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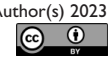

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Infrastructures by the users for users: Motivations, constraints, and consequences of user-driven infrastructuring of mobile phones

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Abstract
Users adapt infrastructures materially to fit their needs, they engage in maintenance and repair, and they learn about the inner workings of infrastructures. Different degrees of user engagement with infrastructures are empirically analysed using the case of user-developed alternative mobile operating systems. Some observations of user agency made already in early studies of the appropriation of media and technology were found to be still relevant: moral considerations motivate users to engage in infrastructuring and users actively negotiate their infrastructural attachments. But 'acting on' infrastructures is also different from 'acting on' devices: the users' experiments with infrastructures require redundancy and they are inherently collective. Moreover, certain designs of infrastructures can enable and demand user-driven infrastructures, while others block it.

Keywords
Agency, appropriation, domestication, end-use, mobile phone, operating system, sustainability

Introduction

In the 1980s and early 1990s, scholars studying the contexts, meanings and consequences of media and technology use (Ang, 1986; Morley, 1986; Silverstone and Hirsch, 1992;

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Sørensen, 1994) found ample empirical evidence to support the claim that what users do when they subject themselves to media and technology is 'under-determined and not undetermined' (Sørensen, 2006: 57). Arguing against various forms of media and technological determinism, this shift freed reception studies and end-user research from the task to find out what media and technology 'does to' people and society and established the qualitative study of users and uses as a research field. A central tenet in these studies is the assumption that 'use' draws on resources that are partly outside capitalist markets and technological rationality, such as family leisure life (Morley, 1986), the moral economies of the household (Silverstone and Hirsch, 1992) and everyday life (Lie and Sørensen, 1996). These cognitive, symbolic and practical resources (Sørensen et al. 2000), which allowed creative appropriation of media and technology, that is, using technologies in ways they were not intended to be used, endowed users with the ability to contest, refuse, and negotiate what was offered to them as commodities to consume.

The recent rise of infrastructure studies seemingly marks the antithesis to the discoveries of the importance of end-users' agency of the 1980s. Infrastructures are large scale, and they do their work behind the backs of users to whom they are invisible in routine use (Star and Ruhleder, 1996). Even worse, created and operated by powerful, global companies, they configure their users' subjectivity (Langlois and Elmer, 2019) and they are 'making new forms of sociality, remaking landscapes, defining novel forms of politics, reorienting agency, and reconfiguring subjects and objects, possibly *all at once*' (Jensen and Morita, 2016: 6). Social relations, subjectivity, politics are all central resources of what was described as creative appropriation in qualitative user studies since the 1990s. If the only way to negotiate with infrastructures is to 'opt-out, for example going off the grid' (Plantin et al., 2018: 299), the price of contestation is to leave society. Use as such would then cease to be a site of agency, resistance is reserved to those few who are able to understand and subvert infrastructures (Farías and Blok, 2016).

In this article, the aim is to do for infrastructure studies what studies of the creative appropriation of devices in use has done for the first wave of reception studies (Alasuutari, 1999) and theories of diffusion (Rogers, 1962) in science and technology studies (STS): reclaim the ability of users to 'act on' (Kannengießer and Kubitschko, 2017; Kubitschko, 2018) infrastructures. The motivation for this is not to insist on the continued relevance of theories and observations from the 1980s. The question is rather, how can use of infrastructures be understood, what are the potential contributions of user-studies to the infrastructural turn, and vice versa?

The cases chosen to explore these questions represent infrastructural power particularly clearly. Mobile phone infrastructures are today ruled by a de facto duopoly of iOS and Android operating systems (MobileApps.com, 2021), which are in the hands of two companies. At the same time, mobile phones have become a central part of the infrastructures that drive everyday life. The cases of user-developed alternative mobile operating systems, LineageOS, SailfishOS and the various free operating systems running on the PinePhone present lessons about the potentials and challenges of users 'acting on' high-tech infrastructures. They present different possible routes to user agency while having to relate to existing, dominant infrastructures, which has far-reaching consequences for the skills required and the uses enabled.

In the next section, before turning to the case studies, the term user-driven infrastructuring is introduced, which sheds light on technology use in everyday life in general. While we meet in the cases special groups, it is argued here, the phenomenon of 'infrastructural inversion in the wild' and of user-driven infrastructuring is a basic feature of media and technology use and builds a conceptual bridge between the insights from infrastructure studies and from studies of creative appropriations of technology in everyday life.

