Science, Technology, & Human Values
Volume XX Number X
Month XXXX xx-xx

10.1177/0162243907311556
http://sth.sagepub.com
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http://online.sagepub.com

From Innovation Community to Community Innovation

User-initiated Innovation in Wireless Leiden

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The role of users in innovation processes has gained increasing attention in innovation studies, technology studies, and media studies. Scholars have identified users and use practices as a source of innovation. So far, however, little insight has been generated in innovation processes in which communities of users are the driving force in *all phases* of the innovation process. This article explores the conceptual vocabularies of innovation studies and actor–network theory and discusses their adequacy for describing and understanding the dynamics of user-initiated innovation processes in which community and innovation are closely intertwined. The authors introduce the concept of *community innovation* and argue for its relevance for understanding the full dynamics of innovations initiated and shaped by user collectives. The article elaborates a qualitative case study of Wireless Leiden, a local wireless network infrastructure in the Dutch town of Leiden initiated, designed, and maintained by a local community of users.

Keywords: *actor–network theory; innovation studies; user innovation; Wi-Fi community; innovation community*

The domain of information and communication technologies has always been a domain in which boundaries between producers and users are fuzzy. Free and open source software is a clear example of how communities of computer users develop all sorts of software.[1] In a similar vein, many popular Web services build on the efforts of, often experienced and skillful,

Authors' Note: We are grateful to four anonymous referees for valuable suggestions on the first draft that helped improve the article.

users. Examples include the many blogs, podcasts, and videocasts; customer-written product reviews on Amazon; and the free encyclopedia Wikipedia. *TIME* (2006-7, December 25, 2006) magazine even put "You" (the Internet user) on its cover as Person of the Year 2006. At the physical layer of telecommunication infrastructures, user-initiated products and innovations are quite rare. This level is dominated by governments and commercial telecom and cable operators who finance, produce, and improve the expensive and often large-scale information and communication infrastructures. However, a free-access ether commons, originally meant for indoor wireless local area networking with Wi-Fi as successful implementation, has inspired users to develop local wireless infrastructures themselves, challenging this organizational dominance.

In the Dutch college town of Leiden, a small group of residents managed to develop a townwide wireless infrastructure (with regional ambitions) offering local residents possibilities for free communication, under the name "Wireless Leiden." Although there are other major Wi-Fi initiatives, like Freifunk in Berlin or DjurslandS.net in Denmark, the completely wireless "backbone" of the Leiden infrastructure is technically unique. Wireless Leiden has grown to a size that can no longer be neglected (and is not neglected) by other players on the infrastructure market.[2] In 2005, Wireless Leiden started to expand regionally, promoted its activities in other cities, and even built two Wi-Fi nets in Turkey, thus stimulating the potential diffusion of freely accessible wireless communication infrastructures.[3]

In this article, we aim to understand the dynamics of innovation processes that are initiated and shaped by a community of users such as Wireless Leiden. Theoretically, we build on the strands of user-oriented research within innovation studies as well as science and technology studies (STS). Together with his collaborators, Eric von Hippel initiated and developed an impressive line of research addressing the active role of users in innovation processes (cf. Von Hippel 1976, 1988a, 2005; Von Hippel and Von Krogh 2003; Franke and Shah 2003; Lüthje, Herstatt, and Von Hippel 2005; Shah 2006). Core concepts in this strand of research are *lead users* and *innovation community*. The second concept seems especially fruitful in our case because the community aspect is central to the development of Wireless Leiden. In STS, the innovative agency of users in the dynamics of technological developments has increasingly drawn attention during the past decade as well (e.g., Oudshoorn and Pinch 2003; Rohracher 2005). These studies often focus on user–producer interaction during the various stages of technological development. As is true of innovation studies, STS have paid less attention to understanding the innovative agency of *communities* of

users. Based on an analysis of Wireless Leiden as case study, this article aims to develop conceptual tools for a better understanding of user-led innovations as a collective process.

Our argument will be unfolded as follows. In the next section, we position our research theoretically within the current concerns of both innovation studies and STS. Next, we offer a two-part description of the rise and development of Wireless Leiden. The first part describes the sociocultural negotiations that shaped Wi-Fi in the period when Wireless Leiden was being initiated. During this phase, lead users, their innovative agency, and information exchange were center stage. The second part addresses the processes of growth and stabilization of the wireless infrastructure as a collective action of an innovation community. We explore the role of ideology, technical competencies, and managerial competencies within the community and their impact on the actual shaping of Wireless Leiden as a townwide, free wireless infrastructure. Finally, we evaluate our empirical findings related to current conceptual vocabularies from innovation studies and STS and discuss how these vocabularies can enrich each other. We conclude by introducing the concept of *community innovation* and discussing its theoretical and empirical merits.

