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RESEARCH ARTICLE

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What Lies Beneath: Unraveling the Generative Mechanisms of Smart Technology and Service Design

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Abstract

The rapid digitalization of products and services has given rise to smart, technological products and services in various industries. While researchers recognize the complexity of digital components embedded in smart services, there exists scarce research on the evolution of product development, smart technology's use, and the mechanisms wherein changes in products and services are triggered and implemented. In this research, grounded on the theoretical basis of layered modular architecture, we study a digital venture in an event management industry and offer a substantive look at the three mechanisms—system-environment fitness, data exploitation, and user expansion—that are responsible for transforming smart technology from a conceptual idea into a real product and from a simple digital device into an integrated smart system. Our research findings offer theoretical insight into the dynamics and fluidity of mechanisms that are relevant to smart technology's design, use, and outcomes.

Keywords: Smart Technology, Digital Innovation, Layered Modular Architecture, Case Study

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1 Introduction

The continuing development of digital technologies is changing the forms and patterns of products that people use every day, such as watches, phones, cars, and even traditional, nondigital goods (e.g., clothes and furniture) (Yoo, Henfridsson, & Lyytinen, 2010). For example, the Apple Watch—with a built-in accelerometer, gyrosensor, GPS, and a number of supporting applications—can record people's daily movements and exercise patterns. The data recorded by smart watches can be analyzed in real time or transferred to other paired devices for personal purposes (e.g., healthcare).

Researchers argue that digital technologies have unleashed a new era of smart, connected products (Porter & Heppelmann, 2014, 2015). When defining the "smart" concept, Porter and Heppelmann (2014) emphasize the viewpoint of the *smart*, *connected product*, asserting that the new forms of such products share three core technological elements that distinguish them from traditional goods: physical components (e.g., mechanical and electrical parts), smart components (e.g., sensors, data storage, software, an embedded operating system, and a digital user interface), and connective components (e.g., ports, protocols, and networks between a product and its database). Technological components enable the development of smart products and facilitate organizations' abilities to access, interact with, and integrate information gathered from various data sources both inside and outside of those technologies. Whereas Porter and Heppelmann (2014) detail the technological characteristics of smart products, Marinova et al. (2017) take a service-oriented perspective by defining smart technologies as tools that comprise information, software, and hardware capable of enabling machine-to-human as well as human-to-human interaction. Through continuous interaction and learning over time, smart digital technologies can adapt and offer customized, attractive services to users (Marinova et al., 2017). Accordingly, smart technologies are built on the simultaneous pursuit of the improvement of technological functions as well as the customization and adaptation of services in their specific contexts of use, which also implies that smart technologies are involved in building integrated systems with device interconnections (both physical and digital) to data and individuals to offer customized and flexible services.

While previous research has provided a fundamental basis for understanding the nature and potential of smart technologies, it has nevertheless been inhibited by two problems. First, most work remains at the conceptual level (e.g., Porter & Heppelmann, 2014). We contend that conceptual views of smart technologies and services offer insufficient insight into the development of such technologies and the mechanisms that influence their transformation and evolution, especially considering the array of already existing innovative hardware/software options available for structuring smart technology solutions. The extant work seems to presume that building and installing smart technologies are unproblematic processes and does not address "dynamic problem-solution design pairing" (Nambisan et al., 2017, p. 226), that limits the understanding of how smart technologies are constructed and used in contemporary organizations over time (Faulkner & Runde, 2013; Yoo, 2013; Peppard, 2018; Nambisan, 2013).

Second, the development of smart technologies now requires multiple interconnected technologies relating to data, hardware, and software in tandem with customized services. However, deploying these technologies is difficult because their technological functions must offer a stable foundation while also being dynamically adapted to services aligning with users' demands (Koutsilouri et al., 2018; Yoo et al. 2010). Nevertheless, we argue that a comprehensive product or platform is achievable. While the creation of smart technology is already a major goal for many companies (Devenport & Kirby, 2019; Rigby, 2017), various issues related to the strategically important adaptation and (re)combination of core technological components for developing smart products and services remain underexplored. To fill this research gap, we aim to extend the smart technology literature by adding empirical content to conceptual statements and elaborating on the generative mechanisms and context enabling these formerly proposed concepts. We do so by examining the development of a smart, technological product and its continuous evolution. As such, we pose the following research question: *How are digital technologies brought together to construct smart products and services over time?*

To address this question, we draw upon the theoretical perspective of layered modular architecture (Yoo et al., 2010) that links relevant technological components of digital innovations, such as smart products (e.g., the device, network, content, and service). This approach involves analyzing both independent components and a combination of digital components that comprise a particular set of smart technologies tailored to offer particular smart services. In addition, we deploy a process approach by undertaking an in-depth case study of Loopd—a digital venture that provides digital offerings for event management. By combining a smart tag—that is, a digital badge that event attendees wear—a mobile app, data analytics, and other digital technologies, Loopd's smart tag system is an innovative solution allowing professional event attendees and organizers to enhance their on-site interactions, access real-time session analytics, and receive customized post-conference reports. The product evolution journey, in this case, starting from a conceptual idea and developing into an integrated smart system, offers researchers a unique opportunity to inform the theoretical development regarding the temporal developments and changes associated with such digital offerings. Our research findings reveal three generative mechanisms (system-environment fit, data exploitation, and user expansion) that motivated the creation of the smart tag system and transformed it from an idea to a real product and from a simple, digital device to an integrated smart system.

The remainder of this research paper is organized accordingly: We first develop a conceptualization of smart products and services by explicating the digital characteristics that make them fundamentally different from traditional goods and then discussing layered modular architecture as the study's theoretical basis. We then detail our research methodology and case narrative. Finally, we conclude with theoretical implications and offer some avenues for future research.

2 Becoming Smart: From Digital Technologies to Smart Technologies

In an earlier study on digital technology, Yoo et al. (2010) distinguish digital technology from traditional information technology on the basis of three fundamental technological properties: reprogrammable functionality, data homogenization (enabled by the discrete representation of data in bits of 0 and 1), and self-reference (which creates positive network externalities).

These unique characteristics form the basis for creating new forms of quickly evolving products. Moreover, Ekbia (2009) asserts that digital technologies are active, imminent, unstable, and loosely bounded entities that constitute and are constituted by their environments. Kallinikos, Aaltonen, and Marton (2013) argue that digital technologies are in constant flux and experience difficulty persisting over time. In their paper, the authors address four pliable elements that constitute digital products: editability, interactivity, openness and reprogrammability, and distributedness (Kallinikos, Aaltonen & Marton, 2013). The nature of editability offers digital technology the ability to continuously modify and update its components. These products are interactive and thus produce pathways along which human agents can activate objects' functions or explore underlying information items. Openness and reprogrammability allow individuals to access and modify content through other agents and devices. Finally, digital technologies are distributable, whereby as transient assemblies of functions, information items, or components spread over information infrastructures or the internet—a condition that sets them strongly apart from physical objects. This research indicates that the functionalities and capabilities of digital technology possess a certain level of flexibility.

Because of an acceleration in complex and innovative technological development and deployment, digital technologies have unleashed a new era of smart, connected products (Porter & Heppelmann, 2014, 2015). Bharadwaj et al. (2013) view these new forms of digital technologies as combinations of information, computing, communication, and connectivity technologies that facilitate product interconnection. Ramaswamy and Ozcan (2018) echo this, proposing the artifacts-persons-processes-interfaces model, which expands the definition of digital technology from a component to a digitalized, networked arrangement. This model articulates a digitalized network comprising related objects (physical and digitalized, including data in the form of numbers, text, pictures, audio, and video), people (including customers, employees, and organization partners), processes (increasingly software enabled with, e.g., algorithms), and interfaces (physical and digitalized). It has become clear that the creation of new forms of smart products involves the formulation of digital technology not only as a physical good that incorporates multiple digital functions, but also as an interactive system with the networked arrangement of information, computing, communication, and connectivity technologies (Bharadwaj et al., 2013). The general consensus is that a digital technology is not fixed, but rather interconnected among multiple technological devices (e.g., El Sawy, 2003).

Departing from a product-focused perspective, in their consideration of smart services, Marinova et al. (2017) argue that digital technology should offer capabilities that enable users to learn from the interactions between machines and themselves in order to coproduce value. This argument focuses on customized service delivery and conceptualizes how both digital technology and the humans involved in coproduction activities can learn and thus *become smart* (Marinova et al., 2017). Similarly, Huang and Rust (2018) identify four types of intelligence required for deployment of a smart service: mechanical, analytical, intuitive, and empathetic. In particular, the capabilities of learning and adapting, based on digital devices, analytics data, intuitional professional skills, and an understanding of interpersonal relationships, constitute the contextual essence of smart services.