Degrees of user-driven infrastructuring

Infrastructure studies in the context of media and Internet research have recently been accused of overreach. Hesmondhalgh (2021), for instance, laments the theoretical vagueness and banality of much of infrastructure scholarship, which he traces back to 'surprisingly little actual theoretical engagement with materiality as such, as opposed to non-material things such as ideas, processes, flows, discourses and so on' (p. 137). Lee and Schmidt (2018) writing a history of the theoretical engagement with infrastructures in studies of computer interaction show how the term has remained vague and contradictory. They call for clear definitions, a clear delineation of scope and limits, being explicit about the 'focal entity', that is, the set of practices supported by an infrastructure, and the explicit articulation of the relations studied (Lee and Schmidt, 2018: 34). In this article, in line with Kannengießer, Kubitschko and colleagues' approach to 'acting on' media and infrastructure, which they root in the practice turn in media studies (Couldry, 2004), Lee and Schmidt's (2018) recommendations are taken up by focusing on specific practices that are directed towards large, socio-technical systems that, as Hesmondhalgh (2021) reminds us, are characterised by large-scale, material structures.

The focus on specific practices is already present in the classic studies of infrastructures that are today quoted as witnesses for the infrastructural turn (e.g. Bowker and Star, 1999; Star and Ruhleder, 1996). Infrastructure scholars learned about infrastructures first by observing the work of a new wave of system building: the implementation of computer-based information and communication infrastructures, which first affected science, then in the 1980s and 1990s reached a larger number of businesses (and is still ongoing). Here, the consequences of infrastructural change were directly observable, including the demanding work of operating, fixing and articulating necessary to make infrastructures work. The central perspectival switch, first applied in these works, and making infrastructure studies possible in the first place, is 'infrastructural inversion', which foregrounds infrastructural relations that are part of an invisible background in routine use (Bowker, 1994).

Today, the study of practices oriented towards the development, maintenance and articulation of infrastructures is carried out by 'generative-designerly' studies of infrastructuring (Simonsen et al., 2020). Here, the 'artful integrations' and 'ambivalent repair' necessary in the design of IT (Information Technology) systems is studied in relation to design interventions (Karasti, 2014; Mikalsen et al., 2018; Pipek and Wulf, 2009). This 'generative-designerly' use of the term infrastructuring is closely related to its 'empirical-ethnographic' use (Simonsen et al., 2020), which helps scholars of infrastructures to attend to 'activities of organizing, managing, and knowing heterogeneous relations, at

once natural and cultural, material and social, and scientific and political' (Blok et al., 2016: 3). Where studies of infrastructures struggle with defining their object, studies of infrastructuring observe specific practices because 'working infrastructures always have to be constructed from the ground up, step by step, taking local contingencies into account' (Blok et al., 2016: 7).

Moving from 'generative-designerly' and 'empirical-ethnographic' encounters with users that engage in infrastructuring to a systematic account of user agency in relation to infrastructures, three sets of observations are particularly relevant.

First, completely in line with classic descriptions of what distinguishes infrastructures from devices (e.g. Star and Ruhleder, 1996), qualitative user studies' basic tenet that media and technology are 'underdetermined but not undetermined' (Sørensen, 2006) still applies to infrastructures. The device focus of user studies has masked the users' engagement with infrastructural themes. But, for example, the question of where to place a TV set in the home, which features as part the objectivation dimension in classic domestication studies (Silverstone and Hirsch, 1992: 20), also forced users to engage with infrastructural questions of finding an electricity outlet and to identify places with good reception. In this context, Bowker and Star employing infrastructural inversion encountered 'many examples of counterintuitive, often humorous struggles with constraints and conventions' (Bowker and Star, 1999: 36). These acts of 'creative appropriation', which result in physical manipulation of infrastructural elements, can be small and annoying only for engineers (see Oreszczyn, 2004 venting his frustration, but they can also be undertaken in the face of considerable risk, as the case of the installation of satellite dishes in countries where they are banned shows (Parks, 2012). But in both cases, the user-driven change of material infrastructures is prompted by the refusal of 'user scripts' (Akrich, 1992), be they about energy saving or about which TV channels can be accessed, which are inscribed into the infrastructures offered.

Second, Star and Ruhleder's (1996) qualification of infrastructures' invisibility as to only apply 'when they do not break down' is important. As any user of infrastructures knows (=everyone), there is a spectrum between a fully invisible, perfectly working infrastructure and its complete breakdown. As Bennet (2005) has shown for the North American blackout of 2003, even this continental disaster was the result of an accumulation of local defects and workarounds. Malfunctions on all scalar levels are indeed a well-known phenomenon in daily technology use. Users are then forced to explore reasons for the failures and to repair themselves, to hire someone to do so or to work around the problems. The extent to which this is necessary depends on local, regional and national contingencies (Trovalla and Trovalla, 2015). If we take 'erosion, breakdown, and decay, rather than novelty, growth, and progress' (Jackson, 2014: 221) as starting points, our attention in the context of the search for user agency is not only directed towards activities of user-led repair but also the continuous acts of maintenance, which prevent malfunctions.