Theoretical Framework and Methodology

For constructing our theoretical framework, we will draw from two fields of research that address the various roles and influences users have in realizing new innovative products and services. Both innovation studies and STS elaborate the active role of users theoretically and empirically. So far, however, these two fields have taken only limited advantage of each other's insights. In their core literature, only few mutual references can be found.[4] Clearly the two domains pursue divergent objectives, as reflected in divergent research agendas. The work of Von Hippel and his colleagues is primarily business oriented and aims to enhance the quality of a company's innovation processes by making companies aware of users as a potential rich source of innovative ideas for product development. Specifically, Von Hippel has developed methods and toolkits for finding and tapping this source. In the field of STS, by contrast, the focus on users is often inspired by a sociopolitical and sometimes normative agenda aimed at involving more social groups in technological development and empowering specific user groups. Moreover, the two fields use quite different methodologies: if innovation studies primarily rely on quantitative methods, the STS tradition

mainly capitalizes on the strategy of "thick description" by doing qualitative case studies.

More recently, however, the mutual interest between these two fields seems to be growing, and it is possible to observe cautious shifts in agendas and methods. Von Hippel has recently broadened the scope of his work by repositioning the role of users as more central and essential in innovation processes (Von Hippel 2005). Instead of depending on what producers offer them, users increasingly are able to develop what they want themselves. This trend toward "democratizing innovation," as Von Hippel calls it, is enhanced substantially by the widespread use of information and communication technology. According to Von Hippel, this trend is not only relevant for industries and companies but also for policy makers and various social groups. While in STS circles, questions on democratizing technology have topped the research agenda for a long time, more recently, the interest in innovation processes has started to grow, even to the extent that today the term *science, technology and innovation studies* has grown common.[5] Although there are still fundamental differences in styles of research between STS approaches and innovation studies, rising interest in understanding the growing role of users in innovation is evident in both fields.

This article aims to develop a further dialogue between the two fields by explicitly drawing together theoretical concepts from both strands in our analysis of Wireless Leiden as a case study. In the next two sections, we discuss how the two fields have conceptualized (1) the innovative agency of users and (2) the innovation dynamics of communities of users.

The Innovative Agency of Users

Von Hippel's long-term and sustained study of the active role of users in innovation has put the innovative agency of users firmly on the agenda of innovation studies. On the basis of earlier work in the 1970s, he introduced the key concept of *lead user* in 1986 (Von Hippel 1976, 1986). Lead users are users who first "face needs that will be general in a marketplace—but face them months or years before the bulk of that marketplace encounters them," and second, they are positioned "to benefit significantly by obtaining a solution to those needs" (Von Hippel 1986, 796). Lead users can—but need not—invent, design, and build their own solutions to suit their needs. Since lead users are aware of future market needs, they potentially serve as an excellent "need-forecasting laboratory for marketing research" (Von Hippel 1986, 791). By emphasizing lead users as a rich resource for corporate innovation, Von Hippel (1988a) elaborated a methodology for marketing

departments to identify lead users as representing the needs of the future market. As such, they possibly play a major part in the design of prototypes of new products.

In his later work, Von Hippel has proposed an institutional forum where users and producers meet (Von Hippel and Katz 2002). Various STS scholars have also stressed the relevance of these institutional loci—referred to as "nexus" (Schot 1992) or "mediation junction" (Schot and de la Bruheze 2003)—that enhance the interrelationship of design and use. These loci are considered important places for social learning processes in which alignments in articulation processes between various actors from both contexts can be established (Rip, Misa, and Schot 1995; Stewart and Williams 2005). In this area, the concerns of innovation studies and STS appear to intersect, but there are differences as well. Whereas Von Hippel has mainly focused on interaction with lead users, as those who represent future market needs, user-oriented STS scholars have advocated the need to be sensitive to the diversity of users, who potentially have quite different needs and agendas (e.g., Oudshoorn, Brouns, and Van Oost 2005). In the latter domain, diversity is articulated along demographic lines (age/gender/class) or different positions (management/end users/nonusers). Although Von Hippel has paid less attention to this type of user diversity, one can credit his work for highlighting lead users as a specific group of users—one that did not arise from the general heuristic of diversity applied in STS. In this article, we argue that *combining lead user analysis with attention for user diversity*—among lead users as well as other types of users—is fruitful when it comes to analyzing the innovative agency of users.

A second concept from the STS vocabulary valuable for analyzing user innovations is "script." This concept explicitly relates artifacts and their usage by suggesting that all designers base their products on envisioned users and specific use situations (Akrich 1992). Accordingly, products contain a script, which is the materialized presentation of envisioned use. The use of a product is described in semiotic terms as the "reading" of its script. In this reading—which essentially involves adapting the new product to user environments—the meanings, uses, or even the products themselves can be changed and adapted. Users may very well read scripts in ways that differ from those intended by the designer. Lead users, in this conceptualization, constitute a specific group of users that adopt specific, informed ways of not just reading but also introducing new scripts, by inscribing characteristics of their specific use situation into the product (which in many cases even applies to its materiality as well).

Central in the script approach, moreover, is the *symmetrical analysis* of interaction between user and artifact. Both users and artifacts can be analyzed as attributed with (inscribed) agency and meaning that enable and constrain user practices and users' agency. Both user and artifact shape and at the same time are shaped by the practice of usage. From an STS perspective, lead users' agency and meanings are analyzed in direct relation to the inscribed agency and meanings (scripts) in the artifacts they use and produce. In our case study, then, we take the agency of artifact itself as a category of analysis—a focus that is absent in innovation studies—and argue its relevance for understanding the dynamics of where and how lead users and their activities come into being.

