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EXPLORING PRINCIPLES FOR CORPORATE DIGITAL INFRASTRUCTURE DESIGN IN THE FINANCIAL SERVICES INDUSTRY

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Abstract

This paper presents corporate digital infrastructure design principles of companies in the financial services industry dealing with data intensive service offerings. The design principles emerged by applying established techniques of the grounded theory method from data we collected in a one case B2B organization which transformed its IT infrastructure. We structured the company's initial problem and identified associated problem requirements and mapping solution components. Based on this case-based design theory building work, we theorized the following design principles: (1) a bidirectional data exchange to enable for customer data integration, (2) the usage of a flexible data model for the data storage, (3) efficient data processing by reduced communication overhead, and (4) small reusable and modular software components enabling standardized, yet flexible customer solutions. Our research contribution is twofold: First we contribute to the emerging literature stream of digital infrastructures. In particular, we shed light on design choices to transform a historically grown IT infrastructure to align with the generative evolution of non-corporate digital infrastructures. Second, we link the findings to literature of co-creation by reflecting our design principles to the layers of IT-value co-creation and reveal interdependencies among these layers.

Keywords: Corporate Digital Infrastructure, Design Principles, Financial Services Provider, IT-Value Co-Creation.

1 INTRODUCTION

Pervasive digital technologies, including mobile, social, cloud and big data technologies (Bharadwaj et al. 2013), substantially influence the behavior of individuals and society. As a result, of what we encounter in the financial service sector, the customers' expectations are changing towards innovative, personalized financial services, which are supposed to be available anywhere at any time. The ongoing cycle of digital technology adoption, scaling, and innovation is rendering pervasive digital technology infrastructural (Henfridsson & Bygstad 2013). Therefore, IS scholars have emphasized the need for a closer examination of digital infrastructures as a new type of IT artifact of high relevance to business and society at large (Tilson et al. 2010). A digital infrastructure is defined as "[…] the basic information technologies and organizational structures, along with the related services and facilities necessary for an enterprise or industry to function. These infrastructures can be further defined with respect to the entity being supported or enabled as global, national, regional, industry, or corporate infrastructures." (Tilson et al. 2010, p. 748). Hence, prior research acknowledges digital infrastructures as a novel and important period in the evolution of IT. Moreover, research on digital infrastructures is an increasingly important field in the domain of IS (Henfridsson & Bygstad 2013; Tilson et al. 2010). In the corporate context, we currently observe an increasing shift from traditional enterprise IT to so-called corporate digital infrastructures. To some extent they share certain key characteristics with digital infrastructures, such as the Internet. In general, these shared characteristics can be described as evolving sociotechnical systems with a heterogeneous, shared, open and unbounded nature (Hanseth & Lyytinen, 2010). Digital infrastructures have a tremendous effect on data. Over 90% of world's data, which has been created over the last years, can be traced back to sophisticated digital platforms and underlying digital infrastructures. The abundance of data, in turn, brings a paradigm change to entire market settings. The future of many incumbent companies lies within the capability of leveraging this data in order to understand their customers' behavior, enabling them to satisfy new demands and increase the revenue (Shim et al. 2015; Bhimani 2015). However, companies, especially incumbents, often struggle to utilize these new and relevant information pools of "[…] past and present, structured and unstructured, formal and informal, social and economic, and which constantly evolve in their content and representation." (Bhimani 2015, p. 66). One reason lies within legacy infrastructures that are not well set up for this shift. For example, conventional storage methods (e.g., relational databases) are suitable for data consistency but inefficient (i.e., not cost-effective) in managing and processing large repositories of data in terms of volume, variety and velocity (Shim et al. 2015). In addition, the demand for a shorter time-to-market, innovative products and services and an increasing specialization make it difficult for single companies to excel at developing a suitable and competitive corporate digital infrastructure on its own. As a result, it becomes beneficial for these kind of companies engage in forms of collaboration and co-creation with specialized corporate digital infrastructure providers for IT, enabling innovative products and services. (Barrett et al. 2011; Grover & Kohli, 2012). Thus, boundaries between companies are increasingly blurring in many ways towards business ecosystems and coordinated networks of companies with digital infrastructures as an enabler to offer value (new or improved products and services, more choice, better information and transparency) to customers (Grover & Kohli 2012, Woerner & Wixom 2015, Weill & Woerner 2015).

