CAN SELF-TRACKING SOLUTIONS HELP WITH UNDERSTANDING QUALITY OF SMART, CONNECTED PRODUCTS?

Research in Progress

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Abstract

Smart connected products (SCPs) have gained significant attention in different domains because they offer numerous benefits and change the form of competition and value creation. While quality is important for SCPs, no holistic quality model is available to target the present quality problems. Furthermore, since the concept of an SCP is quite abstract, a bottom-up approach that starts with a concrete example seems suitable. Therefore, this paper identifies the five key components of SCPs and maps them to self-tracking solutions (STS) in order to show that STSs are appropriate examples. We also analyse quality models in corresponding areas to verify the absence of a holistic quality model for the selected example. This contribution identifies the research gap regarding holistic, stakeholder-oriented quality models and helps researchers understand SCPs better.

Keywords: Quality, Smart Connected Product, Self-Tracking Solutions, Internet of Things.

1 Introduction

The digitalisation of physical products, like thermostats (e.g., NEST), lighting systems (e.g., Philips Hue), or watches (e.g., Apple Watch), seems to 'offer various benefits for both providers and users' (Novales et al. 2016, p. 1). Thus, smart, connected products (SCP) have gained significant attention in different domains, such as home automation (e.g., smart home and smart energy), health care and self-tracking (e.g., smart health), manufacturing and agriculture (Fleisch et al. 2015; Porter and Heppelmann 2014).

The emergence of such products has external (e.g., competition) and internal (e.g., change of business processes) consequences for companies that target these markets (Porter and Heppelmann 2015, p. 39) because SCPs are 'changing how value is created for customers, how companies compete, and the boundaries of competition itself' (Porter and Heppelmann 2014, p. 88).

However, research in this domain is still in its beginnings. No particular standards are available, even common terminology is still missing. Digitized products, Internet of Things, cyber-physical systems or smart objects are just a couple of terms that are used interchangeably. However, even if authors do use the same term, this does not necessarily mean they refer to the same underlying concept (Novales et al. 2016; Püschel et al. 2016, pp. 3–4).

Research literature on (quality) challenges and solutions for SCP in general is even scarcer, as most research seems to focus on their respective application area (e.g., smart home, smart city) only. Thus, the synergies of solving application area independent challenges are neglected; although, for example, privacy or design issues are challenges of SCP in general (Novales et al. 2016, pp. 7–8). Quality is also important for every customer-oriented SCP, as customers use quality as a decision tool in the process of purchase (Freund and Spohrer 2013, pp. 4–5; Lieb et al. 2008, p. 2). Furthermore, SCPs also ‘take quality management several steps farther’ due to new opportunities like real time monitoring (Porter and Heppelmann 2015, p. 102).

But, as the research field is quite new, there is no holistic quality concept that addresses the specific characteristics of SCPs (Brogt et al. 2017, p. 8). Therefore, we see the potential in research for a holistic SCP quality model, which supports developers and researchers with an appropriate foundation. Not neglecting previous work in the different application areas, we want to start our research based on one example of an application area and using inductive reasoning to build a SCP quality model from there on.

For this purpose, it is important to select an appropriate example for SCP that features many characteristics of SCP in general. In this paper, we explain why and to what extent self-tracking solutions (STS) represent SCP, both on a conceptual level and in the problem area of quality. Therefore, we outline the conceptualisation of SCP first. We will also give a brief introduction into the current status quo of quality research in STS as a prerequisite for the future work that is currently in progress.

Therefore, this paper aims to add to the research field of SCPs by answering the following research questions: How can SCPs be conceptualized? To what extent do STSs represent SCPs? What is the current body of research related to the quality of STSs? Since the answers to these questions help us to define SCPs and STSs more clearly, we believe they will also help to identify research gaps and support our future research.