As our argument underscores, the conceptual vocabularies developed in STS and innovation studies may very well enrich each other. Linking up the concept of lead user with user diversity and symmetrical analysis of user–technology relations offers us an analytic framework for studying the innovative agency of users.

The Innovative Agency of Communities

More recently, the rise of the Internet in general and open source communities in particular has boosted interest among scholars in innovation studies for innovations by user collectives, especially the phenomenon of nonprofit collectives producing innovations.[6] To capture the dynamics of open source communities, various concepts were developed: private-collective innovation (Von Hippel and Von Krogh 2003), commons-based peer production (Benkler 2002), as well as community-based innovation (Franke and Shah 2003; Shah 2005). Next to open source, the practices of extreme or specific types of sports—for example, kite-surfing, mountain biking, or rodeo kayaking, and handicapped sport—also provided a rich source of user communities producing innovations in sporting equipment (cf. Hienerth 2006; Lüthje, Herstatt, and Von Hippel 2005; Franke and Shah 2003; Shah 2000).

In 2005, Von Hippel compiled this fast-growing cluster of publications in *Democratizing Innovation*. This is where he introduced the overarching concept of "innovation community" defined as an organized cooperation in the development, testing, and diffusion of user-initiated innovations. Users as well as manufacturers can be members; the innovation community can be purely functional but may also fulfill the role of a social (virtual) community providing sociability, support, a sense of belonging, and social identity (Von Hippel 2005, 96). Although Von Hippel defines innovation community

broadly, he has mainly addressed and analyzed it as a locus or setting for *exchanging* innovative ideas and information among involved individual community members. On the basis of work in STS, we have reason to expect that activities of innovation communities also involve collective work aimed at creating and sustaining stable networks.

Recent user innovation studies, to be sure, have explored the diversity and dynamics of roles participants can take on in innovation communities. In this regard, Von Krogh, Spaeth, and Lakhani (2003) have studied how newcomers' identities in an open source community evolved into those of accepted members, Shah and Tripsas (2004) explored user entrepreneurship by focusing on user innovators starting their own firms, and Hienerth (2006) described the dynamics of user innovation communities evolving into commercial and manufacturing communities after the commercialization process of user innovations through the pioneering activities of user manufacturers. If the user-oriented strand of innovation studies has certainly produced a wealth of concepts and data on community-driven innovation, these studies, too, are limited, notably in two ways. First, most studies on innovation communities either address one aspect (the role of knowledge exchange, the recruitment into an existing community, etc.) or focus on more complex processes at a specific time (e.g., the recruitment dynamics of new members into an existing community). An understanding of the life cycle dynamics of innovation communities (initiation, growth, stabilization, etc.) is lacking. Second, these studies do not offer conceptual tools for understanding the work involved in aligning technical and social elements of community-driven innovations.

To address the latter, we will use the concept of *heterogeneous engineering* (Callon 1987; Law 1991). Engineers not only create and align technological elements, but equally important, they also bring various types of social, political, economic, and cultural elements that are "inextricably bound up into an organic whole" into line with scientific and technological elements (Callon 1987, 84). Heterogeneous engineers continuously perform various types of work to align technical *and* social elements into an actor–network so as to build stable coalitions that are necessary for the successful development and implementation of an innovation. Similarly, innovative users are likely to perform these types of heterogeneous activities when bringing the various elements into line that are necessary for the development and stabilization of an innovation community *and* the innovations themselves (which also constitute the community). This is why we will rely on the perspective of heterogeneous engineering to analyze innovative agency of communities by addressing the *heterogeneity of alignment work* in innovations

communities.[7] Sensitized by STS research on invisible work (Star and Strauss 1999; Shapin 1989), we also seek to move beyond an exclusive focus on core actors and activities in the innovation community by rendering visible the role of community members who perform nonentrepreneurial activities, such as maintenance work and "infrastructures of support."

Given our theoretical concerns, we distinguish two main research questions that we address in the analysis of our case study of Wireless Leiden as innovation community. First, which types of work are involved in initiating and developing a community-driven innovation? And, second, which collective efforts are involved, and how are they distributed across the network to ensure the growth and stabilization of a community-driven innovation?

Method

Our specific theoretical framework and concerns have led us to embrace an explorative qualitative approach based on an in-depth case study. For our data collection, we relied on three strategies. First, we explored all the information provided on the Wireless Leiden Web site and a wiki (http://www.wirelessleiden.nl). This site proved to be a tremendously rich source, because—fully in the tradition of open source communities—maximal transparency is strived for regarding both material and organizational aspects. Minutes of meetings, discussions, and debates were made available online, as well as many technical descriptions, guidelines, and images of the various stages of the technological developments involved. Second, we held seventeen in-depth interviews with ten core actors of Wireless Leiden. Third, we attended seven meetings organized by the Wireless Leiden board between January 2005 and April 2006. At these meetings, we observed discussions, presentations, and workshops, while we also interviewed additional participants.

The Rise of Wireless Leiden as a User Innovation

In this section, we analyze the dynamics of the rise of a user community that created an innovative wireless backbone infrastructure built on Wi-Fi technology. In describing these dynamics, we focus on the identification of lead users of Wi-Fi technology and the types of work they performed to align various actors—human as well as nonhuman—into a new network that would form the basis of the Wireless Leiden (WL) community. To understand

the character and the type of work lead users had to perform to align the Wi-Fi technology with their aims, we need insight into the script—the materialized prescribed use—of Wi-Fi itself. We begin, therefore, with a brief historical detour to foreground how the Wi-Fi technology itself was constructed with a specific use in mind—thus enabling and constraining actual practices of the WL lead users.

