013; Ford 2014; Mertz 2013). Some authors (e.g. Petric and Simpson 2013) have gone so far as to suggest that almost anything that can be imagined can be produced by 3D printing.

During recent years 3D printers and materials have improved, as have 3D software and digital platforms. 3D scanners and software compatible with 3D printing have been developed for a variety of applications. Platforms such as Autodesk and Spark offer 3D design services, optimized for 3D printing. The main industries to benefit from 3D printing have been in the consumer sector, and in the fields of electronics, automotive industries, space, and medical instruments (Mertz 2013; Petric & Simpson 2013). For instance, the automotive industry has benefited from 3D printing in terms of producing tool prototypes and small customized parts. The aerospace industry, for its part, uses 3D printing to produce lighter and stronger components, and to print small numbers of geometrically complex parts from materials such as titanium and plastic (Ford 2014). Nasa (2015) recently announced 3D printing as a key technology for improving space vehicle design and manufacturing; indeed, it indicated that it is coming closer to building an entire rocket engine with a 3D printer. The medical industry has increasingly benefited from 3D printing; thus medical instrument companies can often manufacture unique products, and set up small runs of complex parts (Ford 2014; Mertz 2013; Petric & Simpson 2013).

3. Business models

Business models have attracted academic interest for decades (Zott et al. 2011). Scholars have studied business models from various perspectives to determine many aspects, including how firms can organize their activities (Magretta 2002), create value for partners and end-users (Teece 2010), make a profit (Morris et al., 2005), and enter foreign markets (Ojala and Tyrväinen, 2006). To advance our understanding on business models, scholars have developed models and theoretical frameworks that explain how business models can be planned and developed. For instance, Osterwalder and Pigneur (2010) have developed a business model canvas that can be used as a tool to develop a new business model or to advance the existing one. The canvas is a very useful chart for the purposes of explaining business activity in the context of given organization. However, the recent theoretical framework by Ojala (2016) takes a wider perspective, explaining business model creation and development in the context of a whole industry or ecosystem. Because Ojala's framework includes the aspect of change, it was selected as a theoretical model for this study.

The business model framework by Ojala (2016) includes four different components that might change when a firm develops its business model further. The first component, the product/service, is linked to how the product creates value for other actors in the business ecosystem, i.e. the network of partners. The second component is the value network. The value network includes all the key actors that the firm cooperates with, either directly or indirectly. The third component, value delivery, refers to the actors in the second component, and how the value, based on the product or service, is exchanged between them. The fourth component, the revenue model, explains how the revenue is created among the partners in the network.

In the framework by Ojala (2016), the components of the business model change constantly when a firm operates in the market. The first business model is created through enactment of a business opportunity. This new business model is "tested" in the market to see how it works, and how partners and customers react to the model created. Based on actions in the market, the model might require reassessment, since there can be changes in technology, market conditions, and so on. This leads to the business model development phase, in which the model is developed further to better respond to the needs and requirements in the market. In the final phase, new elements are added.

4. Research method

This study applied a qualitative research method and a semi-structured interview procedure, since the aim was to explain contextual information, and to understand the interpretations and perspectives of the actors. A qualitative study allows actors to articulate their perceptions of situations in the past, and to evaluate the elements affecting their development in the future. In addition, a qualitative research method examines the study phenomenon with a view to understanding people operating within a certain social context (Myers and Avison 2002). For its part, the semi-structured interview is flexible, with good possibilities for in-depth data collection and a detailed understanding of the research phenomenon (Gillham, 2005).

The study covered face-to-face interviews with two companies. One interview was conducted with the CEO of a metal 3D printing company, and two interviews were conducted with the project manager in tractor manufacturing company. Additional information was collected via email communication and from company web-pages and brochures.

The themes and structure of the interviews were pre-planned, and the same questions were asked of all the interviewees. The interview questionnaire was divided into three themes: (1) the company's background and current use of 3D printing, (2) 3D printing´s impacts on the existing business model and its elements, (3) estimations of the impacts of 3D printing on future business model development. The interviewees were able to give comments freely, and to provide feedback. The interviews were audio recorded for later transcription and analysis. The average interview length was approximately 40 minutes.

5. Research findings from case companies

5.1. A metal 3D printing company

The metal 3D printing company offers products for customers in various industries. The owner, who has a background in metal additive manufacturing, considered metal 3D printing to be a promising business. He executed the first market survey in the dental sector, and a second survey some years later in the jewelry industry. Because respondents in the survey indicated an interest in 3D printed metal crowns, bridges, and superstructures, and subsequently, prototypes for items of jewelry, the company created its first business plan for dental products and jewelry products. However, obstacles came up immediately, since financial institutions were not willing to fund the still unknown 3D printing technology; the institutions would advance only 25−30% of the cost of 3D printers, whereas the lending value for CNC (computer numerical control) machines is 80%. Despite some promising signs, it was difficult to get the new business off the ground, and it took another year for the company to find funding. Finally, a German 3D printing machine manufacturer offered a financing solution. The machine was acquired, and the project was able to continue. In addition, the business manager found several private capital investors who were willing underwrite the new 3D printing business operation. In October 2014, the company received its 3D printer, and the first 3D printed metal components were delivered to customers a few weeks later.

"It was a long and rocky road to bring the new technology and business to Finland. Since financial institutions do not understand what 3D printing is about and what is done with the machine, they are unwilling to take risks." (T. Heikkinen, personal communication, October, 27th, 2015.)

After this bumpy start the first business model evolved (Table 1). All the business model components *(the product, the value network, value delivery,* and *the revenue models*) have undergone improvements. The first and the second business model included products only for the dental and jewelry sector, but the company currently offers a wide selection of 3D printed metal components for final and prototype use, providing them to various b-2-b customers in a range of industries. The new business areas seem likely to include metal spare parts to cars. The number of printed products has steadily increased, and in addition to single products, the company also delivers mini-series, such as 20-60 items product orders. Since customers increasingly require finished products, or products resembling end-use items, the company is considering extending finishing services as part of its product portfolio.

Table 1: The business models of the metal 3D printing company

Business model	Products made of steel, cobalt-chrome, silver, and bronze	Value networks	Value delivery factors	Revenue model
Business model #1 and #2	Metal dental bridges, crowns, and superstructures. Metal components for the jewelry market.	Investors, 3D printer manufacturer, customers, trade associations.	Rough product versions. Delivery time. Cost-efficiency.	B-2-B customers.
Business model #3	Metal dental bridges, crowns, and superstructures. Metal components for the jewelry market. Wide selection of metal components and prototypes for various customers. Spare parts for cars. Mini-series production, 1-60 items. Demand for finishing services.	Investors, a 3D printer manufacturer. Customers. Trade associations. Other 3D printing companies. 3D designers. Educational institutions.	Rough product versions. Delivery time. Cost-efficiency. Finished products. Dimensional and quality accuracy. Local service better than in low-cost countries. No interruptions in the customer´s normal production process.	B-2-B customers. Collaboratio n with other 3D printing companies.

During the years of operation, the value network has evolved from investors, 3D printed manufacturers, and customers, to include also other 3D printing companies, 3D designers, and educational institutions. The company is actively participating in industry-related workshops and seminars, and it collaborates closely with national trade associations and city administrations, aiming to increase knowledge of 3D printing knowledge and the business opportunities surrounding it.

In addition, the business model’s value delivery component underwent improvements. The first product versions lacked refinement; however, the company is now able to provide larger and better metal 3D printed components. Customers have indicated that the local 3D printing company provides better metal 3D printed products in terms of materials, dimensional accuracy (20–60 µm), overall quality, and delivery time, as compared to products from low-cost countries. Product accuracy and delivery time are particularly highly valued, since these save costs and benefit the customer´s total production time. Other value delivery elements mentioned included the point that the customer should pay only for the materials and time used to manufacture the 3D products; furthermore, if a customer occasionally needs single parts, the customer’s normal production line should not be interrupted due to delays in the 3D printing.

> “Two weeks ago one customer made the point that the product material must be exactly what he has ordered. The customer said that in ordering from low-cost countries, you never know if the strength values or weldability will be correct. Even though the product may be cheaper, the final result is not the same if the material is wrong. This is important. In addition, our delivery time is 3–7 working days, which means added value for customers.” (T. Heikkinen, personal communication, October 27, 2015.)

The company is willing to deliver more mini-series for end-use, so long as the quality meets the customer’s requirements. Mini-series increase the value experienced by the customer, bearing in mind that having the manufacturing tools and other instruments for small numbers of pieces can prove extremely expensive.

As regards the revenue model, the company earns revenue from products delivered to the customer. The first operating year ran at a loss; however, due to customership and to extension of the product portfolio, the yearly turnover has increased. It is estimated that the turnover will be 4−5 times higher within the next five years. However, the company is still searching for a “cash-cow” product range, i.e. one that would have a truly dramatic impact on revenue. To minimize the business risk, the company prefers to collaborate and co-create value with customers. In future, finishing services will extend the revenue model.

5.2. A tractor manufacturing company

The second case company, a tractor manufacturer, belongs to a corporation providing solutions for the agriculture industry on a global basis. The company´s core business is the production of customized tractors worldwide. The company recently established its own facility called *The Unlimited Studio,* which provides customers with even more precisely tailored and specialized solutions. The studio attends to the customer´s individual needs by providing customer-specific accessories and equipment, i.e. items that are not available directly from the production line. Examples include special lamps and painting finishes, tailored automated extinguishing systems, and alcohol ignition locks. The annual need for special accessories is about 10 – 300 units per year. The company has used 3D printing for prototype and mold purposes (Table 2) as part of its R&D for several years, but in 2015 the company decided to acquire its own plastic 3D printer for R&D, allowing industrial designers to study the 3D printing technology more closely. The research areas of special interest include the capabilities and restrictions of 3D printing, and how it can be applied to mini-series production. The company is investigating the utilization of 3D printing at its Unlimited Studio.

Table 2 A tractor manufacturer´s business models

Business model	Product material: plastic and aluminum	Value networks	Value delivery factors	Revenue model
Business model #1	Customer-specific accessories. 3DP used internally for mold and prototype purposes by R&D + industrial users.	Internal industrial designers and R&D personnel. Customers. Various domestic and international stakeholders. External domestic and international 3D printing service providers. Would benefit from metal printing, if the service was available. Plastic materials are too fragile for the final product.	Easier to outline the entire product and to detect design errors in the early phase. Ability to execute functional tests in the early development phase. Cost effective compared to traditional mold costs. Easier to demonstrate the sketched product to the customer. Improves product quality. 3D printing is utilized increasingly. Depending on the product volumes, decompression molds have greater utility. If 3D printer prices fall and if materials develop, it will be possible for final products to be printed. This will affect the business model.	Reduced cost structure. Quicker production time.

Business model #2	Own printer for R&D and for industrial designers.	Internal industrial designers and R&D personnel. Customers. Various domestic and international stakeholders. External domestic and international 3D printing service providers. Domestic 3D printing manufacturer.	Own 3D printer has improved product development and project schedules. 3D products are ideal for examining product dimensions and durability.	Reduced cost structure. Quicker production time.
Business model #3	3D printed special accessories at business unit called *Unlimited Service.*	Same as Business model #2, complemented with subcontractors, who offer marginal 3D printed accessories for Unlimited Studio.	Marginal accessories cost-effective compared to current methods. More unique accessories.	Reduced cost structure. Quicker production time.

The company´s value network consists of internal and external actors. The external actors consist of customers, plus various domestic and international stakeholders and 3D printing subcontractors. The external 3D printer manufacturer complemented the value network when company acquired own 3D printer. If the quality of the 3D printing fulfils end-use product requirements, the company is interested in using 3D printing subcontractors for Unlimited Studio´s production of special accessories. The reason for using subcontractors is they have the best expertise, notably in printer use, in materials and material properties such as thermal expansion, and in finishing and pricing.

One of the value delivery elements the company mentioned was the designers´ ability to outline the whole product easily, and to detect design errors at an early stage. In addition, the designers were able to examine the product structures, dimensions, and ergonomic aspects. Sculptured samples are no longer needed when prototypes are digitally designed, with the 3D product emerging precisely as designed.

> “Industrial designers no longer need to sculpt the prototype from wood; instead, the product is digitally 3D designed and 3D printed. The designed product is tested and modified if necessary. 3D printing accelerates the design process.” (S. Rauhaniemi, personal communication, October 19, 2015.)

With 3D printed prototypes it is easier to illustrate the sketched product with the customer and to run functional tests before the final products. This improves mutual understanding, and thus reduces the time and costs applicable to the final product. 3D printed prototypes are less expensive than molds produced traditionally, and the delivery time is a few days instead of several weeks. This has impacts on the final product costs. By possessing its own 3D printer, the company has been able to improve project schedules and the overall efficiency of the product development process. Even though the superficial quality of the product surface remains low, it is considered good enough to examine product dimensions and durability.

> ”For example, if we need to validate, if the feel of the handle is sufficient for the fingers; it is difficult to observe this in a display. The 3D printed prototype thus

> accelerates the schedule for the project." (S. Rauhaniemi, personal communication, October 19, 2015)

As a result of 3D printing, the customers receive individual tractors more quickly. For the company, 3D printing has reduced the final product costs and the time used in design, molds, and materials. This has impacted positively on the revenue model. The marginal accessories offered through Unlimited Studio are currently fairly expensive to produce. However, customers are willing to pay extra for individual and tailored parts. Provided that the cost structure for 3D printed special accessories is reasonable, and provided quality expectations are met, 3D printing can prove to be a solution. The company is actively investigating this option, since it will affect the future revenue of Unlimited Studio.

6. Discussion

Considering the impacts of 3D printing technology on company business models, we would argue that 3D printing is connected to changes in the *product, value network, value delivery,* and *revenue model* components of the business model (Ojala, 2016). The manner in which 3D printing impacts on the products relates first of all to the way in which the technology gives greater freedom for product design. For industrial and R&D designers this means possibilities to design and produce new prototypes with new forms and structures, including items which can be difficult or even impossible to produce via traditional methods. As an example, metal 3D printing enables to print nested forms and internal funnels for metal nuzzles. With traditional method, this would be challenging or even impossible. This has a positive influence on product innovations, and on improvements to old products. 3D printing has also extended the product range, both for existing and new customers. The companies´ product portfolios have improved so that they cover a range of prototypes, molds, metal components, and end-use products. It appears 3D printing is important in machinery industry as the costs of 3D printed molds are fractional compared to molds produced traditionally. Both case companies expressed a demand for finishing services, but from different perspectives. The tractor manufacturer indicated an interest in external finishing services if the company were to initiate 3D special accessories for its customers. The metal 3D printing company is evaluating the provision of finishing services, in line with constant customer demand.

The value network varied between case companies, since they represented different business roles in the market. As a private family business, the value network of the metal 3D printing company has evolved to include other 3D printing service providers, in addition to investors, b-2-b customers, and 3D printer manufacturers. For the tractor manufacturer, the most significant actors in the 3D printing value network have been customers, 3D printing subcontractors, internal designers, and a 3D printer manufacturer. The reason for preferring 3D printing subcontractors was they have the best expertise regarding printer use, and in materials and material properties such as thermal expansion, finishing, and pricing.

The value expectations of 3D printing are seen as bound up with a movement from mass-production to mass-customization (Berman, 2012; Ford, 2014). The need for unique and tailored products is increasing; however, with traditional production methods such tailoring is limited due to the cost structure. 3D printing makes it possible to produce unique and tailored products with affordable costs and time, since the customer pays only for the materials and time used in the printing process. 3D printing is also suitable for mini-series, since the unit costs remain reasonable. Both of the case companies preferred to have customers involved with the product design and development process. This is because 3D printing makes it easier to illustrate the sketched product for the customer, and to experiment with its structures, surfaces, and dimensions. Co-creation of the product with the customers increases the experienced value, since it improves communication and mutual understanding of the final product. It thus strengthens the trust between the firm and the customers, while at the same time deepening the customers´ role in the value network. The metal 3D printing company integrated customers with product co-creation, noting that this reduced business risks. It was found that customer involvement reduces the overall project time and costs.

3D printing impacts on the final business model component – the revenue model – in line with more or less traditional revenue models. The metal 3D printing company´s revenue model was based on customer invoicing per orders. Co-operation agreements and the number of products ordered have an impact on pricing. In any case, yearly turnover is expected to increase, due to new customers and to the possibility to provide larger components through partner companies who do 3D printing. For the tractor manufacturer, 3D printing has streamlined and reduced the overall costs of projects. This has an indirect positive impact on the revenue model. In future, 3D special accessories, tailored for end-use, will foster changes in the revenue model, and also in the other business model components.

7. Conclusions

3D printing technology has experienced dramatic growth, with increasing exploitation by various industries. One significant reason for companies to use 3D printing is that it liberates product designers; they can now design and produce personalized and tailored products that would previously have been impossible. For example, metal 3D printing makes it possible to produce individual items and small volume mini-series for various industries including dental, machinery and jewelry industries in a manner that is cost- and time-effective.