In the following sections, we start with analysing the concept of SCPs in detail and then map self-tracking solutions on it (cf. chapter 2). We then present available quality definitions and models (cf. chapter 3) and our conclusions (cf. chapter 4) and future research (cf. chapter 5) afterwards.

As a methodological approach, we used a traditional, narrative literature review, which helped us to get an overview of the theoretical background and available concepts (Boell and Cecez-Kecmanovic 2015, p. 164). Further, we integrated promising papers known to the authors from previous research.

2 Smart, Connected Products and Self-Tracking Solutions

2.1 The Concept of Smart, Connected Products

This research focuses on a combination of physical devices with sensors, mobile applications and web platforms, which can be summarised under the term ‘SCP’ that was introduced by Porter and Heppelmann (2014). To answer the research question regarding the conceptualisation of SCPs, we will present and discuss different conceptualisations available in the literature in the following. An overview can later be found in Figure 1.

Based on their reputation and commonness in this specific domain, we chose the Porter and Heppelmann’s (2014, p. 68) article as basic literature and a starting point for our research. They define SCPs as a combination of three core elements: 1) physical components (mechanical and electrical parts) as basic elements, that are enhanced by 2) smart components (sensors, microprocessors, data storage, controls, software, embedded operating system and enhanced user interface) and 3) connectivity components (ports, antennae, protocols enabling wired and wireless connections) that enable additional functionality.

In the context of the wider Internet of Things (IoT) paradigm – which can be generalised as a variable combination of sensors, networks, actuators, local and cloud intelligence and user interfaces (O'Reilly 2014) – Fleisch et al. (2015, pp. 446–447) define the digitalisation of physical things as five levels of added value: physical things (Level 1), sensors and actuators (Level 2), connectivity (Level 3), and analytics (Level 4), which result in a digital service (Level 5), e.g., in the form a web service or mobile application (Fleisch et al. 2015, pp. 446–447).

Three of these five levels of added value can be directly matched to the core SCP components of Porter and Heppelmann (2014, p. 68): Level 1 = physical components, Level 2 = smart [sensor] components, Level 3 = connectivity components. The two additional levels (Levels 4 and 5) are part of a technology stack provided by Porter and Heppelmann (2014, p. 69) additionally. The therein-included product cloud layer consists, amongst others, of an analytical engine (Level 4) and an application platform (Level 5). The similarity of the models is not surprising under the consideration that Fleisch et al. (2015) indicate Porter and Heppelmann (2014) as one of their sources. However, the levels of added value provide a bidirectional relationship between the levels in contrast to the technology stack. Thus, making it impossible to consider or develop the levels separately from each other, as according to Fleisch et al. (2015, p. 447) there is a need of a deep integration between the digital (e.g., services) and physical (e.g., device with sensors) worlds.

Novales et al. (2016, p. 4) identify five conceptual elements of SCP based on a literature review, which are hybridity, smartness, connectivity, servitisation and ecosystem. All of these elements besides hybridity are not mandatory but potential building blocks. Therefore, the authors argue that different SCPs combine different conceptual elements (Novales et al. 2016, pp. 4–5). As their research also includes the findings of Porter and Heppelmann (2014, 2015), the identified building blocks match with their SCP conceptualisation. Thus, the characteristics from Novales et al. (2016, p. 4) also overlap with the levels of added value of Fleisch et al. (2015, p. 447). Levels 1, 2 and 3 cover hybridity, smartness and connectivity, while Levels 4 and 5 cover smartness and servitisation. Only the ecosystem is not represented directly by the levels of added value. An ecosystem can be defined as a ‘virtual entity’ with the objective of ‘cooperation, interaction and competition’ between different entities, which affects social structures and the surrounding industries by connecting and improving physical infrastructures (Tilson et al. 2013, p. 4633; Zhang and Jacob 2011, p. 147).