The Shaping of Wi-Fi as Indoor Local Area Technology

The emergence of Wi-Fi started with the decision of the American regulatory agency Federal Communication Commission (FCC) in 1985 to allow the use of a special radio technique, called spread spectrum, in an unlicensed part of the ether. This radio technology, previously restricted to military use only, opened the possibility for the creation of high data rate wireless local area networking. By opening the free industrial, scientific, and medical (ISM) radio bands—no (expensive) licenses were needed—for spread spectrum modulation, the FCC deliberately created a niche for experimentation with novel uses. However, at the same time the FCC restricted potential use of this part of the ether by limiting the maximum power of the wireless devices and by prescribing small antennas. FCC (1993) explicitly envisioned only indoor use of this wireless technology (as an alternative to indoor cables). This envisioned use indeed materialized into devices that came on the market based on an agreement of a standardized form of wireless communication (802.11), ratified by the Institute of Electrical and Electronics Engineers (IEEE) in 1997, within the free ether parts offered by the FCC. In 1999, computer producer Apple introduced Wi-Fi to the mass consumer market by selling an inexpensive Wi-Fi card for US$99.

The intended indoor use of Wi-Fi in offices, homes, shopping malls, or airports was firmly inscribed into the artifacts as well as the mandatory regulations. Signals from standardized Wi-Fi equipment only traveled a maximum of one hundred meters because of legally enforced power restrictions—the allowed power level was a mere one-tenth of that of a mobile phone. Furthermore, Wi-Fi devices were equipped with small, integrated antennas with a limited range. The commercial interest of big players in the information and communication technology market was also embedded into the design of the standardized Wi-Fi devices as they could only function in combination with commercial operating systems from Microsoft and Apple. Consumers wishing to control their wireless equipment from within open-source operating systems such as Linux or FreeBSD were left in the cold,

in quite the same manner as those allergic to onions in a MacDonald's (Star 1991).

Evidently, the standardized Wi-Fi equipment has a clear indoor-use-only script that imposed rather forceful restrictions on ways in which these devices could be used, especially for outdoor use. However, Wi-Fi devices not only constrained use practices but also invited and enabled new ones. Some groups of users saw the potential of the Wi-Fi technology for solving practical problems such as providing rural areas and remote villages with broadband Internet. Other, ideologically driven groups of users saw opportunities for Wi-Fi technology to create so-called wireless Freenets—community wireless networks free of governmental or corporate restraints. Wireless Leiden is one such initiative. The type of work that had to be performed by these users to align the Wi-Fi technology with their vision of establishing free wireless communication networks was influenced by the existing indoor-use-only script. The main work the Leiden initiators had to perform in the beginning involved the *reengineering* of the existing Wi-Fi script.

Reshaping Wi-Fi as Outdoor Wide Area Technology

The first ideas about a wireless community network in Leiden can be traced back to 2001 when a Leiden resident, Jasper Koolhaas, discovered Wi-Fi technology. Koolhaas, trained as an electrotechnical engineer and fascinated by computers, networks, and the Internet, saw the potential of Wi-Fi technology for creating a free wireless infrastructure. As he later recounted, his "Eureka" insight into Wi-Fi's outdoor use: "When thinking about this some more, at one point I thought: Holy smoke, this is not just interesting—this is earth shaking. For the first time in history people like you and me can build an infrastructure themselves. Until then something only possible for governments or big companies. . . . Admittedly, radio amateurs where doing the same for some time, but that infrastructure was accessible for licensed HAM operators only. And this is an unlicensed band, free to use for all" (interview October 25, 2005). Clearly, the script of the standardized Wi-Fi devices had both enabling and constraining features for users. It made it possible for them to think of a new, cheap, and free infrastructure, yet its users' connections were constrained by distance. What type of work was needed to reengineer the inscribed script?

By using a local network of computer hobbyists, Koolhaas managed to bring in a few additional motivated participants, among them Marten Vijn, a Linux user. In the autumn of 2001, they started to experiment with Wi-Fi

devices to achieve long-distance connections. In doing so, they performed various types of work to deconstruct the inscribed script in regular Wi-Fi devices. To give an idea of the complexity of this work: they were patching firmware, writing, and adapting device drivers for Linux; they had to find a solution for increasing the range of the radio waves without increasing the output power, as this was restricted legally by FCC regulations; they were experimenting with different types of antennas; and they had to make the devices weatherproof for outdoor use (interviews with Rudi van Drunen, February 23, 2006; Johan de Stigter, December 6, 2005; Evert Verduin, March 27, 2006; Marten Vijn, October 14, 2005; and Lodewijk Voge, April 4, 2006). It turned out to be a difficult task to get the weak radio waves working in the Wi-Fi assemblage they envisioned. The initiators of WL tried to find solutions in using other types of antennas. Increasing the output power was not an option as this would break the formal regulations and would imply an illegal wireless network, risking fines and confiscation of their devices by the Agentschap Telecom that supervises the Dutch radio spectrum. Despite all their efforts and knowledge of computers and computer networks, they failed to get the Wi-Fi radio waves to connect two distant nodes.