It appears that with localized 3D printing, the value perceived by customers improves, due to better product quality, delivery time, and service. Local production improves communication, and it allows the co-creation of product innovations between the customers and the 3D printing companies. This helps the company to be more flexible and agile in adapting or renewing its business model.

Even though 3D printing is now applied in many industries, there are numerous industries and companies that have not yet realized the hidden potential of 3D printing. 3D printing technology is improving rapidly. Combined with other emerging technologies (such as IoT), 3D printing technology could have huge (and still largely unexamined) potential for product innovation and value delivery. This will provide multiple new perspectives for the business models adopted.

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III

DESIGNING, DEVELOPING, AND IMPLEMENTING SOFTWARE ECOSYSTEMS: TOWARDS A STEP-WISE GUIDE

by

Konstantinos Manikas, Mervi Hämäläinen & Pasi Tyrväinen, 2016

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Designing, Developing, and Implementing Software Ecosystems: Towards a Step-wise Guide.

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Abstract. The notion of software ecosystems has been popular both in research and industry for more than a decade, but how software ecosystems are created still remains unclear. This becomes more of a challenge if one examines the "creation" of ecosystems that have high probability in surviving in the future, i.e. with respect to ecosystem health.
In this paper, we focus on the creation of software ecosystems and propose a process for designing, developing, and establishing software ecosystems based on three basic steps and a set of activities for each step. We note that software ecosystem research identifies that ecosystems typically emerge from either a company deciding to allow development on their product platform or from a successful open source project. In our study we add to this knowledge by demonstrating, through two case studies, that ecosystems can emerge from more than a technological infrastructure (platform). We identify that ecosystems can emerge out of two more distinct types of environments and thus the design should be based on the characteristics of this categorization.
Moreover, we follow the approach that design, development, and establishment are not three distinct phases but rather aspects of a single re-iterating phase and thus propose the view of design, development, and establishment as a continous process, running in parallel with and interrelated to the monitoring of the ecosystem evolution.

Key words: software ecosystems; software ecosystem design; software ecosystem health

1 Introduction

The notion of software ecosystems is argued to provide clear advantages compared to traditional software development and distribution as it, among other, accelerates software development, reduces time to market, and increases user and customer segment reachability. It is not a surprise that within the recent years we have experienced an increasing popularity of software ecosystems both as a topic of study and as a means of developing and distributing software (products). Despite the popularity, it is still very challenging to *create* software ecosystems, especially if one should take into consideration aspects of ecosystem survivability, productivity, or health. Few studies have been investigating the conditions of establishment of a software ecosystems and even fewer propose ways of designing software ecosystems. However, this kind of studies tend to either be too specific for a type of ecosystem and thus hard to generalize, or too generic and thus hard to apply. Remarks that are already identified in the most recent and extensive systematic literature review [10], reviewing a total of 231 academic publications studying 129 software ecosystems.

Contemporary public discussion on software ecosystems is much driven by the most visible players in the digital economy, the platforms and app stores of Apple and Google being the usual examples in the discussion. Among the practitioners, this has lead to a platform-centric view of ecosystem thinking where a platform provider is needed to orchestrate an ecosystem. Further, the terms platform and ecosystem are closely connected if not treated almost as synonyms. However, the literature has presented a variety of ecosystems and value networks beyond the platform-centric approach, such as ecosystems build around standards, common business and commonly adopted infrastructure [8]

The limitations of platform-centric ecosystem thinking are, to some extent, visible also in our common thinking on how to build ecosystems. That is, we tend to think that the only way to build an ecosystem is to build a platform and attract participants to it by some means, typically by providing financial benefits to the participants. This underlying assumption may lead to ignorance of a wider view on how to build ecosystems as the viewpoints of actors in the value network and the value creation in the business domain are overlooked if not excluded totally from our thinking.

In this paper, we take the wider view to building ecosystems. We start our journey towards a method for building ecosystems from the observation that ecosystem can emerge out of three distinct types of environments and thus the design should be based on the characteristics of this categorization. We study two cases presenting an actor-rooted and a business-rooted approach to ecosystem building. Adding findings from the two cases to the infrastructure-rooted approach (including platform-centric approach) we propose a process for designing, developing, and establishing software ecosystems based on three basic steps and a set of activities for each step. Moreover, we follow the approach that design, development, and establishment are not three distinct phases, but rather aspects of a single re-iterating phase and thus propose the view of design, development, and establishment as a continuous process, running in parallel with and interrelated to the monitoring of the ecosystem evolution.

2 Background and related work

The field of software ecosystems has an activity that spreads through several years. From the first reference in the book of Messerschmitt and Szyperski [16] and the first publications in 2007, to the day, there have been several studies that have been examining software ecosystems as a whole and attempt to analyse, model, classify, or design software ecosystem. In this context Jansen et al. [7] proposed the analysis of software ecosystems from three perspective: software ecosystem level, software supply network level, and software vendor level.

Campbel and Ahmed [1] propose the analysis of software ecosystems into three components. Manikas and Hansen [14] analyse the literature of software ecosystems and identify, among other, a lack of consistency in what is a software ecosystem. They analyze the existing definitions and identify three main components: common software, business, and connecting relationships. Christensen et al. [3] propose the modellign and design of software ecosystems based on the concept of software ecosystem architecture consisted of three structures: organizational, business, and software. Knodel and Manikas [8] challenge the existing definition of software ecosystems and propose a set of building blocks for software ecosystems. Manikas and Hansen [13] focus on the concept of ecosystem health where they analyse the literature and propose a framework for defining ecosystem health. Hyrynsalmi et al [6] expand on this work to include 38 papers on health, while Hansen and Manikas [5], inspired by natural ecosystems, focus on defining the influence of individual actors to the ecosystem.

3 The cases

In this section we discuss and analyze two cases of designing and building a software ecosystem. The first case is the *telemedicine ecosystem* established around the telemedicine services of the Danish healthcare and the second cases is the *smart city ecosystem* established around the smart city and Internet of Things (IoT) infrastructure and services in an area of one of the most populated cities in Finland.

3.1 Telemedical ecosystem

Danish healthcare, following the tendency in many other western countries, is facing a number of challenges due to changes in the demographics. The increase in life expectancy and decrease of birth-rate in combination with a rapid increase of lifestyle conditions and the continuously improving healthcare diagnosis and treatment are putting a pressure on the economics of a welfare-based[1] and position the continuous care of the elderly and the chronically ill in even more central focus [9]. Telemedicine, comes as solution to these challenges. Telemedicine is understood as the provision of health through a distance. However, telemedical

[1] I.e. funded indirectly by collected tax.

technologies are faced with severe integration and interoperability issues caused by the increasing need to interact with other medical system characterized as "silo" solutions and organizationally complex systems [2]. The establishment of a software ecosystem comes to address these technical challenges and abstract the development of telemedical solutions from the resource-heavy task of integration and distribution.

Thus, the establishment of the telemedical ecosystem deviates from the typical view of ecosystem emergence (i.e. from a successful platform or product). In this ecosystem, the design was motivated from a set of clear incentives. The state and healthcare authorities have been part of shaping and clarifying the incentives, however this kind of actors have not been otherwise active in the design and establishment of the ecosystem. Therefore, the ecosystem was, during design, characterized form the lack of orchestration. The steps taken to establish the ecosystem was[2]:

- Identify and map the existing (and future) actors, (software) systems and their relationships [12].
- Identify the incentives for the different actors and make them explicit [3].
- Build the infrastructure that will support the ecosystem.

3.2 Smart city ecosystem

The second case is the establishment of an ecosystem in the *smart city* domain. The contribution of the digital technologies is considered to form a foundation for so called smart cities. Smart cities are complex systems and consist of multiple domains like transportation, energy, living, and governance. Smart city domains utilize digital technologies by collecting and storing both private and public data. They increasingly release the public information and data sets for external parties. The idea behind releasing the public data sets is to provide a possibility for external stakeholders to develop and create smart applications and services for citizens. Naturally, an ecosystem would support and facilitate the actor and smart city service interaction. An example is the environment for agile software and internet of things product and service development and experimentation with real users (citizens) in real-world settings [4].

In this context, our case, an urban area in one of the ten most populated cities in Finland is on the process of establishing a *smart city ecosystem*. The ecosystem establishment process was initiated by a set of actors interested in the smart city domain. These actors created a consortium that aimed at promoting the interaction of digital and software services in collaboration with independent business models, i.e. an ecosystem. Purpose of the smart city ecosystem is to develop new applications and internet of things service solutions in collaboration with construction companies, smart grid providers, nursing houses, city governance, and citizens. The initial actors in the smart city ecosystem included representatives from universities and city as well as the stakeholders from private

[2] A more detail description on this work can be found in [3, 9].

sector like the network service providers, telecommunications operators, smart locking service providers, and organizations in the privacy and digital identity domains. The citizens have central role in the smart city district. As an outcome of the smart city ecosystem, new applications and services are created to improve the quality of citizens' every-day life and enhance the research and value creation of modern digital technology services in smart city domain. The process of establishing the ecosystem included the following steps:

- Identify and map ecosystem (to-be) actors.
- Define business aspects: actor incentives, value propositions, customer segments, and revenue streams.
- Build technological infrastructure (e.g. platform) to support the ecosystem.

4 Proposed approach

As noted, the two cases studies are examples of ecosystem established by other than a common technological infrastructure (or platform). The telemedicine ecosystem is a business-rooted[3], while the smart city ecosystems is an actor rooted[4]. These two cases contribute with different perspectives on how ecosystem are established. They add more parameters to the up-to-now knowledge of ecosystems being created by a successful or popular technological infrastructure (platform) [10, 11, 14].

Up to the current point and to the best of our knowledge of the field, there is no previous work suggesting an applicable and holistic or generic (i.e. applicable to most or all types of ecosystems) way of creating a software ecosystem. This is the gap that we are trying to address with this approach, as we argue that a method for designing ecosystems that is easy to apply and mature enough would support the maturity of the field both theoretically and empirically.

In our approach, we propose the view of ecosystem design, development, and establishment as one continuous and re-iterative phase rather than three distinct phases. In order to initiate this process, the basic information needs to be collected and the first initial designs need to be drawn. Thus, we identify three main steps in our process to conduct the necessary work for the iterative design. Figure 1 shows the proposed steps and the tasks included in each step. Our approach includes three main steps: pre-analysis, design, and evaluate & monitor. In the subsections bellow we describe these steps. Our approach has a strong focus on the ecosystem health, thus apart from the design, we support the view of continuous monitoring and evolution of the ecosystem making the separation between design and establishment unclear. This is reflected in step 3.

Furthermore, taking the approach demonstrated from our cases, we identify that ecosystem design can occur based on three different ecosystem types: *infrastructure-rooted*, where the ecosystem is established around a technological

[3] I.e. initiated by strong actor incentives.
[4] I.e. initiated by a set of actors to drive the ecosystem development.

Fig. 1. Ecosystem design steps.

infrastructure[5];*actor-rooted*, where the establishment is around a strong actor consortium; and *business-rooted*, where the ecosystem is established around a strong business (or incentives).

4.1 Step 1: Pre-analysis

The initial step for the design of a software ecosystem is to identify the general information and characteristics of the future ecosystem. This includes identifying the applied domain of the ecosystem, i.e. how is the domain defined and what are the general characteristics of this domain. Further, this step includes defining the scope of the ecosystem and marking the borders of what is considered part of the ecosystem. Moreover, this step includes identifying the general *principles* of the ecosystem, i.e. core values and characteristics of the ecosystem that essential for the ecosystem [15]. Finally, part of the pre-analysis step includes identifying what aspects of the future ecosystem already exist that can form the base for the future ecosystem. This step will define whether the ecosystem is actor, infrastructure, or business rooted in step 2.

4.2 Step 2: Design

If we examine how ecosystems are created, the most common way appearing in the literature is from a (software) company opening their platform to external actors or an open source software (OSS) project that is gaining popularity. Examining the existing ecosystems in the industry (or in the literature e.g. the list in [10]), we note that this is not the only way that these ecosystem were established. Part of our proposed approach is to tailor the ecosystem design and establishment according to different aspects that exist in the domain of the future ecosystem. The above mentioned examples of OSS projects or companies opening the platform are examples of a *infrastructure rooted* ecosystems-to-be, since they have the base of what cold eventually become the common technological infrastructure of the future ecosystem. Another category is the *actor rooted*, that are ecosystems where there is a (strong) set or network of actors that can be form the core of the future ecosystem. Finally, there is also the *business rooted*, where there is a existing business potential and incentives (not necessarily for and from many actors) that can be the main drivers to the establishment of an ecosystem. An example of this can be found from the literature on evolution of vertical software industries where ecosystems emerge around new standards and platforms to enable effective collaboration between businesses/enterprises [17, 18].Clearly, the steps towards designing and establishing an ecosystem are different depending on the already existing aspects. Sub-steps (a),(b), and (c) list the actions for each type.

[5] Here using the approach of [8], we identify that an infrastructure can be apart from a platform, a standard or a protocol.

4.3 Step 3: Evaluate and monitor

Finally, as already explained, in our approach we propose the view of the design and development as a continuous and iterative process where software ecosystem design, development, and establishment are not distinct phases but rather part of one continuous and re-iterative phase. In order to achieve that, the ecosystem should be constantly monitored on its evolution and reaction to changes and potential deterioration should initiate new actions on the ecosystem architecture or orchestration. Thus, this step includes activities that focus on identifying what should be measured in the ecosystem to identify evolution and change in ecosystem health. After the measures are identified monitoring and evaluation activities will focus on (i) intervening in the operation of the ecosystem with changes and (ii) evaluating the effect of potential changes (as much as the whole design). It is essential to underline that identification of measures is an essential step as it defines the scope of action within the ecosystem. Too narrow measure might result in lack of overview of the whole ecosystem while not accurate or poorly defined measures might guide to wrong conclusions on the ecosystem activity and evolution.

5 Discussion

This paper aims at bringing focus to a central issue in the field of software ecosystem by proposing a method on designing ecosystems. Although generic and applicable, our method does not cover all the possible and potentially essential aspects in ecosystem design and evolution. One relevant aspect not adequately discussed is the *orchestration* of software ecosystems. The orchestration is central aspect in the health and evolution of an ecosystem and eventually the design of an ecosystem should include concrete considerations on the orchestration, in order to support the different characteristics of the ecosystem, its domain, and scope. Another relevant aspect is the establishment of the proper interfaces both technical and organizational. The different interfaces between the software components (e.g. in the common technological infrastructure) and between the different actors, should reflect the orchestration strategy of the ecosystem and respect the domain, boarders, and roles of the ecosystem and its actors.

Finally, as already discussed, the choice of the proper measures for monitoring the ecosystem is central to the evolution of the ecosystem towards the right direction. The monitored measures should also be influences as much as influence the ecosystem orchestration.

6 Conclusion and future work

In this work, we try to put focus on the gap in research and industry on how to "create" software ecosystems. Using our deep knowledge on software ecosystem literature and industry and experience from designing software ecosystem, we propose a method for designing software ecosystems that is easy to use and applicable. Our method is consisted of three steps and a set of activities for each step.

We are currently empirically validating and improving this method. Further work includes the empirical evaluation and improvement with cases of each different type of design. Moreover, we plan to identify characteristics of the method for specific domains, i.e. how this "generic" method changes when applied to a domain with specific characteristics. It is our hope that this will be a first step towards a better informed and explicit design of software ecosystems and eventually further maturity in the field.

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IV

A FRAMEWORK FOR IOT SERVICE EXPERIMENT PLATFORMS IN SMART CITY ENVIRONMENT

by

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A Framework for IoT Service Experiment Platforms in Smart-City Environments

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***Abstract*— Cities provide an excellent platform for gathering and detection of massive amount of data from cities and citizens. Emergence of new digital technologies inspires not only city governments but also city residents, researchers, companies and other stakeholders in discovering and creating new innovative solutions to solve urban challenges and improve peoples´ everyday life. Developing novel Internet of Things (IoT) solutions for cities and citizens requires facilities where IoT applications and services can be tested and experimented. The challenge for many smart-city test and experimentation platforms (TEPs), like living labs, has been the lack of sustainable value creation model. This has caused many experimentation platforms to perish after the ending of external funding. A vision about how to construct a robust and continuous IoT test and experimentation platform, as well as instruments for it, is required. The IoT service experimentation platform (IoT SEP) framework presented in this paper provides guidelines for this effort. IoT SEP consist of ten dimensions relevant for establishing a sustainable IoT SEP in smart cities.**

Keywords—*smart-city; test and experimentation platform; IoT experimentation platforms; stakeholder; sustainable value creation, value networks*

I. INTRODUCTION

The notion of smart-city has achieved considerable popularity. Cities around the world experience rapid growth and various technologies are used to solve urban challenges. The contribution of the digital technologies is thought to form the foundation for so-called "smart" cities, but one should not forget the human capital, skilled and educated citizens, sustainable environmental solutions and sustainable economic growth as important attributes for smart urban development [1] [2]. Technology like IoT is a viable option to form high quality testing and experimenting platforms in smart cities. Living labs and testbeds are mentioned within the context of various technology experiments in smart cities [5]. IoT service experimentation platforms (IoT SEPs) in urban contexts attract numerous stakeholders, including city, research institutions, technology providers and technology users. The reasons for using IoT SEPs vary by stakeholder. For an experimenting company, the ability to evaluate new IoT service concepts with users in real-life environment may yield more accurate test results than alternative settings. The costs of an evaluation cycle will remain lower in experimental platforms. For other stakeholders like cities and research institutions the IoT service experimentation platform provides an opportunity to collect data from real-life settings. That data can later be utilized for improving existing services or developing new services for citizens and other stakeholders in cities. [5] However, technology experimentation platforms in city environments have faced some challenges. Many of them like living labs, appear to last only the time the funding is granted for. One of the several reasons for this is that smart-city experimentation projects with a high integration of community and users result in more sustainable outcomes than technological or infrastructure-driven projects [6]. On the other hand, there are examples of successful technology-oriented testbeds, which, having the collaboration of research organizations, government and private sector, appeared attractive to private stakeholders so that they wanted to invest on them, too [7].