Thus, the main difference regarding the conceptualisation by Novales et al. (2016, pp. 4–5) is the optionality of the building blocks, while the other authors see them as mandatory parts of a whole. We argue for the consideration of all building blocks, as we see the peculiarity and challenge in combining all the building blocks to one solution. Furthermore, an isolated focus in the context of our research is not helpful because every block has its own challenges (Novales et al. 2016, pp. 7–8), which must be at least solved in the combined product as mentioned above. Also, according to Lieb et al. (2008, p. 4), ‘the production of every specific component itself has to reveal high quality’ in the context of product development. This includes not just the main components like the physical product, but also the supporting technologies as the design of a mobile application, for example, ‘can strongly influence the overall satisfaction and acceptance of the wearable, as a whole’ (Altenhoff et al. 2015, p. 244). If a quality model only focuses on the physical product (wearable) of a STS, this may lead to an unpredictable and probable insufficient quality.

In addition to the already presented SCP conceptualizations, Püschel et al. (2016) derive a SCP conceptualization based on existing IoT (technology) stacks using also, amongst others, the works of Porter and Heppelmann (2014) and Fleisch et al. (2015). Their concept distinguishes four layers: thing, interaction, data and service, which overlaps with the concepts presented so far. The difference is the emphasis of the data, using a distinct layer that focuses on possible data sources and the data usage. The data source can be, for example, the perceived context of the physical thing, while the data usage can be an analytical one (Püschel et al. 2016, p. 8). But, these aspects are also considered in the analytics level (Level 5) of Fleisch et al. (2015) or the smart components of Porter and Heppelmann (2014).

From these four SCP conceptualizations, it can be concluded that SCP consist of three core components: C1: physical components, C2: sensor components and C3: connectivity components. However, two additional components add further levels of value: we subsume the analytical engine from Porter and Heppelmann (2014, p. 69) and the data layer from Püschel et al. (2016, pp. 10–12) under C4: analytical components. Similarly, we subsume the digital service layer from Fleisch et al. (2015, pp. 446–447) and the servitisation building block from Novales et al. (2016, pp. 4–6) under C5: service component. Our conceptualization of SCP can be found in Figure 1.

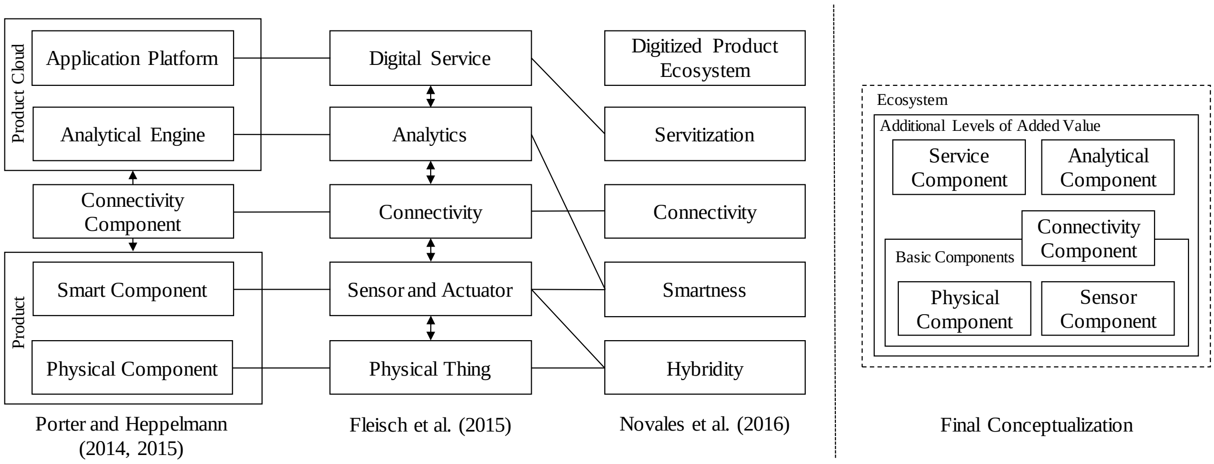

Figure 1: Overview over SCP definitions and their mappings to each other by author (left) and final conceptualization (right)

In summary, we define SCP as a concept that consists of five components (C1: physical components, C2: sensor components, C3: connectivity components, C4: analytical components and C5: service components) that depend on each other in terms of integration.