Majchrzak, Markus, and Wareham (2016) suggest that the discussion related to digital technologies has shifted its focus from technological features to implementations. For example, Leonardi et al. (2016) investigate the application of banking systems that collaborate with retail stores and post offices, and Jha, Pinsonneault, and Dubé (2016) explore the development of an IT-based platform that supports farmers and farming industries. Majchrzak et al. (2016) argue that in order to deploy digital technologies in practical settings, it is essential to investigate their use and users in terms of how the technologies are used (rather than simply their availability) as well as who the actors are and what their goals and values are (in contrast to generic actors). A Stanford University report (2016) also indicates that, since digital technology is developed to effectively collaborate with people, service automation is moving toward building interactive smart systems.

In summarizing the extant literature, it has become clear that the fast pace of digital technologies, coupled with multiple devices, rich data, and network connectivity, are making technologies smart. By drawing upon previous research on smart technologies and their implementation, we articulate smart technologies as digital technologies that comprise data-rich, customized analyses based on an infinite array of interconnected devices or components. Moreover, by continuously learning and adapting, organizations can offer users (e.g., employees, customers) tailored and desirable services. Put simply, we argue that smart technologies arise from the simultaneous pursuit of improving technological functions as well as customizing and adapting services in use.

While prior research has noticed the rising importance of smart technologies, contributions have been mainly prescriptive and normative, thus offering a rather conceptual view for understanding the development of smart technologies. Prior research has generally assumed that building and installing smart technologies involve unproblematic processes, and has failed to sufficiently question and explore how these technologies are formulated and transformed over time. Such prescriptive, static, and normative stances limit our understanding of how smart technologies are developed in contemporary organizations (Faulkner & Runde, 2013; Yoo 2013; Peppard, 2018; Nambisan 2013). In this sense, Nambisan et al. (2017) emphasize that "digital innovation can be viewed as a constant search for and identification of new or evolved problem-solution pairs" (p. 288). Thus, to gain an insightful understanding of how complex smart technologies are constructed, it is essential to examine the problems that may occur throughout the developing processes and the solutions proposed to alleviate these problems. Our paper echoes this aim by placing emphasis on the investigation of the evolutionary process of developing smart technologies.

Furthermore, digitalization has challenged some fundamental assumptions about IT's role in the context of product and service development regarding a product's design, construction with digital technologies, and/or transformation into a smart technology (Faulkner & Runde, 2013; Porter & Heppelmann, 2015; Marinova et al., 2017). Disentangling digital technologies based on the underlying organizational contexts (Bharadwaj et al., 2013; Peppard, 2018; Koutsilouri et al., 2018) and understanding generative mechanisms in organizations have also become increasingly difficult endeavors (Peppard, 2018; Yoo, 2013; Jarvenpaa & Standaert 2018). To tackle these challenges, we argue that the layered modular architecture framework (Yoo et al., 2010) provides a fundamental basis and the organizing logic necessary to unravel generative design mechanisms.

3 Theoretical Basis: Layered Modular Architecture

Yoo et al. (2010) propose the layered modular architecture framework—a hybrid of the layered (Benkler, 2006) and modular architecture of IT, both of which focus on a physical product (Ulrich, 1995). The layered architecture concept originates from Yochai Benkler (2006), who proposed the concept of a networked information economy and suggested a layered architecture framework for IT development based on physical, logical, and content layers. Yoo et al. (2010) expand the layered architecture concept to cover the involvement of contemporary digital technology and maintain that layered architecture comprises four layers: devices, networks, services, and content (see Figure 1). The device layer can be divided into a physical machinery layer (e.g., computer hardware) and a logical capability layer (e.g., operation systems)—the latter provides the physical machine with control and maintenance and thus connects it to other layers.

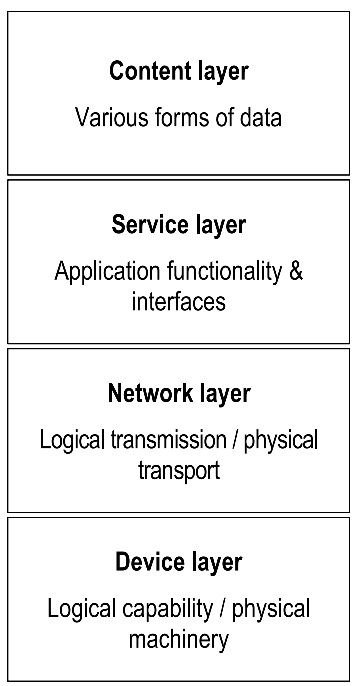


Figure 1. Layered Architecture, Adapted from Yoo et al. (2010)

The network layer is also divided into a physical transport layer (including cables, radio spectrum, transmitters, and so on) and a logical transmission layer (including network standards such as TCP/IP or peer-to-peer protocols). The service layer deals with the application-level functionality that directly serves users as they create, manipulate, and consume content. Finally, the content layer includes data that are stored and shared, such as text, sounds, images, and videos.

While layered architecture provides a useful framework in the form of a technology-centered stack, it fails to consider digital technologies as an integral part of the product and overlooks how product architectures affect a firm's business deployment. To bridge this gap, Yoo et al.'s (2010) layered modular architecture extends the traditional modular architecture of a physical product (Ulrich, 1995) by incorporating the loosely coupled layers of devices, networks, services, and content. The joint concept of layer and modularity is important because physical artifacts, once composed with digital technologies, become complex systems that combine software, hardware, sensors, data storage, microprocessors, and connectivity in various ways. According to Schilling (2000), modularity is a general systems concept described as:

> *The degree to which a system's components can be separated and recombined, and it refers both to the tightness of coupling between components and the degree to which the "rules" of the system architecture enable (or prohibit) the mixing and matching of components* (p. 312).

Yoo (2013) argues that this concept can be perceived as a design rule—whether it be for a product or a process—that defines how a system is divided into subsystems and how these subsystems are interconnected. The concept of modularity offers simplicity in dealing with a complex system and increases flexibility by allowing for the possibility of a loosely coupled product design (Sanchez & Mahoney, 1996) wherein one component may be replaced with another as long as both conform to the same standardized interface. Because traditional product-specific components have become product agnostic (Yoo et al. 2010) and because product boundary and meaning have become fluid (Nambisan et al., 2017), a flexible design rule is essential. Researchers have observed that modularity can provide real options for integrating technologies, products, applications, and markets because it allows for rapid customization and multiple evolutionary trajectories (Sauer, Thielmann, & Isenmann, 2016).

While smart, connected products offer exponentially expanding opportunities for new functionality and capabilities that transcend traditional product boundaries, the changing nature of these products is forcing companies to rethink nearly everything they do—from how they conceive, design, and source products to how they operate and service those products (Porter & Heppelmann, 2014). Increasingly, products and services possess embedded digital technologies, and disentangling digital products and services from their underlying IT infrastructures is becoming ever more difficult (Orlikowski, 2010; Grisot, Hanseth, & Thorseng, 2014; Tilson, Lyytinen, & Sørensen, 2010; El Sawy, 2003). Questions arise as to how an architecture may be built via fusion with a smart technology as well as what generative mechanisms are in play to deploy such a technology's development (Yoo, 2013). As suggested by Yoo et. al. (2010), the framework is suitable for conducting research on the change and evolution of digital innovation. Through an understanding of the evolving layered modular architecture of various smart solutions, we are able to tease meaning out of our case study and theorize the generative mechanism that influences a firm's strategic decisions regarding the launch and refinement of smart technologies and services.

4 Research Approach

We conducted an in-depth case study on a smart digital venture named Loopd, a small start-up company established in San Francisco in 2013. This company began by creating a digital wearable device associated with automated data exchange and analytics to offer an event management solution and facilitate event attendees' social networks. The idea was that, by wearing the devices, the event attendees would automatically exchange their contact information with others when shaking hands. The initial idea was to create a digital wristband, but it remained a prototype that was never launched to the market because of early technical and market promotion difficulties the firm encountered in creating the product. However, the firm managed to transform the idea of a wristband into a smart, connected tag, and the initial vision of a digital device was realized as a smart system interconnected with the wearable device, a mobile app, data exchange, and analytics algorithms, thereby providing automated and customized services for different user groups that aligned with the use environment (illustrated in Figure 2). Within five years, by 2018, the smart tag system had served more than 50 events, 80,000 attendees, and 200 million data points across the technology, healthcare, and manufacturing industries, among others, and had been used for alternative activities never imagined by the company, such as marathons and corporate trainings. The expansion of Loopd's smart technologies and services signals a rupture of product and industrial boundaries, thus suggesting further implementations for different use contexts and industries.