For digital platforms, it is crucial to reach the critical mass and open platform interfaces to third parties for the development of a sustainable and expanding platform. A digital platform without open interfaces does not enable the creation of a scalable business platform.[8] By achieving critical mass and opening platform interfaces to third parties, the IoT service experimentation platform may improve value creation and lead to more sustainable performance of IoT SEPs in city context. However, if specialized IoT devices, infrastructure or customer interaction is needed, the scale of IoT SEP may be limited. Thus it is more appropriate to talk about economy of scope instead of economy of scale.

In business networks firms sharing common interests have motivation to develop sustainable relationships that provide mutual benefits [9][10]. These mutual benefits created by the network are also referred to as value networks. A value network might include suppliers, customers and strategic partners providing value to each other. By belonging to value networks, a firm will benefit from the value networks' resources, receiving direct or indirect value [11]. Direct value may include goods, services and revenue obtained through material exchange or indirect intangible benefits like knowledge or improved market and networking potential [12][11].

Establishing a robust IoT service experiment facility and engaging relevant stakeholders in city context is not a trivial task [5][13]. The core value that IoT provides is the information created through connected devices. IoT improves our understanding of the surrounding world, and, at best cases, IoT SEP provides for its stakeholders learning experiences that would otherwise be impossible to have. The prerequisite for testing and evaluating relevant IoT scenarios with real-life (end-) users in real-world environment is mutual trust and commitment between stakeholders. [6]

In order to fulfill the expectations and needs of all stakeholders of the IoT SEP, a model for sustainable value creation is required. The purpose of this study is to examine existing testing and experimentation platforms for technology and constitute a framework for evaluating the IoT SEP in smart-city environments.

This paper is organized as follows: after the introduction in Section I, Sections II and III review previous literature on TEPs and on value networks. Section IV proposes a framework containing ten dimensions for evaluating IoT SEPs in smart cities. In Section V, the framework is applied in two empirical cases, in the Smart Santander and Smart Kalasatama projects. Section VI discusses the results, and Section VII summarizes the work and draws conclusions.

II. Test and experimentation platforms

A platform is defined *"as a reuse of sharing of common elements across complex products or systems of production"* [14]. Complementing it is a collection of common assets like human and social capital, processes, components, technologies and infrastructures [15][5]. A platform system has three elements; a core, components and the interfaces between them. Platform systems and its components can evolve, but the interfaces remain stable [14].

Four different types of company platforms are identified; transaction, innovation, integrated and investment platforms. A transaction platform is based on a technology, product or service and it acts as an intermediary to facilitate transactions between users, buyers, or suppliers. An innovation platform is based on a technology, product or service providing a ground for other companies to develop complementary technologies, products and services. An integrated platform, combining a transaction and an innovation platform, is not only for exchanging technologies, products or services but also for third-party developers to innovate new technologies, products or services. Investment platform acts as a holding company and/or an active platform for investors. It is established by companies with a platform strategy. [16]

ICT has proved to be a significant driving force not only for the emergence of industrial platforms but also for the appearance of test and experimentation platforms in cities [7][5][17]. Industrial ICT platforms like Google, Apple and Microsoft are platforms for products and services, and they provide also a place for external stakeholders to design new complementary technologies, products and services (integrated platform). Reusable common components and technologies form a basis for an industry platform, which is characterized by openness to external parties. The degree of openness related to for example information access, costs of common assets and platform access varies. [17]

Network effect is a prominent feature of digital platforms: the more users are engaged with the platform the more attractive that platform becomes for other potential users, and the more users the platform manages to attract the more value the platform generates for its stakeholders. Network effects can be divided into direct and indirect network effects. In direct network effect, users attract and generate new users; in indirect network effect, users attract other platform users or stakeholders, including product or service developers, to join the platform. [16]

ICT solutions are often tested on various types of technology-test and -experimentation platforms before final release. These platforms aim to accelerate technologies and innovations and to improve understanding of the socio-economic changes related to digital technologies and ICT developments [7][5][6]. As complex systems, cities provide multidimensional environments for testing modern ICT technologies. Previous research [7] has paid attention to European broadband open-innovation platforms and distinguished six different test and experiment platform types (Fig. 1.).

Technologies, products or services in the early development phase are tested in **prototyping platforms**, which are characterized as closed in-house design and development facilities. However, prototyping platform is also utilized as a platform where nearly market ready concepts and new business models are developed and tested in collaboration with other participants. Trust between stakeholders carries significant weight in prototype platforms. **Testbed** provides a standardized laboratory environment and is used for testing yet immature new technologies, products, services and sometimes even marketing concepts. Risks of the test hazards are minimized in testbeds. Depending on a testbed´s openness with regard to stakeholders, the testbed may induce the creation of new innovative technologies. [7] **Field trials** are regarded as agile platforms for several stakeholders and even final users. They are used for specific small-scale tests, testing technical features of new technology, product or service in a limited real-life environment. [7]

Fig. 1. Test and Experiment platforms [7].

Living labs provide an environment for technology experimentation in real-life context, and their users are integrated to technology innovation process already in the early phase of product development lifecycle. A living lab platform with user involvement provides more context-specific insights on technology development and acceptance processes, improving mutual stakeholder interaction. In addition, user involvement enables value co-creation and technology co-production with other living lab stakeholders. Experiments run in living labs improve overall understanding of technology impacts and integration to society. Characteristic to living labs is they are run in large-scale contexts such as cities and that their life cycle is rather long. [7][5][6][18]

Market pilots are utilized when a product or a service is close to maturity and ready for commercialization. A market pilot platform is not open, and a product or a service is released for a limited number of end users who will receive market data before the final launch. Finally, the purpose of **societal pilots** is to introduce a rather mature new product or services in a real-life context. Public involvement in societal pilots is high, as the aim is to produce new societal innovations. [7]

As previously mentioned, cities provide a complex real-world environment and thus numerous advantages for various information technology experiments. Many of the test platforms presented by [7] are valid in smart-city context. However, certain attributes like scalability and real-world experiment environment are significant when establishing IoT TEP in smart-city context. City-level experiments enable ICT developers and other stakeholders like research institutions to iteratively asses and validate immature or nearly market ready IoT services and applications. By engaging real users to early IoT services or application development processes the developers also receive valuable hints of usefulness and acceptance of the technology solutions during the iterations. [3][5] Other advantages the cities provide for ICT experimenters are heterogeneous IoT applications and devices in diverse experiment domains. [4] Collecting and monitoring data from traffic, water and energy consumption, air pollution, public buildings and lighting are examples of the diverse city domains where various IoT devices and applications have been implemented and experimented with [18][19].

The ICT and smart-city IoT TEPs are characterized by openness, user and public involvement, real-world test environment, scalability, IoT heterogeneity and architecture design. Vertical scope, duration and commercial maturity are also mentioned as being TEP characteristics. (Table 1.)

TABLE 1. TEP characteristics

TEP characteristic	Reference
Openness	[3][4][5][7][19]
Public involvement	[4][5][7][18][19]
User involvement	[3][4][5][7][13][18]
Real world experimentation	[3][4][5][18][19]
Scale	[3][4][5][7][18][19]
IoT heterogeneity	[3][4][13][19][20][22]
Architecture design	[3][4][13][18][19][20][21]
Vertical scope	[3][7]
Duration	[7]
Commercial maturity	[7]

Openness here describes the way TEP results are available and open for all stakeholders. Public and user involvement explains how actively policy makers and citizens are involved in TEP activities. Real-world environment implies the way the tests and experiments are implemented in natural and realistic settings and scalability how TEP scales from small to large. IoT heterogeneity describes the diversity of IoT devices and applications. Architecture design illustrates the interoperability of heterogeneous IoT devices and applications and how data is collected and processed. Vertical scope measures the degree to which stakeholders are involved in TEP from different levels in value chain. Duration is related to the degree of TEP stability, and commercial maturity illustrates how close the tested technologies, products and services are to market introduction.

III. Value networks

Firms sharing common interests in business networks have motivation to develop and maintain relationships that provide them mutual benefits [9][10]. The networks are dynamic and may change when a firm deepens its existing relationships, establishes new ones or ends the problematic ones [23][24]. The firm is dependent on resources controlled by other firms. It can compensate for its limited resources, either by developing its position in an existing network, or by establishing new networks [9].

The firm’s value network may include suppliers, customers and strategic partners who provide value to each other. The value provided can be divided into three categories: 1) goods, services and revenue, as part of material exchange, 2) knowledge regarding the services and technologies and 3) intangible benefits that go beyond actual services and are not accounted in the financial sense [12]. In case of IoT SEPs the main stakeholders include the parties listed above, the city, technology providers, companies experimenting with their services and users of those services, among others. The main value received by the experimenting firm is the ability to evaluate new IoT service concepts with users in their every-day environment better than with alternative settings. The relative advantage of IoT SEPs may be due to a faster cycle from product concept to evaluation, lower cost of an evaluation cycle or set-up, better fit, higher number of experimental users available, better research support for experimentation or some other benefits provided by the experimentation platform or the other stakeholders in the IoT SEP value network. The value provided by the experimenting firm may be material or intangible benefits related to exchanged value, such as the interest of users to experiment with new products, the interest of a partner to gain knowledge of a new technology or the interest of a public party orchestrating a network to activate new business development in an IoT SEP.

Many experiment platforms, especially living labs, have suffered from the lack of sustainable value creation model after project funding has been used up to set up the platform. Following the logic of platform economics [17], a platform enterprise orchestrating a value network has to use resources to establish and maintain the network or platform. If the value network orchestrator is a public organization in a PPP setting, the motivation to use public funding beyond the project is limited. A sustainable value network requires sufficient volume of value creation throughout the network to maintain a healthy network. This is also referred to as ecosystem health [25] and includes productivity, robustness and niche creation components.

IV. Framework for IoT service experiment platform - dimensions to evaluate IoT SEP

Cities are responsible for their residents´ wellbeing, and therefore cities have many functions and activities that must work together without interruptions. This sets high requirements for city governance, management and ICT architecture.[14][13] ICT plays a significant role in city development: the city´s ability to collect data from various sources and to analyze data to improve diverse city services turns a traditional city into a smart one [13][5]. As a complex system cities provide a multifaceted foundation to test and experiment new digital technologies and ICT solutions in real-life user context [7]. Numerous smart-city IoT test and experiment initiatives demonstrate good results, but the challenge is the sustainability of TEPs. It seems the integration of the community and users to technology experiments improves the duration of technology TEPs [6]. On the other hand, the lack of sustainable value creation and lack of business model may influence negatively the technology TEPs` duration in smart cities [20]. Regarding the TEP continuity and importance of sustainable value creation model, city authorities need instruments for creating and developing such IoT SEPs that are attractive enough for external stakeholders to participate in IoT SEP activities. Fig. 2 presents a framework with ten dimensions, which are the elements significant for establishing a sustainable IoT SEP ecosystem.

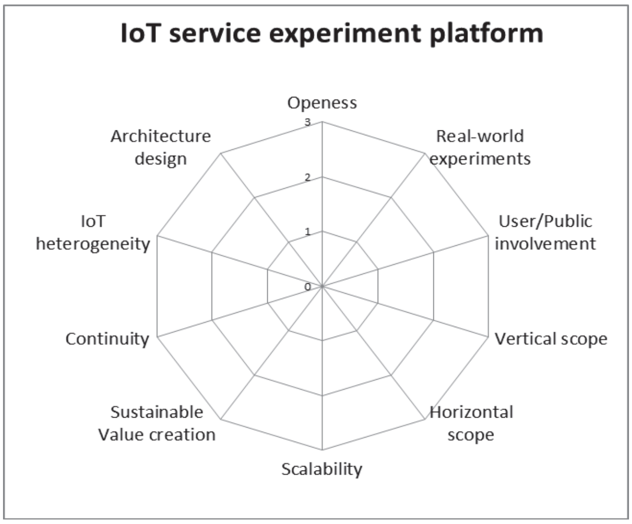

Fig. 2. A framework to evaluate IoT service experiment platform in smart-city.

The dimensions extended from the TEP characteristics presented in Table 1 are scaled from 0 to 3. Value 0 represents no activities, value 1 moderate, value 2 good and value 3 excellent performances.

Openness (Fig. 2) is related to the degree the stakeholders have access to certain assets of IoT SEP. These assets may include facilities, information, infrastructure, technologies or user communities. Openness also describes the level an IoT SEP is integrated to other test and experiment facilities. [7][5] **Real-world environment** indicates the level at which the experiments are executed in natural and realistic environment [3][4][5][18][19] . P**ublic and user involvement**, which describes the level to which city authorities and citizens are involved in IoT SEP, is vital as cities are commonly regarded as the primary initiators and enablers of smart-city experiments. Therefore, the interest of city administrators and their involvement in IoT SEP is significant. Recently, the users' and especially the end-users' role in smart-city IoT experimentation have been highly emphasized. By integrating users in the early phase of product development and testing, the IoT developers and researches can receive instant feedback of their product or service. This information is valuable as it provides data for further development of IoT services and improves understanding of technology acceptance and social impact of IoT solutions. [5][6][7]

Vertical scope describes the degree to which stakeholders from different stages of value chain are involved in TEP, from technology providers to end users. Vertical and horizontal scope also describes how IoT SEP is integrated to other test and experiment platforms. [7][5] Many smart-city initiatives have been created around a vertical industry or an industry emphasizing the goals of a single vertical theme, such as energy efficiency, traffic or health care. The vertical approach will also influence the choice of employed technologies and standards that will best support the needs and requirements of a chosen industry. **Horizontal** scope describes TEPs´ wider set of applications and services combining data from multiple industries to service developers. That approach challenges and associates costs on finding a balanced set of technologies while matching the requirements for all the verticals targeted. However, potentially it can reach a wider user base for services based on new services.

In order to receive extensive and deep data in city context, IoT experiments need to be executed in large-enough **scale** with real users in real environment. The scope may vary from a laboratory environment to a living lab providing scalability to test and experiment with IoT services. Platform scalability creates more value and attracts more users. In digital platforms, scalability is regarded as an outcome of initial success and together with network effect acts as a foundation for further growth. IoT SEP can act as a catalyst for this through implementing an efficient and effective experimentation process that provides significant added value for service and product development firms. [7][16]

The challenge of TEPs in city context has been the lack of **sustainable value creation** and **continuity** once the funding has dried out. The more an IoT SEP is able to attract users the more value is generated through direct or indirect network effects. This will provide more opportunities for co-creation and evaluation of new ideas and scenarios in collaboration with users: citizens, research institutions, companies, city administrators and other interest groups. This also will enhance the sustainability and continuity of IoT SEPs. [5][6][18][16] IoT heterogeneity and architecture design illustrates the diversity of IoT devices and applications and interoperability between them. The level of architecture design also indicates a city´s ability to design and manage complex data sources and streams from various domains.

V. Smart Santander and Smart Kalasatama experiment platforms

In this section two smart-city projects, Smart Santander in Spain and Smart Kalasatama in Finland, are evaluated through the IoT SEP framework presented in Fig 2. These projects were selected because they provide large-scale real-world experiment environments, aiming to deploy IoT infrastructure around Santander, Kalasatama and partner cities. The citizens and visitors of Santander and Kalasatama are integrated as active users in IoT services. SmartSantander´s target is to install 12,000 sensors, actuators and tags around Santander and 8,000 sensors to other European partner cities in order to collect environmental and traffic data, among other data. [26] Kalasatama provides a ground for external companies to pilot new digital services [27]. Both Smart Santander and Kalasatama provide an experiment platform for researchers, companies, application and service providers, user communities and city administrations. Smart Santander and Kalasatama are monitored and the data is collected through websites, project open calls and academic papers.[26][27] Here we evaluate them through ten dimensions of IoT SEP presented earlier in this paper in (Fig. 2). The grading of evaluation runs from 0 to 3 as explained in Section IV.