In other words, the distinct features of SCPs include the digitalisation of non-digital products (e.g., from watches to smartwatches) (Jarrahi 2015, p. 1769), the possibility for extension by simply adding additional elements into their ecosystem (Zhang and Jacob 2011, p. 147), the hardware and software combination that creates value for customers and companies (Jarrahi 2015, p. 1769) and the possibility to perceive the environment and operate in an autonomous manner (Roy et al. 2017, p. 258).

2.2 Self-Tracking Solutions as Examples for Smart, Connected Products

Despite being a new research field, there are already many different examples of SCPs in very different application areas as demonstrated in the article of Porter and Heppelmann (2014). But neither every example, nor every definition of SCP combines all of the building blocks of SCPs (Novales et al. 2016, pp. 4–5). Thus, not every example is an appropriate example for our future research, as the consideration of all components is important (as explained in the previous section). Thus, in the following, we will explain to what extent STSs are appropriate examples of SCPs for our future research by highlighting what components of SCP are covered and what additional advantages they offer.

STSs support consumers in tracking different parameters of their daily activities. Although the tracking of one’s own training or nutrition in itself is not a new phenomenon, the technology support and data collection possibilities are (Fawcett 2015, p. 249; Jain and Jalali 2014, pp. 100–102). Along with mobile health applications, they promise numerous advantages on individual (e.g., improved health or fitness), organisational (e.g., improved performances or less sick-leave) and national levels (e.g., improved health care system) (Albrecht 2016; GfK 2016; PwC 2016, pp. 19–22). The most prevalent STSs are fitness bands and smart watches (both are also known as fitness trackers,) and smartphones with fitness applications (BMJV 2016, p. 3; Maas and Rohleder 2016; PwC 2016, pp. 19–22).

Although smartphones with fitness applications seem similar to the concept of an SCP, they are different, as they are missing a connected external device (e.g., bracelet). They contradict the basic component hybridity and the concept of digitalisation of physical products. Although one could argue for the smartphone as being the physical component, it still does not fit the idea of digitalisation of a physical product, as a smartphone is a multi-purpose device that does not focus on self-tracking. Furthermore, more people seem to use a dedicated STS (24% in total; 18% bracelets + 6% smartwatches) than a smartphone with a fitness application (13%) to track personal health or fitness data (Maas and Rohleder 2016, p. 6). Therefore, we do not consider smartphones with fitness applications in this research.

Regarding fitness tracker solutions, popular vendors (e.g., FitBit, Jawbone and Garmin) provide solutions that usually consist of the following components:

- A physical component (e.g., a wristband) (C1)
- Sensors for measuring different parameters (e.g., steps, pulse or activity duration) (C2)
- A connection to a processing node (e.g., Bluetooth connection from wristband to smartphone) (C3)
- Additional analytical functions (e.g., using sensor data to detect the type of activity in a mobile application) (C4)
- A digital service (e.g. adding performance comparison in contrast to friends in a web-based dashboard) (C5)

Besides viewing the recorded data and behavioural advice, the corresponding mobile applications might allow the user to add additional data manually (e.g., ingestion, thus replacing C1 and C2 with manual input). Additionally, it often allows achievement sharing on social networks or directly in the application (e.g., FitBit Application available for Android and iOS). Thus, a mobile application connected to a provider is able to cover C4 as well as C5.

STSs can also be part of digital ecosystems. For example, the manufacturer FitBit offers a smart scale that can be used with other products made by the company. In this case, a customer could access their weight data with the same mobile application used for the activity data provided by a wearable device.

