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Published in:
European Conference of Information Systems

Publication date:
2021

Document Version
Tidlig version også kaldet pre-print

[Link to publication from Aalborg University](#)

Citation for published version (APA):
Svangren, M. K., Ananjeva, A., Persson, J. S., Mouritsen, L. K. E., Nielsen, P. A., & Sperling, K. (Accepteret/In press). Infrastructuring In Digital Transformation: An Action Case Study Of District Heating. I *European Conference of Information Systems*

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INFRASTRUCTURING IN DIGITAL TRANSFORMATION: AN ACTION CASE STUDY OF DISTRICT HEATING

Research Paper

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Abstract

Digital transformation is reshaping the public sector's provision of the physical, information, and human infrastructures that make a society function. Therefore, we need to understand and help support the infrastructuring that different stakeholders do in a digital transformation to make digital infrastructure work. Against this backdrop, we report a two-year action case study of the digitalization of district-heating infrastructure in a Danish municipality. From our engagement in the development and diffusion of smart metering and a personal energy assistant for 39.830 households, we analyze three defining types of infrastructuring in this digital transformation: 1) Digitalizing heat supply metering, 2) Digitalizing consumers' heating practices, and 3) Digitalizing through partnering. We explain how digital transformation has two-way relationships to the stakeholders' infrastructuring work and breakdowns that make digital infrastructure visible. Finally, drawing upon the extant research, we discuss how our study contributes to the research on digital transformation in the public sector.

Keywords: Infrastructuring, Digital Transformation, District Heating, Action Case Study.

1 Introduction

Following the current societal discourse, many public organizations are taking action to reduce their carbon footprint by, for example, transitioning to more sustainable energy forms. In this process, digital transformation is reshaping the way citizens access the public sector and its underlying physical, digital and human infrastructure. Digital transformation is *a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies* (Vial, 2019). A highly topical *entity* in this regard is the infrastructure underlying humans' unsustainable consumption and organizations' promotion of sustainability (Hampton *et al.*, 2013).

For information systems research of digital transformation in the public sector, a topical context is sustainable energy production and consumption. In Denmark, district heating is a widely implemented solution supplying 64% (1.7 million) of Danish households (Danish District Heating Association, 2020). District heating is prevalent in the Nordic countries and can be described as a network of pipes with pressurized hot water used to heat individual buildings, neighborhoods, or towns (Lund *et al.*, 2014). The consumers can be served from a centralized plant or distributed heat-producing units operated by district heating suppliers. Danish district heating is shifting to sustainable and renewable sources such as wind, geothermic, or solar, which constitutes 52% of the produced energy in 2020 (Danish District Heating Association, 2020). Many district heating providers aim to deliver fully renewable heating, but

this demands lower water temperatures in distribution pipes and more efficient heat consumption in buildings. These goals are embraced by the concept of 4th generation district heating (Lund *et al.*, 2014). Towards this concept, the district heating provider in the municipality of Aalborg in Denmark, Aalborg Forsyning, is trying to make consumers engage in and change their heat consumption. This process aligns with digital transformation as it is triggering significant changes to the existing district heating infrastructure by digitalizing former physical aspects such as meters and annual consumption feedback. In this way, digital transformation aligns with 4th generation district heating to engage consumers more in their heat consumption (Hvelplund *et al.*, 2019; Krog *et al.*, 2020).

This paper reports from our two-year action case study with Aalborg Forsyning and its digital transformation of district heating in Aalborg municipality. We use an action case, a mixed approach between action research directed at change and case study research directed at understanding adapted from (Braa and Vidgen, 1999) and (Mathiassen, 2002). To the best of our knowledge, research on digital transformation in the public sector is predominantly case-oriented, descriptive, and retrospective. This orientation is useful in generating theory, developing concepts, and promoting new insights (Walsham, 1995), but it does not promote information systems researchers' engagement in digital transformation. In a Swedish municipality, Bengtsson and Ågerfalk (2011) developed an actor-network configuration for illustrating the complex relationships characterizing digital transformation and sustainable innovation. The actor-network configuration included information systems researchers as change actants in enabling digital transformation (Bengtsson and Ågerfalk, 2011). We similarly argue that information systems researchers can play an essential role in public sector digital transformation.

We seek to understand and improve digital transformation towards 4th generation district heating in Denmark as *infrastructuring*, which describes the ongoing work that sustains infrastructures (Bowker and Leigh Star, 2000; Law, 1994; Pipek and Wulf, 2009). Our focus on infrastructuring processes supplements the platformization process view (Bygstad and Hanseth, 2018) that is often related to digital transformation. Against this backdrop, we address the following research questions: (1) What types of infrastructuring do stakeholders conduct as part of a digital transformation of district heating? (2) What kinds of breakdowns trigger these stakeholders' infrastructuring? In this paper, the central stakeholders in consideration are Aalborg Forsyning, its consumers, and the action case researchers.

The paper is structured as follows: First, we outline the related research on digital transformation, infrastructure, and infrastructuring, followed by our action case study with Aalborg Forsyning and its consumers. In the findings section, we present three types of infrastructuring and their inherent breakdowns experienced in our case. We then discuss how our answers to the research questions and a proposed theory of infrastructuring in digital transformation resulting from and guiding our action case study are contributions to information systems research. Finally, the paper ends with a short conclusion.