Finally, and related to the first two points, knowledge about infrastructures is unevenly distributed among users. When new uses of technologies are explored by pioneer communities (Hepp, 2016), media-savvy activists (Stephansen, 2019), lead-users (Von Hippel, 1988), but also when the sources of small annoyances are traced in regular use, users

employ a wide variety of strategies to learn about infrastructures. This infrastructural inversion 'in the wild' is facilitated by tutorials on YouTube, by experiments conducted by the users, or by seeking help from other users (Stewart, 2007). In any event, for some users these practical engagements yield in-depth knowledge, which goes far beyond their immediate use case.

These observations introduce three distinct forms of user agency related to infrastructures: as object of material adoption, as object of maintenance and repair and as object of knowledge. As we have seen, there are different degrees to which user agency can be implicated in these three types of relation: users make material changes of varying size and consequence, they engage to varying degrees in maintenance and repair, and they may know more or less about the inner workings of the infrastructures they use. On the one end of a continuum, we find users who have created their infrastructures themselves, they are tasked with its repair and maintenance, and they have in-depth knowledge about the infrastructural relations their creations are part of. These users differ from professional infrastructure providers only by the fact that they are users as well. On the other end, we encounter users who are completely aligned with the scripts inscribed in their infrastructures, they have no responsibility for repair or maintenance, and they know nothing about them. Both extremes represent ideal types. It is reasonable to assume that most users will find themselves in between, even though the distribution of users along the continuum certainly is skewed towards the pole of no agency. Users with limited agency in relation to the infrastructures on which they depend will still experience episodes of malfunction, which may prompt them to learn and repair and they may execute simple maintenance tasks. For the empirical study and theoretical analysis of user-driven infrastructuring, these limited engagements are as relevant as extensive efforts to create, maintain and completely understand 'one's own' infrastructure.

In the empirical research for this article, I have focused on user groups that are more than average involved in user-driven infrastructuring. They were not picked based on an assumption that they are pioneers for things to come (Hepp, 2016). As will be discussed extensively in the final section, the special cases that were selected here, engage in activities that ultimately challenge the notion of use as well as the notion of infrastructure. By focusing on a group that differs considerably from the majority of users, the analysis aims to contribute to a better understanding of both possibilities for user agency in infrastructures and its limitations. Since the intention still is to be able to generalise the findings generated analysing a special group, a focus on differences in depth of infrastructuring within and between the three groups studied here, and of limits of user-driven infrastructuring is necessary, as well as an explicit discussion of how these differences can be extrapolated towards groups with more sporadic engagements.

How to study user-driven infrastructuring

> *[R]esearchers are engaged in constructing the field [of infrastructures] through the myriad of choices they make about what aspects of the complex and extended phenomenon deserve their focus.* (Karasti and Blomberg, 2018: 234)

In this quote, the problem of establishing an *a priori* definition of what belongs to an infrastructure and what does not is implicitly acknowledged. Attending infrastructuring, that is, the practices connected to the development, maintenance and articulation of these 'complex and extended phenomena', addresses the problem by turning it into an empirical question. That empirical studies of infrastructures constitute their object, means for the study at hand, which starts with a guiding interest in end-users' involvement in infrastructuring, that it must be reflexive regarding the limitations of user activities *vis-à-vis* other participants in the observed infrastructuring activities.

The choice of cases analysed here deliberately starts with observations of user resistance to a large-scale infrastructure, which is dominated by powerful infrastructuring entities: mobile phone networks that in 2022 are dominated by the de facto duopoly of Android and iOS operating systems. These networks contain many entities that are involved in their infrastructuring, such as contract manufacturers, network operators, device manufacturers, app developers, and regulatory bodies. By purposefully sampling three user groups which to different degrees 'act on' these entities, the work of integrating and relating done by users becomes visible as source of agency as well as its limitations are revealed.

The user groups of three specific generally available open-source alternatives were selected for analysis. Other open-source efforts could have been included, for example, Samsung's Tizen, UBPort's Ubuntu Touch, Purism's PureOS, Firefox OS, and a number of Android-based OS (e.g. GrapheneOS, CalyxOS). LineageOS, which is a continuation of CyanogenMod, and SailfishOS stand out mostly because of their age: both have been in continued and active development and use for a little over a decade. The PinePhone, which was launched in 2020, was included because it adds open hardware to open software. Moreover, their development models, user communities, and infrastructures differ sufficiently to allow a comparison along the dimension of different degrees of user-driven infrastructuring.