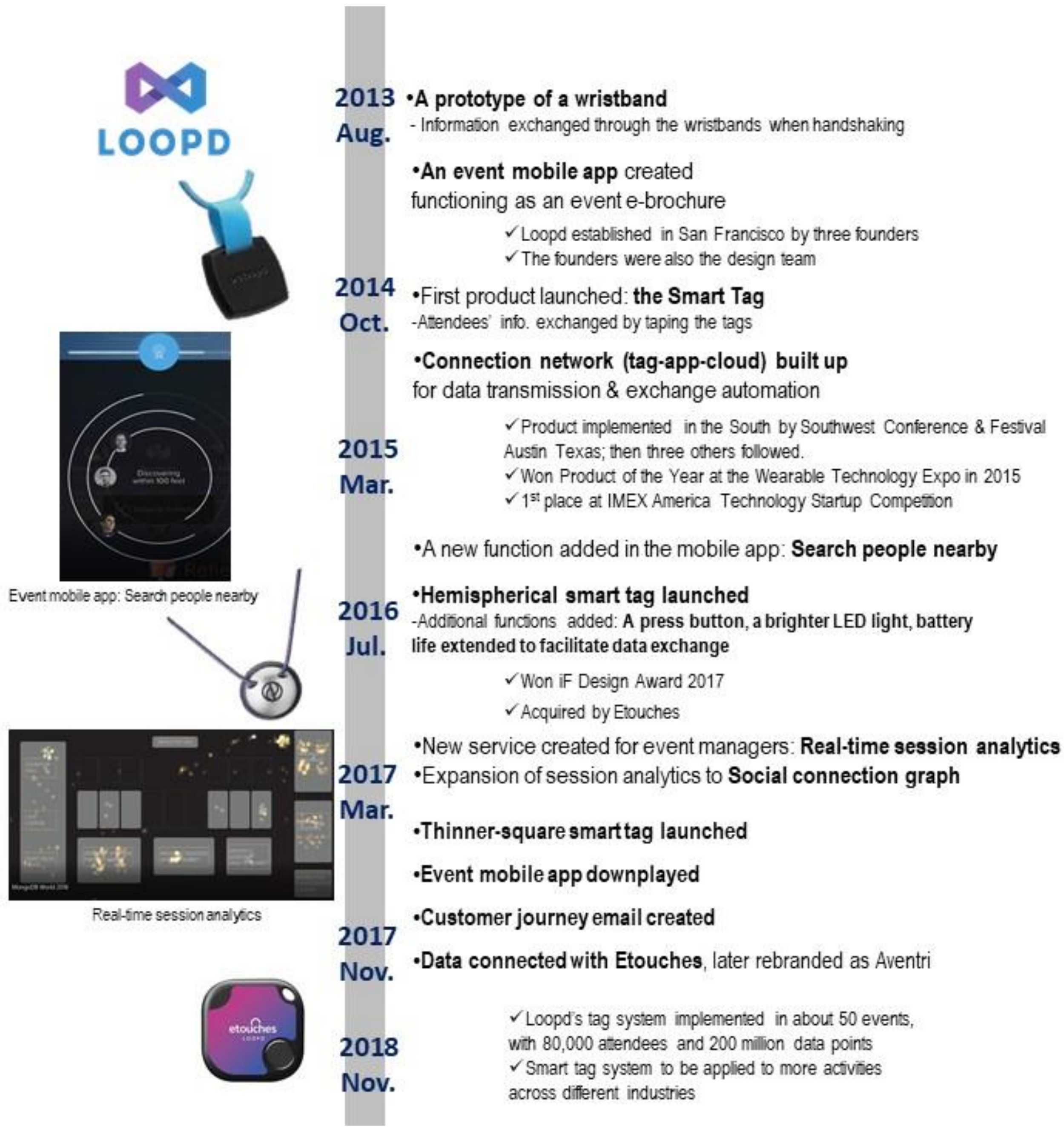


Figure 2. The Evolution of Loopd's Smart Tag System and Relevant Initiatives

Loopd was selected for the case study for two main reasons. First, the development of its smart system was considered to be an "unusually revelatory" case (Eisenhardt & Graebner, 2007) in demonstrating the dynamic problem-solution design pairing for digital innovation management (Nambisan et al., 2017). As discussed in our case narrative below, within five years, Loopd's digital offerings, initiated with the simple idea of offering smart, digital business card exchanges via a wristband for conferences and trade shows, was transformed into an adaptive and flexible system that could be tailored for various contexts of use. This case offers a promising opportunity for researchers to develop an in-depth understanding of how the company engaged in identifying and matching market needs with user actions and digital artifact features along its smart innovation journey. Second, this case helps us "get closer to the theoretical constructs" of the layered modular architecture framework to "unravel the underlying dynamics of phenomena that play out over time" (Siggelkow, 2007, p. 22) through an empirical study. In proposing a research agenda for digital innovation, Yoo et. al. (2010) suggest that this framework may be applied to answer questions such as "what are the factors that influence a firm's strategic choices on digital product platforms?" (p. 731) Here, we apply the framework as our theoretical lens for that precise purpose: to unveil the generative mechanisms in the evolving development of Loopd's smart system.

Our data collection commenced in fall 2015 when we met one of Loopd's founders. Since then, we have followed this firm's development through informal conversations, discussions, company business plans, and presentation materials via regular meetups and email exchanges. One of the authors also attended a number of presentation sessions in which the aforementioned founder demonstrated Loopd's products and services. In addition, through this founder, we were able to conduct semistructured interviews with other key members of Loopd, including two other co-founders, the senior stack engineer, and a data scientist; these interviews served as our first primary data source. Conducting interviews with all Loopd's co-founders and key members has allowed us to gain a clear and complete understanding of this company's historical development and process from the creation of a simple device to a complex smart system that deals with interconnected products, services, people, and processes.

All major decisions between 2013 and 2018, including business and product design, were made by the three founders we interviewed. Having interviewed the key respondents, we are confident in our data's richness; since the co-founders were also the technological designers, they possess strong knowledge and a clear understanding of the initiatives and events related to Loopd's development history. We developed a semistructured interview guide using the theoretical layered modular architecture framework to help us capture each digital component's features. For instance, we asked the founders to describe the circumstances under which a decision was made about the functions that needed to be modified, created, or removed and to describe how the company decided which functions were prioritized to be changed or redesigned. The interviews were tape-recorded and transcribed, and each lasted about two to two-and-a-half hours in length.

In addition to interviews, we visited the location where the technical team is based on three occasions. During these visits, which served as our second primary data source, we observed several generations of the company's smart tag system and developed a deeper understanding of the technical operations behind it. The third data source comprised our access to a wide range of secondary data, including the smart tag user guide, company press releases, Twitter postings, marketing documents, user case studies, company business plans, and product demo videos. This rich set of secondary materials further enhanced our understanding of the evolution of Loopd's smart product and services over time. The dataset from these three sources is detailed in Table 1.

The data analysis was conducted in the three steps that are detailed in Table 2. First, using the data collected from the informal conversations, interviews, secondary materials, and site visits, we established a time line to illustrate the development of and changes made to Loopd's major products and services between August 2013 and November 2018. The time line's illustration covers the case's chronological development from a wearable device to an integrated system as well as the key business initiatives relevant to the tag system.

Second, following the principles of interpretive research on a dialogical process between theoretical concepts and empirical materials (Walsham 1995; Klein and Myers 1999), we applied the layered modular architecture framework to procure a detailed analysis of the changes made to the smart tag system. The theoretical framework's application helped us identify the missing gaps in empirical evidence, which were resolved through additional data collection among key informants via email or telephone; that is, we apply layered modular architecture as "part of an iterative process of data collection and analysis" (Walsham, 2006, p. 324) to enable us to gain valuable insights from the field data. Through this exercise, we developed Table 3, which summarizes the smart system's transformation throughout the identified development stages. Based on the empirical evidence and identified product feature changes, we devoted our efforts to identifying why different product features changed, how data were collected and offered as useful content, how diverse groups of users employ Loopd's system in action, and what concerns emerged from such use. The above exercise led to the development of the case narrative. To ensure the credibility and reliability of our empirical work, we validated our interpretation of the case narrative and findings with all three of Loopd's co-founders.

The third step focused on the mechanisms that led to the evolution of smart technologies. From such a perspective, mechanisms provide an explanatory model for phenomena described by qualitative data (Steel, 2005; Mayntz, 2004), which is helpful when data are difficult or impossible to quantify in terms of specific, measurable variables—as is our case. As explanatory resources, generative mechanisms bridge the gap between social laws and behavioral descriptions. Mechanisms provide a causal representation of phenomena and simultaneously serve as the foundation for generalization to other contexts (Hedström & Swedberg, 1996)

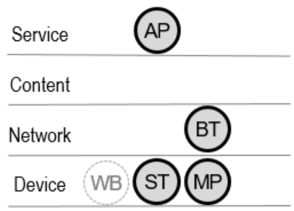
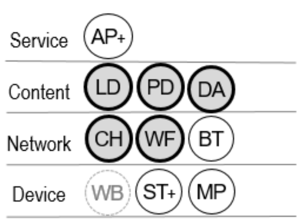
Table 1. Summary of the Primary Data Collection Results