The Smart Santander project is divided into four subsystems: AAA (authentication, authorization and accounting), testbed management, experimental support and application support. Smart Santander is open for domestic participants, but the project has been deployed also in Belgrade/Pancevo in Serbia, Guildford in the UK and Lübeck in Germany. Two open calls for European project partners were issued during 2012 – 2013. The purpose of the open calls was to attract exciting experiments, experimentally-driven scientific research with high impact and evaluations that utilize features provided by the Smart Santander facility. Both open calls were targeted to public and private R&D organizations with expertise in smart cities and IoT. The first project period was for one year in 2012 and the second for six months in 2013. The first call covered 3-5 experiments with 1-2 partners for each experiment. As a result, nearly 50 proposals, of which half came from industry partners, were received. After the first call, 4 new partners were selected. Second call included 4-6 experiments for 1-2 partners per experiment.

Smart Kalasatama is a district of Helsinki in Finland. It is estimated that by 2035 around 21,000 inhabitants will live in the area, which provides job opportunities for 8,000 people. Sustainability and business-friendly environment are the driving forces of the area. Smart Kalasatama is a partner for the bIoTope project in aiming to build an IoT OPen innovation Ecosystem for connected smart objects. BIoTope is implemented in Lyon, Helsinki and Brussels regions. The first pilots executed in Smart Kalasatama included smart-mobility services, effective waste management, food waste reduction and co-creation of local services. The next call for new innovative pilots is targeted for health and wellbeing services. Kalasatama pays 1,000-1,800 euros for each pilot carried out there. The purpose of the pilots is to provide service experience for citizens.

A. *Openness*

The aim of the 20,000 sensors in four cities (Santander, Belgrade/Pancevo, Guildford and Lübeck) is to provide real-world data for developing novel applications and services for city and citizens. Smart Santander is open for research institutions and companies providing additional benefits for other stakeholders in Smart Santander project (Fig. 3.).

Kalasatama belongs to the 6aika project, which aims to provide a platform for open innovations, open data and interfaces, as well as open participation and customership. There are six Finnish cities participating in the project. Their partnership with cities of Lyon and Brussels through the IoT OPen innovation Ecosystem (bIoTope) project extends the interfaces for data and IoT solutions (Fig. 4.). [29][28]

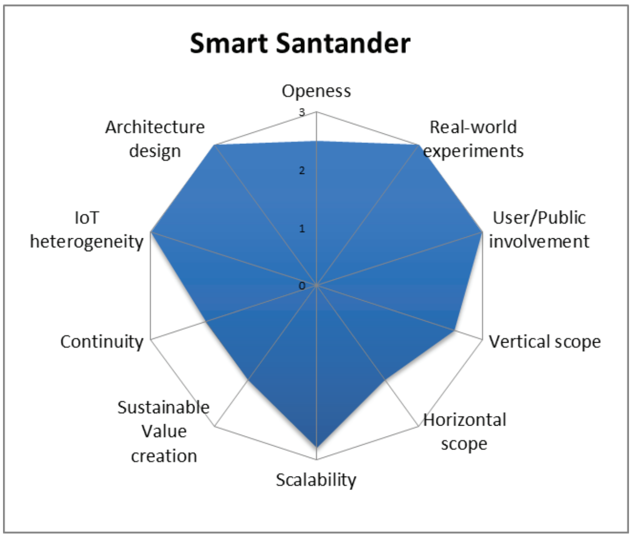

Fig. 3. Smart Santander Dimensions

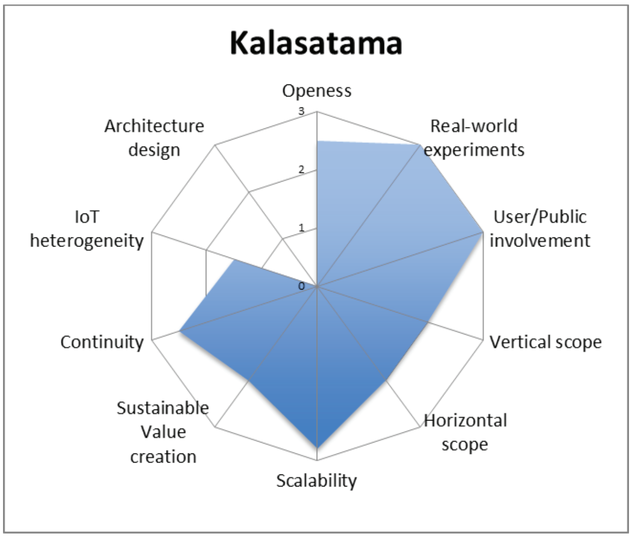

Fig. 4. Smart Kalasatama Dimensions

B. User/Public involvement

City administration and citizens are significant actors in Smart Santander and Kalasatama. The primary task of the applications and services is to create value for city authorities and citizens in order to improve their lives. Public governments are enablers and citizens active participants both in Santander and Kalasatama.

C. Vertical and Horizontal scope

The current Smart Santander infrastructure targets transportation, energy and environment. The goal is to extend the infrastructure to cover new application domains. One aim would be to create a mechanism to evaluate end-user feedback or quality of experience automatically or semi-automatically during experimentation. Kalasatama provides a living lab facility for agile pilots. Its pilots have included smart-mobility services, effective waste management, health and wellbeing services and co-creation of local services.

D. Scalability

Scalability in the Smart Santander project varies from indoor to citywide experimentations. Smart Santander is implemented in four European cities. With 12,000 sensors, Santander forms the widest real-life IoT experimentation platform in the Smart Santander project. Guildford functions as an indoor test environment with 250 sensor nodes. The Lübeck facility consists of 300 stationary sensors and provides information for commercial use, for example bus timetables and locations. The EkoBus system is deployed in Belgrade and Pancevo. The system utilizes public transportation vehicles to monitor environmental parameters such as temperature, humidity and CO2 information for city authorities and information such as arrival times and location of the buses for end users. The system utilizes 60 devices, but there is no direct access to any IoT nodes. Smart Kalasatama pilots are implemented in the Kalasatama district, which is connected through partnership projects to other smart-city platforms in Finland, Belgium and France.

E. Sustainable value creation

The objective of both Smart Santander and Smart Kalasatama is to produce innovative IoT applications and services which clearly demonstrate benefits and value for the city, its residents and stakeholders. As an example, SmartSantanderRA application is being developed to provide information on nearly 3,000 places in Santander. The application provides real-time data on traffic, weather and bike rental services, for example. For the European researcher community, the Smart Santander infrastructure provides a platform to carry out scalable IoT experiments in a real-life environment. Agile pilots in Smart Kalasatama have produced applications and digital services which improve food and waste management, and neighborhood aid services as well – a neighborhood aid platform, NappiNaapuri, connects Kalasatama residents who need aid in everyday situations.

F. Continuity

The Smart Santander project received funding of around 10 million euros from EU to carry out large-scale technology testing in Santander city. The funding was granted for four years, starting from 2010. As the sensors are permanently placed around the city, data is still being collected even though the funding period is over. The data is used globally for research purposes and locally to develop services and applications. The Smart Kalasatama infrastructure built for agile pilots provides an environment for continuous piloting of products and services.

G. IoT heterogeneity

Smart Santander offers a diverse set of IoT devices and systems. The IoT nodes consist of actuators, sensors, QR and NFC tags and mobile-phone-based sensing platforms which are connected via various network technologies. The aim is to deploy around 20,000 actuators, tags and sensors around the partner cities in Europe.[4]

Smart Kalasatama is a new district being developed in Helsinki. Residential buildings have their own data centers, where for example energy consumption data is collected. Moreover, a broader, heterogeneous IoT network is evolving, and it is expected that diverse IoT systems will emerge.

H. Architecture design

The architecture design in the Smart Santander platform is based on three-layered architecture. The layers consist of IoT device, IoT gateway and server levels. Most of the experimental IoT devices are at the IoT device level. The IoT gateway node level links the IoT devices at the edges of the network to the core network infrastructure. The server level consists of server devices which are connected to the core network infrastructure. The architecture design is well-planned and implemented. [4]

Information of the architecture design from Smart Kalasatama was not available in public sources, and thus could not be evaluated. However, the absence of public data implies that no open architecture design has been deployed so far.

VI. Discussion

Technology test and experimentation projects in smart-city environments tend to decline once project funding has finished. Some studies show that integrating communities and users to ICT experimentation platform activities results in more sustainable outcomes. Another factor effecting platform sustainability is the critical mass. Achieving a critical mass requires large-enough user base to make the platform attractive for other users and external service developers and providers. Wide horizontal and vertical scope, i.e. the ability to have stakeholders from multiple industries and from technology providers to end users will increase the number of participants in the IoT SEP. The smart-city experimenting platform should therefore provide open interfaces, share assets, create efficient and effective experimentation processes and be compatible with other city platforms.

Reaching the critical mass results in network effect, which is one of the success indicators of sustainable digital platforms and a turning point for a platform´s continuity and growth towards a self-sustaining platform. In the case of Smart Santander and Kalasatama, the technology experimentation platform is extended from the original region to other European cities. As the end-users of the Smart Santander and Smart Kalasatama platforms are the citizens, they enable experiments in real-life environment with real users to be carried out. Smart Santander makes possible both small and large-scale experiments with its partners. Smart Santander collaborates widely not only with research institutions in Europe but also with research institutions outside Europe. Smart Kalasatama has provided a platform for several agile pilots producing services valuable for citizens. Later on, it will benefit from collaboration with other cities in Finland and Europe. Both Smart Santander and Smart Kalasatama have attracted various application and service developers. However, it remains unclear how many service providers and companies have been involved in Smart Santander and how many new innovations Smart Santander has generated. Smart Kalasatama attracted 52 offers after the first call for agile pilots. Four pilots were selected to carry out the prototype tests in Kalasatama. Applications for mobility services and social web services were developed to improve everyday lives

It appears that Smart Santander has managed to create a large-enough user community, open interfaces and effective and efficient experimentation processes, so that the stakeholders such as city administration, global scientific community and private sector are showing great interest in maintaining the Smart Santander experiment platform. This supports the argument about the importance of critical mass in the creation of compatible and open platforms with other platforms in city context. However, the network effect and revenue model for the Smart Santander innovation platform remains unclear. Smart Kalasatama is taking just the first steps with technology experimentation platform activities; nevertheless, the results of the agile pilots have been valuable and encouraging. It is expected that Smart Kalasatama will produce innovative and beneficial applications and services in collaboration with the partner cities in Finland and Europe.

VII. Summary and Conclusion

One of the main challenges of test and experimentation platforms in city context has been the lack of sustainable value creation models. This has resulted in the discontinuity of experimentation platforms after the external funding has ended. It is argued that obtaining a critical mass with real-life users and providing open and compatible platforms in city context improve sustainability and value creation of IoT SEPs in smart cities. This critical mass can be supported best if the platform scope covers multiple industries and stakeholders from technology providers to end users, i.e. a wide horizontal and vertical scope. Altogether, we were able to identify eight relevant factors from the previous literature and, in this paper, we extend the list with sustainable value creation and horizontal scope. Out of these, we constructed and presented a framework consisting of ten dimensions essential for sustainability of service experimentation platforms in smart-city environments.

The dimensions are openness, real-world experiments, user/public involvement, vertical and horizontal scope, scalability, sustainable value creation, continuity, IoT heterogeneity and architecture design. These dimensions represent the significant elements for establishing a sustainable IoT SEP and a robust ecosystem around it.

For practitioners, this framework provides a means to evaluate and guide the development of IoT SEPs. For researchers, the framework provides insights for future research on IoT SEP ecosystems and value formation in city context. In addition to these, we call for further research on relevant business models for IoT SEPs in smart-city context.

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V

IMPROVING SMART CITY DESIGN: A CONCEPTUAL MODEL FOR GOVERNING COMPLEX SMART CITY ECOSYSTEMS

by

Mervi Hämäläinen & Pasi Tyrväinen, 2018

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A. Pucihar, M. Kljajić Borštnar. P. Ravesteijn, J. Seitz & R. Bons

Improving Smart City Design: A Conceptual Model for Governing Complex Smart City Ecosystems

MERVI HÄMÄLÄINEN & PASI TYRVÄINEN

Abstract Smart city concept is a viable nominee to solve the dilemmas urbanization creates globally. By means of digital technologies like Internet-of-Things, artificial intelligence and data analytics cities aim to optimize city performances like mobility, environment, security, health care and social services. Furthermore, cities actively endorse usage of digital technologies to foster digitalization and new business innovation to nurture local economy and social well-being. Smart city market is growing, but simultaneously fragmented smart city markets and initiatives face challenges with governance, ecosystem orchestration and continuity. Transformation to smart city is a complex long-term process, which requires collaboration with heterogeneous stakeholder groups and capabilities to evaluate wide spectrum of new digital technologies and their fitness to diverse city functions and processes. This sets high demands for the smart city governance and management. A smart city conceptual model (SCCM) presented in this paper aims to assist cities with this endeavor. SCCM observes complex smart cities from organizational and technical perspectives providing practical instrument for smart city stakeholders to lead city towards data and digital technology assisted smart city. SCCM considers four primary dimensions, strategy, technology, governance and stakeholders. Each primary dimension is complemented with sub-elements, which all together form meaningful interrelations and provides comprehensive and systematic approach for the smart city design, development and implementation.

Keywords: • Smart city • Strategy • Governance • Stakeholders • Technology • Ecosystem • Digital technologies •

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1 Introduction

The smart city concept attracts city governments, industries and academia globally. In the area of EU alone, over 1300 smart city related proposals, commitment and project exist. European cities invest on information and digital technologies to renew power grids, buildings, public transportation and waste management systems. (European innovation partnership on smart cities and communities.) By investing on modern smart city technologies cities aim to enhance city security, optimize city processes and usage of scarce resources and improve data driven city governance. Cities aim also by means of digital technologies to foster new knowledge creation and innovation and stimulate local businesses and collaboration. (Baccarne, Mechant & Schuurman, 2014; Batty et al., 2012; Caragliu, Del Bo & Nijkamp, 2011; Gabrys, 2014; Li, Nucciarelli, Roden & Graham, 2016; Zanella et al., 2014.)

Even though smart city has been a trendy phenomenon and smart city markets are growing it is worth bearing in mind that each city should focus on developing the smart city from its own particular needs and perspectives. As cities are constantly evolving systems and vulnerable to external uncertainties (Jabareen, 2013) smart city initiatives should be considered as long-term development process, which impacts for instance city strategy, resources, capabilities and stakeholder relations. Creating a specific *smart city strategy* is proposed to consider and analyze city´s macro environment, but also evaluate feasibility of the new digital technologies in diverse city domains and recognize resources and capabilities needed for the smart city transformation. The specific smart city strategy also addresses risks and funding needs for smart city initiatives.

Objective of this paper is to present smart city conceptual model (SCCM) that assists cities and their stakeholders to carry out robust smart city initiatives and enhance sustainable smart city ecosystem design and development. Foundation for SCCM is derived from the systematic literature review of the smart city ecosystems and value networks. SCCM originates from a perception that design and management of the complex smart city is not a trivial task and many smart city initiatives have failed due to weak smart city governance, ecosystem orchestration and insufficient digital technology knowledge and capabilities. SCCM aims thus to clarify complex smart city governance, ownership, orchestration and decision making procedures and advance technological compatibility and correct skills and resource allocation in cities Furthermore, SCCM aims to provide tools to accelerate competitiveness, transparency and economic growth in cities.

This paper first discusses the methodological principles and secondly presents the conceptual foundations for the smart city conceptual model. Conclusion section summarizes and finalizes the paper.

2 Methodology

Smart city is a complex phenomenon, which interest diverse research disciplines like social and environmental sciences, information systems, computer and engineering, urban development and business & economics. Purpose of this paper is to build a smart city conceptual model, which derives its foundations from the literature of the smart city ecosystems and value networks in diverse research fields. Jabareen (2009) suggests that qualitative methods are adequate and useful for building conceptual frameworks from the multidisciplinary literature. Grounded theory as a research method offers a procedure for conceptual framework analysis and building conceptual frameworks (Jabareen, 2009). As an inductive theory the grounded theory allows the salient concepts to emerge from the literature (Wolfswinkel, Furtmueller & Wilderom, 2013) and identify the major concepts relevant for the study phenomenon (Jabareen, 2009). Due to the multidisciplinary nature of the smart city phenomenon, the principles from the "Grounded-Theory Literature-Review Method" by Wolfswinkel et al. (2013) and the conceptual framework analysis by Jabareen (2009) were utilized when conducting the literature review. The literature review addressed the search terms "smart city", "intelligent city" or "digital city" ecosystems and "smart city", "intelligent city" or "digital city" value networks. The search terms were applied to Scopus, Web-of-Science, SAGE Journal Online and AISeL databases. (Table 1.)