In terms of methodology, the study leverages the fact that collaboration between users who engage in infrastructuring of mobile phones happens in public fora. These represent easily accessible archives of concerns, activities and limitations that infrastructuring users encounter. Each of the alternatives studied here has a home page that refers their users to dedicated user-fora, which were then explored for particularly active discussions in the time span from May 2021 to May 2022. These fora are also places in which peer-to-peer technical support takes place. The posts that attracted most user engagement measured in the number of 'upvotes' or comments, however, were those that took up questions directly relevant for this article, which often went beyond the fixing of a particular problem by addressing larger questions of infrastructuring.

More specifically, for the section on LineageOS, the Reddit forum dedicated to the operating system was used, which resulted in a corpus of the 23 most popular posts and their comments. The ranking of popularity used here leveraged Reddit's mechanism of 'upvotes', that is, the posts analysed were marked by more than 100 users as relevant and interesting. The forum ordered by 'upvotes' is accessible here: https://www.reddit.com/r/LineageOS/top/. There could be a concern for secret algorithms skewing this ranking since Reddit is not publicly disclosing the inner workings of its ranking algorithms. However, this was shown to be particularly relevant for the ranking according to the

category called ‘hot’. In the ‘top’ ranking, the number of ‘upvotes’, that is, the aggregate of deliberate acts by other users to give the post more visibility, is transparently noted for each post.

For SailfishOS, a dedicated forum exists, where the 16 most active threads, defined as post with more than 100 comments, were analysed: https://forum.sailfishos.org/top?order=posts This forum does not possess a mechanism of deliberate ‘upvoting’, but the number of other users commenting or answering questions is a strong indicator of the relevance that they are willing to ascribe to the posts.

The same mechanism was used in the case of the PinePhone, a dedicated forum which analyses and invites ‘General discussions’ (https://forum.pine64.org/forumdisplay.php?fid=127&datecut=9999&prefix=0&sortby=replies&order=desc). Here, the 11 posts with the most comments were analysed. Since this forum counts the date of the last reply, posts were filtered out manually that started outside the period May 2020–May 2022.

The chosen approach has several weaknesses. First, we have no indication about the demography of the studied users. While studies of similar hacker or open-source communities point to gender imbalances (Nafus, 2012), an analysis of these gendered patterns or other potentially relevant traits – for example, age and formal education – is impossible given the material at hand. Moreover, in all three cases, the forum owners obviously can change rankings and exclude posts. Both the PinePhone and the SailfishOS forum are operated by companies that have commercial interests that can influence their moderation policies. In fact, the analysed material contains complaints about forum censorship in the case of the SailfishOS forum. However, the analysis is conducted based on the assumption that the topic of user-driven infrastructuring is uncontroversial, given that all three alternative mobile phone operating systems are at the core geared towards supporting this kind of activity.

In the analysis, I will call posts ‘popular’ as a shorthand for that they have either, in the case of Reddit, received ‘upvotes’ of a substantial number of other users, or in the case of SailfishOS and PinePhone generated discussions among at least three users. These criteria together with the thematic analysis also informed the decision that saturation was reached and lower ranked posts could be excluded from the analysis.

Overall, reflecting the open and general nature of these fora, the posts covered vastly different topics, but they could be categorised into a limited number of themes. In the analysis, categories that contribute to our understanding of user-driven infrastructuring were singled out and analysed in depth using a close reading. This reading was first based on tracing how the discussions unfolded in the individual threads, then on categorising threads within one group and, finally, on comparing categories between the three groups studied.

Empirical observations

In the presentation of the three cases, which now follows, first a brief history and description of the three alternative mobile phone infrastructures is given. After that, the user groups’ main concerns are described along central themes encountered in the user fora.

Three alternatives

LineageOS. In 2013, user cyanogen, in real life known as Stefanie Kondik, recounted the story of the rapid rise of an alternative mobile operating system for Android phones written 'by the users for users' (Kondik, 2013). What started in 2009 with one message on the discussion forum XDA Developers, where she had made available a ROM for the first commercially available Android phone T-Mobile G1, became CyanogenMod, which was later available for a large variety of devices and had an estimated 50 million users in 2015 (Forbes, 2015). CyanogenMod attracted startup funding, was ruined and forked to become LineageOS.

Compared with other alternative mobile phone operating systems, LineageOS runs on the largest variety of hardware. This is possible because it piggybacks on Alphabet's Android Open-Source Project (AOSP), which provides the source of the Android operating system, including software updates with new functions and security patches. LineageOS, then, is created by combining device specific drivers (vendor drivers) with the Android sources, re-branding and cleaning up ('debloating') the user interface, and adding or removing less important functions. This result is a compiled ROM, which is made available for download. Users 'flash' this ROM on their device, which is a demanding process that is not without risk. If something goes wrong, the danger is to 'brick' the phone, making it impossible to instal an operating system. A precondition is in all cases to unlock the bootloader, that is, to change the software beneath the operating system level to allow the loading of an alternative operating system. Device-specific instructions of how to do so are provided by LineageOS.