2 Related Research

In the following section, we specify the concept of digital transformation using (Vial, 2019) and present examples of digital transformation in the public sector. In Section 2.2, we introduce the notions of infrastructure and infrastructuring and extend the concept of digital transformation as involving infrastructuring work.

2.1 Digital Transformation

The digitalization of the public sector enables digital transformation at a societal level. It can improve the quality of services provided by the public sector to citizens and the quality of life of the affected citizens (Agarwal *et al.*, 2010). The notion of *improvement* is essential and signifies not only an element of change but also a positive impact of digitalization (Vial, 2019). This notion is emphasized in the conceptual definition of digital transformation as *a process that aims to improve an entity by triggering significant change to its properties through combinations of information, computing, communication, and connectivity technologies* (Vial, 2019). Vial (Vial, 2019) identifies improvement as an expected, but not guaranteed, outcome of digital transformation. A digital transformation's scope and scale is a *significant change* or high-level impact, making it different from IT-enabled transformation and

digitalization typically associated with *information, computing, communication, and connectivity technologies* (Vial, 2019).

In the prevalent literature on the digital transformation of public healthcare, its expected outcome is the positive impacts of health information technology in lower mortality rates, improved vaccination rates, and patient safety (Agarwal *et al.*, 2010). Another positive impact of digital transformation is increased stakeholder integration in an otherwise disconnected and heterogeneous healthcare system (Agarwal *et al.*, 2010). This positive impact is supported by (Cordella and Paletti, 2018), who describe digital transformation's ability to enable new relationships and dynamics between multiple stakeholders in the public sector (Cordella and Paletti, 2018). They argue that digital technology can enable public service *co-production* by integrating citizens and public- and private organizations. This co-production is a public sector activity to *produce public services with the support of external resources made available to the public administration by external actors* (Cordella and Paletti, 2018). In e-government research, the integration of multiple stakeholders in digital transformation is an essential activity. This activity can maximize value beyond the economic profit for the stakeholders involved (Rose *et al.*, 2018). Involving multiple stakeholders can, however, generate a conflict of interests, increase citizen expectations, and hinder innovation (Flak and Rose, 2005).

Another challenge for digital transformation is the growing complexity and interconnectivity of digital technology in the public sector, which in some cases, hinders citizen involvement and reduces the benefit (Wunderlich *et al.*, 2019). If citizens do not use public services, these services become irrelevant on a grand scale. For example, to transform German households' adoption of sustainable technologies, understanding consumer values can be useful for positively affecting the national level adoption (Wunderlich *et al.*, 2019). This understanding can be acquired through consumer involvement in digital transformation (Piccinini *et al.*, 2015). However, large scale digital transformation in the public sector also calls for attention to the digital infrastructure.

In this paper, we complement the platformization process view (Bygstad and Hanseth, 2018) that is often related to digital transformation with a focus on infrastructuring that is driven by experienced breakdowns in the infrastructure. We seek to understand and improve digital transformation towards 4th generation district heating in Denmark as infrastructuring, which describes the ongoing work that sustains infrastructures (Bowker and Leigh Star, 2000; Law, 1994; Pipek and Wulf, 2009).

2.2 Infrastructure and Infrastructuring

The concept of infrastructure has been widely adopted in information systems research to conceptualize interconnected systems (rather than stand-alone systems) (Henfridsson and Bygstad, 2013). This research covers different settings, e.g., health, telecom, government, manufacturing, levels of analysis, e.g., group, organization, industry, and society, and technologies, e.g., standards, platforms, and the Internet (Hanseth and Lyytinen, 2004). Understandings of infrastructure in these areas differ (Henfridsson and Bygstad (Henfridsson and Bygstad, 2013). Some see infrastructure as it plays out in the complex interdependencies between socio-technical elements (Braa *et al.*, 2007; Ciborra *et al.*, 2000). Others see infrastructure as networks of human and nonhuman actors (Aanestad and Jensen, 2011; Hanseth and Monteiro, 1997). In this paper, however, our framework builds on Star and Ruhleder's definition of infrastructure as relationships between organized practice (Star and Ruhleder, 1996).

Infrastructure is traditionally considered something upon which something else "runs" or "operates", such as a system of railroad tracks on which rail cars run (Star, 1999). In critiquing this consideration, Star and Ruhleder (Star and Ruhleder, 1996) proposed that infrastructure is the often invisible socio-technical structures that are part of the background for other kinds of work (Star, 1999). Building on these notions, (Star and Ruhleder, 1996) propose that infrastructure only becomes infrastructure in relation to *organized practice*. For example, to district heating providers, pipes in the ground, heat pumps, and meters in peoples' homes are infrastructure. For consumers, the infrastructure might consist of the things they interact with daily, that is, thermostats and radiators in their homes. On the other hand, for the developers of smart meters or thermostats, they are not infrastructure, they are topic. (Star and Ruhleder, 1996) further outline nine properties of infrastructure as 1) embedded into other structures, social arrangements, and technologies; 2) Transparent to use in the sense that it invisibly

supports the task at hand; 3) either spatial or temporal – it has reached beyond a single event or on-site practice; 4) learned as part of membership; 5) links with conventions of practice in the sense that it is shaped and being shaped by communities of practice; 6) is embodied into other structures through standards; 7) is built into the installed base; 8) is fixed in modular increments; and 9) becomes visible upon breakdown.