Table 4: Search terms and databases

Search terms	Scopus Elsevier API	Web-of-Science (WoS)	SAGE Journals Online	AISeL	Total
"smart city" + ecosystem	41	21	29	8	99
"digital city" + ecosystem	0	1	6	0	7
"intelligent city" + ecosystem	4	3	3	0	10
"smart city" + value network	25	12	2	11	50
"intelligent city" + value network	1	0	0	0	1
"digital city" + value network	3	3	0	2	8
Total	**74**	**40**	**40**	**21**	**175**

Search terms covered articles from social and environmental sciences, information systems, computer and engineering, urban development and business & economics disciplines. Alltogether 175 articles were found, but after removing dublicates 126 journal articles were left. Document titles and abstracts were reviewed and 44 papers were selected for closer review. Based on the key terms that emerged from the literature concepts of strategy, technology, governance and stakeholders formed the parent dimensions for the smart city conceptual model. The sub-concepts were derived from the literature review complemented with the relevant articles from the literature of strategy and organization management, software ecosystems and from the literature of the smart city technology test and experimentation platforms.

3 Conceptual Foundations

Objectives of the robust smart city is to accelerate and reduce costs of the city services and enhance the return on investments (Vilajosana et al., 2013), accelerate economic growth and competitiveness and transparency (Perez, Poncela, Moreno-Roldan & Memon, 2015; Yovanof & Hazapis, 2009). An explicit smart city design clarifies complex smart city governance, stakeholder relationships, orchestration and decision making procedures (Scuotto et al., 2016; Vilajosana et al., 2013) and advances technological compatibility and correct resource allocation in cities (Carvalho, 2015; Scuotto et al., 2016; Vilajosana et al., 2013; Veeckman & van der Graaf, 2015), but above all smart city initiatives should aim to improve the quality of citizens lives. The following chapters present the conceptual foundations for the SCCM, which consists of *strategy, technology, governance,* and *stakeholder* dimensions (Fig 1). Strategy dimension considers aspects of smart city vision and strategy, capabilities and digital strategy. Technology dimension discusses about digital technologies, architecture design, technology experimentation and security and privacy issues in smart city. Vertical and horizontal scopes conclude technology dimension. Governance section describes orchestration of the smart city stakeholders and ecosystems and considers funding and risk management elements. Final, the fourth stakeholder dimension elaborates quadruple helix and stakeholder value.

3.1 Strategy

Strategy is defined as an analytical process of intentional action plans and stream of decisions (Minzberg, 1978) to achieve the long-term goals under certain conditions (Mintzberg & Waters, 1985). Strategy is also considered as a cohesive response to diagnosed challenges (Rumelt, 2009) identified in the operational environment. Strategy is a deliberate and inclusive plan of action to commit and dedicate the whole organization to common goals. Strategy identifies the use of resources, predicts and evaluates the risks and indicates willingness of action to accomplish the goals. (Henderson, 1989.) Strategy dimension clarifies smart city vision and strategy, digital strategy and enhance to figure out required capabilities.

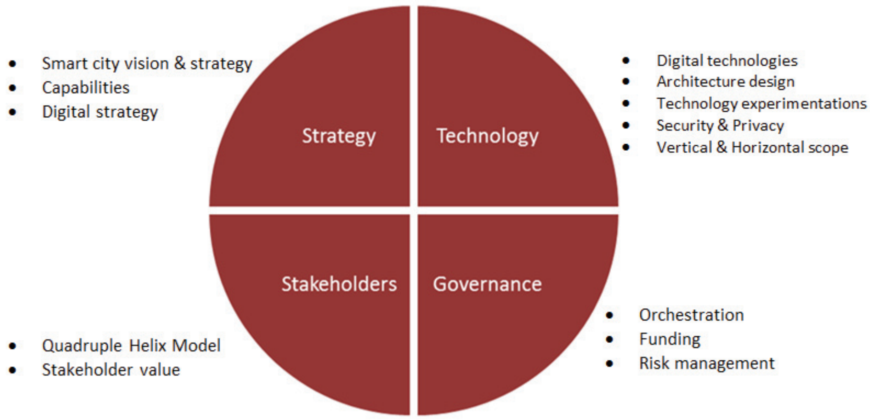

Figure 6: A conceptual model for the smart city design

3.1.1 Smart city vision, strategy, capabilities and digital strategy

Smart city vision´s aim is to express the idea or image of a desirable future (Nanus, 1992) the city is seeking from the smart city initiatives. Vision is characterized as consistent, vivid and dynamic narrative that creates shared meaning of the future clarifying organization´s ambitions and ideology (Collins & Porras; 2005; Levin, 2000). Smart city vision thus acts as a means of communications and is a catalyst for inspiration during the turbulent times and change (Levin, 2000; Nanus, 1992).

Transforming city towards smart city is a long-term journey that requires changes in the city strategy and resources allocation. A specific *smart city strategy* recognizes the changes in political and social conditions, but further identifies the changes that occur in technologies, legislation and economy. The smart city strategy sets goals and considers resources and capabilities required for successful smart city implementation. Smart city capabilities refer to city´s ability to create technical, management and governance skills and knowledge to design and orchestrate innovative and sustainable smart city initiatives that creates value for its stakeholders (Baccarne et al., 2014; Komninos, 2011; Scuotto et al., 2016; Tillie & van der Heijden, 2016). In broader perspective the smart city strategy also considers the impacts of climate change and global political situations on cities´ circumstances.

Ongoing decade has been the rise of new digital technologies. Digital technologies are perceived as a combination of heterogeneous information, cloud computing, communication and connected devices (Bharadwaj, El Sawy, Pavlou & Venkatraman; 2013) complemented with technologies like social media, mobile, big data and data analytics (Ross et al., 2016), artificial intelligence and blockchain technologies. Digital technologies are applied in diverse parts of organization infrastructures. Business units, capabilities, processes and services are interconnected with digital technology solutions

(Bharadwaj et al., 2013). IS literature discuss about combining the strategy and business strategy and calls the fusion as *a digital business strategy (*Bharadwaj et al., 2013; Mithas, Tafti & Mitchell, 2013; Ross et al., 2016). The digital business strategy is defined as organizational or business strategy (Bharadwaj et al., 2013; Ross et al., 2016), which consists of complex and interrelated elements (Mithas et al., 2013) like digital resources and capabilities that create and deliver differential value for the organization operating under constantly changing environment (Bharadwaj et al., 2013; Ross et al., 2016). The digital business strategy thus considers how IS and business strategies jointly not separately reacts to changes in operational environment and create value for the organization and its stakeholders.

In the smart city context digital strategy should support and be aligned with smart city strategy. Smart city strategy envisions the future state of the city by means of digital technologies and considers how complex digital technologies are integrated to the city´s infrastructure to enhance the city processes and functions, service design and capability creation. The smart city strategy acknowledges the common goals and value creation possibilities to citizens and stakeholders in public and private sectors by means of digital technologies.

3.2 Technology

Technology is information, skills and processes to accomplish tasks or artifacts. From sociotechnical perspective technology covers all the elements needed for the output; people, machines, systems and methods, processes, and economical and physical environments. (Kline, 1985; Banta, 2009.) Technology dimension discusses about digital technologies, architecture design, technology experimentations, security and privacy element and vertical and horizontal scope.

3.2.1 Digital technologies and architecture design

Digital technologies like Internet-of-Things (IoT), artificial intelligence (AI), blockchain, big data and data analytics are rapidly escalating and influencing multiple industries and cities. Heterogeneous IoT technologies are widely used in diverse smart city domains to monitor city activities like traffic, parking places and air quality. The data generated and analyzed from IoT network enable more precise data of the city status providing fuel for more accurate decision making. (Sanchez et al., 2014.) AI and blockchain are technologies that are entering into smart city initiatives. AI mimics natural intelligence and cognitive abilities and utilizes technologies like face recognition, machine learning and natural language analysis. AI is utilized e.g. in analyzing health data to optimize public healthcare services and activities (Jiang et al., 2017). Blockchain in turn is a decentralized network, where data is transparent, immutable and transactions are verified. Blockchain technologies are experimented in the areas where control over the personal data and privacy are critical. (Pazaitis, Filippi & Kostakis, 2017; Zyskind & Nathan, 2015.) Digital identities are example of entities, which contain sensitive information like social security numbers, passwords and usernames. In smart city context blockchain based digital identities improves data transparency and individual´s rights for his/her personal data and reduce risks for data breaches. Smart cities globally are discovering use cases to test and experiment new technologies in diverse city domains.

Foundation for *enterprise architecture* concept originates from the need to combine complex business and information systems (IS) (Zachman, 1987). Enterprise architecture is used as a blueprint (Simon, Fischbach & Schoder, 2013) to describe the components, relationships and interactions of the business processes and information systems (Aier, Kurpjuweit, Saat & Winter, 2009; Ross, Weill & Robertson, 2006; Buckl et al., 2010) and to support orchestration and alignment of the business and IS in the organization (Aier et al., 2009; Müller & Reinert, 2014). Enterprise architecture is like a shared language that clarifies and enhances the communication between organization´s internal and external stakeholders (Aier et al., 2009; Buckl et al., 2010).

In the smart city context architecture design is an instrument to categorize complex city organization into simple, descriptive and well-defined parts (Müller & Reinert, 2014; Zachman International). Smart city architecture design **enhances interoperability and integration of the complex technical components to smart city infrastructure and supports communication and requirements management among stakeholders.** Smart city architecture design provides long-term views on city´s systems, processes, capabilities and digital technologies and **increases smart city implementation success, communication and value creation among the stakeholders.** (Aier et al., 2009; Buckl et al., 2010; Ross et al., 2006).

3.2.2 Technology experimentations in smart cities

Technology test and experimentation platforms (TEP) like testbeds, living labs and prototyping platforms provide facilities to test and experiment new ICT and digital solutions with real users before final release (Ballon, Pierson & Delaere; 2005). For an experimenting organization technology tests and experiments provide facilities to develop technology solutions iteratively and evaluate solution´s feasibility and usability in real-world with real users. Additionally TEPs provide more accurate test results and reduces costs of an evaluation cycle and improves technology innovation and user adoption. (Hämäläinen & Tyrväinen, 2016; Sanchez et al., 2014.)

Cities provide multidimensional environment for developing and testing diverse combination of digital technologies. In the smart city settings living labs have been popular environments to test new technologies and solutions. Elements like involvement of the city and citizens, heterogeneous digital technologies, openness, real-world experiments and scalability are fundamental to technology experimentations´ success in the smart cities. Opening smart city TEPs to external stakeholders´ use the city enhance heterogeneous digital technologies´ reliability and interoperability in the real-world city domains. Simultaneously access to the smart city assets like TEP facilities, information, application development interfaces, technologies and user communities are available to the smart city stakeholders. (Hämäläinen & Tyrväinen, 2016; Olivares, Royo & Ortiz, 2013; Sanchez et al., 2014; Schaffers et al., 2011; Yokoyama, 2015.)

Real-world smart city use cases benefit all the stakeholders in the smart city ecosystem. There for real-world smart city technology experimentations are emphasized when implementing new technologies in the cities.

3.2.3 Security and privacy

Term cyber security is defined as "the protection of cyberspace itself, the electronic information, the ICTs that support cyberspace, and the users of cyberspace in their personal, societal and national capacity, including any of their interests, either tangible or intangible, that are vulnerable to attacks originating in cyberspace" (Von Solms & Van Niekerk, 2013). Along with the protection of the ICT infrastructure and information, the cyber security concerns the protection of the individuals and the infrastructure of the society and the whole nation (Von Solms & Van Niekerk, 2013). *Privacy* refers to individual´s rights to his/her personal data. Oliveira & Zaïane (2004) determines the privacy as "users´ rights to conceal their personal information and have some degree of control over the user of any personal information disclosed to others".

Digital technologies are integral part of the smart city initiatives and new digital technologies are widely applied in multiple city domains. However, the more digital technologies are applied in the smart city infrastructure, the greater the potential for vulnerabilities and data breaches. Actualized cyber-attacks may in the worst cases paralyze city´s power grids and water supplies or disable the critical telecommunication connections. Unprotected digital smart city solutions may also lead to misuse of private data or data breaches. Smart cities are forced to consider carefully cyber security and issues like ownership and access to the city´s digital services, platforms and data (Carvalho, 2015; Merlino et al., 2015; Mital, Pani, Damodaran & Ramesh; 2015; Lengyel et al., 2015) to guarantee the safety and security of the smart city.

3.2.4 Vertical and horizontal scope

Many smart-city initiatives have been created around a certain *vertical industry* or an industry emphasizing the goals of a single vertical theme, such as energy efficiency, traffic or health care. The vertical approach in smart city initiatives influences the choice of employed technologies and standards that will best support the needs and requirements of a chosen industry. (Hämäläinen & Tyrväinen, 2016.) Focusing only on particular vertical restricted data silos may emerge. This may prevent more extensive technology and data adoption and exploitation in smart cities. *Horizontality* in smart city context describes a wider set of IoT devices and other wireless sensors, applications and services combining data from multiple city domains and industries to service developers. The horizontal approach contributes broader set of data and expands the possibilities to create new services based on integrated vertical data.

3.3 Governance

Governance is defined as "the sum of the many ways individuals and institutions, public and private, manage their common affairs. It is the continuing process through which conflicting or diverse interests may be accommodated and co-operative action may be taken". (Commission on Global Governance, 1995.) Governance dimension consists of ecosystem orchestration, funding and risk management.

3.3.1 Smart city ecosystems and orchestration

Ecosystem *management and orchestration* enhances the evolution and sustainability of the ecosystem and increases the value for ecosystem actors (Korpela, Ritala, Vilko & Hallikas, 2013; Manikas, Wnuk & Shollo, 2015). The orchestrator´s role is to form common vision for the ecosystem and facilitate ecosystem emergence (Korpela et al., 2013) and sustainability. The orchestrator manages and leads the actors to desired common direction (Korpela et al., 2013) and ensures ecosystem decision making process (Manikas, 2016). Furthermore, the orchestrator co-ordinates the critical resources required for the ecosystem evolvement and enhance the creation of trust and value among the ecosystem actors (Autio & Thomas, 2014).

Smart city is determined as an organic, collective and collaborative ecosystem (Baccarne et al., 2014; Komninos, 2011), which co-create sustainable innovations and engender innovative entrepreneurial, social and innovation ecosystems to improve the economy, human capital and quality of life in a city (Baccarne et al., 2014; Komninos, 2011; Roth, Kaivo-Oja & Hirschmann, 2014; Schaffers, Ratti & Komninos, 2012). In the smart cities multiple ecosystems and numerous stakeholder relationships exist. Smart city ecosystem orchestration and clear role management improve communication and value creation among stakeholders and thus enhance the success of smart city initiatives.

3.3.2 Funding and risk management

Funding and financial resources are critical for the smart city initiatives. Both public and private investment organizations fund the smart city projects of various scales. Funding programs are available for infrastructure development, capacity building, and research and innovation activities. Little is known about the smart cities´ return-on-investments (ROI) or smart city investments´ impacts on socio-economic issues like employment and new business model innovations. Standards and metrics to evaluate the success of the smart city strategy and investments are thus emphasized.

Smart cities generate opportunities, but simultaneously also risks. In complex and decentralized organizations like cities demand for coordinated risk management policy exist (Oulasvirta & Anttiroiko, 2017). Risk management should have a strategic focus (Duckert, 2010) and be aligned with organization strategy. In the smart cities risks concern not only technology and network infrastructures, but also smart city organization and government. (Nam & Pardo, 2011.) There for smart city should evaluate internal and external risks and reflect them to strategy and consider impacts to organization, financing, legislative issues and stakeholder relations. (COSO, 2016; Oulasvirta & Anttiroiko, 2017).

3.4 Stakeholder

The stakeholder theory observes stakeholder relations and describes how organization operates through stakeholder relations and how stakeholder interests and value expectations are considered and met. The stakeholder theory emphasizes to create value for its stakeholders in an effective way as it enhances the stakeholders´ commitment and responsibility. (Freeman et al., 2010; Jensen, 2001.) Freeman (1984) describes stakeholder "as any group or individual who can affect or is affected by the achievement of an organization´s purpose". The components of the quadruple helix and stakeholder value are covered in the stakeholder dimension.

3.4.1 Quadruple helix and stakeholder value

Triple-helix, university-industry-government, partnership has been the dominant collaboration model in the smart cities. Aim of the trilateral triple helix networks is to benefit the knowledge created in each organization and engender new innovations and innovation ecosystems (Etzkowitz, 2003). Industries´ interest in the smart cities is to experiment and employ new technologies in the real-life environment and discover new value creation and business opportunities. For public organizations like city and academia the smart city concept provides environment for developing and testing technologies, but also potential for new knowledge creation, service design and possibility to stimulate local economy and interdisciplinary research activities. In the smart city context it is emphasized to extend triple helix model to include people and civil society as the forth helix and form *quadruple helix* partnerships. In the smart cities the citizens are seen as co-creators and social innovators (Carayannis & Campbell, 2011; Komninos, Pallot & Schaffers; 2013; Petersen, Concilio & Oliveira, 2015) who may own such a social capital and knowledge from their livelihood (Lea, Blackstock, Giang & Vogt; 2015) that is valuable for improving the community´s living conditions and environment. By integrating local community and citizens to urban development the city strengthens bottom-up smart city development and improves technology acceptance among the citizens (Ballon et al., 2005; Lea et al., 2015; Schaffers et al., 2011).