Primary data source: Interviews		
Role	**Responsibility**	**Interview method**
Co-founder 1	Founding CEO, responsible for engineering, design, and business direction	Informal discussion; formal semistructured interview; email exchange
Co-founder 2	Product lead and inventor of hardware, firmware, and wireless protocols	Formal semistructured interview; email exchange
Co-founder 3	Software lead and developer of iOS, Android, and web-based products	Formal semistructured interview; email exchange
Senior full-stack engineer	Responsible for bridging the front end, back end, and operations systems	Informal discussion; formal semistructured interview
Senior data scientist	Responsible for enhancing data collection and analysis procedures as well as developing analytical products	Informal discussion; formal semistructured interview
Primary data source: Site visits		
Location	**Value of site visit in this research**	
Software development site	We made three site visits wherein we built closer relationships with our interviewees and gained access to the demonstration of several generations of smart tags, apps, and customer journey emails onsite.	
Secondary data source		
Types of documents	**Internal/public data**	**Key value of the document in this research**
Smart tag user guide for clients	Internal	Enhance our understanding of the design and use of different generations of the smart tag
Company press releases	Public	Develop a time line for major products and business initiatives
Twitter posts	Public	Develop a time line for major products and business initiatives
Marketing flyers	Public	Enhance our understanding of the company's business strategy
Company business plans	Internal	Contribute to our business strategy and product development
User case studies	Public	Contribute to our understanding of the smart tag system's application in context of use
Product demo videos on Loopd's website	Public	Contribute to our understanding of the smart tag system's application in context of use
YouTube videos for product introduction and tutorial	Public	Enhance our understanding of the smart tag system's application in context of use

Table 2. Data Analysis Approach

Stages	**Tasks**	**Outputs**
1. Identify major development phases of products and services	• Establish time line for key business initiatives and major product changes between August 2013 and June 2018	Chronology of key business initiatives and different generations of products (Figure 2)
2. Construct case narrative	• Apply the layered modular architecture framework to understand the nature of product architecture at different stages • Develop the case narrative by focusing on the problem-solution design pairing logic • Validate our interpretation of the case narrative with three founders	Case narrative on the unique innovation trajectory of Loopd's digital offerings (Table 3)
3. Identify generative mechanisms	• Define each mechanism's nature and the related components in each identified mechanism	Three generative mechanisms of smart products and services (Table 4)

Table 3. Trajectory of Loopd's Digital Offerings

Layered modular architecture	Phased objectives, problems, and responding solutions
Product formative stage	
 AP: Mobile event app BT: Bluetooth WB: Wristband ST: Smart tag MP: Mobile phone	**Phased objectives:** The initial idea was to develop a digital wristband based on handshaking. The wearable device would automatically exchange event attendees' information in natural event settings when the wristbands were connected via Bluetooth. **Unexpected problems that occurred:** While the value of a wristband was acknowledged, it remained a prototype that never entered the market because of: • technological constraints; the wristband did not completely distinguish the intended handshakes from unintended hand gestures; • potential clients' and investors' concerns for the difficulties associated with enhancing the novel device's user friendliness; and • comments from customers and investors, which recommended that Loopd consider a more natural extension of what attendees already wore (e.g., a name badge) rather than an additional device. **Solutions to the objectives and problems:** • Loopd created the smart tag (similar to a "conference badge" tag) to replace the wristband. The attendees were to exchange their contact information by "tapping and connecting" with others' tags. • To enhance user friendliness, the team simultaneously developed a mobile event app that functioned similarly to an event e-brochure. **Phased outputs:** The smart tag associated with the event app replaced the wristband and became the firm's first product package.
Data-centric stage	
 AP+: App's new function "search people nearby" LD: Location data	**Phased objectives:** At this stage, Loopd's focus was to make the smart tag more functionally advanced and practical for events to support attendees' social networking. To this end, three major tasks related to data exchange automation were enacted: • Loopd constructed the tag's network, connection hubs, wi-fi, Bluetooth, and the cloud server to facilitate data collection, transmission, exchange, and storage. • A new app function called "search people nearby" was created to allow that attendees use their mobile phones to discover others nearby. • The tag was shaped into a metallic hemisphere to make it more aesthetically appealing, attract event attendees' attention, and encourage that they wear the devices more often. **Unexpected problems that occurred:** • The "tap-and-connect" design for data exchange became a considerable issue; because attendees' information exchanged unexpectedly, this problematic operation led to its redesign. • The smart tag's attached light signaled data exchange, but the bright headlights in conference venues increased attendees' difficulty with actually seeing the light. Users often complained that the data exchange operation was not visible.

<table>
<tr>
<td>PD: Personal contact data
DA: Data analytics algorithms
CH: Connection hub
WF: Wi-fi
BT: Bluetooth
ST+: Hemispherical tag with a press button</td>
<td>Solutions to the problems:
• To solve the problem of unwanted data exchange, the smart tag was redesigned with an added press button such that attendees' data were exchanged by pressing the button to activate it.
• The light on the smart tag was stronger to accommodate the event venues and to signal data exchange.
Phased outputs:
• The smart tag system was launched to the market in October 2014.
• The smart tag was no longer a simple device associated with an event app, but rather a smart, connected system that combined the device, the app, and the network connection to automate the attendees' data transmission and exchange.
• The shift from device-focused to data-centric led the firm further toward data analytics and encouraged the development of possibilities to connect with external datasets (e.g., Etouches).</td>
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<tr>
<td colspan="2">Service adaptation stage</td>
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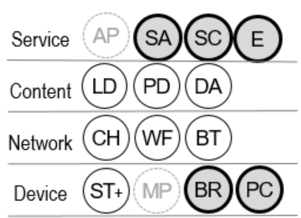
<td>

SA: Real-time session analytics
SC: Social connection graph
E: Customer journey email
BR: Big screens
PC: Personal computers
ST+: Square-shaped thinner tag</td>
<td>Phased objectives:
At this stage, Loopd emphasized an expansion of user bases. Their strategy was to increase various user groups (i.e., attendees and event managers/organizers) by supporting them with multiple services.
• In addition to supporting attendees' convenience, Loopd created real-time session analytics as well as a visualization interface specifically to support event officers and organizers for event management.
• Another new service called the "social connection graph" was created to support event managers in analyzing the attendees' grouping and interests in relation to the session analytics.
• These services could be demonstrated on personal computers or large screens (e.g., TVs) at the events.
Unexpected problems that occurred:
While the fashionable tag gained users' attention and won Loopd several design awards, it posed two problems:
• It was expensive when considering mass production, and thus cost became a concern.
• Users liked to fit the tag into their event badges, but the tag's shape made doing so difficult.
• Maintaining three projects concurrently (the smart tag, event mobile apps, and real-time data analytics) became a heavy load for the start-up from financial and human resources aspects.
Solutions to the problems:
• The smart tag's shape was changed back to a square and became thinner such that attendees could easily fit them inside their badges.
• Loopd customized off-the-shelf cover cases that reduced the tag's modularization cost by twenty percent; it was minimally stylish and more practical.
• Considering its low download rate, Loopd downplayed the mobile app's role in its system.
• Loopd focused on data analytics, and a synthesized report (i.e., a customer journal email) was created to serve event attendees.
Phased outputs:
• The smart tag system served more than 50 events, 80,000 attendees, and 200 million data points across the technology, healthcare, and manufacturing industries, among others.
• Flexible and adaptive serves allowed the firm to expand the smart tag system to several alternative industries, such as corporate trainings and marathons.</td>
</tr>
</table>

A mechanism's outcome is called an "explanandum"—that is, the phenomenon we explain as the observed phenomena (i.e., the layered modular architecture of Loopd's smart systems at different stages)—while the explanation itself is known as the "explanans" (Hempel & Oppenheim, 1948). The goal herein is to uncover the underlying mechanisms that produce outcomes through a process called "retroduction," which realizes the generative mechanisms by inferring them from the observed events. The emerging themes led to the conceptualization of generative mechanisms, and we labeled those derived from our data analysis as *system-environment fitness*, *data exploitation*, and *user expansion*.

5 Case Narratives: The Development of the Smart Tag System for Event Management

Loopd's three founders met while they were studying at the university. In an entrepreneurship program, they came up with the business idea to exchange information through a wearable device via handshaking. One founder recounted:

> *When we were at an event, I see most of my friends were looking at their mobile [phones] and using [them] to add each other's information and interacting virtually … I was thinking—what if we can make a wristband to exchange information by handshaking instead of using mobile phone[s].*

With this wristband idea in mind, the three individuals teamed up to validate their business concept; one founder was in charge of the business strategy, another focused on the hardware, and another oversaw the software development. In 2013, they founded Loopd in San Francisco and targeted the attendees at conferences and trade shows because they had noticed that, while exchanging contact information mattered at these occasions, solutions for doing so had yet to be smartly provided. The development of Loopd's smart tag system was evolutionary; our emprical data suggest that the system's transformation went through three revolutionary stages—*the product formative*, *data-centric*, and *service adaptation* stages. In the product formative stage, the co-founders (also the designers) devoted most of their efforts toward converting their conceptual idea of a connected wristband into a tangible product. After experiencing a series of product formulation difficulties, Loopd's first product—that is, a wearable tag with a mobile event app—was launched to market in late 2014. Since then, their primary focus has started to shift toward data-related tasks. This stage consisted in activating and optimizing users' data and increasing the possibility of user information being exchanged automatically. This data-centric stage led the company to achieve the goal of enhancing the event attendees' social networks. Consequentially, beginning in early 2017, diverse functions with the fundamental basis of data collection and analysis were added to provide services to user groups for different purposes. The constant changes in the design of the smart tag offered us a dynamic view to study its development trajectory. In Table 3, through the lens of the layered modular architecture perspective, we elaborate on the appearance of the three stages in connection with their phased objectives as well as the problems that the firm faced and responded to.