While infrastructure is a useful term to describe various structures that sustain our activities, it does not describe the variety of effort that goes into its integration and the ongoing work required to maintain it (Bossen and Markussen, 2010). In correspondence to the features of infrastructure outlined by (Star and Ruhleder, 1996), the notion of *infrastructuring* as a verb has been suggested to describe the ongoing work that builds and sustains infrastructures (Bowker and Leigh Star, 2000; Law, 1994). Building on the work of (Star and Ruhleder, 1996), Pipek and Wulf (Pipek and Wulf, 2009) defines infrastructuring as the *in-situ design work of tailoring and configuring the infrastructure*. They further argue that infrastructuring can be understood as design and as *a motivated, transformational activity that individuals or groups perform*. Motivated means that every design activity has a goal or at least an intention. Transformational means that it induces a change that is intended to have a longer-lasting effect. Towards this end, (Karasti and Blomberg, 2018) note that no one owns the infrastructure, but rather it is shaped through infrastructuring by many stakeholders e.g., both companies and users. (Bannon and Ehn, 2012) add that infrastructuring is an ongoing process rather than a one-time activity.

Following Pipek and Wulf's work on infrastructuring, it is important to consider the point when infrastructure becomes visible to its users and where in-situ design and in-situ work activities become manifest (Pipek and Wulf, 2009). Most often, infrastructuring is initiated by breakdowns either from the technological side (e.g., the infrastructure actually stops working) or from the users' side (e.g., the infrastructure actually works but is perceived as not working or inadequate to fit users' expectations and needs) (Pipek and Wulf, 2009).

In this paper, we see digital transformation as involving infrastructuring with inherent breakdowns (Star and Ruhleder, 1996). We use the term breakdown, which should be understood as when the infrastructure *breaks* so that it no longer invisibly supports the task at hand either from the technological or user side. We use the term infrastructuring to describe the effort that goes into resolving such breakdowns while simultaneously enabling and facilitating digital transformation.

3 Method

This paper reports from two years of collaboration between practitioners and researchers to understand the digital transformation of district heating provision to private households. We chose the action case approach (Braa and Vidgen, 1999) to address the two research questions in 'what' the infrastructuring and breakdowns by stakeholders are in this case. The action case approach is particularly appropriate as the focus has been on digital transformation towards a more sustainable energy provision and consumption. In this collaboration, we as researchers have been participant-observers partly focusing on understanding the case over time and partly participating in making changes in practice, cf. Figure 1. Figure 1 shows how an action case lies between studies focusing on intervention, as in *action* research, and those focusing on interpretation, as in *case* studies.

Based on this research design, we (1) select and describe a case, (2) describe how we have collected the empirical data, and (3) how we have analyzed the data to arrive at the findings.

To examine the digital transformation of district heating, we have collaborated with the district heating provider in the city of Aalborg in Denmark, Aalborg Forsyning. The city municipality owns Aalborg Forsyning. District heating is the most widespread form of heating in households in Denmark and consists of a network of pipes with pressurized hot water used to heat individual buildings, neighborhoods, or towns (Lund *et al.*, 2014). Aalborg's district heating strategy is to deliver fully renewable and efficient heating, involving lowering of the distributed water temperature. This lower temperature will lead to lower grid losses and support renewable heat sources (sometimes referred to as 4th generation district heating) (Lund *et al.*, 2014, 2018).

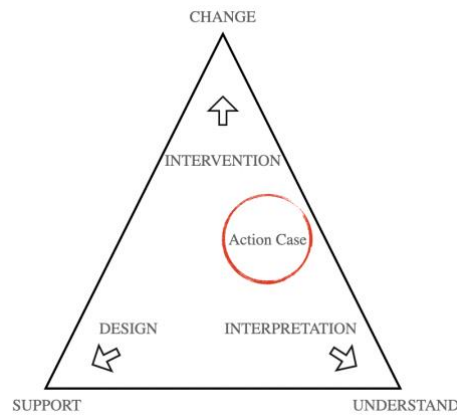


Figure 1: Action case as a mixed approach between action research directed at change and case study research directed at understanding, adapted from (Braa and Vidgen, 1999) and (Mathiassen, 2002)

For Aalborg Forsyning to deliver heating with a decreasing carbon footprint and eventually based solely on renewable energy, the consumers must change how they consume heat. This transformation is difficult as it is largely “uninteresting for most consumers”. In the digital transformation, Aalborg Forsyning wishes to engage consumers more in understanding and changing their consumption. As a first move in this direction, new smart meters have been installed connecting and sending data every hour to a central data hub. On top of this, Aalborg Forsyning provides consumers with a mobile application, a personal energy assistant named *Watts* informing them about meter readings and budget monitoring.

We collected data from several central stakeholders. Firstly, we participated in a series of meetings over two years (fall 2018 – fall 2020) with Aalborg Forsyning. We took on participant-observers’ role in these informal meetings and discussed status and plans for their digital transformation. These meetings served two purposes: (1) appreciating the domain of district heating; and (2) exploring the challenges and solutions facing Aalborg Forsyning in transforming district heating. From Aalborg Forsyning participated five people responsible for the digitalization. From the researchers participated 5-7 researchers from the disciplines of energy planning, sustainable building design, and digitalization. We gathered data in audio recordings, in brief minutes, and researcher notes.