The main participation of users in infrastructuring is conducted in relation to their own phones: users participate in testing early versions of the provided ROMs, and when users have access to the functions, they deem necessary for daily use, they will use the phone as their 'daily driver', which means that it is the device which is used in everyday life for all mobile phone–related tasks. This indicates that they have several phones at their disposal, which they distinguish by the degree of infrastructural inversion: the 'daily driver' 'just works' for daily tasks, while in the case of the other devices, a more experimental approach is used involving collective error tracking and reporting and frequent 're-flashing'.

The second aspect of infrastructuring in the development of LineageOS relates to services provided for networked phones. Here, LineageOS has inherited from CyanogenMod a dual strategy: in 2009, Google threatened legal consequences if those parts of the operating system that give access to Google services would not be unbundled from the operating system (Kondik, 2013). The compromise was to make access to services provided by Google an optional add-on, which can be easily 'flashed' onto a phone on which CyanogenMod is already installed. Without these so-called 'gapps', above all location-based services and the means to search and instal applications through Google's Play Store are not available. Users who do not want to use these services have created alternatives, for example, F-Droid, an app store for open-source applications, and location services that work without Google's servers, for example, the micro-g framework. Despite these efforts to 'ungoogle' Android phones without compromising its functionality, the resulting phones will always lack access to certain services, such as the ability to

use banking apps whose security functions are tightly bound to the restricted device access allowed in regular Android phones.

SailfishOS. The story of SailfishOS does not start with an individual programmer like LineageOS, but with a group of Finnish engineers employed by Nokia. They founded a new company, called Jolla, in October 2011 in which they developed further Nokia's Linux-based MeeGo mobile operating system, which was soon after discontinued by Nokia. Since then, they have added to this core a gesture-based user interface layer, they have engaged in the production of hardware and they provide an optional, proprietary Android compatibility layer based on Google's AOSP. This is provided as paid-for extra, while the operating system itself is available for free. The profitability of this company, which aims at providing a technologically mature, open alternative to iOS and Android, has always been precarious. In 2022, Russian investments, attracted by the promise to make Russia more independent from US software firms, have been reduced, leaving the company in search for new investors. But the biggest crisis so far occurred in the years around 2015, when due to a miscalculation, a crowdsourced Jolla tablet could not be shipped to most backers, who lost their deposits. After that, Jolla downsized and focused on software, providing a complete, independent mobile operating system running on a limited range of hardware options. Selected models included in Sony's open devices programme are currently the most popular of these.

After the move from being a software and hardware company to only providing the operating system, SailfishOS is like LineageOS in at least two respects: the operating system is adapted to existing phone hardware creating challenges in the interplay between soft- and hardware. And the Android compatibility layer is realised through Google's AOSP. Different from LineageOS, the independent development of the operating system itself and that it is open source has consequences for the question of which kind of infrastructure users encounter here. Most notably, the development of applications is – except for some core applications – in the hands of users. While Jolla offers an infrastructure through which their own and user-generated programmes that are vetted by company employees can be distributed (the Jolla Store), users have added software distribution mechanisms such as Harbour and more recently Chum. Thus, when users find that a certain application is not available, they can either write one themselves using a user-friendly software development kit (SDK) provided by Jolla or move to the Android subsystem with all the choices and infrastructural consequences described in the case of LineageOS.

PinePhone. The PinePhone is the newest alternative to the iOS-Android de-facto duopoly. It started shipping in 2020 and was announced as 'generally operational' as a phone but 'not consumer ready'. The company producing the PinePhone, Pine Store Ltd, formulates its mission as

> *to deliver ARM64 devices that you really wish to engage with and a platform that you want to be a part of. As such, the community – PINE64 – and the Pine Store company are interlocked and intertwined, but separate entities. (https://www.pine64.org/philosophy/)*

The open character of the PinePhone has indeed spawned a flurry of software distributions for the PinePhone, with many major Linux distributions like Arch and Debian being adapted by volunteers to the small screen and touch interactions.