It took the experiences and knowledge of two Leiden radio amateurs to control the radio waves. These radio hobbyists brought in a good working and cheap antenna that was developed in radio amateur circles, the so-called quad antenna.[8] The version specifically modified for Wi-Fi use, called a bi-quad, improved the amplification of the radio waves significantly. Constructed out of a few parts only, it was easy to build and cheap as well. In "line-of-sight" situations this antenna bridged distances of several kilometers (interview with Evert Verduin, March 27, 2006).

Now that reengineering of range had succeeded, the indoor part of the script still had to be reengineered into a design that allowed outdoor use. The bi-quad antenna was weatherproof, but the electronics of the Wi-Fi equipment were not. In principle, one could connect an outdoor antenna to the indoor electronic parts by using a cable, but this would reduce the quality of the antenna signal. Therefore, the WL initiators chose to develop a new "integrated" outdoor device and thus had to find ways to protect the delicate electronics against rain and wind. Simple and cheap objects like drainpipes and plastic lunchboxes were used to house both antenna and electronics. Using home-built outdoor Wi-Fi nodes, the first data packet of the Wireless Leiden group was successfully transmitted in January 2002. In the following months, two more nodes were added, resulting in a rudimentary wireless network structure that basically fulfilled the same functionality as a wired backbone.

The group of Leiden Wi-Fi initiators successfully reengineered the existing Wi-Fi devices from short-range indoor devices into long-distance outdoor devices. The vision of a free infrastructure for Leiden residents that Jasper Koolhaas had articulated some months before had now become so realistic by the successful reengineering activities that in August 2002 the initiators decided to establish the formal association called Wireless Leiden (Van Drunen et al. 2003). Its main purpose was to further develop the wireless infrastructure that Leiden residents could use to communicate freely with each other.

User-initiated Innovation as a Collective Activity of Reengineering

This long-distance outdoor Wi-Fi device can be characterized as a lead users' innovation. The users involved envisioned a new type of use/need that was not anticipated by the producers of the Wi-Fi device and they were to benefit from solutions to that need as well. The dynamics of this lead users' innovation can be characterized in two ways. First, these users actively resisted an explicit inscribed script of an existing device. This script itself defined the type of work that needed to be done before the reengineering of this script was successful. And second, this reengineering was a *collective* activity. The exchange of information and knowledge was not only essential in realizing this lead users' innovation but also the alignment of different types of knowledge. In this case, combining the knowledge of three different domains—computer networks, open source software, and radio waves—proved crucial. These different types of knowledge were distributed over more than one person.

The actors in the WL project had quite different backgrounds. Pooling their diverse interests, expertise, resources, and contacts enabled them to collectively engineer a wireless network configuration that worked. Although literature on users as sources of innovation conveys the image of the "professional amateur" (Leadbeater and Miller 2004), most engaged in the project were professionally involved in careers related to issues that needed to be solved. For instance, professional network infrastructure builders both in the field of wired and wireless topologies were involved, as well as actors with experience relating to organization structures, programming of embedded devices, open source software development consultancy, or writing complex algorithmic software.

In a user-initiated innovation in which the needed expertise and knowledge is distributed across various actors, it is likely that one of them fulfills

an explicit coordinating role. In the WL case, it was the initiator, Jasper Koolhaas, who in the process took on the role of lead user; he aligned and coordinated both the human and the nonhuman actors required for realizing a reengineered Wi-Fi device.

A second finding from this case is that lead user innovations can be understood as the result of a social process in which the actual shape is negotiated among the actors and the envisioned user and use situation are configured (Woolgar 1991). Koolhaas translated his ideal of a Freenet—a free and cheap wireless network available for everybody—into requirements that had to fit the needs of ordinary residents of Leiden as end users. This led to (re)design choices that were in line with legality, low costs, reliability, constructability, and usability. Interestingly, the two radio amateurs who joined this project after some months had established already in 1999 a long-distance wireless connection of nine kilometers between their respective homes for sharing broadband Internet with HomeRF, an alternative wireless local area network standard, that failed to create wide industry support. However, for their connection, the two bought an expensive professional hi-gain antenna. Because they acted on their purely personal needs, the radio amateurs had no incentive to share their solution. Only through active efforts on the part of Koolhaas, who serendipitously found out about their homebrew wireless connection, they became involved in the WL initiative. This is a nice example of what Von Hippel (1994) calls "sticky information," which is only available locally if not individually. Because the ideals of the WL initiators were public-oriented, from the outset, the WL initiative relied on the openness and accessibility of their information and knowledge as a central organizing principle. Translating the ideology of sharing knowledge into technology, they installed a wiki—a Web site accessible for reading *and* writing by anyone—as a way to collect and communicate all information about their project and actively involve new participants.[9]

The Growth of Wireless Leiden as a Community-driven Innovation

When the collective reengineering of the existing Wi-Fi technology was realized, the newly established association faced the challenge of putting this wireless network into use as well as to expand it and increase its number of users. Building a freely accessible wireless network for general public use and organizing both the growth and stabilization of a townwide structure with only volunteers as human resources seemed a challenging task. Sustaining

a large-scale system involved lots of maintenance activities, but hiring employees for routine tasks was no option for this volunteer initiative.