Secondly, we conducted semi-structured interviews with key managers leading the digital transformation. One manager heads the energy supply side, and one heads the digital innovation side. The interviews’ purpose was to gain insight into decisions taken, reasons behind, key breakdowns, and proposed solutions. We used interview guides and recorded them through Microsoft Teams.

Thirdly, in the fall of 2019, we conducted focus group interviews with seven consumers before they were equipped with a smart heat meter and had access to their heat data in the *Watts* app. The focus group interviews were audio-recorded. The focus group interviews addressed expectations and interest in data use of digital metering and prospects of the application *Watts* as well as interviewees’ prior experience with saving energy, e.g., insulation, new windows, and new thermostats.

Fourthly, in the spring and fall of 2020, we conducted semi-structured interviews with 6 consumers after the meters were installed and after they got access to their heating data in the *Watts* application. The interviews were recorded in MS Teams. The interviews addressed their use of and experience with the *Watts* application and how that had or could influence their thinking about their heating practices and investing in energy renovation. Findings were continuously discussed with the involved stakeholders to judge and verify their relevance.

We analyzed the empirical data through the following steps:

1. Listen to all recordings, transcribe, then read all transcriptions and other texts to familiarize us with the empirical data.
2. Based on the framework of infrastructure, infrastructuring, and breakdowns, cf. Section 2, critically identify quotes in the data and code these appropriately.
 - a. The quotes are selected and coded if they shed light on ‘what’ or ‘why’.
 - b. What infrastructuring work are stakeholders doing?
 - c. Why are they doing this and what is the breakdown?
3. Link the quotes and codes to the infrastructure, cf. Section 2, to identify how infrastructuring and breakdowns relate to the features of infrastructure.
4. Elicit from this the defining infrastructuring types and structure the network of quotes and codes accordingly.

In the following section, we report our findings of three defining infrastructuring types. Under each type, we analyze the activities that stakeholders (i.e., Aalborg Forsyning, Consumers, and ourselves) do to resolve breakdowns experienced in the digital transformation of district heating infrastructure.

4 Findings

A goal for Aalborg Forsyning is to base its heat production on renewable energy, which the company has already been working on actively for more than ten years. This process has intensified lately with the impending shutdown of the local coal-fired power plant in 2028 which they have, so far, based their heat production on. Aalborg Forsyning has already started to expand the capacity of the physical infrastructure, including expansion into new supply areas. However, consumers’ heating practice plays a pivotal role in achieving the goal of sustainable heat production because they are often inefficient (e.g., they use too much heat or do not sufficiently cool the return water), which can lead to potential overinvestments in physical infrastructure (district heating pipe network). Therefore, Aalborg Forsyning is undertaking the project of making consumers use heat more efficiently by engaging them in their consumption through the digital transformation of district heating infrastructure.

In the digital transformation, Aalborg Forsyning and its consumers are conducting infrastructuring in response to breakdowns experienced in digitalizing infrastructure. This section describes the key findings relating to the infrastructuring performed by Aalborg Forsyning in its attempt to make consumers use their heat more efficiently. We present three types of infrastructuring: Digitalizing heat supply metering, digitalizing consumer’s heating practices, and digitalizing through partnering.

4.1 Digitalizing Heat Supply Metering

Digitalizing heat supply metering is a type of infrastructuring we found, both, Aalborg Forsyning and its consumers did, driving the digital transformation of district heating infrastructure. This type of infrastructuring included Aalborg Forsyning and its consumers’ responses to breakdowns in using supply metering data. Below we describe Aalborg Forsyning and consumer’ activities to resolve breakdowns inherent to digitalizing heat supply metering.

The installed base and scope of the district heating infrastructure became visible to Aalborg Forsyning as a limitation towards supplying metering data to consumers. Aalborg Forsyning was digitalizing flow-based heat meters by replacing them with smart meters to get detailed data about consumer heating. An early breakdown for Aalborg Forsyning was the challenge of getting data from individual consumers, which relates to the current installed base of flow-based meters that do not support sufficiently temporal data. When using traditional flow-based meters, the consumer gets feedback on heat consumption annually, while smart meters could provide data on each household’s consumption down to the minute. Smart meters’ radio transmission of the readings also allowed Aalborg Forsyning to supply its consumers with detailed data about their heat consumption. The shift to smart meters had

also proven difficult. It involved interferences and delays in data as expressed by the head of energy supply in Aalborg Forsyning:

“Our largest challenge, almost from day one, is the delay on the data. Sometimes it’s two days, and it’s funny, because that’s extremely fast compared to what we are used to, but the ordinary consumer for instance is used to looking things up on Facebook instantly and not having to wait days before it gets into the app” – **Head of energy supply, Aalborg Forsyning**

Against this backdrop, Aalborg Forsyning worked on fixing data inconsistencies using existing consumption data, to fill in the missing data. However, after two years of operation, they still faced data inconsistencies, especially in urban areas where a high degree of radio communication interferes with the signals from the digital heat meters.