Nevertheless, knowledge on architectural design choices of corporate digital infrastructure is still scarce. Therefore, several authors emphasize the importance of exploring design principles of digital infrastructures and call for future research on this topic. Previous work already highlighted possible directions by asking so far unanswered research questions related to the design aspects of digital infrastructures (Tilson et al. 2010, p. 757; Yoo et al. 2010, p. 733; Yoo 2010, p. 227; Lusch & Nambisan 2015, p. 163). Specifically, Tilson et al. (2010) emphasizes the investigation of digital infrastructure design, evolution and nature by conducting case studies embedded in its real-world context.

We aim to shed light on this lack of understanding by examining a case of a specialized B2B financial services provider. The case company faced the challenge to transform its legacy corporate IT infrastructure towards a corporate digital infrastructure to make use of the increase in volume, variety and velocity of data. In addition, we show that the new corporate digital infrastructure facilitates for forms of IT value co-creation, i.e., where multiple organizations can collectively leverage IT.

Thus, our contribution highlights design knowledge about specific architectural design principles of corporate digital infrastructures that allows them to become embedded sociotechnical systems of a heterogeneous user base. In particular, we aim to explore architectural design choices of corporate digital infrastructure by focusing on specific technical aspects. Our research question is formulated as follows: *"What kind of design principles should guide a financial IS services provider in transforming its corporate digital infrastructure in a data-heavy context?"*. Therefore, our contribution is closely linked to Tilson's et al. (2010) call for research, who already emphasized the need for future research on architectural design principles of digital infrastructures in general, including corporate digital infrastructures. To address the research question, we conducted and analyzed 17 interviews at the case company and several additional relevant documents. Following Beck et al. (2013), we used a *theory-generating design science* research approach by applying grounded theory methodology techniques.

The remainder of the paper is structured as follows. Before presenting our methodology regarding our data collection and analysis, the upcoming section presents a focused theoretical foundation to our case. Then, we provide the case synopsis by introducing a company description and a case narrative that explains the companies' challenges with infrastructure 1 (I1) and the derived solution requirements for infrastructure 2 (I2). Finally, we explain the components of the solutions in place developed by the case company (I2) and derive general design principles of corporate digital infrastructures in the financial services sector.

2 THEORETICAL FOUNDATIONS

2.1 Digital Infrastructures

Tilson et al. (2010) emphasize that digital infrastructures constitute a new class of IT artifacts. The fundamental driver of digital infrastructures is rooted in the technical process of digitizing, i.e., converting analog signals into a binary form. Digitizing triggered a convergence of digital devices (being able to store, communicate and process almost any type of information), networks (supporting almost any type of services) and industries (blurring boundaries between formerly separated actors). In addition, the extensive digitization brought forward generativity, the capability of a system to create a new output even without any input of the system's owner itself. This also means, digital infrastructures can never be viewed as "complete", encompassing many possible uses whilst actors are constantly inventing and sharing uses (Zittrain 2008). They enable actors to (re-)combine any information available within the network and facilitate opportunities to cocreate innovations. Distinct properties of generative digital infrastructures are, a recursive character, flexibility, scalability and they vary of data being processed. Digital infrastructures are recursivly organized, meaning technical capabilities and services delivery are loosely coupled. Therefore, they are able to challenge incumbent companies by generatively creating new business infrastructures. Digital infrastructures can make seemingly effortless use of any required function provided by its digital or physical network. This means that they are extremely flexible towards new service or application creation. In addition, it is easy to replace or upgrade components of digital infrastructures in an inexpensive manner, which contributes to their scalability. Finally, digital infrastructures transport bits, i.e., universal material that can have diverse meanings, marking a fundamental difference to physical infrastructures such as industrial-age product architectures (e.g., industrial machines) (Tilson et al. 2010).