Therefore, STSs cover not just some of the SCP components, but all of them. From an economic point of view, they're also low cost compared to other SCPs but provide many different sensors and functionalities. They are used by consumers independent of age (teenagers, adults, as well as seniors), gender (female and male), or health situation (sick and healthy people) and for different reasons (e.g., reaching goals, or rewards collecting) as the research of Gimpel et al. (2013, p. 7) and Rooksby et al. (2014, p. 1165) indicates. They are also quite popular (PwC 2016), making them valuable research objects for general SCP research questions.

But despite their wide dissemination, STS users cannot be motivated to use their STS device in the long term (Ledger and McCaffrey 2014, pp. 4–7; PwC 2016, pp. 5–6; research2guidance 2016, p. 17). The corresponding solutions suffer many different challenges, like missing interoperability, platform heterogeneity, unclear use-cases, sync or privacy problems (De Moya and Pallud 2017; PwC 2016; Rooksby et al. 2014).

These kinds of quality challenges are neither exclusive to STS, nor in some cases exclusive to SCP. As the concept of SCP is new in all of its application areas, it is to be expected that challenges occur in all of them, especially since some of these concepts are built on each other. Smart cities, for example, incorporate the concepts of smart homes, smart healthcare or smart energy among many others (Silva et al. 2018, pp. 704–705). Therefore, besides domain specific challenges like waste management in smart cities, certain challenges occur in different application areas similarly. Smart home or smart city, for example, also show challenges like data security and interoperability, as well as technology acceptance or device reliability issues regarding smart objects (Alaa et al. 2017, pp. 57–60; Silva et al. 2018, pp. 709–710). Moreover, Novales et al. (2016, pp. 8–9) identify a list of 37 managerial SCP challenges, which affect different parts of their SCP building blocks including data quality, support for new business models, multi-actor coordination and user experience. Otherwise, integration issues resulting from missing interoperability and platform heterogeneity are basic topics in the information systems discipline. Therefore, they are not exclusive to STS or SCP.

Thus, STSs not only cover all of the conceptual components of SCPs, but also represent many SCP quality issues and offer additional research advantages. By this means, they are appropriate research objects regarding research into quality issues and solutions of SCPs.

3 Quality Models for Self-Tracking Solutions in the Context of Smart, Connected Products

A first literature search did not reveal any STS-specific quality models. This is not surprising as the popularity of STS grew along with technology developments (e.g., smartphone, smart watches) only in recent years (Fawcett 2015, p. 249). However, STS/SCP consist of the aforementioned five components and not just a single service, software or physical product. For these singular components, different quality concepts are available and should be taken into account before conceptualising any kind of STS-specific model as they offer valuable insights into characteristics and relationships of different factors. Thus, in the following, we introduce models and standards for the different components of STS/SCP to give insight into their possibilities and limitations. Our focus will be on C1, C4 and C5, which are clearly central topics of information system research. The quality of the components C2 and C3 is still important for a high qualitative SCP but more from a hardware-oriented and engineering-based perspective, which is not part of our actual research. This will also illustrate the complexity of quality regarding STS/SCP as an aggregation of its components.

C1 – Physical Component Quality: The ISO 9000 is a well-known product quality standard with a certification program that has had 'a major impact on worldwide commerce' (Stevenson and Barnes 2001, p. 50) and that is applicable for any type of product and business domain. It defines quality as the 'degree to which a set of inherent characteristics […] of an object […] fulfils requirements' (DIN EN ISO 9000:2015, p. 39). The ISO 9000 includes the concepts of process, stakeholder and service orientation to a certain degree (DIN EN ISO 9000:2015, p. 10). However, despite its success, it remains a high-level abstract concept that applies to various application domains with a strong focus on requirement-orientation, users and physical products.