Responding to Aalborg Forsyning’s activities digitalizing heat supply metering, consumers valued the availability of data about consumption. Few consumers knew how to read data from their meter and relied on their annual bill to get an overview. Consumers experienced a breakdown in the limited use of data and knowing how to act on heating data. This breakdown relates to the transparency and embeddedness of the current infrastructure. District heating infrastructure is reliable, and often runs with little involvement from the consumer, and becomes visible only when something goes wrong. For example, John, a consumer and owner of a single-family house with district heating, had an open issue regarding his annual heat bill:

“Right now, we have a very annoying case open with the energy provider. In the last year, we’ve used 1600m³, whereas in the year before that we’ve used 800m³. So that’s a doubling [...] There’s no clear answer why, but the energy provider seems to think it’s a faulty valve” – **John, Consumer**

John’s heating meter was located in his basement and not easily visible to him, so he did not read it very often as he had trouble climbing down the stairs. As such, he had been unaware of any problems (the temperature in his house was still the same) and had discovered the breakdown too late when the yearly bill arrived. He was unsure how to map the numbers on the meter to any specific part of the heating system in his house and could not solve it. He had contacted Aalborg Forsyning with his issue but argued that having metering data in a digital format would allow him to identify a potential problem more quickly because he then could access it digitally.

Before Aalborg Forsyning had completed installing smart meters in consumer homes, we started the collaborative research project by carrying out research activities to help improve its consumers’ digitalization experiences. When we entered, Aalborg Forsyning was interested in learning more about their consumers and the potential to change consumer heating behavior beyond the surveys they previously had conducted. We contributed to this process by reporting findings from focus group studies to Aalborg Forsyning published at a Nordic Conference on Human-Computer Interaction (Kvist Svangren *et al.*, 2020) and in an international journal on energy planning (Krog *et al.*, 2020).

In summary, *Digitalizing heat supply metering* is a type of infrastructuring carried out to resolve a breakdown in using flow-based metering data. This breakdown became a reason for replacing the existing infrastructure with smart meters and a reason for digitalizing heat supply metering. On a larger scale, digitalizing heat supply metering helps Aalborg Forsyning and its consumers create a digital infrastructure for digital transformation towards 4th generation district heating in Aalborg. This digital transformation provides Aalborg Forsyning with a vision of efficient and sustainable heating for digitalizing heat supply metering. We intervened in this infrastructuring by helping Aalborg Forsyning understand its consumers’ breakdowns in using analog metering data before receiving smart meters. Our investigation also helped Aalborg Forsyning understand its consumers’ different visions of efficiency and sustainability for a digital transformation in their district heating.

4.2 Digitalizing Consumers' Heating Practices

The next type of infrastructuring is digitalizing consumer' heating practices responding to breakdowns in informing consumers' heating practices. Below we describe Aalborg Forsyning and consumer activities to resolve breakdowns in changing heating practices.

Aalborg Forsyning was in the middle of implementing several features meant to inform consumers in the personal energy assistant *Watts*, which is a smartphone application visualizing the data provided by smart meters. Towards this end, the current scope and embodied standards of infrastructure providing information to consumers (annual letter with flow-based information) had not proven enough to get consumers interested in changing their consumption practices. As such, finding other ways of informing the consumers about their consumption, by changing scope and standards, was a key activity responding to the breakdown of consumption knowledge and a lack of interest, as expressed by a manager from Aalborg Forsyning:

“For us, the consumers must be a part of this transition, but that is a difficult task. For the past 10 years in Aalborg we have looked into it and found that there's almost nothing as uninteresting for people as energy use in their houses. People want to save money and have a low energy consumption, but getting people engaged in their consumption is just not very sexy. So, the task we have is getting consumers more engaged” – **Head of digital innovation, Aalborg Forsyning**

To address this breakdown, Aalborg Forsyning implemented hourly consumption feedback to give consumers an overview of consumption. However, although consumption feedback was seen as important to increase consumers' knowledge about how much heat they use, it was also a goal to provide a reference point to know if consumption was high or low. Also implemented, was a budget that was calculated from last year's consumption and weather forecast data versus households' current consumption. Furthermore, Aalborg Forsyning had also implemented features to motivate consumers. One feature implemented was an overview of how efficient consumers were in using heat overall, that is, if they in their households are good at cooling the water that is returned to Aalborg Forsyning. Another feature was an alarm function triggered if consumption were beyond regular use.

Responding to *Watts*'s features, most consumers found it interesting that they could be informed about their consumption on their phones instead of waiting for the annual bill, and they felt that they were able to learn about their heating practices. One consumer, Louise, who had been very interested in saving heat from the beginning, explained that she had used the information to lower her consumption. However, the practices built up around the use of the current infrastructure and as such, the set of conventions following it. Several consumers reported that they initially opened the application multiple times a day but that the interest faded over time. As a breakdown, most consumers did not want to follow their consumption closely, they were used to district heating infrastructure he did not frequently have to addend to. They did not see it as a tool to change behavior but more as a preemptive tool where alarms could notify if something went wrong. For example, Peter, a consumer and owner of a single-family house, who was very interested in environmental issues, did not think that he would be able to change his consumption based on information about his consumption alone:

“The amount of money we buy heat for is so low that, in my indolence, I don't want to act upon it unless something goes wrong [...] I don't think information about my consumption would change my consumption because I also don't want to be cold. So something else is needed besides that” - **Peter, Consumer**

Practice and conventions go further than information about consumption. Although Peter found the idea of saving heat compelling, he did not find it especially appealing to change his practices based on information about consumption alone and something else was needed. Delving into this, informing to change heat consumption behavior becomes more complex than just consumption information. For example, Peter and several other participants came with additional suggestions of how *Watts* could inform them to reduce heat consumption. For example, some argued that they would much rather invest

in energy renovations of their houses that could reduce heat consumption overall and that it would be beneficial if Watts also could inform about ways to make such decisions. Besides investing in energy investments, Peter and others also reported conventions of practice interfering with the decision on changing heat consumption such as leveraging resources spent on changing heat practices against the cheap price of district heating and a comfortable indoor climate.