5.1 The Product Formative Stage

At the beginning of Loopd's founding, the dominant effort was centered on crafting a digital device (i.e., a wristband) that could automatically exchange personal information through handshaking in order to facilitate event attendees' social networking. The team envisioned that if attendees could exchange information as naturally, easily, and simply as possible by wearing this device, then they would perceive its value as a "digital business card." This idea was acknowledged by potential corporate customers (i.e., event organizers) and investors; however, the team faced insurmountable challenges and was forced to terminate their plan of creating the wristband.

First, because of technological constraints, the wristband was not able to distinguish between the intended handshakes and other hand gestures, and thus it encountered problems with accurately determining whether the wearers wanted to exchange contact information. As the software lead explained: "[For so long] we were trying to figure out what algorithm we were going to use to detect [a] handshake, so it would tell differences between handshake[s] and other hand gestures, say, dancing." Second, when the firm demonstrated the idea at sales and investor presentations, concerned voices began to rise. They believed that the wristband, although novel and topical, may have encountered difficulties in attracting event attendees' adoption and thus may have impeded market acceptance. To improve its user friendliness and acceptance, comments from event managers and potential investors suggested that Loopd consider a more natural extension of what attendees already wore (e.g., a conference name badge) rather than asking them to wear an additional device. The software lead recalled:

> *Investors brought up an interesting question about the differences [the wearable technology] makes if you have the device on your wrist versus something you wear around your neck, like a conference badge … We took the idea and started rethinking about our design.*

Because of the wristband's unresolvable technological problem and less-than-assuring feedback from investors and clients, the team made the critical decision to drop the wristband and redesign a proximity-based, bidirectional "conference badge" tag for event attendees to wear around their necks. Owing to the start-up's financial limits, the team concentrated on building up the tag's functionality, battery life, and a careful software design to enable speedy data transmission. The team named the first product "the smart tag."

At the formative stage, the device looked economical, and the founding CEO joked "we also call it the ugly type." Nevertheless, they achieved their primary objective of making the device practical and functional. Attendees exchanged their contact information by "tapping and connecting" their smart tags. To increase user friendliness, the team took an earlier suggestion from some potential customers to develop a mobile event app. The event app functioned similarly to an e-brochure in that its content included a conference agenda, map, new contacts, and personal schedule management. The firm believed that, from an innovation perspective, an event app did not add much value to their offerings although included in their smart product package was nevertheless a strategic necessity. They also considered the event app an effective feature for convincing event managers and investors of the wearable's value, claiming: "we have an event app, too. But we also have this new [wearable] as something adding more business value" (Founding CEO). As a consequence, the smart tag associated with the event app became the firm's first product package.

5.2 The Data-Centric Stage

To facilitate speedy and seamless information exchange among the attendees, the team next started to build up a system to automate data transmission and exchange. Toward this end, the tag's network, which consisted of connection hubs, wi-fi, Bluetooth, and the cloud server, was constructed. The process of use included the following steps. After registering for an event, the attendee's contact information would be pre-stored in a tag (i.e., serving as a digital business card) prior to the event. When the event commenced, this attendee would be assigned a specific tag with his or her contact information built in. The attendee could wear this tag at the event venue to exchange information with others by tapping their tags and to check into and out of the particular sessions attended. This tag therefore recorded the contact information of the individuals with whom this attendee exchanged information as well as the sessions in which he or she participated. Through the interconnected operations, once attendees started using their tags, their contact information was automatically uploaded into the cloud server and then made accessible to all attendees on the mobile event app.

To facilitate attendees' social networking, a new mobile app function called "search people nearby" was created to allow attendees to discover others nearby and request new contact connections using their mobile phones. To account for privacy issues, the app function allowed the attendees to control the information they shared and set the information to anonymous mode if they did not wish to be found. Therefore, Loopd's product was, at this stage, no longer an individual device, but rather a smart, connected system that combined the device, event app, and network connection, allowing attendees to seamlessly exchange information. The smart tag system was launched to the market in October 2014.

While the original concept of data exchange between two attendees was based on the simple action of tapping tags to connect, the convenient method unexpectedly caused a serious problem that the team did not anticipate. After an event, when the users returned their tags to a bin, data were automatically exchanged when the tags touched each other, resulting in many user complaints. A founder recounted the chaotic situation at that time:

> *A problem occurred when people returned [tags] and dropped them into a bin. The movement caused the consequence of a smart tag exchanging information with most tags in the bin. We got so [many] complaints about people receiving contact information that they didn't want to have.*

The problem of unwanted data exchange led to a necessary redesign. Around that time, Loopd received a few complaints from other events about the invisibility of data exchange related to the tag's dimly lit design. A light was attached to every tag and would flash when two tags were connected. However, because the dim light was unsuitable for these event environments, the users had no way to check whether or not their tags were connected and whether or not the information exchanges had been completed. At this stage, data exchange began to dominate changes in the tag's device and functionality. A founder recounted:

> *This [tag] was basically based on tap and connect. The idea is to tap the tag next to someone else's, and there would be a light indicating the exchange of data being completed. The problem is that the light on the device was not very clear after you tap on someone's smart tag. Normally, in a conference event, you have a very bright headlight, which makes it even more difficult for the attendees to see light on the smart tag.*

To tackle the above data exchange issues, the product lead addressed Loopd's plan for product redesign at that time: "[the redesign of the tag was set to] make sure there is a press button for data exchange, and to make this button as well as the light visible enough when people press [the tag];" the software lead added: "also to ensure having a bright light won't kill the battery life."

After learning valuable lessons from the data exchange issues, Loopd encountered opportunities to approach more events and larger occasions, such as the South by Southwest Conference and Festival in 2015, which attracted more than 600 attendees who made more than 10,000 new connections with 260,000 data points collected through the smart tags. In the same year, Loopd also received a number of industry recognitions for its product and business idea, including Product of the Year at the Wearable Technology Expo and the first-place award at IMEX America—a technology start-up competition. The firm's reputation started growing, which helped it secure more funding from investors.

With more resource inputs, the team realized that the tag needed to be more fashionable so that event attendees would be encouraged to use it, which would thus help it gain further market attention. For this purpose, the team decided to work with product designers to craft an aesthetic appeal for the tag. The founding CEO explained this rationale: "we thought that a good design would help us to gain more market attention. Also, the attendees would be attracted to the product and start using it more at events. We really want to stand out." The company then worked with an external product designer and launched a new smart tag in 2016, featuring a modern look with a hemispherical shape and metallic surface luster. The team found that the tag's modern look not only encouraged users to wear it more often, but also attracted considerable market attention and led to several design awards, such as the iF Design Award in 2017—a major industrial goods recognition.

Having served a number of events, the Loopd team realized that while creating a device was an important first step, there was an increasing need to offer services to various groups of people; they believed the data collected by the smart tag could play a key role in doing just that. The firm realized the data they collected could be useful not only for event attendees but also for event managers. As one founder explained:

> *On data analytics, it was more a combination of what we heard and we learned. We entered this industry to enable an easier way to exchange contacts, and then we realize, as we were doing this, we can also collect data and offer analytics about where people spent time. This is something which no one in the industry had before … This basically results in us thinking what is it on the analytics side that we can do for the event organizers to gain good insights and to benefit the attendees.*

Realizing the increasing importance placed on data analytics, Loopd allocated additional resources to data analytics and expanded the corresponding team. Their innovative focus on data analytics attracted industry attention. In 2017, the smart system was acquired by Etouches (later rebranded Aventri), a global event management company. Etouches's acquisition offered Loopd the new possibility of connecting to external data. The Etouches CEO explained the benefit of this acquisition:

> *Data is the future of events, so it is critical as an organization that we are able to provide our customers with the most advanced solutions in the industry to increase the impact of their events. The Loopd team has been able to create a product that greatly surpasses competitors in terms of innovation, user experience, and overall effectiveness.*

5.3 The Service Adaptation Stage

Realizing the potential of data analytics, the team started articulating that data may be used to develop customized and desirable services for various user groups. With that in mind, they created a new service called "real-time session analytics." By utilizing the movement data captured by attendees' smart tags, this analytics solution afforded event organizers real-time information with a visualization interface (e.g., attendees' traffic flow), which resembled a dashboard displaying the number of attendee visits and returns and their average duration in nearly real time. The data scientist recounted:

> *Tag ID, battery information, time stamp, and tag strength through the smart hubs, the information was uploaded to the cloud every second. We then work on the relationship between hub location and floor plan; this is how we began working on our session analytics.*

This service can be customized and adapted to suit event layouts and session configurations. The real-time data are displayed on event officers' personal computers or larger screens (e.g., TVs) to monitor overall attendance. This solution became an effective support strategy for event organizers in managing their events in a timely and efficient manner, which included their ability to reallocate support personnel to sessions where they are needed most. Thereafter, a service called the "social connection graph," which displayed the attendees' social networks at the event and indicated the most active attendees and influencers, was created for event management.