C4 and C5 – Analytical and Service Component Quality: The ISO 25000 series was developed as a merged standard of earlier attempts to address the special demands of the software engineering domain (ISO/IEC 25000:2014(E), p. 19). It defines three separate quality models: quality in use, software/system product quality and data quality (ISO/IEC 25010:2011(E)). Most recently, an IT service quality model supplemented the series (ISO/TS 25011:2017(E)). In contrast to the ISO 9000, the series does not focus on the satisfaction of customer requirements, but on the satisfaction of stated and implied needs (ISO/IEC 25000:2014(E), p. 6). Although the standard is more domain-specific than the ISO 9000, it remains an abstract concept applicable for many different software products. The standard also provides only singular models for the different aspects instead of an integrated model. The IT service quality model is a supplement defined most recently and is not yet considered throughout the other documents of the standard.

Service quality in general is defined and conceptualised in many different quality models throughout literature. Seth et al. (2005, pp. 933–934) identify 19 service quality models and conclude 'that there does not seem to be a well-accepted conceptual definition and model of service quality'. Even more recent literature still suggests and conceptualises new service quality models as, for example, by Miller et al. (2013). However, despite their heterogeneity, service quality models also share common aspects: 'They propose a multidimensional service quality conceptualization that it is inherently linked to the measurement of consumer quality perceptions' (Martínez and Martínez 2010, p. 29).

Different than service or software quality, mobile application quality is also determined by the quality requirements stated in the respective provider guidelines, such as from Apple for iOS (Apple 2018) or from Google for Android (Google 2018a). These guidelines provide various insights into the design of the application that influences, for example, the usability of the application, a factor also found in the ISO 25000 series (ISO/IEC 25010:2011(E), p. 3). Google even provides its mobile application developers with distinct quality guidelines for Android (Google 2018b). However, these concepts are often very provider-specific and support a certain perspective on quality that might not always be in accordance with other stakeholders, such as those from the health care domain (Grundy et al. 2016, p. 1052).

Additional Concepts and Stakeholder Integration: Physical, software, service and mobile quality are not the only quality facets of STS/SCP. Information quality or interaction quality, for example, might also be taken into account as important parts of an overall quality understanding (Akter et al. 2016, p. 5). Furthermore, different concepts have recently found their way into different quality model proposals of different domains, such as concepts of perceived hedonic value (pleasure through aesthetic, experiential or sensory benefits a user perceives) and perceived utilitarian value (functional, instrumental or practical benefits a user perceives). These concepts affect consumers' attitudes towards products (Hsu and Lin 2016, p. 43; Im et al. 2015, p. 168), as well as utilitarian and hedonic information quality (Akter et al. 2016). This focus on characteristics perceived by a user are also found in approaches like the Technology Acceptance Model and its extensions (Venkatesh et al. 2003). With regards to IoT, O'Reilly (2014) even argues for the term 'the Internet of things and humans' (IoTH) to emphasise the important role of the customer, especially in the context of IoT.

Not just user, but stakeholder orientation and integration are topics argued for in research literature. Examples can be found in the context of value co-creation (Enquist et al. 2015, p. 330), designing systems (Benyon 2013, p. 43), project management (Nelson 2005, pp. 364–365) and smart city development (Marrone and Hammerle 2018).

Products, services, information systems and applications all can have many different stakeholders. Due to scarce resources, it is not always possible to involve, for example, different users in the design (Marshall et al. 2015, p. 311) as a stakeholder can be 'any group or individual who can affect or is affected by the achievement of a corporation's purpose' (Freeman et al. 2007, p. 6). In context of mobile health applications, Albrecht (2016, pp. 37–38), for example, identifies nine relevant actors: federal governments, advocacy groups, manufacturers, providers, lay users, professional users, researchers, utilities and payers. The example of STS also shows how different even the user stakeholder group can be and how many providers might be involved in the development process (e.g., smartphone, bracelet and sensor providers), influencing the quality of the product. But, not involving, for example, users in the development process can lead to misconceptions about the requirements (LeRouge et al. 2013, e252-e253)

Although the concept of stakeholder orientation has been part of the ISO 9000 concept, the customer perspective is emphasised instead (DIN EN ISO 9000:2015, p. 10; Stevenson and Barnes 2001, p. 46). The ISO 25000 series emphasizes the concept of stakeholder consideration and integration at many points throughout the standard and even argues that not all quality characteristics will be relevant to every stakeholder (ISO/IEC 25010:2011(E), p. 3). However, despite its stakeholder emphasis, the term 'user' is used instead of stakeholder in the various definitions provided within the standard.