After we had been involved in the project for a year, the first consumers had tried Watts and were familiar with its functionalities. Similar to the initial focus groups, we acted as mediators investigating consumer responses and behavior when getting information about consumption through Watts's features through interviews with individual house owners. While our interest was academic, this process also elicited breakdowns happening for, both, Aalborg Forsyning and its consumers. Our results acted as direct input to the company's incremental "trial and error" approach to development. This approach fits well with the feature of infrastructure being fixed in increments rather than at once. Our results were reported and considered for the next iterations. Our involvement continues with a follow-up study on the use of Watts a year after deployment.

In summary, *digitalizing consumers' heating practices* is a type of infrastructuring carried out by Aalborg Forsyning and its consumers to resolve breakdowns in informing heat practices. These breakdowns provided stakeholders with a reason to inform consumers about their heating practices. On a larger scale, *digitalizing consumers' heating practices* helps Aalborg Forsyning and its consumers create a digital infrastructure for digital transformation towards 4th generation district heating in Aalborg. This digital transformation provides Aalborg Forsyning with a vision of efficient and sustainable heating for digitalizing heat supply metering. Our intervention in this infrastructuring through an understanding of consumers' breakdowns in using the application Watts. We also contributed to Aalborg Forsyning's understanding of consumers' willingness and desire to change heating practices as more complex than consumption feedback could resolve.

4.3 Digitalizing through Partnering

A final type of infrastructuring we found was digitalization through partnering. We found actions to resolve breakdowns in accessing knowledge, such as engaging in partnerships to gain the competencies required to digitalize infrastructure. Below we describe Aalborg Forsyning and consumer activities to fix breakdowns in digitalization through partnering.

Aalborg Forsyning has strong expertise in district heating. However, venturing into new areas of expertise about digitalization gave rise to a breakdown related to them being strangers to the knowledge contained within. Having these competencies in-house did not fit Aalborg Forsyning's core business focus on district heating. Instead, their alternative has been to engage in partnerships with other stakeholders who already are experts in their given area gaining knowledge through this collaboration. Examples of such knowledge are installing, configuring, and maintaining smart meters. Towards this end, professionals, such as plumbers, handle installing the district heating infrastructure's smart meters. In calibrating and maintaining and calibrating smart meters a core partner is the leading smart metering provider in Denmark who also delivers smart meters for electricity. They take care of calibrating and gathering data from smart meters and provide the data that keep the Watts application updated.

Access to knowledge about application development was important to enable informing consumers' heat practices. Towards this, a core partner is one of the primary electricity providers in Denmark, who is the primary driver of Watts. Aalborg Forsyning's head of energy supply explained the partnership:

"When we started this, only a handful of similar apps were available on a national plan that could do this. So we could go to one of those companies and ask if we could join. But we did not think the number of users on those apps was particularly good. We thought that we could do better. Then we started with a clean slate and started discussing. We involved a couple of software companies but quickly realized that it would cost millions [...] But then, I can't remember who in the group, that talked to someone, that then talked to someone else, you know, we talk a lot across companies. They have heard that

someone in [Electricity company] had received a large bag of money to develop something similar to what we need. Of course, they were not a heating company, but here was the opportunity to create something really cool. So, we engaged in a partnership with them.” - Head of energy supply, Aalborg Forsyning

To provide their services, the electricity company got more users and feedback on ways to develop the application further, such as user requests. A third partner is the consumers that Aalborg Forsyning supplies with heat. These consumers are co-creators in two ways. Firstly, Aalborg Forsyning has a focus group of consumers that comment on concrete functionality and visual elements in Watts before it goes into production. Secondly, Aalborg Forsyning also receives feedback from consumers for future iterations.

Although not with the sole purpose of saving energy, learning about infrastructure was also important for interested consumers as a part of membership and partnership with Aalborg Forsyning. While only a few found it interesting to actively monitor consumption, several could see the benefit of saving money or getting a better indoor climate. The breakdown for consumers is that it previously had been difficult to access knowledge. Many of the consumers we spoke to, had been informed by Watts, and through that accessed knowledge that had previously been non-transparent to them. Some had used Watts to confirm their current consumption, some were using it as a tool to track their consumption, and others saw the potential to inform if something went wrong in their consumption. Although with slightly different motives (e.g., saving money or achieving a better indoor climate), many of the consumers we interviewed also had an interest to gain further insights into what they could do to use heating more efficiently. The consumers participating in focus groups, similarly, saw it as an opportunity to gain insights into the digitalization of district heating.

Our role, as partners of Aalborg Forsyning, has been to support knowledge access about its consumers. For the consumers, our involvement has resulted in accessing knowledge about district heating and their consumption. As researchers, we had an interest in learning about infrastructuring in digital transformation. We experienced a breakdown in accessing knowledge, e.g., cases to study. Partnering has enabled us to understand digital transformation, and we will continue with this practice. We are currently deploying a joint survey of Watts and home renovation, where Aalborg Forsyning helps shape questions through their expertise in district heating and provide access to participants.