Like in the previous two cases, infrastructuring is performed in relation to the device itself, for example, in software adaptation to the hardware of the device, and also addressing the wider infrastructures through providing services that are enabled through the networks the phone participates in. However, hardware adaptation is simplified by the fact that the hardware was selected with the subsequent task of adaptation in mind. Both hardware adaptation and the provision of services 'around' the phone are taken care of by the different open-source distributions that run on the phone in each their own way. The phone is then treated as yet another Linux computer participating in the respective distribution specific networks built around open standards. This creates all kinds of problems for the functionality, for example, when package managers (the 'app stores') provide versions of the software that are not adapted to phone usage, or when popular apps, like specific messaging apps, are not yet available for Linux. In these latter cases, developers work around the restrictions by re-implementing the communication protocols – if they are open – or by simply using the desktop app on their mobile device accepting bad usability on the small screen.

The lack of a software-based core of the development, which was AOSP for LineageOS and SailfishOS for Jolla, has created a splintered multitude of communities that improve their products often based on the work of individuals or small groups of volunteers that cater to small user groups. Even within one of the more popular operating systems for PinePhone, PostmarketOS, three different teams are each developing their own different user interface, which makes for three widely different user experiences.

User concerns. Analysing the user fora, four main themes were found that each distinguish the three user groups in relation to their engagements with user-driven infrastructuring: posts that discuss the relationship between different users and uses, posts that document the users' motivations and their interest in learning about the diverse ways mobile phone infrastructures are built, posts that perform collaborative experimenting with soft and hardware, and finally, posts that – in the case of the PinePhone – show how far users are willing to go to be independent from larger infrastructures.

Grateful and angry users. The most frequent category of posts (10) in discussions of LineageOS is 'thank you' posts from users to all or specific maintainers. For example, user AntonMadness writes in February 2022 under the heading 'All good things come to an end':

> *I'm super happy with my 8–9 year old Samsung Galaxy S3 Neo running Lineage OS. But I got an email from my provider stating that 3G is going to be shut down the 31th of this month. And since the S3 doesn't have hardware support for 4G. This will render the thrust worthy S3 a bit useless and it shall be put down. It's a sad day. This post is because I want to thank everyone at Lineage OS for enabling me to keep using the S3 for the last 3 years. It was an amazing run and I really enjoyed using the phone. De-googling to phone extended the (second) battery life to 2 days. And the device is still really snappy and fully usable up until this day. So: Thank you LineageOS. :-)*

This post addresses two aspects that are relevant for the question of user-driven infrastructuring and that are present in the other 'thank you' posts as well. First, it reveals the wish to *not* buy a new mobile phone as major motivation for the use of LineageOS. A regular phone's end of life will be decided by a company which at any time may stop providing updates. Being independent from decisions made and services provided by the company here is described as preserving 'snappy' usability, and AntonMadness like other users in this discussion seems to be emotionally invested in his devices that he is 'sad' to have to replace them. Second, it is an aspect of infrastructural change which is outside the range of LineageOS, the phasing out of 3G networks, which forces him to buy a new phone. LineageOS can only cover the software side of things.

In the case of Jolla, thank-you posts are absent. Two of the 16 most popular posts in the period analysed here accuse the company Jolla of not producing a usable operating system or even engaging in forum censorship, when users complain about malfunctions. They employ a frame of reference where a paid product is supposed to work flawlessly, forgetting that they do not pay for the operating system as such but only for the Android support which is outside Jolla's control. Moreover, these instances show a difference in degree of willingness to do infrastructural inversion. For instance, user 808 in November 2021 defends his angry accusation that after an update 'nothing works' to which another user responds by asking for more detailed explanations that would enable the community to either fix the problems or to help:

> *The devs [developers] need to do better. I did my part as the user to try to explain. I should not have to type in commands to change properties to make a thing work. The best fix is better Q/A before pushing the OS out to the release branch.*

The part of users, according to 808, is not to engage in activities that create a functioning device. Users are to be protected from this task by developers and their quality assurance of releases. The angry attack prompts different responses, some positive some negative but mostly constructive in the sense of trying to help, such as in the example of user attah:

> *[. . .] i hope you realize there is nothing Jolla could do to fix that – perhaps beyond work on VoLTE/RCS – which they are doing, just not on a time frame fitting certain unsupported markets. Here is the logger tool for the telephony subsystem: https://openrepos.net/content/slava/ofono-logger 12 If it is indeed something amiss, i'm sure they be happy for some logs.*

There are two infrastructural aspects to attah's answer: first, they hint at the possibility that some of 808's problems are related to the wider infrastructure, the 'certain market', which 808's particular phone is part of. Second, attah conveys information which would allow 808 and other users to understand better where the problem lies through logfiles, which record technical information about error messages. With this information, attah claims, the mistakes could be fixed, or at least workarounds devised.

The discussions regarding PinePhone, finally, show no trace of grateful or angry users. Here, the users embrace their own responsibility to deal with problems themselves, to create fixes and to share them with other users.