Summary: A large number of models for very different branches and areas of application are available that affect a potential STS-specific quality model. Organisations today already tend to use multiple quality management methods in parallel (Johannsen 2013, p. 999). Although no (holistic) STS-specific quality model is yet available, the integration of available models into a multi-dimensional model seems, despite their multitude, necessary in certain ways. Nevertheless, the integration approach yields certain challenges that must be considered beforehand. Johannsen (2013, p. 1002), for example, identifies different interpretations, naming conflicts and competing interdependencies as major challenges for quality management method integration.

4 Conclusion

The goal of this paper was to conceptualize SCPs and to show to what extend STSs are an appropriate representation of this concept. We also introduced the current body of research related to the quality of STSs. We showed that STSs fit the concept of SCPs quite well since all aspects of the definition and the distinct features described are present. Moreover, STSs show problems with quality that are also present in SCPs. Finally, our literature review revealed that existing concepts in related areas are mature but not sufficient (e.g., service quality) because only isolated aspects are targeted (e.g., quality of the physical product).

Thus, we see a high potential for developing a holistic quality model for SCPs based on STSs. However, this task is not without certain challenges. First, the model must address the demand in recent literature for a stakeholder-oriented approach. Second, STSs consist of a physical product (wearable), a supporting mobile application and an optional web application, all of which are connected with the help of connectivity elements. Thus, quality concepts concerning physical products, information systems, mobile applications and web applications must be analysed in detail and aggregated for the context of SCPs. Similarities, differences, gaps and possible conflicts or mutual support must be identified since concepts related to quality differ from each other in different domains.

This research has a few limitations. The applied methodology provides limitations that might hinder the identification of all available literature in the area of concern. Likewise, due to the length limit of the conference, not all approaches could be analysed in detail, as the research field of quality is highly complex and has a long history and different understandings. Nevertheless, the results of this research allowed us to justify the initial research gap for the example of STSs, which created a foundation for future research. With the multi-layered definition of SCPs, a comprehensive description of the concept is available with different starting points for analyses. Furthermore, the presented example (STS) has viable prospects for future research.

5 Future Work

Our future research will be based on design science research (DSR) and the information systems research framework (Hevner et al. 2004, p. 80; Hevner 2007, pp. 88–91). The approach will be used to develop a quality concept for STSs (and ultimately SCPs in general) that considers the relevant stakeholders, requirements and characteristics of such products.

We expect our future work to contribute to theory and practice in two main ways. First, the developed concept of quality will help researches and practitioners to obtain a better understanding of quality in the fields of STSs and SCPs, which will subsequently help to provide insights into the corresponding challenges. Furthermore, the planned research process will provide an overview and classification of the quality models and concepts that are currently available in the body of knowledge. Second, our research will contribute a specific concept of quality for STSs. This will provide researchers and practitioners with a framework to classify and understand existing, domain-specific problems. Furthermore, the comprehensive analysis of requirements will help practitioners design STSs.

The next step is to design the research approach in detail. Starting with a systematic literature review, the focus will be on the systematic identification and classification of quality models to design, develop and evaluate the planned artefact and to overcome the limitations of this paper. After finishing the entire process, the development of methodological artefacts, such as process models to ensure a certain level of quality or quality management systems, will help to provide better, stakeholder-oriented products that are based on our concept of quality.

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