2.2 IT Value Co-Creation

Over the last decade, co-creation gained an increasing attention (Galvagno & Dalli 2014, p.6), which led to examining the topic from various angles and across multiple disciplines encompassing a diverse set of theories (e.g., Galvagno & Dalli 2014; Greer & Lei 2012; Ranjan & Raed 2014). More recently, research on business value of IT emphasizes co-creation of value through IT as an important future research topic (Kohli & Grover 2008). Grover and Kohli (2012) explore IT value co-creation by analyzing capabilities and metrics in a multiform environment. From the relational view a company's critical resources span boundaries, which are possibly embedded in its inter-firm routines and resources (Dyer 2000; Dyer & Singh 1998, Grover & Kohli 2012). The theory highlights four sources of competitive advantage from relationships among companies: a) relationship-specific assets, b) knowledge sharing routines, c) complementary resources/capabilities, and d) effective governance. The asset layer describes two or more companies of which at least one of them contributes specialized assets or network facilities. This enables value creation in unison with the partners' resources, resulting in new digital/physical products or services. The participating companies would singly not be able to extract a comparable value on their own (e.g., specialized IT hard- and/or software). The complementary layer describes IT-based resources/capabilities among partners that complement each other. Value creation may be facilitated by identifying and exploiting these complements (e.g., IT functionalities or capabilities such as IT skills or real-time product availability, which complements the partners' resources). The knowledge-sharing layer is about sharing information and know-how, which supports decision-making and strategies for better or more innovative products and services. Sophisticated IT infrastructures and processes may positively influence the absorptive capacity (e.g., the sharing of analytical software or knowledge repositories). However, all actors need to benefit from sharing and using knowledge. The governance layer is characterized by establishing a (in-/ formal) control structure to minimize transaction costs and to stimulate new value co-creation (Grover & Kohli 2012).

Several pieces of research explore the co-creation of IT value (e.g., Ceccagnoli et al. 2011; Rai et al. 2012; Sarker et al. 2012). Rai et al. (2012) show evidence from the logistics industry on inter-firm IT capability profiles and communication for co-creating relational value. They found a set of IT functionalities (single-location shipping, multi-location shipping, supply chain visibility, and financial settlement) that could be used to manage inter-firm logistics processes of physical goods, information, and finances across locations. The authors demonstrate that these inter-firm IT capability profiles and inter-firm communications show an interaction but also a direct effect on the relational value. Thus, IT value co-creation was achieved by establishing IT-based capabilities. Sarker et al. (2012) explore the value co-creation in relationships between an Enterprise-Resource-Planning (ERP) vendor and its partners. Using a revelatory case study, the authors show different mechanisms of value co-creation in a B2B environment and contingency factors that influence the mechanisms. Those Partners who adopt ERPs, are able to add value to the ERP by customizing and modulating software add-ons. Therefore, partners can co-create value by a sharing of resources and capabilities in order to raise the value of the ERP for end customers. Ceccagnoli et al. (2011) highlight a case of enterprise software, and reveal the possibility of value co-creation in a platform ecosystem. The authors examine whether the participation in an ecosystem may improve the business performance of small independent software vendors (ISV). Their findings show that participating in a major platform owner's platform, the whole ecosystem associates with an increase in sales and a greater likelihood of launching an initial public offering of ISV. This impact is larger for ISV with greater intellectual property rights or stronger downstream capabilities (unique knowledge). The paper shows the importance of interoperability between software products, and "[…] stresses that value co-creation and appropriation are not mutually exclusive strategies in inter-firm collaboration." (Ceccagnoli et al. 2011, p.263).

However, the existing literature is not sufficient when examining it from an angle of digital infrastructures. Digital infrastructures may facilitate IT value co-creation because they are a "[…] fertile ground for sharing of assets, development of digital capabilities, sharing of knowledge and facilitating governance" (Grover & Kohli 2012, p. 229). Yet, little is known about how and which specific design choices of digital infrastructure can be associated with IT value cocreation and how these relate to the proposed relational view components, i.e., the layers of IT value co-creation.

3 METHODOLOGY

Our research follows a *theory-generating design science research* approach by using grounded theory methodology techniques (Beck et al. 2013). These lead us to our outcome, the "design principles" of corporate digital infrastructures. The concept of design principles is derived from design science research. However, while traditional design science research deals with IT artifacts that were built, tested and finally evaluated by the research community, we highlight a case in which the construction of a complex IT artifact was performed by a company (Iivari 2007). Such cases can benefit from behavioral science influences that are used for theorizing, like the grounded theory method, and vice versa. The theory-generating design science research approach proved to be useful in previous studies e.g., Simon et al. (2014) developed a business architecture framework to examine the support of enterprise architecture management within corporate strategic management. Through the combination of both methods, design science and grounded theory techniques, the authors are able to immerse deeper in the research area. To identify the type of contribution, Gregor and Hevner (2013) introduce a framework for design science research knowledge contribution in a research project context. The framework is a 2x2 matrix with the dimensions of a "low" or "high" solution maturity and application domain maturity. A high application domain maturity and low solution maturity describes an improvement, i.e., the development of novel solutions for already known problems. An invention is typically a new solution for new problems and therefore it is characterized by a low application domain maturity and low solution maturity. Exaptations are the extension of known solutions to new problems and, therefore, the application domain maturity is low and the solution maturity is high. When application domain and solution maturity are both low, i.e., one applies known solutions to known problems, is known as routine design. By focusing on maturities, the framework helps to highlight research opportunities and knowledge contribution, especially for the categories improvements, inventions and exaptations.