Value proposition is associated with the stakeholder relations and business model design. Value is linked to benefits (Rescher, 1969) each stakeholder is seeking from the value networks and stakeholder relations. Received value may occur in the form of goods, services, financial profits, cost savings, knowledge or in improved quality (Allee, 2008; Sainio, Saarenketo, Nummela & Eriksson, 2011), but received value may further emerge in-directly in the value networks (Allee, 2008; Ojala & Helander, 2014; Ojala & Tyrväinen, 2011). Access to a new market or resources that otherwise are unreachable are examples of the in-direct value in the value networks (Ojala & Helander, 2014).

Smart cities are growing markets attracting multiple organizations and stakeholders. Despite of tremendous possibilities the smart city phenomenon creates, leading smart city from pilot stage to more mature level takes time and results may be realized with extended period of time. Smart city strategy, quadruple helix collaboration and ecosystem orchestration and management improve communication and trust among stakeholders and enhance to evaluate value propositions and business potential in the smart city projects.

4 Conclusion

This paper elaborated and presented smart city conceptual model (SCCM), which aim is to strengthen smart city design and ecosystem governance. The rationale for elaborating SCCM emerge from the perception that cities´ have inadequate capabilities to govern complex smart city ecosystems and manage rapidly changing digital technologies in city setting. Due to these reasons many nascent smart city projects perish after the project funding is used. Aim of the SCCM is to assist smart city practitioners to form long-term smart city vision and strategy, facilitate the governance of the heterogeneous stakeholder relations and digital technologies and to assist evaluate risks and funding needs. SCCM aims further to enhance the smart city stakeholders to outline and evaluate smart city projects and assist to unlock the barriers for business model innovation and value creation in the smart city ecosystems. SCCM consists of four main dimensions, strategy, technology, governance and stakeholder and their sub-components. SCCM dimensions and sub-components form meaningful interrelations and provide comprehensive approach to design smart city initiatives and ecosystems.

It is highlighted to integrate social, economic and ecological perspectives to enhance social sustainability in society (Eizenberg & Jabareen, 2017). One of the emphazised goals for smart city initiatives is to improve the quality of citizens´ lives. Including social and political aspects in the SCCM would extend perspectives for more resilient and sustainable smart city design. Further, indicators to measure and analyze smart city initiatives are emphasized to support the management and success of the smart city projects.

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VI

A FRAMEWORK FOR SMART CITY DESIGN: DIGITAL TRANSFORMATION IN HELSINKI SMART CITY

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A Framework for a Smart City Design:

Digital Transformation in the Helsinki Smart City

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Abstract. Recently, there has been substantial interest in the concept of a smart city, as it has been a viable solution to the dilemmas created by the urbanization of cities. Digital technologies—such as Internet-of-Things, artificial intelligence, big data, and geospatial technologies—are closely associated with the concept of a smart city. By means of modern digital technologies, cities aim to optimize their performance and services. Further, cities actively endorse modern digital technologies to foster digitalization and the emergence of data-based innovations and a knowledge economy. In this paper, a framework for a smart city design is presented. The framework considers a smart city from the perspective of four dimensions—strategy, technology, governance, and stakeholders. The framework is complemented with sub-dimensions, and the purpose of this framework is to strengthen the governance and sustainability of smart city initiatives. Further, the proposed framework is applied to the Helsinki smart city, the capital of Finland. The objective is to analyse the Helsinki smart city through dimensions presented in the framework and learn how the city of Helsinki governs and implements its smart city initiatives.

Keywords: Smart city, digital technology, strategy, stakeholders, open data, technology experimentations

1 Introduction

Cities are lucrative areas for economic growth, as 80% of the current global GDP is produced in cities (Dobbs et al., 2011). This trend is likely to continue as urban areas already provide homes to over half of the world's population, and the number is estimated to increase by 66% by 2050. In addition to economic wealth and prosperity, urban areas offer more versatile job opportunities and alternatives for advanced education. Further, urban areas also provide conducive environments for new innovations and businesses. The reverse side of urbanization and improved prosperity is an increased volume of consumption, waste, and pollution. According to UNEP (2013), over 75% of the world's energy and material flows are consumed in cities. Along with rapid urbanization, cities are likely to consume even more natural and non-renewable materials, as urbanization sets demands for the construction of new residential areas and improving city infrastructures and services. As an example, cities must renew and build transportation, energy, and sewer network infrastructures and systems, as well as build new premises for hospitals, schools, and day care centres to guarantee fulfilment of their mandatory functions. It is also worth noting that increased population itself consumes more natural and non-renewable resources to satisfy basic necessities and accomplish the desires and purposes of individual human life. It is emphasized that local city governments place strategic focus on sustainable and resource-efficient urban development. It is highlighted that cities must design denser urban areas and invest in modern low-carbon infrastructure solutions. Further, existing studies also argue that the shift from traditional carbon-intensive infrastructure to low-carbon infrastructure alternatives require a 5% increase in infrastructure investments in cities. Thus, cities must have improved abilities to effectively manage resource flows and enhance resource efficiency by focusing on smart land use and investing in modern urban digital infrastructures (IRP, 2018).

The concept of a smart city has been a popular phenomenon, and multiple cities worldwide have adopted smart city practices in urban development. Further, information and communication technologies (ICTs) and novel digital technologies such as Internet-of-Things (IoT), artificial intelligence (AI), and data analytics play an integral role in the implementation of the concept of a smart city. The European Union (EU) defines a smart city as ‘a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business’. Alternatively, a smart city is defined as ‘a city, in which ICT is merged with traditional infrastructures, coordinated and integrated using new digital technologies’ (Batty et al., 2012). Caragliu, Del Bo, and Nijkamp (2011) define a city as smart ‘when investments in human and social capital and traditional (transport) and modern ICT communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory government’. The ITU-T Focus group (2015) and ISO (2015) summarize that a smart city is an innovative city that uses ICTs to improve the quality of life of residents, thereby enhancing the efficiency of urban operations and services and improving sustainable socio-economic and environmental outcomes by responding to the challenges of urbanization.

The objectives of smart city initiatives and the use of digital technologies enable the streamlining of city processes and not only make city services more accessible for residents but also enhance the resource management and efficiency within the city (Aguilera, Peña, Belmonte, & López-de-Ipiña, 2017). Further, smart city practices aim to reduce the costs of city services and improve the return on investments (Vilajosana et al., 2013), accelerate economic growth, competitiveness and transparency, as well as stakeholder participatory in the cities (Abella, Ortiz-De-Urbina-Criado, & De-Pablos-Heredero, 2017; Perez, Poncela, Moreno-Roldan, & Memon, 2015; Yovanof & Hazapis, 2009). New digital technologies applied in 'soft' city domains such as education, health and social care, and city administration (Petersen, Grazia & Oliveira, 2015) aim to foster knowledge creation and enable the emergence of new knowledge-based businesses and digital innovations (Baccarne, Mechant, & Schuurman, 2014; Li, Nucciarelli, Roden, & Graham, 2016). Smart city initiatives also aim to enhance social inclusion and prevent inequality among the citizens.

Deploying novel digital technologies across an organization's activities is a long-term process that impacts an organization's structures, capabilities, and existing IT infrastructures and systems (Davenport & Westerman, 2018). Thus, the design, management, and governance of digitalized and interconnected smart city operations and ecosystems are not a trivial task. Research has identified that numerous smart city initiatives tend to fade away when project funding is used (Diaconita, Bologa, & Bologa, 2018; Hämäläinen & Tyrväinen, 2016). The objective of this paper is to shed light on the elements that are relevant for robust digital transformation, ecosystem creation, and orchestration in a smart city. In order to achieve this objective, this paper presents a smart city design framework, which is derived from prior literature in the area of smart cities and smart city ecosystems and is adapted from the smart city conceptual model (SCCM) presented by Hämäläinen and Tyrväinen (2018). The smart city design framework is founded on four dimensions—strategy, technology, governance, and stakeholders—and is complemented by sub-dimensions. The smart city framework aims to improve the process of digital transformation within the city and assist smart city stakeholders in the private and public sectors to clarify complex smart city governance, ownership, orchestration, and decision making procedures. The framework also highlights the importance of technological compatibility, appropriate skills, and resource allocation in smart cities in order to ensure robust and well-grounded smart city implementation. In this paper, the smart city design framework (Hämäläinen & Tyrväinen, 2018) is applied to analyze the smart city of Helsinki in Finland through the abovementioned four dimensions and learn about smart city practices and implementation in Helsinki.

The remainder of this paper is structured in the following manner: Section II presents the principles of the digital transformation within organizations. Section III delves into the conceptual foundation of the smart city design framework, and Section IV covers the research methodology. Section V discusses the specific case of the Helsinki smart city and evaluates smart city initiatives in Helsinki through the smart city framework. Section VI summarizes the findings, and Section VII concludes the paper.

2 Digital transformation

Digital transformation is perceived as a paradigm shift (Berman & Marshall, 2014) resulting in 'changes that the digital technology causes or influences in all aspects of human life' (Stolterman & Fors, 2004). Digital transformation is also understood as 'technology-induced change' (Legner et al., 2017) that may have radical or disruptive features (Morakanyane, Grace, & O'Reilly, 2017) that revolutionize prevailing practices by disrupting the trajectories of established businesses, and change the structures of industries and value networks (Au et al., 2018; Gimpel et al., 2018; Weil & Woerner, 2015). Digital technology evolution is all the more embedded in social areas (Legner et al., 2017; Tilson, Lyytinen, & Sørensen, 2010) and is driven by individual persons (Legner et al., 2017), which makes digital transformation with digital technologies a complex and uncertain process (Hess et al., 2016; Sahu, Deng, & Mollah, 2018). Since digital technologies have ubiquitous impacts on organizations and industry functions, it is emphasized that *a strategic focus* must be placed on how to conduct long-term digital transformation (Chanias & Hess, 2016; Henriette, Feki, & Boughzala, 2016; Hess et al., 2016; Legner et al., 2017; Matt, Hess, & Benlian, 2015; Ross, Beath, & Sebastian, 2017; Sebastian et al., 2017).

IT strategies are traditionally developed to manage IT infrastructures, tools, applications, and IT services (Gerster, 2017; Hess et al., 2016) that support an organization's functions and processes (Teubner, 2013). Differentiated from IT strategy, it is suggested that a specific *digital strategy* must be created that assists organizations to reflect on business perspectives and consider the resources, capabilities (technical and human), and financial aspects that are required in digital transformation (Bharadwaj et al., 2013; Matt, Hess, & Benlian, 2015; Mithas, Tafti, & Mitchell, 2013; Ross et al., 2016). Digital strategy evaluates the influence of digital technologies on the structures and process of organizations and observes possibilities for new business models and value creation among existing and new stakeholders (Bharadwaj et al., 2013; Morakanyane, Grace & O'Reilly, 2017; Hess et al., 2016; Legner et al., 2017; Matt, Hess & Benlian, 2015; Prince, 2017; Rauch, Wenzel & Wagner, 2016; Ross et al., 2016; Sebastian et al., 2017; Singh & Hess, 2017). Thus, digital strategy is a holistic view for top management to evaluate, manage, and govern the digital transformation journey (Chanias & Hess, 2016).

3 Framework for a smart city design

Along with heterogeneous stakeholder groups from private and public sectors, the city must perform its statutory tasks and activities around the clock without interruptions. A holistic overview of how a city transforms itself to a smart city and how digital technologies are applied in diverse city domains is needed. In the following account, a framework adopted from Hämäläinen & Tyrväinen (2018) is presented (Fig 1). The framework contains four central dimensions—*strategy, technology, governance, stakeholder*—and other sub-dimensions. The strategy dimension considers aspects of a smart city's vision, strategy, and capabilities. The technology dimension discusses the digital technologies applied in smart cities, as well as the data, technology experimentation, security, and privacy issues. Vertical and horizontal scopes conclude the technology dimension. The governance dimension describes the orchestration of the smart city stakeholders and ecosystems and considers funding and metrics to evaluate smart city performance. Finally, the stakeholder dimension elaborates on stakeholders and stakeholder value in smart city ecosystems.

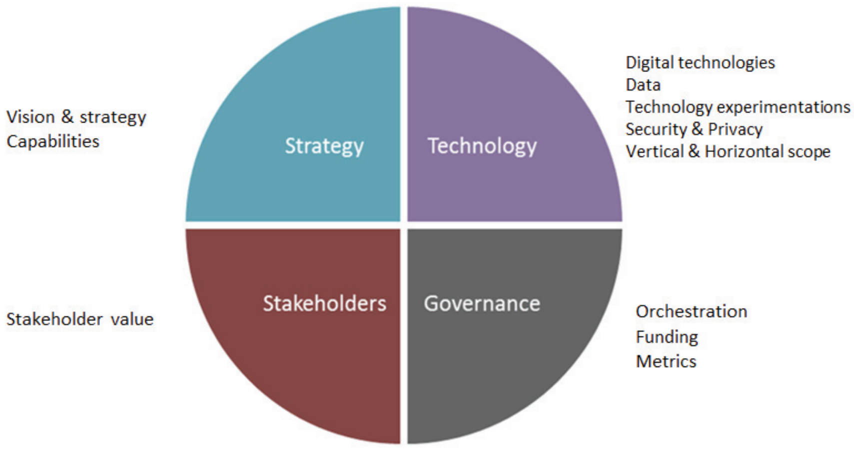

Figure 1 Framework for Smart City Design (adopted from Hämäläinen & Tyrväinen, 2018).

3.1 Strategy

Cities operate under a constantly evolving environment, which puts pressure on the city's governance and management. The strategy for a digital or smart city identifies the changes that occur in both national and global political, legislative, and economic landscapes, and also considers the impact of social and technological changes. As contemporary urban development relies on modern digital technologies (Lu, Tian, Liu, & Zhang, 2015), smart city vision and strategy envisions the future state of the city by means of digital technologies. Smart city strategy sets strategic guidelines on how a city must develop and integrates digital technologies to diverse urban infrastructures in order to enhance sustainable city design and performance (Hämäläinen & Tyrväinen, 2018). From a broader perspective, the smart city strategy also considers the impacts of climate change and evaluates the manner in which digital technologies can be employed to enhance material usage and reduce emissions within the city.

(a) Capabilities

Smart city strategy considers the goals, resources, and capabilities required for the successful implementation of creating a smart city (Scuotto, Ferraris, & Bresciani, 2016; Tillie & van der Heijden, 2016). The resources and capabilities of a smart city refer to both technical (Sarma & Sunny, 2017; Schleicher, Vögler, Inzinger & Dustdar, 2017) and human capabilities like knowledge to manage smart city design and orchestrate innovative data-based smart city ecosystems that create value for its stakeholders (Abella et al., 2017; Baccarne et al., 2014; Komninos, 2011; Komninos, Pallot, & Schaffers, 2013; Scuotto et al., 2016; Tillie & van der Heijden, 2016).

3.2 Technology

(b) Digital technologies

Emerging digital technologies such as IoT, AI, cloud computing, big data, and data analytics are rapidly expanding in urban areas, thereby creating multifaceted digital and data ecosystems (Aguilera et al., 2017). Schleicher et al. (2017) call smart cities 'data behemoths'. Rapidly increasing online city services, ICT connected city infrastructures and fast adoption of internet-connected technologies like sensors, video surveillance and lightning systems are applied in diverse city infrastructures. Applying modern smart city technologies to diverse smart city infrastructures helps to accumulate exponentially historical and real-time data from heterogeneous city domains and activities (Rathore et. al., 2018; Schleicher et al., 2017). Further, positive experiences from cloud computing have encouraged cities to invest on 'pay-as-you-go' cloud computing solutions. The collection of cloud computing components such as infrastructure-, platform-, and software-as-a-service provide new dimensions for more affordable, scalable, and easily available ICT service provisions for cities. One of the main characteristics for cloud-based service provisions is that the user is charged only when using the platform or service (Hernandez, Larios, Avalos, & Silva-Lepe, 2016; Petrolo, Loscri, & Mitton, 2017). Moreover, scalability and cost efficiency are the undoubted advantages cloud computing provides for cities.