Surely, this challenge was taken up by the project's initiators energetically. Whereas by the middle of 2002 the newly established WL association had a rudimentary wireless network in place consisting of four nodes and a dozen of involved users, by the end of 2004 the network was extended to more than fifty wireless nodes (covering approximately the downtown area), while around eighty volunteers performed various kinds of tasks and approximately two thousand local residents connected to the wireless network for activities such as Web browsing, file sharing, chatting, gaming, and making voice-over Internet Protocol (IP) phone calls.

In this section, we will unravel the type of work and activities required to establish, extend, and stabilize such a wireless network. If one may understand the earlier development as a collective process of reengineering an existing technology by a group of lead users, we analyze the further development of Wireless Leiden as a *community-driven* innovation. We elaborate the concept of innovation community put forward by Von Hippel—who actually focused on the role of information exchange—by addressing the variety and heterogeneity of activities performed in such a community.

Aligning New Actors, Shaping Heterogeneous User Roles

To realize the project's growth, both the wireless infrastructure and its user base were developed simultaneously; one could not evolve without the other. Managing this complex coevolving of the material infrastructure together with the organizational community structure required very *different types of work.* In this process of aligning, coordinating, managing, and regulating the various material and human actors, *different types of user roles* were constructed, and various kinds of work and responsibilities were distributed across these various user roles.

The Organizational User as Sponsor

One of the first issues to be tackled by the initiators—most of whom joined the board of the WL Association—involved the cost of the new wireless nodes. Until then, they themselves had paid for the technology they needed to purchase, but this was not doable anymore now that their goal was to realize an extended, free public infrastructure.[10] Meanwhile, a new Wi-Fi enthusiast Huub Schuurmans had joined the initiative, and he brought with him new knowledge and expertise that played a central role in organizing and coordinating the further growth of the network. Schuurmans was a former

public relations officer from oil company Royal Dutch Shell and a former scientific attaché for the Ministry of Economic Affairs who founded the Netherlands Office for Science and Technology in Silicon Valley. He was an expert on, as he put it, "open innovations, managing public relations, and creating a footprint" (interview with Huub Schuurmans, October 9, 2005).

Schuurmans proved to be the driving force behind a continuous, intensive publicity campaign resulting in widespread publicity for WL, and he arranged contacts with various Leiden organizations that might want to support the WL network. For instance, he asked various organizations to sponsor a node. The first official node sponsor was the local software company Cope that decided to sponsor two new nodes. In return, Cope used the WL infrastructure as its own virtual private network allowing employees' safe and free access to the company network from their homes. In fact, this new *sponsor–user* role approach provided the model for integrating local companies and other donor organizations into the project's infrastructure. Sponsors would pay for new nodes, which in turn were given the sponsors' names, and more important still, they became *users* of the WL wireless infrastructure as well. WL could offer them a virtual private network with a better performance than any commercially available system. As Koolhaas explains, "This company Cope paid for two nodes and, well, in an organizational sense this was the first building block of Wireless Leiden. Earlier, the focus was on technical issues, but now it grew more into an organization because the basic idea itself became clearer: a company would fund the building of new nodes because it would serve their own needs, yet it would be helpful to other people as well. Thus this model reinforced the network's inner dynamic" (interview with Jasper Koolhaas, October 25, 2005).

After the first companies had started to pay for new nodes, the Wireless Leiden organization managed to convince public organizations such as local schools and libraries to join the project as well. At one point, the enthusiasm to participate in WL was so enormous that the WL volunteers in charge of constructing and programming the nodes could not keep up with the new requests.

The Volunteer User

In 2002, the influx of Wireless Leiden enthusiasts increased sharply, while the small group of Wi-Fi initiators meanwhile evolved into a much larger group consisting of dozens of volunteers. To manage all these people, the notion of "official Wireless Leiden volunteer" was invented. Actually, this was just a way to make the existing situation explicit, whereby only registered members had access to e-mail correspondence. There was another new element: to become an official volunteer, one had the sign a contract. This contract was meant to

protect volunteers against liability claims pertaining to, for instance, accidents that might occur during the building of a new network node, such as people or things falling off from a rooftop. At the same time, a volunteer also officially waived his rights to any intellectual property claims. For this purpose, two WL members employed as lawyers developed a specially crafted "Wireless Leiden license." The contract was meant to prevent people from patenting novelties invented by using the Wireless Leiden network.

To coordinate all those new volunteers effectively, various subgroups were formed in which volunteers could specialize in issues tied to the Wireless Leiden project that had their particular interest, such as building nodes, maintaining the Web site, and writing software code. In addition, another WL participant, Dirk-Willem van Gullik, former president of the Apache software foundation, introduced the "who-builds-decides" rule to prevent endless debates without getting anything done. Over time, several formalized procedures organized the Wireless Leiden community, while the WL board held control over the "interface" used toward the "outside" world.

The Residential End User

In January 2003, Internet service provider Demon sponsored WL with access to three of their advanced digital subscriber line (ADSL) Internet lines. This allowed WL to offer free Internet access (at least to the World Wide Web part of the Internet) to local residents. This new option attracted many new users, and in this way WL configured a new type of user: the residential end user who wanted to associate himself of herself with WL to surf the Web or e-mail through a free Web mail account, but who was not interested in additional services.