Emphasizing data analytics not only allowed Loopd to offer more flexible services, but also inspired the team to experiment with their services in other use contexts such as corporate training. One corporate client asked Loopd whether it was possible to implement its system to both automate attendees' session tracking and measure their training hours. Loopd found that the real-time session analytics function could be applied to multiple contexts of use for various purposes. The software lead explained:

> *[A client company] required attendees to stay for at least ten minutes in a session to receive their training credits. As attendees walked in and out of the sessions, their complete dwell times totaled instantly, and training credit reports were easily created by the event team for easy upload into [the client company's] training system.*

With multiple services added, Loopd's smart tag system operated auspiciously to serve both event attendees and event managers. The complete system meant that the team offered their solution of a wearable tag, a mobile event app, and real-time data analytics. However, maintaining these three crucial projects was a difficult job for the start-up company and the founders commented on the rising issue of prioritization; in fact, one stated: "having mobile app, hardware, and data analytics is like having three different projects. Most of the companies or start-ups would try to focus on one, make it the best of the breed. Rarely you find companies doing all three." Another founder added: "we were trying to manage the event app, analytics, smart tags, and logistics, too. After a while, it gets a bit overwhelming."

Questions about the fashionable smart tag's economics began to arise because the tags were relatively expensive to manufacture, which thus reduced profits. Moreover, Loopd received a few comments from the attendees, claiming that the device was shaped awkwardly although it did look generally pleasing and trendy. It was observed that the attendees preferred inserting the tags inside their event badges, but the hemisphere shape made it difficult to do so, thus motivating the device's redesign.

Based on their previous user experiences, the Loopd team had a more thorough understanding of what worked well and what did not. The software lead recounted how the team determined the specification for the device's next version:

> *We had a few requirements: first, it needs to have a button, thin and square shaped. Second, it needs to have [a bright] LED light. Third, it has to be cheap … Instead of designing ourselves, we went on Alibaba website and looked for different types of Bluetooth lost-and-found trackers, which were already available in the market. We then repurposed the trackers by customizing the firmware and adding our logo. We had the product lead and another team member flying to China, talking to [a] manufacturer, and working out the process.*

As a result, the new smart tag was shaped into a thin, flat, and square format. By customizing the off-the-shelf product, the cost was reduced by twenty percent. One Loopd team member remarked that the new tag was "minimally stylish, but much more practical." The new version of the tag was launched in June 2018.

Moreover, the team had to evaluate their distribution of resources between the event app and data analytics. The decision was critical, but the team reached a consensus: "at the end, we decided to move effort a bit away from users' event app. We are moving more towards a data direction," as the software lead described. The team additionally decided to downplay the event app because of a low number of app downloads; the software lead indicated "we saw the average adoption rate for [the] event app is about fifty percent," while another echoed "[even in a better situation], for example, in one conference, although there were more [than] 2,000 attendees, the event app was downloaded approximately 1,500 times." Since the team recognized the problem of some attendees *not* downloading the event app to access data, they started discussing the possibility of allowing attendees to access and organize the data exchange without the app. The founding CEO commented:

> *Actually, relying on an app can be problematic. In an event, [to use the app] an attendee would need to have a wi-fi connection, be willing to search and then download the app, and apply for an account for using it. These set up obstacles for attendees to use the app.*

They came up with the idea of the "customer journey email." As the software lead explained:

> *We thought that the customer journey email was an interesting idea, as like a "souvenir" after an event. Attending an event was like having a journey, and after that you had a souvenir which recorded whom you had met and what sessions you attended … Now the value added from us is that you don't have to download the app, you can just get what we call the customer journey email from us.*

The customer journey email summarized the information ranging from the sessions the attendees visited, the connections they made, and their interaction time lines, among other variables.

By the end of this study, Loopd had implemented its event management system for about 50 events across many different industries. Moreover, this smart tag system had expanded to some activities the founders never expected. With regard to marathons, one founder mentioned:

one marathon organizer from Boston used our smart tag in their activities. We were surprised what the tag could do for it. I guess what they actually needed was to calculate the time duration each runner spent and the location. The data can be easily extracted from our database.

Another founder added "it was once used to support an event organizer to find a missing person. We did not expect the time stamp data could be used for that purpose." Loopd's smart tag system demonstrates a case of smart technologies that were smartly developed and, in fact, broke product-related and industrial boundaries.

Table 4. Generative Mechanisms of the Smart System

Generative mechanisms	Key initiatives and evidence
System-environment fitness mechanism	**Fitness with human movement** *"we were trying to figure out what algorithm we were going to use to detect [a] handshake, so it would tell differences between handshake[s] and other hand gestures"* (Product Formative Stage). *"Investors brought up an interesting question about the differences [the wearable technology] makes if you have the device on your wrist versus something you wear around your neck, like a conference badge … We took the idea and started rethinking about our design*" (Product Formative Stage). **Fitness with the use environment** *"The problem is that the light on the device [to signal data exchange] was not very clear after you tap on someone's smart tag. Normally, in a conference event, you have a very bright headlight, which makes it even more difficult for the attendees to see light on the smart tag*" (Data-Centric Stage). *"We noted that quite a few attendees liked to insert the tag inside their event badges, and the hemispherical shape made it difficult to do so*" (Service Adaptation Stage). *"relying on an app can be problematic. In an event*, [to use the app] *an attendee would need to have wi-fi connection, be willing to search and then download the app, and apply for an account for using it. These set up obstacles for attendees to use the app*" (Service Adaptation Stage).
Data exploitation mechanism	**Automated data generation** *"To stimulate social networking at an event, automated data exchange is a key … We thought that if attendees could exchange information as naturally, easily, and simply as possible by wearing this device, they would perceive its value as a digital business card"* (Product Formative Stage). *"Data transmission automation and real-time exchange need a lot of space, so we built connection hubs, wi-fi, Bluetooth and the cloud server to facilitate data collection, transmission, exchange, and storage*" (Data-Centric Stage). **Efficacious data exchange** *"A problem occurred when people returned [tags] and dropped them into a bin. The movement caused the consequence of a smart tag exchanging information with most tags in the bin. We got so [many] complaints about people receiving contact information that they didn't want to have*" (Data-Centric Stage). *"We started with our analytics by having dashboard and traffic flow. And then we redo our architecture so that we can support a larger event. We also work on UI and then add session analytics*" (Service Adaptation Stage).
User expansion mechanism	**User friendliness enhancement** "*Some potential customers suggested to develop an event app … This app did not add much value to our product, but it seemed to help the users to understand what our smart tag was used for*" (Product Formative Stage). "*we thought that a good design would help us to gain more market attention. Also, the attendees would be attracted to the product and start using it more at events*." (Data-Centric Stage). **Services repackaged for different user groups and industries** *"This [focus on data analytics] basically results in us thinking what is it on the analytics side that we can do for the event organizers to gain good insights and to benefit the attendees*" (Data-Centric Stage). *"Real-time session analytics and social connection graph[s] were specifically for the event organizers, not for the attendees*" (Service Adaptation Stage). *"We were surprised what the tag could do for [the marathon]. I guess what they actually needed was to calculate the time duration each runner spent and the location*" (Service Adaptation Stage).

6 Research Findings

The narrative above details the development of Loopd's smart tag system with different objectives as well as its dynamic problem-solution pairing, as indicated in Table 3. Nevertheless, we argue that the observed smart tag system evolution was not merely a series of accidents or coincidences. Thus, in this section, we dig deeper into our narrative and uncover the underlying three mechanisms driving the formulation and transformation of the smart tag system: *system-environment fitness*, *data exploitation*, and *user expansion*. In identifying these three mechanisms, we demonstrate a systematic (re)combination of the device, network, content, and service layers as well as the changes enacted in each layer that significantly influenced how the Loopd's tag system was created and adapted into its smart form. In Table 4 above and the following section, we illustrate and develop them further.

6.1 System-Environment Fitness Mechanism: Fitness with Human Movement and the Use Environment

The fitness mechanism refers to the wearable device's nonintrusive design that mimics the body appropriately. Specifically, it relates to the fit between the device and the service being used in the wearer's environment. We found that the fitness mechanism, which includes both *fitness with human movement* and *fitness with the use environment*, demonstrates the wearable device as having been created and transformed as an outcome of integrating the device, the network, and the content layers supporting the service layer.