Our case focuses on a global financial services company (FSC) that operates as a market data consolidator. Through a well-established connection to the case company, we were given the unique opportunity to gain access to this case. Initially, we were interested in a broad research objective by studying the transformative impact of digitalization on the company.

Interviewee position	**# of interviews**
C-level executive	4
Senior business leader	6
Senior IS leader	2
IS domain expert	4
Project manager	1
Total number of interviews	17

Table 1. Data collection overview

Our data collection consisted of multiple sources. We were allowed to conduct fact-to-face interviews with employees of the case company and record these on tape. We interviewed 17 employees over a period of a year, the average duration of an interview was about 80 minutes. All interviews were transcribed, which resulted in over 250 single spaced pages. These were imported to the software ATLAS.ti for further analysis. Table 1: Data collection overview, provides insight on the distribution of the interviewees position within our focal company.

The data collection is enhanced by multiple company documents that were passed on to us, such as presentation slides, reports etc. In addition, we made use of any public additional data available e.g., documents on the internet such as press releases. In sum, we collected and analyzed 37 additional documents. The documents complemented our research by providing important information on e.g., historical events like strategic decisions, product and service offerings on both, the legacy infrastructure and the new corporate digital infrastructure.

Before the interview started, we briefly introduced ourselves and informed the interviewee about our research. Our interview questions were non-standardized and path-depended on the insights we successively obtained. Thus, individually tailored to each interviewee. For example, when we interviewed participants with different backgrounds e.g., the business or IT department, customized questions guaranteed an in-depth insight by asking comprehensive and detailed questions, that thus could be of interest to each interviewee (Charmaz 2006). The questions itself were usually asked open-ended and in a general manner, for example, "can you please reflect about limitations of the corporate legacy infrastructure". Additional questions were asked, when further information was needed, e.g., "can you please elaborate on this particular event further. What were the motives behind it". In sum, this intense interviewing allowed us the desired flexibility for an in-depth research process.

For the process of the data analysis, we utilized techniques from the grounded theory methodology (Glaser & Strauss 1967; Urquhart 2013). At first, we openly coded the data, segment by segment, with the same meaning and identified categories among our codes. During the analysis of our data, we noticed that the company's corporate infrastructure transformation explained the most behavior of our interviewees, i.e., it was a topic that came up frequently. For example, our interviewees would depict problems, by pointing out essential requirements that could not be fulfilled with the former corporate infrastructure I1. Our coding became more focused, which also guided us in selectively collecting further data where it was needed. It can be describes as an iterative process where we went back and forth between data analysis and data collection (Charmaz 2006; Glaser & Strauss 1967). As the new corporate infrastructure became core of our analysis and we also deepened our knowledge in the literature of IT infrastructures and IT infrastructure transformation. Additional theoretical sampling helped us to implement theoretical insights about the IT artefact. We noticed that the new infrastructure had shared characteristics with digital infrastructures such as the internet e.g., in becoming more shared, open, scalable etc. (see section 1 Introduction and 2.1 Digital Infrastructures). We identified the IT artifact as a corporate digital infrastructure, being in line with digital infrastructures, which "[…] can be further defined with respect to the entity being supported or enabled as […] corporate infrastructures." (Tilson et al. 2010, p. 748). At the same time, we noticed that only little is knowledge exists on the very corporate level. In addition, previous work highlighted yet unanswered research questions related to the design aspects of digital infrastructures (Tilson et al. 2010, p. 757; Yoo et al. 2010, p. 733; Yoo 2010, p. 227; Lusch & Nambisan 2015, p. 163). This also lead us to the corresponding research question of *"What design principles should guide a financial IS services provider in transforming its corporate digital infrastructure in a data-heavy context?"* It also guided further data collection on the corporate digital infrastructure design choices. The integration of literature on IT value cocreation became part of our study as we explored the design of the corporate digital infrastructure along with the characteristics, functions and outcomes e.g., to "*create new products […] together with our customers"*, as one interviewee explained. The research process was repeated in order to gain a saturation, where new data only contributed a negligible amount of information to our study. Finally, this process yielded to the outcome of design principles of corporate digital infrastructures, which are presented in section 5 of this research paper.