WL facilitated end users who lived in the parts of Leiden that were covered. WL users living outside of the reach of existing Wi-Fi nodes initiated the construction of new nodes to link their neighborhood to the WL backbone themselves. To realize new nodes, they performed various heterogeneous activities: finding a sponsor, asking volunteers to assemble and program the node, locating suitable locations to put nodes on, and getting permission and electricity from homeowners. The board of the WL association organized open meetings for interested residents to work on creating new nodes.

This new type of end user, however, no longer needed to have either the knowledge about installing outdoor Wi-Fi or the motivation to let the overall project succeed. One of the radio amateurs, the WL member Johan de Stigter, sold ready-made Wi-Fi aerials, a product with commercial potential. To make it easier for end users to connect to the "free Internet," he developed a black-boxed end user solution. This made it no longer necessary to tinker

with and disassemble commercial routers and soldering one's own bi-quad antenna to produce a "drainpipe client hack." His company Gandalf released a 250 euros plug-and-play device called Wandy (a contraption of handy and WAN (Wide Area Network). This way, De Stigter developed "drain-pipe clients" into a mature consumer product.[11] The Wandy kit contained everything users needed, provided they were able to receive the Wi-Fi waves in their neighborhood. His kit was available at a Leiden electronics shop that also offered additional installation assistance if needed.

The "Maintenance User"

With the increasing number of nodes, volunteers, and end users, maintenance of the network became a topic of discussion. The growing group of residential end users implied higher expectations about the reliability of the Wireless Leiden network and its services. The number of nodes increased sharply, requiring routine maintenance work. Although there were lots of volunteers by now, most of them were only willing to try out new and "exciting" things and were much more reluctant to perform "routine" jobs. To solve this problem, in April 2004 the WL board constructed a new user role: the node adoption volunteer (NAV). These special volunteers were prominent users of a specific network node, and if "their" node was functioning erratically, they were usually among the first to notice. Or, a local user of a certain node who complained a few times when a node was not functioning properly was asked to become responsible for keeping an eye on a local network node. In case of a malfunctioning, the NAV was supposed to check the situation, to press the reset button, and to test if the connection came "up" again. If not, the whole node was disconnected and brought to one of the more experienced volunteers and exchanged for a working one. To assist the NAVs, more technically experienced WL users produced special standardized checklist forms to assist them with on-site node failure debugging. By constructing the role of the NAV, the WL network builders delegated some aspects of the maintenance work to local users.[12]

The Wireless Leiden Community as a Sociotechnical Network

In our Wireless Leiden case study, we encountered phenomena that cannot be described adequately by the theoretical framework offered by Von Hippel (2005). Particularly his concepts of "innovation community" and "lead user" fall short. Where in the innovation community concept information exchange between (lead) users is central, our empirical findings illustrate that the

innovation community members perform many more activities. More central than exchange of information is the continuous coordination of the heterogeneous resources that make up Wireless Leiden.

Furthermore, our analysis reveals that the shaping of this wireless infrastructure should take into account a wide variety of different types of users, rather than be understood in terms of lead users only. The WL case comprises an array of different user roles, each one of them contributing to a specific and vital element of the growth and stabilization of WL. Both the wireless infrastructure (the innovation) and the organization structure (the community) developed in mutually interconnected ways. In the same way as Hughes (1983) described all the work that had to be done by Edison to build up the "networks of power" to bring electrical lighting into the homes of the American people, the Wireless Leiden cooperative had to create a supportive network as well to make the "free wireless" to be considered as a configuration that "works." The entanglement of the Wireless Leiden infrastructure and community is visible in the way a wireless network node functions. We understand it as a hybrid entity of technical elements—antennas, cables, software, Wi-Fi devices, the roof—as well as human elements, including the sponsor, the builder, the node adoption volunteer, the roof owner. Without any of these elements, a WL node would not function properly or exist in the first place.

For realizing the growth and stabilization of Wireless Leiden, the diversity of available skills and competencies proved crucial. In the early period, the necessary skills were primarily of a technical nature and geared toward the disciplining of radio waves, but aside from technical and programming skills, in the phase of growth and stabilization, managerial, organizational, PR, and juridical skills helped to solve many problems. The growth and stabilization of the wireless infrastructure was based on constructing, aligning, tuning, and supervising the heterogeneous user groups. Skillfully organized and timed PR activities contributed to the numerous successful alignments between various social groups and Wireless Leiden. It is in particular the heterogeneity of all these activities that contrasts with Von Hippel's singular focus on the circulation of information.

Understanding Wireless Leiden as "Community Innovation"

Von Hippel and his collaborators have focused on how technical innovations often find their origins in a social community of experienced users.

Although this approach has been productive, this conceptualization of innovation community does not allow for describing user-initiated innovation processes where the community is *part of the innovation itself*. Or, formulated alternatively, it is inadequate to assume an a priori distinction between the "technical" innovation and the "social" community, let alone a causal relationship. Our case study of Wireless Leiden shows that its development can be understood as a process of *coevolution* of both the technical infrastructure and the social community.