'How do you guys do it?'. LineageOS users, due to the mostly frictionless user-experience of this alternative mobile phone operating system, have little reason to engage actively with the soft- or hardware of their phones, as long as they do not engage in further adaptations, as, for example, 'ungoogling' the phone. But this does not make them regular, passive end-users. They are eager to distinguish between themselves and those that do not run custom ROMs, whom they see as victims of 'evil' company policies. This happens for instance in one popular post, which starts with a rant by user matzees from December 2021: 'A locked bootloader is one of the worst thing a company can do to its customers. [. . .]' To which user vilidj_idjit answers:

> *AGREED. Selling shit like this should be illegal. But these scum corporations know that masses of ignorant morons will buy their locked garbage anyway, especially if they make everything ridiculously over-complicated so no one understands wtf is going on . . . [. . .].*

The anti-company sentiment is a common occurrence and is also presented in a more nuanced form in a thread started by user DickNose22 with the title 'How do you guys do it, when billion dollar corporations can't?' (March 2022). The stance expressed in this thread is summarised by user xmagusx: 'Obviously the corporations can, they simply don't, and won't ever do so unless compelled by law somehow. [. . .]' And user Slinkwyde adds an explanation reproducing the image of the open-source ethos based on gift giving and reciprocity (Vasudevan, 2021):

> *[. . .] It's the power of open-source collaboration over the Internet, building on the work of others, and people who are motivated by getting the most out of their device, rather than by profit from selling customers a new device. Plus, these developers can accept donations and put this skill and experience on their resumé.*

A different analysis is offered in a popular thread in which users discuss whether LineageOS is threatened by developments in the industry, in which user ElectriConcept writes in June 2021:

> *[. . .] That said, Linux is an OS built by and for engineers, designed to maintain compatibility with historic use cases and with a large and understood-not-ideal-for-DRM [digital rights management] architecture. That's part of why Google is developing Fuchsia and Zircon and Titan. So if you're looking for canaries, that's it – a widespread migration of Android to the Zircon kernel. Titan's already here on Google phones. As for what happens afterwards, it's hard to tell, but it's not immanent [. . .].*

Here, the dependence on Google is acknowledged and the relation is presented as dynamic, where the company may develop in ways which would render LineageOS impossible.

In the case of SailfishOS, questions related to 'How to do it' are treated as open to discussion. Here, users are not taught about open-source development models, these are mostly taken for granted. Instead, 4 of the 16 most popular posts are related to long and winding discussions about how the community should organise itself. These threads perform infrastructuring in relation to questions of how users should relate to each other and which tools they should use to do so.

Also, PinePhone users take the open-source model of development for granted. They leverage existing tools and organisations, which have been developed by various Linux distributions. The main work done here is to adapt these structures to the small screen and specific uses of mobile phones.

Learning by collaborative experimenting. Above, we have met a LineageOS user who was forced to buy a new phone because his old phone had become obsolete due to incompatibilities with the wider infrastructure. For SailfishOS and PinePhone users, giving up and buying a new phone is not an option. Instead, they try to find workarounds.

An example for this is one of popular post about SailfishOS, which is started by user nephros in March 2021. They ask a technical question regarding one specific change in an update and quickly become an example of unfolding user-led and collaborative infrastructural inversion. The case is the introduction of AML (Advanced Mobile Location). As users discover during their discussion in which they relate results of their experiments with their devices, and into which eventually also a Jolla representative becomes involved, this is a change mandatory for mobile phone operators in which during emergency call location services are automatically switched on, and a silent SMS is sent containing the location data. After learning about their mobile phone's role in this emergency infrastructure, reactions are negative: '[. . .] I don't need Big Brother's supervision of my life!' (lhodas, 03.28.22). But other users point out that this change could be lifesaving. The solution then is user-driven infrastructuring, first proposed by users and then by a Jolla representative (jlaakonnen, 03.30.22) that informs the users that a command issued by the user on the command line will disable the service.

As will be described more in depth in the next section, PinePhone users encounter incompatibilities with the wider infrastructures daily. Of the 11 posts, three with the most answers (12,897, 14,272, and 11,675) describe the users' experience that their mobile phone operator does not allow the use of the PinePhone's modem hardware, flagging it as 'incompatible'. Engaging in infrastructural inversion, users then exchange information on how to reach the whitelisting of their device including borderline illegal ways of circumventing the ban, for example, through spoofing the phone's universal identification number (IMEI).