4 CASE SYNOPSIS

4.1 Brief Company Description

The focus of our research paper is the corporate digital infrastructure of a global financial services company that operates as a market data consolidator, vendor and IT service provider. Typical customers are banks and brokers providing financial information services to self-directed retail investors (end customers). Therefore, FSC is a typical business-to-business financial intermediary. FSC gathers data from a large number of suppliers, conducts quality assurance, harmonizes the data and stores it on its digital infrastructure for further processing. The processed data comprises the full universe of financial market data (Alvarez 2006), as well as news feeds provided by international news agencies as well as macroeconomic or regulatory data. Information can be obtained in end-of-day, delayed or real time quality if available. In total, over 200 suppliers are connected to their infrastructure from all over the world. Moreover, FSC enriches the data with additional information such as derived financial key figures and calculated metrics. FSC's main pillars of business are threefold. First, the company develops and maintains web presence, i.e., portals for customers. Second, FSC sells access to its infrastructure and data to customers. By doing so, customers can develop solutions themselves e.g., applications or portals. Third, FSC offers a desktop and a corresponding mobile solution, which provide valuable information related to financial markets and contains various tools for analysis.

4.2 Case History

FSC operated a legacy corporate IT infrastructure that resulted in a company merger of formerly two separated infrastructures. The reason for this being, that FSCs management wanted to realize synergies from the merger and so decided to migrate customers to its infrastructure. However, during the migration process FSC realized that they were no longer able to provide their customers with all the expected functionalities. Thus, in order to satisfy existing customer requirements, FSC started to integrate missing functionalities, resulting in a "patchwork-infrastructure" (I1). During the last decade, changing requirements (chapter 4.3), due to the digital imperative, which needed to be met, challenged FSC's I1. An interviewee remembers:

"During the years the […] products became more differentiated, more specific with specific characteristics [talking about financial derivatives and unstructured data]. This was not foreseeable at the beginning."

The limitations of the IT infrastructure became undeniable as customer solutions couldn't be provided as required. For example, at some point, it became difficult to build certain customer solutions across the different databases of the patch worked system. One interviewee analyzed the situation:

"We were aware, that the more we said we cannot build it, the more we were in danger that our customers will look out for another service provider. However, at this time, we also knew that there was no other company, at least in our market, that could fulfil those requirements. Hence, it became clear to us, that if we are quick enough we can position a unique selling point."

Consequently, the idea to start developing specific components for a new corporate digital infrastructure (I2) was brought up by the IT department and jointly agreed on with the business department. One interviewee reflected on the circumstances leading to this decision:

„It was an odd situation. Our infrastructure was a piecework of two legacy systems. Therefore, we brought up a dedicated program, which was supposed to address the consolidation of both."

The program aimed to achieve a single standardized corporate digital infrastructure I2 by reducing the data redundancies existing across the patchwork-infrastructures, achieving less complexity and shutting down legacy systems. The new infrastructure should be future proof to arising customer demands and facilitate for innovative solutions. A critical contextual factor is also the ability to make use of the relevant data universe (including customer data), which has rapidly increased in its volume, variety and velocity within the financial services industry over the last decade –and still is.

4.3 Description of Problems with I1 and Requirements for I2

4.3.1 Service Co-creation and Innovative Solutions

FSC's customers have a large amount of valuable in-house data. Combining customer data such as specific financial products or end customers' profiles with the FSC data universe would facilitate co-created services to develop innovative financial information services. For example, customers have their own recommendation lists for financial instruments. Integrating those lists, FSC could offer customized services like complex search queries for end customers e.g., searching for all instruments on the customer's recommendation list (customer data) with the best performance of the last year (FSC's data). Another example are end customer recommendations. Through the (anonymized) hosting of end customer portfolios and watch lists of financial instruments, FSC could offer recommendation services like "customer A has funds X, Y and Z in his portfolio, thus recommend funds Z to customer B who also has funds X and Y in his portfolio".

However, the capability to integrate such customer data was limited in I1. FSC's infrastructure was rather designed as an unidirectional source of information, i.e., gathering information from different suppliers and storing them for retrieval. Therefore, the full potential, to make use of its network, including customers, had not been realized with I1. One interviewee reflected upon the problem requirement:

"We need to get data from diverse sources in a normalized way in our infrastructure. Integrating customer data would enable us to develop innovative solutions. However, this is not possible with physically separated data [referring to I1]."