(c) Data

In recent years, cities have released city data sets such as geographical and location information for public use. Open city data is not only used by the city's government, but also other stakeholders such as citizens, application developers, and third party organizations that exploit open city data for personal or public purposes (Aguilera et al., 2017). However, legislation like the *General Data Protection Regulation (GDPR)* in Europe prohibits and prevents cities from publishing data that is sensitive and critical from privacy and safety perspectives. High volumes and velocity of the city data add demands related to data management. Capabilities to process and analyse the city data are needed so that the data is useful for actors in smart city ecosystems (Khan et al., 2017; Rathore et al., 2018). Along with human capabilities, data engineers and scientists, technologies such as data analytics and AI speed up data processing and enhance data integrity and accuracy (Srivastava, Bisht, & Narayan, 2017). In the smart city settings, AI has been used to analyse data from video surveillance cameras and drones, which keep an eye on city environments and surroundings (Srivastava, Bisht, & Narayan, 2017).

(d) Technology experimentations in smart cities

The International Resource Panel (IRP, 2018) emphasizes that cities must develop and apply urban experimentation policies. Cities certainly have environments that offer multifaceted domains for diverse smart city technology experimentations. Technology tests and experimentation platforms (TEP) such as testbeds, innovation and living labs, and prototyping platforms have been dominant facilities for smart city technology and service development and experimentation (Ballon, Pierson, & Delaere, 2005; Schaffers et al., 2011). Heterogeneous urban domains offer numerous advantages for technology experimentations. For smart city practitioners, real world city-level experiments not only enable iterative technology and service development but also provide access to collection of data from real users. During smart city experiments, developers receive valuable information on product usability and developers may simultaneously validate feasibility and user acceptance of smart city technologies and services (Hämäläinen & Tyrväinen, 2016). Ten relevant dimensions for establishing robust smart city technology experimentation platforms have been identified. These dimensions are openness, real-world experiments, user/public involvement, vertical and horizontal scope, scalability, sustainable value creation, continuity, IoT/data heterogeneity, and system architecture design. These dimensions prove to strengthen the emergence of the smart city ecosystem and the duration of smart city TEPs (Hämäläinen & Tyrväinen, 2016).

(e) Security and privacy

Information systems are applied to almost all fields in our societies and emerging digital technologies are an integral part of smart city initiatives. A disadvantage of the ubiquitous cyber-physical systems is that there is an increase in the potential for security and privacy vulnerabilities. The term cyber security is defined as ‘the protection of cyberspace itself, electronic information, ICTs that support cyberspace, and the users of cyberspace in their personal, societal and national capacity, including any of their interests, either tangible or intangible, that are vulnerable to attacks originating in cyberspace' (Von Solms & Van Niekerk, 2013). However, the more the frequency of application of digital technologies in smart city infrastructure, the greater the potential for vulnerabilities and data breaches. Thus, security and privacy themes must be placed at the top level in smart city development.

(f) Vertical and Horizontal scope

Many smart city initiatives focus on improving certain city verticals such as transportation or energy. Emphasizing certain verticals in smart cities may influence the choice of employed technologies and standards that best support the needs and requirements of a particular vertical industry (Hämäläinen & Tyrväinen, 2016). According to Schleicher et al. (2017), city data is isolated and restricted to exist in silos. If smart city development focuses only on a particular vertical, it may prevent more extensive technology and data adoption and exploitation in smart cities (Hämäläinen & Tyrväinen, 2016), thereby resulting in the emergence of data silos. Schleicher et al. (2017) emphasize the prevention of the emergence of data silos in smart cities by enabling ubiquitous access to heterogeneous and interconnected city data. *Horizontality* in the context of a smart city context implies how a wider set of data from multifaceted city domains and activities are collected, combined, and utilized. The horizontal approach contributes to a broader set of city data and expands the possibilities of creating new services based on integrated data in smart cities (Hämäläinen & Tyrväinen, 2016).

3.3 Governance

Growing markets in a smart city attract various organizations and stakeholders from private and public sectors. Smart city governance could be defined as 'the sum of the many ways individuals and institutions, public and private, manage their common affairs' (Commission on Global Governance, 1995). Smart city governance consists of multifaceted organizations, processes, and stakeholder relations; it also deals with legislations and policies (Ruhlandt, 2018). Moreover, smart city governance is a body that envisions the future state of the smart city, provides strategic leadership and resources, ensures dialog and decision making in smart city ecosystems, and assesses the performance of a smart city and the quality of its citizens' lives. (Baccarne et al. 2014; Recupero et al., 2016; Tillie & van der Heijden, 2016; Veeckman & van deer Graaf, 2015.) Further, smart city governance considers long-term financial needs (Vilajosana et al., 2013) to ensure robust and long horizon smart city implementation (Komninos, Pallot & Schaffers; 2013) as well as to reduce costs and improve resource efficiency in a city (Díaz-Díaz, Muñoz, & Pérez-González, 2017).

(g) Funding and Metrics

Major (upfront) investments are needed to successfully deliver smart city initiatives (Vilajosana et al., 2013; Díaz-Díaz, Muñoz, & Pérez-González, 2017). In European settings, digital urban development is one of the priority agendas and smart city funding is allocated through the EU to improve infrastructure—such as transport and water networks and waste management—as well as to improve the energy efficiency of buildings (European Commission). Globally, international organizations (e.g. United Nations Industrial Development Organization, UNIDO) provide funding for sustainable environmental development, such as green industries, sanitation, and waste management (Adapa, 2018).

Little is known about actual metrics to evaluate smart city performance. However, organizations such as the International Organization for Standardization (ISO), British Standards Institutions (BSI), and International Telecommunication Union (ITU) have developed guidelines and key performance indicators (KPIs) to plan and measure smart city performance. The aim of the standards and harmonized metrics is to clarify the complex city processes, urban planning, and needs of multifaceted stakeholder groups. Smart city standards assist cities to compare procurement proposals and reduce barriers to system integration in complex city organization and infrastructures. Further, these standards provide practical step-by-step guides and function as valuable tools for smart city practitioners and stakeholders to transit a city towards becoming a digitized smart city (BSI, ISO, ITU.)

3.4 Stakeholders

Smart cities are described as collaborative innovation ecosystems (Komninos, Pallot, & Schaffers; 2013; Komninos & Tsarchopoulos, 2013) that generate new opportunities for start-ups, multinationals, academia, and cities themselves. Public organizations may collaborate with private companies to develop novel city services that optimize city activities, reduce costs, and save scarce city resources. For enterprises, multifaceted smart city domains provide an environment to experiment and employ new technologies in real-world settings and discover new business and value-creation opportunities in the context of the smart city context (Hämäläinen & Tyrväinen, 2018; Sarma & Sunny, 2017). Thus far, public-industry partnership has dominated smart city initiatives; however, lately, integrating citizens and civil society in the development of a smart city has been emphasized. *Quadruple helix* (public-private-people) collaboration pursued to enhance social inclusion as citizens is seen to lead to the emergence of co-creators and social innovators (Abella et al., 2017; Komninos, Pallot, & Schaffers; 2013; Mayangsari & Novani, 2015; Petersen et al., 2015) in cities. Including citizens in smart city ecosystems is justified by the perception that citizens may own specific knowledge and earn social capital as part of their livelihood (Lea et al., 2015; Mayangsari & Novani, 2015), which may benefit a community's living conditions. Further, quadruple helix collaborations further enhance technology diffusion and reduce technology resistance in cities.

(h) Stakeholder value

Even though the concept of a smart city has been a popular phenomenon, numerous smart city projects tend to decline once project funding is obtained (Diaconita, Bologa, & Bologa, 2018; Hämäläinen & Tyrväinen, 2016). It must be noted that smart city development is a long-term process, which requires capabilities and resources to generate *added value* for the stakeholders involved in smart city ecosystems (Hämäläinen & Tyrväinen, 2016; Gagliardi et al., 2017). Competences to orchestrate and manage complex technical, human, and business ecosystems are needed to transform a conventional city from the stage of being a smart city pilot to one of mature smart city development. A clear understanding of the actors' roles and responsibilities in the smart city ecosystem has positive influences on ecosystem health and the experienced value of stakeholders (Autio & Thomas, 2014; Korpela et al., 2013; Manikas, 2016). This is also true for smart city ecosystems. The role of an ecosystem orchestrator is to facilitate the ecosystem, its resources, actors, and objectives. A smart city orchestrator ensures a harmonious decision-making process and interaction (Manikas, 2016) so that the objectives of a smart city are achieved and value-added smart city applications and solutions are created in such a city (Abella et al., 2017; Adapa, 2018; Bifulco, Tregua, & Amitrano, 2017; Hämäläinen & Tyrväinen, 2016).

4 Methodology

The foundation for the smart city framework presented in this paper originates from the prior work presented by Hämäläinen and Tyrväinen (2018). The framework was applied to the Helsinki smart city. Data for empirical research was collected by interviewing persons and stakeholders involved in the development of the Helsinki smart city (Table 1). The semi-structured interview protocol was employed in interviews, which provided flexibility and the possibility for a deeper understanding of the development of Helsinki. Interviewee 1 represented the Helsinki environmental protection unit and was in charge of Helsinki city's energy and climate statistical data. Interviewee 2, Deputy CEO, represented the Smart Kalasatama project at Forum Virium Ltd. Interviewees 3 and 4 represented Helsinki Region Infoshare, an organization that releases Helsinki city's open data. Interviewee 5 was a community manager at Smart Kalasatama project, who was responsible of stakeholder relations. Interviewees 6 and 7 represented residents of the Smart Kalasatama district. All interviews were audio recorded and transcribed after the interviews. Additional data was collected by attending workshops related to smart cities and seminars in Finland, as well as reviewing official Helsinki city reports, documents, and websites. Data was collected during the period May 2017–February 2019.

Data collection			
Interview	**Role**	**Unit**	**Date**
Interviewee #1	Environmental planning	Helsinki city	23.4.2018
Interviewee #2	Deputy CEO	Forum Virium	20.4.2018
Interviewee #3 and 4	Project manager and designer	Open Data Helsinki city	26.3.2018
Interviewee #5	Community manager	Smart Kalasatama	17.5.2017
Interviewee #6	Resident 1	Smart Kalasatama	17.5.2017
Interviewee #7	Resident 2	Smart Kalasatama	17.5.2017
Workshop	**Place**	**Organizer**	**Date**
Open Data Day 2018	Helsinki	Open Data Finland	1.3.2018
City Business - Cities as platforms	Oulu	City of Oulu	6.6.2018
MyData 2018	Helsinki	MyData	29.-31.8.2018
Public material	**Publisher**		
Helsinki city strategy	Helsinki city	https://www.hel.fi	2017 -2021
ICT Policy	Helsinki city	https://www.hel.fi	2015 - 2017
Web page	Helsinki Region Infoshare	https://hri.fi/fi/	
Web page	Forum Virium	https://forumvirium.fi/	
Agile pilot cookbook	Smart Kalasatama		
Web page	Smart Kalasatama	https://fiksukalasatama.fi/en/	
Web page	Stadin ilmasto	https://www.stadinilmasto.fi/	
Web page	6-aika smart city project	https://citybusiness.fi/materiaalit-ja-julkaisut/	

Table 1 Empirical data collection

5 The Helsinki smart city in Finland

The capital of Finland, Helsinki, has over 600,000 inhabitants. The total area of the city is 719 km^2, of which almost 70% is sea (502) and 30% is land (217). The population density in Helsinki is almost 3000 inhabitants per km^2. Smart Kalasatama is a strategic smart city development district in Helsinki. It is a new residential area, which is expected to provide homes for approximately 25,000 inhabitants by 2040. As a strategic smart city development area, Smart Kalasatama provides facilities for agile smart city pilots with a multi-stakeholder collaboration. The development of Smart Kalasatama is facilitated by Forum Virium Helsinki (FVH) Ltd., an innovation business unit owned by Helsinki city. Further, Helsinki is part of the 'The Six City Strategy' project, which delivers smart city pilot projects in fields such as smart mobility, open data, health, and circular economy in the six largest cities in Finland. 'The Six City Strategy' project was selected as Finland's flagship project for the EU Cohesion Policy's 30th anniversary year. In addition, Helsinki has achieved podium places in several smart city competitions. Helsinki was elected as the number one city at the European Capital of Smart Tourism 2019 competition and the best city for providing digital Mobility-as-a-Service (MaaS) services. (Forum Virium Helsinki, 2018; Helsinki city, 2018; 6Aika project, 2018). In the following account, the smart city framework presented in Figure 1 is applied to the Helsinki smart city.

5.1 Strategy of the Helsinki Smart City

The updated city strategy for the period 2017–2021 proclaims Helsinki to be 'The Most Functional City in the World'. Helsinki commits to take concreate actions to produce high quality city services with strong citizen inclusion. The city aims to be a resident- and user-oriented city, where people may live in a safe and trustworthy environment. Trust, safety, and social coherence are elements that create a competitive edge for Helsinki (Helsinki City Strategy, 2018). However, as expressed by interviewee 2, Helsinki city does not have a specific *smart city or digital strategy*, but the goal of Helsinki is to be the best city in the world to benefit digitalization (Helsinki City Strategy, 2018). Interviewee 2 indicated that in the future, the concept of smart city will be 'a new normal'. The current Helsinki city strategy includes numerous smart city elements and development areas. As an example, Helsinki aims to develop digital solutions that are easy to follow and engage in regardless of who has created the digital services (Helsinki City Strategy, 2018).

(i) Capabilities

Based on the city strategy, Helsinki aims to improve its personnel's capabilities in emerging digital technologies, such as AI and robotics, by providing specific training and education for digital technologies. A specific *Chief Digital Officer* position was established to ensure that digital transformation is actualized in diverse city domains. Helsinki aims to digitalize city services so that they are available around the clock. A new data-based concept of 'smart education' is set to be developed around education services. The smart education concept utilizes data analytics to provide more individual learning design and experiences. The objective of the smart education concept is to further enhance the learning processes and offer education services, regardless of time and space, for students of all ages in Helsinki (Helsinki City Strategy, 2018).

5.2 Technology: Digital technologies

The ICT and data administration department of Helsinki city operates under its Economic Development and Planning Division. The ICT department is responsible for the steering and development of compatible digital technologies in diverse city domains. The department is also responsible for city-wide enterprise architecture and ICT infrastructure design and implementation. Helsinki targets to provide low-threshold technology innovation and experimentation services and enable digitalized data availability for external stakeholders. The city actively experiments and benefits from data analytics, AI, sensor and IoT technologies in multiple city domains (Helsinki ICT Policy).

(j) Data

The data obtained from Interviewee 1 plays a central role in smart city development. The key issues in this regard are the content of the data, how information is distributed to relevant target groups, and how information is utilized in decision-making processes. As an example, the environmental protection unit of Helsinki initiated multiple projects to release existing data series for public use. Based on statistical environmental data series, a 3D model, Helsinki Energy and Climate Atlas, was created to bring transparency to the energy consumption of city buildings. A visual tool helps a city to assess and analyse energy consumption in diverse city buildings and, thus, react to energy leakages and enhance energy efficiency, particularly in old buildings.

The concept of open data was introduced to the Helsinki administration in the year 2009. Subsequently, a specific organization, Helsinki Region Infoshare, was established to organize and manage open data initiatives in Helsinki and its surrounding cities. In European settings, the Helsinki regional public libraries were the first ones to publish raw data from over 680,000 works for public use in 2010. The Helsinki city strategy states that Helsinki will be a leading city in terms of releasing and utilising public open data. Currently, Helsinki and its regional cities have published almost 650 data sets and opened almost 120 interfaces for external stakeholders. Helsinki Regional Transportation, Service Map Application Programming Interfaces (APIs) and geographical data—such as maps and postcodes—have been the most popular interfaces and data sets that are applied by open data users. Although Helsinki city has increasingly begun to release public data sets, not all of its city organizations publish their data for public use. Interviewees 3 and 4 mentioned that city organizations such as social and health services have legitimate grounds that prevent extensive data sharing with the public. For example, a recently published General Data Protection Regulation (GDPR) in Europe tightens the protection of personal data and limits city organizations to collect, share, and use data that contains personal information such as name, address, and social security number. Other factors such as prejudice, deficiency in capabilities, and lack of time and money were mentioned as reasons that prevent other city organizations to implement open data initiatives. However, Interviewees 3 and 4 also mentioned that strategic focus on open data, successful open data projects, and practices and improved ICT solutions have lowered the prejudices and resistance towards open data. Further, the interviewees indicated that the open data concept must be promoted more actively in diverse city domains and that, currently, sufficient resources are not reserved for these purposes.