In summary, *digitalizing through partnering* is a type of infrastructuring carried out by all stakeholders during this action case study to resolve the breakdown in accessing knowledge. Limited knowledge about digitalization theory-practice has made Aalborg Forsyning, its consumers, and us as researchers engage in partnerships. On a larger scale, digitalizing through partnering helps Aalborg Forsyning and its consumers access knowledge about each other to create a digital infrastructure that helps each part save resources. This digital transformation enables Aalborg Forsyning to meet its vision of efficient and sustainable heating. Our intervention by reporting an understanding of consumers' breakdowns to Aalborg Forsyning helps them to increase consumers' benefit from district heating through digital resolve. As researchers, we have also gained valuable understandings of a digital transformation process towards more sustainable heat provision and consumption through this partnership.

5 Discussion

In an action case study with the Danish district heating supplier Aalborg Forsyning, and its heat consumers, we addressed the research questions: (1) What types of infrastructuring do stakeholders conduct as part of a digital transformation of district heating? and (2) What kinds of breakdowns trigger these stakeholders' infrastructuring? In answering these two questions, we found three defining types of infrastructuring that resolve inherent breakdowns and create a digital infrastructure for a digital transformation towards 4th generation district heating. The first type of infrastructuring is *digitalizing heat supply metering* triggered by Aalborg Forsyning and its consumers' breakdowns in using metering data. The second type is *digitalizing consumers' heating practices* triggered by breakdowns in informing households with diverse and variable heating practices. The third type of infrastructuring is *digitalizing*

through partnering triggered by Aalborg Forsyning and its consumers' breakdowns in accessing knowledge for developing effective digital solutions for district heating.

To make our study and its findings transferable beyond district heating to other digital transformation contexts, we propose a theory to explain infrastructuring in digital transformation. According to Gregor's (2006) taxonomy of theory types in information systems research, this theory is a type II theory that provides explanations but does not aim to predict with any precision. The explanation is a process theory focusing on the dynamics of change instead of variance theories as distinguished in (Van de Ven, 2007).

The notion of infrastructuring provides an alternative view of the work required to achieve digital transformation in the public sector. In this view, digital transformation can be perceived as *a process that aims to improve the infrastructure by triggering significant change to its properties through involving infrastructuring work*. Based on this perception, the digital transformation process consists of dynamic, transformational activities that individuals or groups perform (Pipek and Wulf, 2009). In support of this, our findings emphasize *digitalizing through partnering* as a pivotal infrastructuring activity in digital transformation in the public sector, thus highlighting the collaboration aspect of infrastructuring. Digitalizing through partnering can be perceived as a type of value network in which *complex relationships among multiple stakeholders with potentially competing interests are created for the benefit of customers* (Vial, 2019). However, as presented in Figure 2, consumers are also a part of this value network. Digitalization of district heating towards 4th generation district heating has changed the consumer-supplier relationship, as suggested in other digital transformation research (Piccinini *et al.*, 2015). The consumers became empowered through co-creation activities, while Aalborg Forsyning became more consumer-centered by acquiring feedback directly from the consumers themselves or mediated by us.

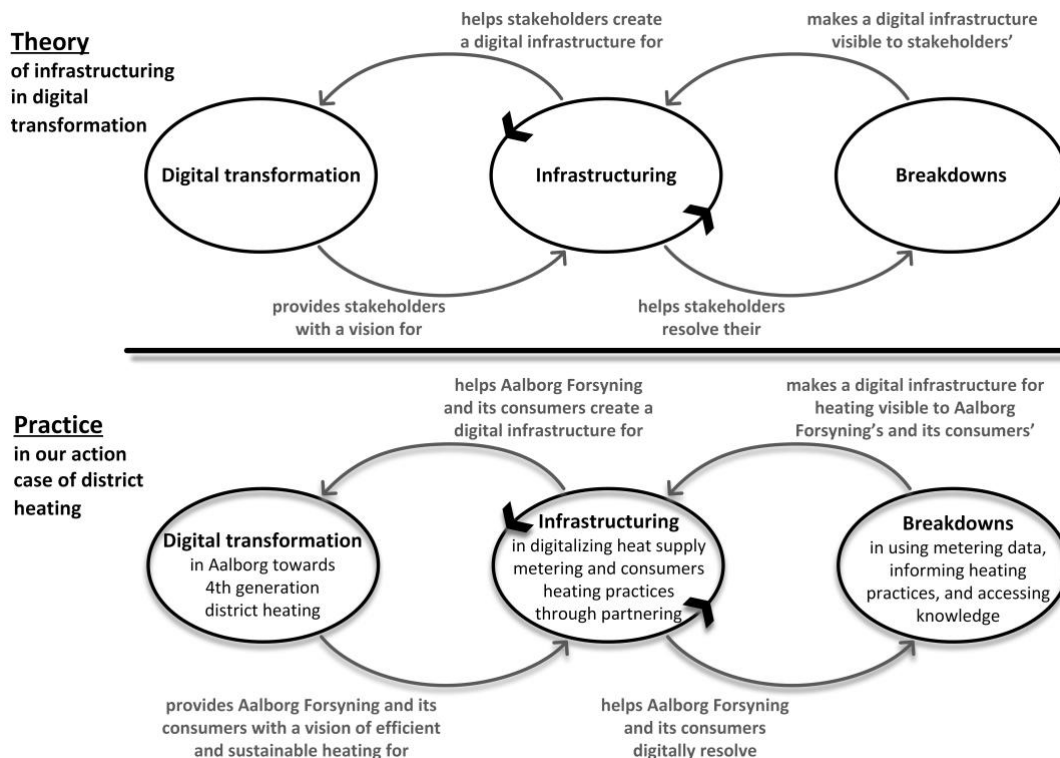


Figure 2: Theory and practice in our action case of infrastructuring in digital transformation