4.3.2 Data Storage for Low-Latency Querying a Complex Data Universe

The financial market data on FSC's infrastructure usually comes from different sources with different characteristics (e.g., structured or semi-structured). Therefore, the storage needs to be flexible in order to account to this diversity and allow data requests that leverage the data available. Consequently, such complex data requests may require accessing many different data fields and provide a response time that is appropriate to time-critical financial information services.

A problem with FSC's legacy infrastructure was its capability of efficiently handling this flexibility to provide such quick responses. Therefore, the data needed to be stored in a way, that allowed both the flexibility in regard to assessing the full data universe, as well as low data latency. However, as I1 was based on a normalized relational data model, the necessary denormalization caused a relatively high CPU and memory usage as one interviewee told us:

"It is terrible for [such complex] requests, you need intense denormalization and consider how to efficiently store the data in your memory for those requests. This means: How we want to retrieve the data should determine our [future] data model"

Therefore, a data storage was required that could handle the increasing volume and variety of relevant data and meet the required efficiency of data retrieval in terms of speed but also CPU and memory usage.

4.3.3 Data Processing Meeting the Properties of a Financial Data

The financial service sector is characterized by a data universe of diverse varieties. For example, classic financial market data typically shows a well-defined structure (Alvarez 2006). In addition, data within news feeds are semi-structured, i.e., they contain textual data as well as additional structural information (e.g., headline, text, date, etc.). Data variety further increases when additional sources such as customer specific data are considered. Another aspect related to data processing is data velocity. In many situations, financial decision making and investing relies on the latest information and therefore, real-time data processing is a key element of high-performance financial IT infrastructures in which e.g., computer systems become market participants by being involved in high-frequency trading on the basis of milliseconds (Gomber & Haferkorn 2013). Finally, the overall volume that needs to be processed by the corporate IT infrastructure has significantly increased, which can be explained due to an increasing number of financial market transactions (i.e., trading data), a growing number of trading venues in addition to classic exchanges, as well as new data sources such as those extracted from social media. Overall, the corporate IT infrastructure needs to meet the challenges that come along with the properties of big data (Laney 2001).

The capabilities in regard to data processing of an IT infrastructure also relies on the performance of the underlying server-to-server communication. An efficient data transmission between servers can be achieved through an appropriate server-to-server protocol. However, the server-to-server protocol of I1 is characterized by processing data tables via a classic web protocol http csv leading to communication overhead. One interviewee explained that this protocol was not suitable anymore and a new protocol was needed that meets this requirement for I2:

"I1's server-to-server protocol is not as efficient [anymore] as we desire in our business. A request takes at least XXX milliseconds because a certain amount of transmission control protocol connections need to be established in advance. […] The question of which protocol is used is important for the clients. Particularly under difficult circumstances like high latencies or low data rate/bandwidth frontends our clients should still be able to operate"

4.3.4 Cost Pressure and Time to Market

Another issue was related to the development of individual front-end solutions e.g., web portals providing financial information to retail investors or professional bank advisors. Existing portals were developed on an individual basis resulting in corresponding implementation efforts, times and costs. In addition, future maintenance of the implemented portals turned out to be a burden for FSC, especially, if there was a change in its development team. Developers that newly joined the development team had to familiarize with the specific solution designs. Thus, a requirement for the new corporate digital infrastructure I2 arose with a solution that could allow for implementations providing easy-maintenance and that could be development more quickly as one interviewee reflected:

"Standard projects are much faster to develop and easier when it comes to the future maintenance of it"

5 I2 PROBLEM SOLUTIONS AND DESIGN PRINCIPLES

5.1 Design Principle 1: Customer Data Integration

In order to enable the creation of new services that fully leverage the existent data universe, FSC's new digital infrastructure I2 needed the ability to store data from their customers in additional to those of the classic data sources. As mentioned, I1 was described as a unidirectional source of information where FSC gathers information from different sources, conducts a quality assurance, harmonizes the data and stores them on its infrastructure for further processing. However, the data exchange among

FSC and its customers was limited. Thus, the architectural design of I2 now provides an API for FSC's customers and allows integrating precious private data via custom fields in the data base. Therefore, the capability of a bidirectional data exchange characterizes I2 towards a shared infrastructure.