For this reason, we want to propose the concept of *community innovation* as a way to conceptualize the type of user-initiated innovations whereby the community itself is an essential element of the innovation. This concept makes it possible to understand the specific dynamics of these types of user-initiated innovations, and we would like to single out three of its advantages in particular. First, the concept allows us to analyze growth and stabilization of the innovation as the result of the activities of a community of actors who are users and producers simultaneously. For many of the actors involved, it is precisely the expertise originating in this "double" role of creating and using an innovation that fuels their active involvement. Von Hippel (2005) also addressed this phenomenon for explaining lead users' activities. In contrast, the concept of community innovation draws attention to the diverse competencies and expertise of multiple users necessary to deal with the dynamics of growth and stabilization of the innovation.

Second, the concept of community innovation foregrounds work required for innovation by heterogeneous collectives, most notably the coordination of the alignment and management of the various actors. In the case of Wireless Leiden, this coordination was predominantly performed by a core group of approximately eight to ten community members, who, as it happens, also constitute the board of the WL Association. For the understanding of the dynamics of growth, stabilization, and the actual shape of the Wireless Leiden community innovation, the characteristics of this core group, most notably their skills in engineering the technical and social simultaneously, seemed central. The composition, the shared ideology, the range of competencies, and the knowledge distributed across the core group—all these factors have greatly influenced the actual shape WL has taken as a free-to-use wireless infrastructure with a wireless backbone that in terms of its size is globally unique.

A third benefit of the community innovation concept is that it portrays innovation as an evolving sociotechnical network in which both human and nonhuman actors are active and become aligned. Innovations such as Wireless Leiden can be studied as a sociotechnical chimera, built from a variety of

different elements: all kinds of different people, e-mail clients, Web sites, ideals about freedom, dreams about huge free infrastructure networks, unlicensed ether bands, cheap consumer-grade Wi-Fi devices, computers, antennas, TV satellite dishes, laws and regulations about Wi-Fi use, and international standards. The social and ideological characteristics of the innovation community and the type of knowledge and expertise available in the network have shaped the technological, material aspect.

Clearly the community innovation concept needs further study and elaboration. A qualitative analysis of other types of innovations by user communities, such as Wikipedia and Second Life, may reveal other dynamics of growth and stabilization. Also, studies of cases of failed innovations will possibly contribute more insights into the circumstances and conditions of distinct patterns in the various stages of community-driven innovations.

As our argument has demonstrated, the notion of community innovation can develop into a relevant conceptual tool that helps to increase our understanding of current and future tendencies in an emerging civil society in which ordinary citizens become more and more actively involved in shaping their technical and social environment. These same tendencies are identified as well by the currently influential innovation expert Charles Leadbeater and, last but not least, also by Eric Von Hippel, who suggested that innovations by users will be key to twenty-first-century innovation (Leadbeater and Miller 2004; Leadbeater 2007; Von Hippel 2005).

Notes

1. A noncomprehensive overview of academic studies on free and open source software (FOSS) is available from http://opensource.mit.edu. Although numerous articles on FOSS have appeared, Lin (2005) states in her assessment of the current literature that "research done from the sociological perspective p.1 " is still a lacuna.

2. At the end of 2005, Wireless Leiden covered most of the Leiden area and registered over thousands of different Internet Protocol (IP) addresses.

3. Press release available from http://www.wirelessleiden.nl/pers/persberichten/persbericht_karaman_reis.shtml.

4. This finding is based on the analysis of the three core book publications, two on user studies in science and technology studies (Oudshoorn and Pinch 2003; Rohracher 2005) and one core book from innovation studies (Von Hippel 2005).

5. For example, the current European Network of Excellence PRIME (Policies and Research on Innovation in the Move towards a European Research Area) is exemplary. Whereas Oudshoorn and Pinch (2003) only footnoted Von Hippel in their overview of the role of users in technology development, they explicitly discuss the user-oriented innovation studies in a review of user-technology relations in 2007 (Oudshoorn and Pinch 2007).

6. Community informatics is another strand of literature that deals with questions about information and communication technologies (ICT) innovations by, for, and in communities. For recent overviews, see Gurstein (2000), Keeble and Loader (2001), Day and Schuler (2004), or Schuler and Day (2004).

7. Truffer and Dürrenberger (1997), for example, address the relevance of heterogeneity by emphasizing the role of "outsiders" in creating "innovative milieus."

8. Radio amateur Clarence Moore invented the quad antenna. In 1951 he received a U.S. patent for it (US2537191). Available from http://www.pentodepress.com/receiving/patents/2537191.pdf.

9. Because of increasing "link spam," the wiki was closed off, and a subversion server took over the role of document and code repository (interview with Jasper Koolhaas, October 25, 2005).

10. The costs of a robust node, consisting of two interlinks for backbone communication and one access point for local access, are 1,000 to 1,500 Euros (interview with Jasper Koolhaas, October 25, 2005).

11. The Wandy kit was not exclusively targeted to Leiden residents but to a wider market for broadband Internet access solutions in remote places such as camping sites. More information is available from http://www.wandy.nl.

12. An overview of node adoption volunteers is available from http://wiki.wirelessleiden.nl/wcl/cgi-bin/moin.cgi/NodeAdoptieVrijwilligers.

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