We found that the designers' consideration of the device fitness with human movement was the generative mechanism that significantly influenced the wearable device's creation and transformation. It first emerged in the formative period as the device-focused stage in which the team programmed the wristband's physical mimicry of a handshake for automatic information exchange. The initial wristband idea was valued by investors and potential corporate customers because they perceived its potential to reduce the inconveniences of exchanging information via paper-based business cards. If the handshake mimicry were to be properly captured, the wristband would then be considered to be a nonintrusive device that could, eventually, facilitate the automatic exchange of information. However, because of unresolvable technological constraints, the wristband did not accurately distinguish intended handshakes and other hand gestures, which impeded its production. While the Loopd team was dealing with the technological issue, they took suggestions from investors and potential corporate customers to create a natural extension of what attendees already wore rather than an additional physical device. As a result, a new wearable device—the smart tag—was created. This new smart tag did not intrude at all with the users. The considerable change from a wristband to a tag was based on the consideration of building a device that would align with human movements and would pose minimal intrusion.

Moreover, we identified another fitness mechanism—that is, the fitness with the use environment. This mechanism generated the transformation of the product into a smart device and influenced the wearable device's shape. Although the hemisphere-shaped tag looked generally pleasing, attendees experienced difficulty fitting the tags into their conference badges. To align with the use environment, a thinner square-shaped tag was suitable for simpler insertion into attendees' badges.

The event app's creation and subsequent dissipation is another example that demonstrates how the fitness mechanism drove the smart system's evolution. The mobile app was considered topical at that time, but its low download rate implied that its presumed popularity was not realized. Consequently, the team opted to replace it with the journey email service because "attendees use email for communication already and prefer to have contact information and exchange sent to their email" (Software Lead). As a result, the old-fashioned medium (i.e., email) substituted the relatively advanced application (i.e., the mobile app) in the smart tag system's configuration. This mechanism also influenced the team's component selection for device, content, and services layers, such as the brighter LED light for making data exchange visible to account for the bright headlights at event venues and a battery with high-energy density. Overall, we found that the fitness mechanism led the company to design the smart tag system to provide its users with convenience, as they were then able to *smartly* use the device within their environments.

6.2 Data Exploitation Mechanism: Automated Data Generation and Efficacious Data Exchange

In Loopd's smart tag system, the digital device's incubation (i.e., wristband or tag) was driven by the core value of automated contact information exchange. The team perceived the value of an automated data exchange function through a wearable device and planned to develop a digital wristband that could automatically exchange contact information at conference events. The later-created smart tag also maintained data exchange functionality as the central value through its design. The data generation mechanism drove the reinforcement of the data exchange and the functionality of data collection and analytics; thus, data were exchangeable among peers. The interrelated data generation and exchange functionality also increased the wearable device's usage value; that is, the wearable technology collected and generated data (i.e., users' personal and location data) on location and in real time. Once the data were ready they could be used for analysis and exchange purposes. This mechanism generated benefits not only for those wearing the devices, but also for the event organizers managing the event activities. Moreover, because this mechanism emphasized automated data collection and exchange, Loopd made specific decisions regarding the network of connected components and devices. The network's design, in which sensors collected and transmitted data through wireless technologies, stored and computed data in the cloud. This mechanism was also key for inducing the development of algorithms that cleaned and analyzed data for its conversion into valuable information.

While the data mechanism generated the smart tag system's central value, we determined that the initial belief regarding automated data exchange was inconsistent throughout the smart tag system's evolution. Automated data exchange was initially one of the most dominating forces driving the device's development; however, this function appeared to be problematic when users returned tags to a bin causing their data to be exchanged automatically and unexpectedly. Loopd received complaints about users receiving unwanted contact information. Subsequently, a push button that initiated data exchange was added to later models. This initiative demonstrated that automation might be important for constructing a smart system but not necessarily for considering the context of use. This case demonstrates that to construct a smart system, the automation concept may be required but should not always be the guiding principle; that is, automated data generation is important, but the efficacy of data exchange is crucial for rendering the data transmission system *smart*. Interestingly, we discovered that the problem of automated data exchange, which can be considered an issue occurring in the data layer, was resolved by the modification of the physical device, which represents a different layer in layered modular architecture. As a result, event attendees were able to accurately obtain data exchange functionality. The exploitable data mechanism found in this case study demonstrates that data collection may be automated but that data exchange must be efficacious. Furthermore, this mechanism highlights that the homogenization of data in a digital product allows designers greater flexibility to explore and utilize functionalities from other layers to address issues that arise in another layer.

6.3 User Expansion Mechanism: User Friendliness Enhancement and Service Repackaging

We noted that the configuration of Loopd's smart tag system was driven by the combination of two user expansion mechanisms: one aimed at *enhancing user friendliness* and the other targeted at expanding the user base through *service repackaging*. The user expansion mechanism played an important role in guiding the device's transformation from a wristband to a tag and in the creation of various service applications.

The novel, disruptive user friendliness and openness of such an innovation, affected the speed and scale of the new product's acceptance in the event industry. As the founding CEO explained, "the event management industry is an older industry, and it is not an industry [that is] adapting [to] technology easily. We have to work quite a bit in figuring out the way to demo our products." This consideration led Loopd to bundle the semi-innovative mobile app with the new wearable device as one product package rather than solely emphasizing the smart tag's creation. The user expansion mechanism also drove the team's decision to craft the tag with an aesthetic look. The tag was then shaped into a metallic hemisphere that looked more fashionable and appealing. This change not only encouraged greater use of the tags, but also won Loopd industrial design awards and significantly raised its market attention. Although this new design greatly increased production costs and forced the team to reevaluate the necessity of the aesthetic design, the team realized that transforming the device into an appealing aesthetic form was fundamental for increasing its use.

Moreover, the user expansion mechanism led to the creation of various services for a variety of user groups, including the event app, real-time session analytics, and social connection graphs. While the smart tag collected the same types of data, it was determined that the interpretations of its usefulness varied according to the nature and objectives of events. One founder elaborated on how the user context determines the value of data, claiming:

> *One conference we had was an internal event for employee corporate training, so the ability of exchanging contact information and building connection is not important. The only thing that matters here is the use of the smart tag to calculate the time of checking in and out of a session, as this would affect the training hour. For another event, which was targeted at entrepreneurs, so connection through the smart tag became important, but not so much about session analytics summarizing where an attendee had been and for how long.*

Loopd's experience serving various industries with different user contexts secured great opportunities for the company to provide different services; that is, Loopd utilized the same digital capabilities (e.g., the device, connective networks, and data) to provide multiple, flexible, and adaptable services, and thus address multiple contextualized problems. We maintain that Loopd's ability to serve diverse industries and user contexts through various applications was largely based on their optimization of the many layers of digitally modular capabilities. Consequentially, differentiated service packages can be efficiently created and effectively provided.

7 Discussion

In response to our research objective of investigating the construction and evolution of a smart technology, we conceptualize such a technology as a complex system with interconnected technological elements that offer flexible and tailored services to different user groups and use contexts. Previous research in this field states that developing a smart, connected product requires an integration of not only complex technological components (Porter & Heppelmann, 2015, 2014; Yoo et al. 2010), but also capabilities that provide adaptive services to diverse contexts of use (Ramaswamy & Ozcan, 2018; Marinova et al. 2017). The requirements imply that it is challenging for a smart system to be both stable and flexible enough to serve diverse purposes and future possibilities. The current literature, however, offers a rather conceptual and normative view of constructing a smart system and thus provides scarce insights regarding how it is formulated and transformed over time. This motivated us to look into an actual construction of a smart technology in a dynamic, systematic way in order to contribute not only to the theoretical discussion but also to present an empirical account of how these technologies are created.

By tracing the evolution of Loopd's smart tag system from the theoretical lens of layered modular architecture, this study has identified three generative mechanisms: system-environment fitness, data exploitation, and user expansion. In our case, we found that these mechanisms generated a systematic (re)combination of the device, network, content, and service layers and contributed to changes within each layer that significantly influenced the transformation of Loopd's wearable device into a smart system. From the perspective of the system-environment fitness mechanism, this study distinguished two aspects of fitness (i.e., fitness with human movement and fitness with the user environment), which, although interrelated, exert different impacts on the decisions made in designing and changing the smart system. We observed that the two fitness mechanisms do not operate coincidentally but function through a strategic integration of device, network, and content layers with the specific goal of supporting the service layer. Previous research points out that a smart technology (especially a wearable device) should adapt to the body's movements and should not intrude upon the user's physical movements or gestures (Bonato, 2005; Park & Jayaraman, 2003; Zhang & Poslad, 2013). Our findings echo this viewpoint, but our case further explains the concept of fitness by demonstrating that, in addition to fitness in terms of body movement, a smart technology should also be able to fit the use environment so that smart service can be developed. While both mechanisms are relevant in this case, it is important to distinguish between these two levels of fitness because they lead to different design requirements and considerations for the smart system's initial creation and later transformation.