It lets FSC step beyond the role of a pure data consolidator by now creating products together with its customers. For example, FSC co-created an innovative solution, where product recommendations are possible on the basis of end customer risk characteristics (customer data) e.g., "end customer A shows a set of individual risk characteristics which leading to a particular standardized risk classification. Based on the risk classifications, products are recommended that fit to the end customer". Therefore, customers are not just an additional resource but FSC's I2 facilitates IT value co-creation in the form of innovative solutions. One interviewee explained to us:

"The initial focus was to enable such flexibility [the openness towards integrating heterogeneous data]. Now, we are starting to design and create new products […] together with our customers."

5.2 Design Principle 2: Flexible Data Model for Data Storage

In order to process the increasing volume and variety of data in a timely manner, FSC came up with a solution that enables a scalable yet flexible retrieval and storage of data. Due to this, they are more efficient in CPU and memory usage at the same time. The solution was, to implement an array data model for real-time operations. The data model consists of multiple dimensions that can contain multiple attributes. For a two-dimensional example, there are dimensions of time and instrument ID. For each time-instrument ID combination, an array contains an attribute price. For any data request that also needs to access price data, the desired coordinates of time and instrument ID can be accessed efficiently. In contrast, the former data model would have to hold redundancies (in this specific example two copies) of the data to decrease the access time. one combination would have been organized by time-instrument ID and one combination organized by instrument ID-time. As the two-dimensional example was only to show the purposes, one can imagine that for more complex requests with n possible dimensions and m possible attributes, the new flexible data model allows a far more efficient use of memory and CPU. Especially, since FSC usually does not know in advance, what kind of requests will need to be made, by newly developed complex information services. In contrast, the former data model was not capable of providing data access in such a flexible and holistic manner. One interviewee explained:

"Structuring our data in "multidimensional arrays" for real-time operations lets clients send specific requests, without a significant increase of the memory or CPU usage"

5.3 Design Principle 3: Efficient Data Processing by Reduced Communication Overhead

To address the requirements that come along with the processing of big data, FSC decided to replace the infrastructure's underlying server-to-server communication protocol to improve the performance of data processing. As there was no suitable solution at the market, the company had to develop an individual protocol providing a low latency and reduced communication overhead. An important feature of the protocol is the "versioning", the support for request dependencies. For example, the object of an existing request is set on date, which is "accurate by day", is changed to date "accurate by second". Then, the protocol compiler updates any message (which is the smallest entity in the protocol that can be transmitted) related to a new version that uses the new type of data. Handling this complexity via an automatically generated code reduces communication overhead and increases the efficiency of the server-to-server communication.

"To handle this complexity […] you want to have support via an automatically generated code. Consequently, we developed a protocol that accounts for performance and pragmatism requirements"

5.4 Design Principle 4: Small, Reusable and Modular Software Components

FSC knew that many customer requirements for web application development are similar. Therefore, the company came up with the idea to do less customer specific (re-)coding. By doing so, the company wanted to address the need for reduced individual implementation efforts and lower maintenance costs. An IT component was developed that contains and provides widgets, which represent small, reusable modular software components. Each widget is designed to addresses a more generic application derived from past solutions. For example, there are widgets for charts, news, gainers or losers lists etc. Only little customization for the selected widgets of a customer solution has to be done. One interviewee explained that this enabled FSC to be:

"[…] more efficient in creating web applications by using ready-to-go building blocks [which means] less effort in maintenance of financial web application. Moreover, "[…] you do not have to code everything from the scratch but you can use predefined customizable widgets that are derived from past customer requirements we are aware of."

6 INTEGRATION AND DISCUSSION OF THE DESIGN PRINCIPLES

The overall contribution of our study to the IS knowledge base is the set of four design principles of corporate digital infrastructures that present design knowledge contributions, following Gregor and Hevner's (2013) framework. First, we contribute to the IS knowledge base by suggesting a new solution to a known problem, i.e., improvement type (see DP3). In particular, the problem of achieving efficiency in data processing is well known. Whilst our DP3 suggests a new solution to this, i.e., reducing communication overhead and complexity, which in our case was done by replacing the protocol of server-to-server communication embedded in the underlying corporate digital infrastructure. Second, we contribute to the IS knowledge base by suggesting the extension of known solutions to new problems, i.e., exaptation type (see DP1, DP2, and DP4). For example, in our case, the known solution of modularity in systems and architecture design was transferred, for the purpose of creating web applications in a more flexible, timely and at the same time cost-efficient way, as suggested by DP4. Similarly, DP1 and DP2 provide prescriptions for transferring known solutions to new problems.