(k) Technology experimentations

Helsinki city has established an independent company, Forum Virium Helsinki (FVH) Ltd., for developing new digital innovations and city services in collaboration with private companies, other public organizations, and citizens. City-level strategy and FVH emphasize that Helsinki will be an attractive and leading city for agile smart city technology experimentations, thereby stimulating new business activities in the city. A user-driven approach and agile smart city development are FVH's key drivers. Currently, FVH runs digital technology development and experimentations at Smart Kalasatama as well as at other city districts. During the years 2015–2018, FVH has organized 21 agile smart city technology and service experimentations in Kalasatama. Each pilot lasts six months and pilots are run twice a year. FVH procures pilots with a maximum of 8000 euros. The smart city pilot themes have included, for example, smart-mobility services, effective waste management, food waste reduction, and co-creation of local well-being services. FVH's slogan 'fail fast, learn fast' indicates that stakeholders may test smart city solutions in a areal-world city environment with actual users and simultaneously learn if the smart city solution is viable on a larger scale. Smart Kalasatama agile pilots and technology experimentations have raised interest not only in Helsinki but also in other cities in Finland and Europe. Due to high interest displayed towards agile urban development through technology pilots, a cookbook for Agile Piloting was published in the spring of 2018. The Smart Kalasatama cookbook presents the best practices and lessons learned in Kalasatama smart city pilots. Smart Kalasatama emphasizes maximizing learning and integrating diverse stakeholder groups for user-driven smart city development. (Smart Kalasatama.)

(l) Vertical and horizontal scope

Numerous smart city initiatives and experimentations in Helsinki have concerned mobility, environment, and circular economy development. Helsinki has actively developed functional smart traffic systems to reduce emissions and created advantages for modern technologies and sharing economy principles to modernize urban mobility. (Helsinki city strategy.) Mobility-as-a-service is one of the most extensive efforts that have taken place in Helsinki. As a result of mobility and transportation development, new data-driven innovations and services have emerged. An application called 'Whim' aggregates both public and private transportation services in one place, thereby offering users services such as city bikes, taxi, and private car services at an affordable monthly fee. Whim liberates citizens from car ownership, thereby making urban life more flexible and resource-efficient. Another digital service created by Helsinki city is a digital platform called 'Service Map'. 'Service Map' encompasses almost all city services, thereby making it easier for citizens to browse and search city services through one digital platform. Both Whim and Service Map platforms utilize open data sets published on HRI's open data platform. Helsinki's ICT department develops ICT policies that support the implementation of the city strategy. Further, the ICT department harmonizes ICT systems so that city services are compatible and digital data content and interfaces are easily available for city stakeholders. The city actively enhances the emergence of open ICT ecosystems by offering fair and equal opportunities for third parties to develop new digital city services (Interviewees 3 and 4, 2018; Open Data Day, 2018.)

(m) Security and privacy

Helsinki's ICT policy states that new ICT training programs must focus on smart city development by enhancing security and privacy issues in diverse city domains. Interviewee 1 expressed that privacy and data protection issues may prevent extensive use of data in certain cases. Interviewees 3 and 4 indicated that city lawyers are used to consulting diverse city organizations, for example, with data privacy matters. Thus, Helsinki considers security and privacy issues and renews ICT procurement practices in this field.

5.3 Governance

In terms of smart city governance, Interviewee 2 expressed that the notion of a smart city is currently related to the manner in which cities govern their ICT systems and data and how they integrate new digital technologies into city infrastructure. Another strong trend in the smart city development discourse is a participatory and citizen-driven/centric approach. In the case of Helsinki, an organization that governs the development of the Helsinki smart city and related initiatives does not seem to exist; however, instead, the development of the smart city is decentralized. Numerous Helsinki smart city initiatives run by FVH are project-based and funded by the EU. Interviewee 2 indicated that due to intensive competition for funding, the projects are rather arbitrary. Interviewee 2 summarized the development of the Helsinki smart city in the following manner:

'We have put huge efforts for developing agile pilots and creating an experimentation culture in Helsinki. It has been an excellent way to motivate and mobilize the entire urban society to develop concrete smart city solutions, for example, related to mobility and health care. Developing a culture for agile pilots and technology experimentations has activated Helsinki city officials, citizens, and start-ups to develop and figure out how to benefit from novel digital technologies and what the future of the city will look like. It is definitely worth it to continue agile pilot and experimentation activities and consider how to extend and draw agile pilots on city-level strategic projects and procurements'.

Interviewee 2 continues and envisions that,

'when technologies evolve, we have artificial intelligence, data, robotics and so on, the city infrastructures and governance must not only adapt to changes, but a city must be governed and managed in another way. The smart city will be the new normal'.

Interviewee 2 also emphasizes combining top-down and bottom-up urban development. This implies that a city-level strategy is needed to deliver investments for infrastructure development; simultaneously, the strategy must engage all stakeholders from private and public sectors and the civil society to develop urban areas. In a top-down/bottom-up urban development approach, the city opens up its data interfaces and develops ICT systems so that each citizen may participate and use his/her resources to improve the quality of lives of the citizens of the city. In the case of Helsinki, agile pilots and new technology experimentations are the means for the development of a smart city. As the development of a smart city evolves in Helsinki, it could be expected that this development progresses from agile pilots to a more mature smart city governance approach.

(n) Funding and metrics

Interviewee 2 indicated that the work of FVH is project-based work. Smart Kalasatama itself is a city's strategic development project and is, thus, funded by Helsinki. However, the agile smart city pilots and experimentations are funded by diverse EU funds. In addition, local and national public organizations have participated and invested in the Helsinki smart city pilots. Due to high competition and uncertainty of the smart city project funding, Interviewee 2 pondered that a city-level smart city development might potentially provide a more solid funding base. One example of the smart city organization or initiatives funded by Helsinki city is Helsinki Regional Infoshare (HRI) for open data services. HRI is an organization that receives funding from Helsinki, other regional cities, and public organizations in Finland. In addition, the digital city services that are developed on the basis of open data are funded by Helsinki. None of the international smart city standards are applied in Helsinki. However, metrics to measure smart city agile pilots organized by FVH are determined by funding organizations. Although the precise metrics to measure benefits from open data initiatives are not set and measured, Interviewees 3 and 4 estimated that, for example, open procurement data has resulted in 1–2% savings in city procurement activities.

5.4 Stakeholders

The strategy of creating 'The Most Functional City in the World' implies that a functional city is extended to involve all citizens and stakeholders in Helsinki. Helsinki is a user- and resident-driven city, which benefits from open data to stimulate the emergence of start-ups and high-growth companies, and offers an advantageous environment for agile pilots and experimentations (Helsinki city strategy). The FVH has executed city-level strategy and actively implemented *quadruple helix* smart city collaboration and development in Smart Kalasatama and other areas in Helsinki. The agile pilots applied in Smart Kalasatama integrate the entire urban society: city, citizens, start-ups, civil society, academia, and large companies. The principles of agile pilots and stakeholders involved in technology experimentations are presented in Figure 2.

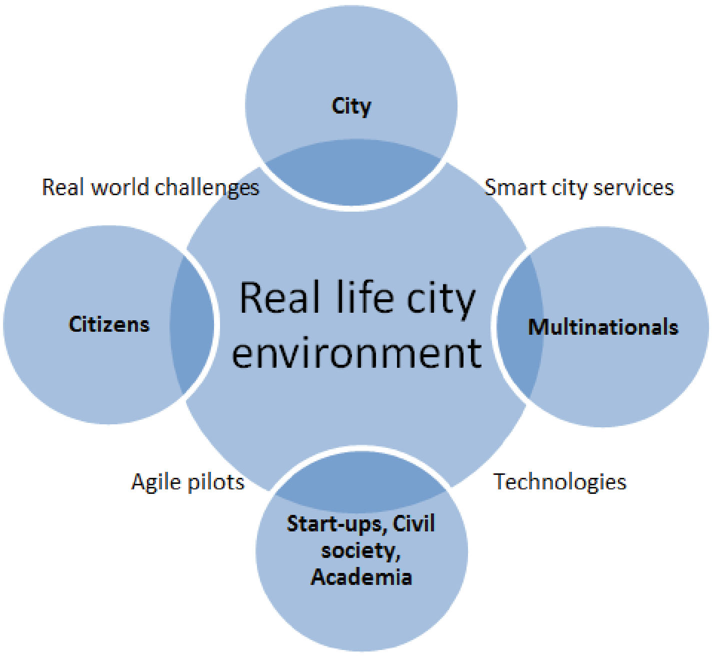

Figure 2 Smart Kalasatama Quadruple Helix (adapted from the Smart Kalasatama presentation)

Another environment created for a *quadruple helix* collaboration in Helsinki is called *Maria 01 area.* Maria 01, a co-working area, is a low threshold meeting place where individuals, third-sector actors, companies, and city officials can collaborate and co-create solutions for citizens and other customers. Maria 01 aims to stimulate individual developers and start-ups to create new digital city services based on open data and accelerate the emergence of new innovations and businesses (Helsinki city strategy).

(o) Stakeholder value

Helsinki has managed to create an attractive smart city experiment and agile piloting culture, which stimulates and integrates diverse stakeholder groups. For Helsinki city, agile pilots have made smart city development more concrete and visible and opened up possibilities for learning about which smart city solutions work and which do not. The ‘fail fast, learn fast’ approach is well adopted in Smart Kalasatama. Further, agile pilots have stimulated the creation of a smart city ecosystem and trust among the stakeholders of the Helsinki smart city. Interviewee 5 highlighted the FVH’s role as a facilitator during agile pilots and emphasized that agile pilots must create value for the stakeholders of a smart city. As a facilitator, the FVH functions as a hub for different stakeholders, lowering the threshold for communication and access for agile pilots. Further, in a facilitator role, the FVH is able to eliminate, for example, legislative barriers or authorization requests from authorities, which streamline the process of agile pilots. Interviewee 5 emphasized that stakeholders' experience contributes to the success of agile pilots and willingness to participate in pilot activities.

Interviewees 5 and 6 represented Smart Kalasatama residents. Both residents considered agile pilots to be beneficial and had a positive attitude towards technology experimentations. The possibility of influencing and being involved in the Smart Kalasatama development was a major reason for attending agile smart city pilots. Interviewee 6 mentioned that certain pilot solutions improved his quality of life. However, both Interviewees 5 and 6 agreed that they would like to receive information regarding the service after the experimentation period is over. They stated that they would like to know whether a beta version of the service or solution will be provided and improved upon and whether it would be available later on.

Due to lack of time and resources, this research did not include the experienced stakeholder value from developers who conducted the agile pilots. Developer data would have enriched the research in terms of stakeholder value. Similarly, the experienced stakeholder value from Helsinki open data is limited to Interviewees 3 and 4. From their perspective, public city data has increased transparency and is expected to increase civic participation and bottom-up urban development. Other benefits that the city has received from open data are internal savings and resource efficiency, as data is ubiquitously available for all. The third benefit mentioned by these interviewees is the hope that the provision of open data stimulates new business and improves the competitiveness of the companies in Helsinki and Finland. However, clear evidence of new business was not present.

6 Summary

Digital transformation is a multifaceted long-term process that influences an organization's structures, processes, resources, capabilities, and stakeholders. This paper presented a framework for smart city design that was applied to the development of the Helsinki smart city. The smart city design framework considered the Helsinki smart city through four dimensions: *strategy, technology, governance*, and *stakeholders*— and their sub-dimensions (Fig. 3). Each dimension is scaled from 0 to 3. Value 0 indicates no activities, value 1 indicates moderate performance, value 2 indicates good performance, and value 3 indicates excellent performance.

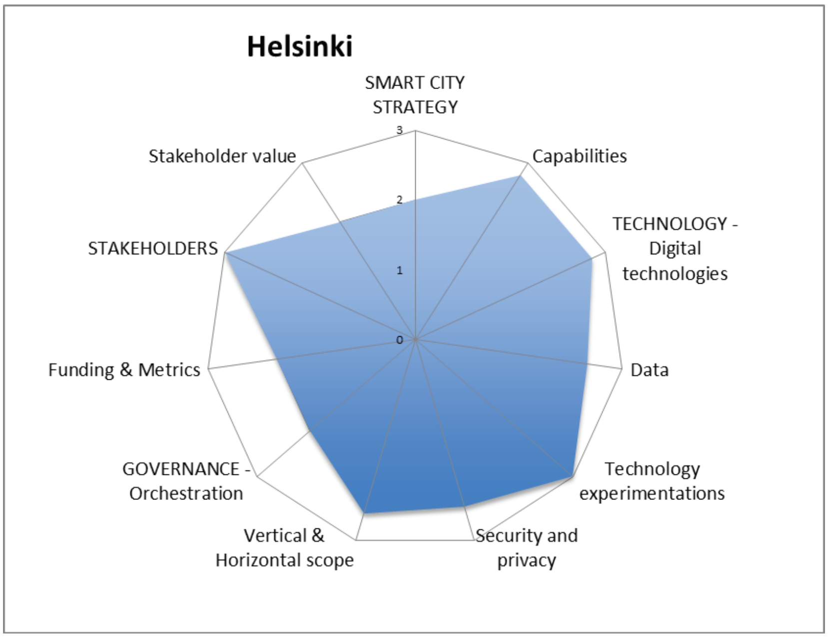

Figure 3 The development of the Helsinki smart city through four dimensions

In the case of Helsinki, specific digital or smart city strategy is missing, but a valid city-wide strategy for the period 2017–2021 supports city development through digital technologies. Interviewee 2 indicated that the smart city will be the new normal, which implies that digitalization and digital technologies are a natural part of urban development. The Helsinki city strategy emphasizes digitalization, user-centric development, civic society engagement, and agile technology pilots. In order to support digital transformation Helsinki has recently hired a Chief Digital Officer to ensure robust digital transformation and smart city delivery in diverse city domains. Helsinki also educates and trains its personnel in modern digital technologies, but not all city divisions have sufficient resources to fully implement digital technologies.

Further, Helsinki aims to develop the entire city as a platform where new and creative city solutions are developed and experimented with. In order to achieve this objective, Helsinki has established a separate innovation unit called the FVH Ltd., for agile digital technology testing and smart city development. The aim of the FVH is to activate digital innovation and organize agile technology experimentations in diverse areas in Helsinki. In addition, Helsinki has managed to create a specific experimentation culture for novel digital technologies like IoT solutions and data usage within diverse city organizations. The city has initiated numerous initiatives to exploit existing data series from different city organizations. Helsinki Region Infoshare (HRI), an open city data platform, is an example of the work Helsinki has committed to in terms of promoting and using data in the development of a smart city. The HRI platform systematically releases open city data sets and interfaces for public use. In order to avoid emergence of data silos and enhance data horizontality, Helsinki aims to harmonize its ICT infrastructure and eliminate the barriers that prevent cross-border data flows among city organizations. Security and privacy issues are of relevance and, in certain cases, may prevent extensive use and publication of city data.

A major proportion of the development work for the Helsinki smart city is short-term and project-based. The FVH, as a separate innovation unit, orchestrates individual smart city projects and facilitates agile technology pilots in practice. In addition to quadruple helix collaboration, FVH and other Helsinki city organizations develop smart city solutions that are relevant for the city, citizens, and other actors in the city. The development of a smart city in Helsinki is rather scattered, which makes the governance of the smart city slightly confused. A clear connection between short-term agile experimentations and long-term smart city development is difficult to discern. However, smart city initiatives and pilots, particularly in Smart Kalasatama, are considered valuable for city stakeholders, such as residents and city authorities. Smart Kalasatama residents expressed that agile pilots are beneficial, but they would have liked to receive information about the solution after the pilot was completed. Further, due to time limitations, stakeholders that develop smart city solutions were not involved in this research.

Numerous Helsinki smart city initiatives are funded through diverse EU funds, Helsinki city, and private organizations. The metrics to measure the outcomes of smart city initiatives are determined by funding organizations, but no international standards for smart city activities are applied in Helsinki. In addition, empirical data did not reveal information about the metrics used to measure the city-level digital transformation process.

7 Conclusion

Digital transformation is a complex and long-term process, which influences an organization's structures, processes, resources, capabilities, and stakeholders. Digital transformation is all the more embedded in social areas that influence all aspects of human life (Stolterman & Fors, 2004). This paper presented a framework for smart city design. This framework shed light on the elements that are relevant for robust smart city implementation and enhanced effectiveness of smart city governance and quadruple helix collaboration. The framework was applied to the Helsinki smart city and considers smart city initiatives from the four major dimensions of *strategy, technology, governance,* and *stakeholders*, as well as their sub-dimensions. Helsinki does not have a specific smart city or digital strategy, but the city-level strategy considers digitalization and user-oriented urban development as one of the areas that is accord-ed priority. In the future, a smart city may be considered the *new normal*, thereby implying that digital technologies and data are embedded in urban development. However, specific smart city or digital strategies might enhance digital transformation and clarify the governance and investment needs for the development of a smart city. In addition, a specific smart city strategy could consider how to integrate agile technology pilots with city-level strategic projects and procurements and, thus, also accelerate the socio-economic aspect of the development of a smart city.

The agile smart city pilots applied in Helsinki have engendered a strong experimentation culture in Helsinki, which has proven to be an efficient means to enhance socio-technical systems and technology acceptance within the city. Moreover, the quadruple helix collaboration is a well-accepted form for agile pilots and smart city implementation in Helsinki. Drawing closer attention to value-creation aspects might improve the satisfaction of stakeholders and, thus, the robustness and duration of smart city initiatives. Applying international smart city standards would improve the analysis and results of smart city implementations.

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