We perceive the two-way relationship between the stakeholders and the transformative activities illustrated in Figure 2 as an emergent characteristic of digital transformation. This view emphasizes the non-sequential properties of the digital transformation process, and it complements the notion of

platformization (Bygstad and Hanseth, 2018). Platformization is the *stepwise* transformation process towards a platform-oriented infrastructure (Bygstad and Hanseth, 2018). However, through active participation, we gained first-hand experiences highlighting the intricacy of the infrastructuring and digital transformation in the public sector. Our findings show that this transformation process is driven by breakdowns to various stakeholders and not only the planning of it. Therefore, we argue that infrastructuring, which is an ongoing and interdependent process rather than a stepwise process, better explains digital transformation in the public sector.

Our argumentation with this action case study has limitations. First, the high level of engagement required to conduct an action case study; some may argue, is not compatible with scientific rigor and limits the study's generalizability (Avison *et al.*, 2018). However, through active participation, we gained first-hand experience with infrastructuring work and its inherent problems (Nielsen and Persson, 2016) that are difficult to obtain through an interpretive case study without an attached form of engaged scholarship (Van de Ven, 2007). Through both interpretation and intervention, we developed a theory that still could be useful beyond the case of district heating. This theory might be transferable to other digital transformation cases in the public sector. We call for future research to examine our theory's explanatory usefulness in other contexts of digital transformation. The theory may help explain the success or failure of digital transformation processes as a complementary view to other understandings in information systems research.

Another limitation is the scope of our research. In our action case study, we were only involved in digital transformation of district heating in a single municipality in Denmark. District heating companies and the municipalities that govern them are diverse. The differences might be related to the economy, size, sustainability initiatives, citizens, and partners, which might affect the digital transformation process in some municipalities. This limitation calls for a collaborative study with other district heating companies and municipalities, to investigate how our theory unfolds on a larger scale. More importantly, we point to a need for such research in other areas of the public sector. Other researchers may look into elaborating aspects of infrastructuring and breakdowns i.e., by focusing on different stakeholders or organizations. Lastly, we also see that further research is needed towards stakeholder values and valuations (Rose *et al.*, 2018) on how they experience breakdowns in infrastructuring, thus bringing forth how stakeholders can provide a vision for digital transformation and vice versa. This research direction may fruitfully complement extensive research on public sector digitalization values (Twizeyimana and Andersson, 2019). More specific directions could be the public sector issues of manager' prioritizations (Rose *et al.*, 2015), strategy (Persson *et al.*, 2017), decision making (Ranerup and Henriksen, 2019), data governance (Benfeldt *et al.*, 2020), and artificial intelligence (Toll *et al.*, 2020).

We further suggest that our theory (c.f. Figure 2) has implications for practice. If a practitioner reads the theory not as a prediction but as a framework that can explain relationships. One may use the framework to ask questions to ponder in the process of digital transformation. It may start in all of the three processes, say in breakdowns. If a breakdown occurs, the infrastructuring that could resolve it may reflectively be taken as an opportunity to modify and evolve the digital infrastructure. If, on the other hand, a digital infrastructure contains a vision, one may ponder about which infrastructuring this will raise or what infrastructuring may well be necessary. That, in turn, may lead to thinking about which breakdowns to expect. From this, we suggest that the theory's simplicity has the advantage that it can be a practical instrument.

6 Conclusions

This paper proposes an understanding of digital transformation as infrastructuring based on a two-year action case study of a district heating provider and their ongoing work to make consumers engage in and change their consumption to better support sustainable and renewable heating sources. This work was part of a digital transformation with significant changes to the existing district heating infrastructure by digitalizing former physical aspects such as meters and annual consumption feedback. Through

informal meetings, focus groups, and interviews with the district heating provider and its consumers, we elicit three defining types of infrastructuring with inherent breakdowns in the district heating infrastructure.

The first type of infrastructuring was *digitalizing heat supply metering*, triggered by breakdowns in the district heating supplier and its consumers' experiences using metering data. The second type was *digitalizing consumers' heating practices*, triggered by breakdowns in informing households with diverse and variable heating practices. The third type of infrastructuring was *digitalizing through partnering*, triggered by breakdowns in accessing knowledge for developing effective digital solutions for district heating.

Our action case study proposes a theory explaining infrastructuring in digital transformation as two-way relationships between digital transformation, infrastructuring, and breakdowns. First, we propose that infrastructuring helps stakeholders resolve their breakdowns and that these breakdowns make a digital infrastructure visible to stakeholders' infrastructuring. Second, we propose that infrastructuring helps stakeholders create a digital infrastructure for digital transformation and that digital transformation provides stakeholders with a vision for infrastructuring. Following this line of thought, we argue that our theory complements other views on digital transformation (e.g., platformization). We further suggest that our theory can help practitioners and researchers explain a digital transformation in other contexts for purposes of both understanding and change.

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