With regard to IT value co-creation, our design principles contribute to the existing literature. In line with Barrett et al. (2011) and Grover and Kohli (2012), specializations of companies are beneficial for collaborations and promote value of co-creation. Based on our insight from the case, FSC's decision to embark the infrastructure transformation led to further specialization of this company as a data consolidator, vendor and IT services provider. DP1 yields an enhanced, heterogeneous data universe from which actors may (re-)combine resources to co-create products and services. Therefore, DP1 can be viewed as a prerequisite for co-creating innovative products and services with customers. It enables customers to populate their data to the infrastructure and strengthens the partnering relationship with these companies. Integrating partner resources and co-create innovative solutions is associated with the asset layer, because isolated companies cannot extract similar value on their own. (Grover & Kohli 2012). *Second*, DP2, DP3 and DP4 can be associated with the complementary capabilities layer. DP2 improves the real-time (product) availability and enables handling the ever increasing volume and variety of relevant data, without significantly increasing the memory- or CPU usage. Customers benefit from this capability, because speed is a fundamental advantage in many application fields of the financial services sector. Similarly, DP3 improves the data processing capability of the corporate digital infrastructure in terms of its underlying server-to-server communication performance, which addresses the data velocity. Finally, DP4 is the use of small, reusable and modular software components in order to build web applications. Thus, companies that do not have the capability of building these solutions in a quick and cost efficient manner, can draw from FSC's specialization via

DP4 in order to collaboratively build web applications. In sum, the three design principles are valuable capabilities, which can serve as complements for other companies that cannot easily build this capability/resource on their own.However, noticing that our design principles are distributed across different layers of a three tier architecture (presentation tier, application tier and data tier), interdependencies between the layers of IT-based value co-creation surface. DP1 customer data integration, DP 2 data storage and DP3 data processing describe which and how data are stored and transmitted (data tier). DP4, describes the presentation via e.g., web application (presentation tier). Therefore, interdependencies amid the layers of our design principles yield a greater source of value when considered on a whole. For example, a customer integrates data (DP1) which are then displayed via a co-created widget in a web application (DP4). Therefore, an additional contribution is the acknowledgement of interdependencies between the layers of our design principles and how co-created value creates options for further expanding value.

Design Principles (DP)	Description	DSR Contribution	Co-creation of IT Value
DP1: Customer Data Integration	allow for bidirectional data exchange	exaptation	asset layer
DP2: Data Storage	use of a flexible data model, scalable requests	exaptation	complementary capabilities layer
DP3: Data Processing	reduce communication overhead, reduce complexity	improvement	complementary capabilities layer
DP4: Small, Reusable and Modular Software Components	enable standardized, yet flexible and customized customer solutions	exaptation	complementary capabilities layer

Table 2. Integration of the Corporate Digital Infrastructure Design Principles

7 CONCLUSION

Many incumbent companies across various industries, including the financial services industry, face the key challenge of adapting historically grown legacy IT infrastructures to the generative evolution of digital infrastructures. Many of them are open, shared, heterogeneous, and overall different in many respects from corporate digital infrastructures. In our study, we worked with FSC, one case company faced with exactly this challenge, and identified a set of design principles that may guide future efforts of companies facing a similar type of problem in a similar context. With this IS design knowledge contribution, we address a frequently mentioned call for future research by prior studies on digital infrastructures (Tilson et al. 2010). Additionally, we reflect underpin our finding with literature of value co-creation and show how the architectural design choices are related to the relational view, i.e., layers of IT value co-creation Grover and Kohli (2012). Building upon this, we show how the design principles on different layers interact with each other and when combined may generate a larger source of value. In sum, as dynamics of cooperation and competitions among companies evolve and boundaries between them are blurring, we highlight digital infrastructures as an important opportunity for IT value co-creation.

Future research: We like to acknowledge that future research may extend or alter our design principles as new knowledge is generated or different cases in different settings will be analyzed. In addition, the focus of our study was placed on the technical aspects of digital infrastructures. Future research should be extended to sociological aspects of digital infrastructures, since they are regarded sociotechnical systems. Furthermore, tracking the digital infrastructures over a longer future period of time, i.e., a longitudinal case, may examine the architectural design choices from an evolutionary point of view.

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