The data exploitation mechanism appeared to be influential in the smart system's (re)design. This case reconfirms statements made by previous researchers (Porter & Heppelmann, 2015; Shankar, 2018), suggesting that the capability to automate data collection and connection plays a key role in constructing a smart technology. Nevertheless, the evidence in this study indicates that, while automated operation is important, it should not always be the guiding principle; that is, although automated data generation can lead to efficient and convenient data transmission, the efficacy of data exchange is crucial for allowing a data transmission system to become smart. In our case, data generation and exchange were built to enhance event attendees' social networking based on their information sharing. Thus, the users' willingness and propensity for information sharing needed to be valued. Jarvenpaa and Staples (2000) found that one's propensity for sharing information through electronic media is greater when the information is closely related to the person sharing it. This sharing propensity is reinforced in individuals who enjoy both sharing with their peers and being aware that their peers know who they are (Lin & Lu, 2011). Our findings extend these studies by further explaining how data are gathered and exchanged to support the smart system's development and transformation. Through the analysis of layered modular architecture, we have a better understanding of its operation in relation to the data exploitation mechanism. We discovered that when designers considered the linkage among content, network, and device layers, the automated data generation mechanism was the driving force. However, when designers considered the content layer along with the service layer, the efficacious data exchange mechanism became more prominent.

Third, the user expansion mechanism was found to build upon the data exploitation mechanism. We found that the value of data can be optimized for crafting different services to satisfy diverse user groups. The diversity of services consequently resulted in the expansion of user groups. While prior studies have indicated that diverse services are fundamental for inducing the development of algorithms that clean and analyze data for their later conversion into valuable information for user convenience (Bonato, 2005; Park & Jayaraman, 2003; Zhang & Poslad, 2013), our findings regarding the user expansion mechanism extend the understanding of the use and optimization of data to cover its linkage with service adaptation. In particular, we found that this mechanism enhanced user friendliness, increased users' willingness to try a new, innovative product, and increased market attention. It also improved the possibility of service repackaging and satisfied different user groups' demands. The effective user expansion mechanism was, in part, the result of users' willing or unwilling acknowledgment of the device's interpretive flexibility. According to Bijker (1995), a device's interpretive flexibility indicates that it holds different meanings for different stakeholders (Doherty, Coombs, & Loan-Clarke, 2006). For users, the smart tag device served as a fashionable way to exchange data, while, for corporations, using the smart tag in conference hosting presented an effective way to collect and analyze data concerning their products. We determined that the smart tag system's ability to serve diverse industries and user contexts (e.g., corporate trainings and marathons) was largely the result of the reprogrammable functionality, data homogenization, and self-reference characteristics of digital innovation, which enabled integration and modularity of the multiple layers so that a stable, combined technological foundation could be used to support different service packages.

These three mechanisms motivated the actions taken by the designers that enabled this system to accomplish different phased goals throughout the product formative, data-centric, and service adaptation stages, resulting in an effective evolution outcome for the system's implementation at various events. Our findings offer insight into the specific concerns and issues relevant to the construction and evolution of a smart technology and makes several theoretical contributions. First, as argued above, the extant smart technology literature is primarily conceptual in nature and takes a static componential view by focusing on either one layer (e.g., data, Porter & Heppelmann, 2015) or several influential factors related to the smart technology's use (e.g., a static view, Marinova et al. 2017). In this study, we applied layered modular architecture as a theoretical basis for offering a configurational perspective that advances current knowledge regarding how a conceptual idea can be effectively transformed into a smart system. We systematically analyzed the development of a smart technology by covering the multiple technological layers involved, including the device, network, content, and service, throughout its developing stages of production formulation, data centralization, and service adaptation. As the development of a smart system is not a fixed, unproblematic process, we observed that the designers in this case systematically combined or recombined the different layers that led to the creation of the smart system. Moreover, we found that the designers smartly sorted out problems in one specific layer by changing the designs in another layer (e.g., the data issue in the content layer was resolved by a change made in the device layer). This process helped us recognize that the solutions that the organization adopted in response to the problems it encountered can expand across the boundaries of different layers. The evolution of Loopd's smart offerings illustrates the concept of generative digital modules, which "are most often designed without fully knowing the 'whole' design of how each module will be integrated with other modules" (Yoo, 2013, p. 230). This argument was vividly portrayed in our case narratives and findings, which reveal that the problems and solutions arrived at during different stages are not necessarily planned or fully known a priori. To offer a comprehensive understanding of a smart technology's development, we took a close look at its creation, transformation, the (re)combination of its digital materiality and components, and the user experience, all of which reflected its original design.

Second, the findings regarding the three mechanisms add to the limited knowledge in the smart technology field by focusing on the evolution of smart technology. Despite calls to unpack the underlying mechanisms that drive the formulation and evolution of digital technologies (Hung, Kuo, & Dong, 2013; Majchrzak et al., 2016; Yoo, 2013), very few attempts have been made to focus on the mechanisms that support how these technologies are developed over time. Henfridsson and Bygstad (2013) and Huang et al. (2017) represent two of these few attempts. The former, by focusing on the evolution of a digital infrastructure, identified three mechanisms that lead to successful evolution outcomes: adoption, innovation, and scaling. The latter found that a digital venture can radically increase its user base through the operation of three mechanisms: data-driven operation, instant release, and swift transformation. These studies identify various types of mechanisms to understand different digital designs (e.g., digital platform, digital infrastructure) that are relevant to our research. Nevertheless, our research aim specifically focuses on the development of a smart system and addresses how its configuration is driven by generative mechanisms over time.

Third, considering smart technology to be one form of digital innovation, Nambisan et al. (2017) highlight that it is essential to regard the dynamic innovation process as "a sporadic, parallel, and heterogenous generation forking, merging, termination, and refinement of problem-solution design pairs" (p. 226). Addressing problem-solution design paring can help improve the understanding of how a smart technology develops and can help identify how firms integrate internal and external resources and successfully capture opportunities to solve problems as they emerge. By extending the smart technology concept to cover its formulation and transformation, we contribute to the smart technology literature by addressing the evolution of the smart technology phenomenon.

Furthermore, our research demonstrates that balancing desirable features with the availability of organizational resources is particularly relevant when testing market acceptance of a new technology. This is related to the work of Yoo et al. (2010), who argue that in order to balance the requirement of both organizational resources and quality, a firm should create new meanings for their digital products and services. Our case indicates that, at an early stage, Loopd devoted greater effort to designing the device and network layers than to designing the content and service layers. A tangible product materialized, gaining market acceptance and growth at an early stage. Later, after Loopd had achieved a certain level of market penetration, the founders started exploring "combinatorial innovation" in the form of real-time session analytics, social connection graphs, and journey emails by "gluing components from different layers" (Yoo et al. 2010, p. 272). At the same time, the firm was able to cut down the wearable's production costs without diminishing the value of its aesthetic appeal in attracting users. This strategy echoes previous research findings pointing out that the strategies of pursuing smart technologies depend on the firm's phased goals. For example, a start-up company with uncertain sources or scarce support (Nambisan, 2017) may need to pursue a strategy that focuses on developing smart components until it has established a stable user basis or an acceptably competitive advantage (Svahn, Mathiassen, & Lindgren, 2017; Yoo et al. 2010). Our research adds empirical content to the extant body of knowledge by demonstrating that companies redefine and recombine digital materiality in their efforts to achieve an appropriate balance between the market appeal of their products and their production costs.

8 Implications and Conclusions

Our research contributes to the emerging smart technology literature (Porter & Heppelmann, 2015, 2014; Marinova et al., 2017; Ramaswamy & Ozcan 2018) by providing an empirical study that focuses on problem-solution design pairing. While researchers have widely accepted that the vast improvement in digital technology is leading to automated and interconnected information, hardware, and software and is thus posing significant opportunities and challenges for business processes (e.g., interactions with customers, service processes), the "smart" concept remains vague especially regarding its implementations. Moreover, the methods for building smart technologies remain complicated and underexplored. Our research findings operate behind the dominant conceptual work on the nature of smart technology and empirically examine the developmental path of an integrated smart tag system. Thus, we contribute to the extant smart technology literature by uncovering generative mechanisms and developing theoretical insights related to the formulation and transformation of smart technology, thereby addressing the phenomenon's evolution.

In particular, drawn from the theoretical basis of layered modular architecture (Yoo et al., 2010), our research offers a substantive look at the mechanisms underpinning attempts to develop a smart wearable technology integrating the device, network, content, and service layers, as played out in our case study. While we identified three generative mechanisms that led to the smart technology's creation and subsequent evolution, these generative mechanisms by no means attempt to constitute major theory; rather, we suggest that they help open the door for theorizing the dynamic nature and path of smart technology projects over time. These generative mechanisms may serve as a starting point for researchers interested in smart technology design because they constitute an initial framework and serve as concepts that can contribute to further qualitative studies as well as confirmatory, quantitative models.

This research has inherent limitations. First, while Loopd offered a unique research case for exploring smart technology's evolution, we recognize that the joint ventures of this company and its collaborative firms (e.g., Etouches) will become increasingly relevant for the future of Loopd's product and services; business collaboration certainly exists in digital innovation as an important influence. In future research, studying the interactions among various companies may prove useful for identifying business-related mechanisms that affect the development of smart technology. Second, our study focused on wearable technology. Although this emphasis helped us to identify three generative mechanisms based on the specific technology studied herein, we do note that the generative mechanisms may be different for other digital devices comprising various technological features. As such, future research may wish to encompass or compare the configuration of mechanisms among different devices.

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