For them, learning by experimenting in addition is directed towards the hardware itself. The experimental approach employed there can be observed up close in another thread (14,840) started by KNERD in June 2021, in which users experiment with their devices to find out whether the bad battery life of the PinePhone is hardware or software related. To achieve this, they methodically connect and disconnect various hardware components noting down the results, which resembles very much the activity of scientific experimentation in a laboratory. Latour (1983) reminds us that one strength of laboratory experimentation is that the error in trial and error has no consequences on the world outside the laboratory, which allows iterations until a solution is found. When, for example, a 'daily driver' phone misses an important phone call due to the modem software crashing silently, the users may be able to find a solution after a while, but the harm is already done.

When is a phone not a phone any longer? While devices running LineageOS and SailfishOS mostly seem to work and be used as 'daily drivers' by their users, PinePhone users appear to encounter strong barriers against this kind of use. PinePhone user jro, explicitly addresses this question in September 2021 (13,861) by asking: 'Are you using the Pinephone as your daily driver?'. The answers are instructive as they describe what motivates PinePhone use, and which compromises the users are willing to accept. User zetabeta reports that 'some/many things are missing'. This, however, is acceptable for him because: 'i call it a victory. i do not trust goodroid anymore'. Most answers are cautiously optimistic, they report some problems in daily use and extensive experimenting until they land – for the time being – on a system that most of the time works. User RRman represents these users: 'I too use it as a daily driver with Manjaro Phosh stable on eMMC and works fine for calls and sms. I've tryed almost all other builds and this is the one that works the best for me'. Other users do not seem to be satisfied with only using 'calls and sms' and report that they use other phones as 'daily drivers', most often LineageOS as 'the second best' option, which 'still' is superior because it is 'just working', that is, it is able to fade into the background of daily use.

The PinePhone clearly is used more as a device to learn and experiment with mobile infrastructure in a laboratory sense than to be used in the 'real world'. If it works, it is a 'victory', which relies heavily and by design on a community of open-source developers, whom it tries to cater for providing an 'attractive' and affordable toy. The focus on the hardware distinguishes the PinePhone from the operating systems discussed so far. As we have seen above, experimentation is extended into this domain, and for the time being, several restrictions for daily use are the consequence that prevents the phone from being used by many users.

Beyond mobile phones, beyond expert users

The cases presented here provide lessons for user-driven infrastructuring that, as will be argued in the remainder of this article, contribute to both infrastructure studies and the study of the creative appropriation of media and technology in use. In what follows, I first structure the presentation of these lessons following the three forms of user-driven infrastructuring that were derived from the literature: material adaptation as reaction to the rejection of scripts, maintenance and repair, and infrastructures as object of knowledge. Particular attention will be given to the question to which degree the observations can be extended to other infrastructures and to user groups that are less engaged in infrastructuring than the ones observed here. Then I will discuss the relation between the design of infrastructures and the possibilities for user-driven infrastructuring. A paragraph on lessons for both infrastructure studies and the study of creative appropriation of media and technology concludes the text.

First, there is the observation that users engage in smaller or bigger material adaptations of infrastructural elements. For mobile phones, this was motivated by a general desire to take control combined with concerns for sustainability and privacy. The scripts embedded in regular mobile phones were rejected with great emphasis, most explicitly by LineageOS users. A parallel to 1990s' studies of domestication of media and technology is that users of alternative phones talk in moral terms about infrastructures, for example, blaming corporations for being 'evil'. Looking back, Silverstone (2006) recounts the

surprising frequency in which questions of morality were part of the adoption of new technologies in the observed households, inspiring the domestication approach in the first place. The move from device to infrastructure corresponds to an extension of concerns about the morality of devices, which referred often to family life and child rearing, to the morality of infrastructures and the themes of global surveillance and sustainability. In the empirical material presented above these morally motivated material adaptations were of varying depth and consequence. Where PinePhone users went far in the adaptation of software and devices to achieve their goals, LineageOS users could expect to find a phone that in terms of functionality did not differ from regular phones after installation. Extrapolating to users with even less ability or motivation to engage in infrastructuring still can be motivated by similar normative commitment. For example, it is clearly an act of material adaptation when users cover their laptop cameras to avoid surveillance.

Second, when it comes to user engagement in *maintenance and repair*, the alternative mobile phone users presented here worked with devices that were in more or less constant need of care. They dealt with this unreliability by establishing redundant infrastructures. First, there were dedicated experimental devices whose infrastructural relations were subject to continuous maintenance and repair. In addition, the users had a need for reliable connectivity, which was fulfilled by also using a 'daily driver', that is, a device whose infrastructural connections worked transparently and reliably. This parallel use enabled experimentation with infrastructure.

Nowadays, we see a large movement in which users' daily infrastructures are interrogated for their environmental impacts (Blok et al., 2016: 8–9; Kannengießer, 2019), which provides many examples for a similar rejection of the *status quo*. The cases explored here share with these 'experiments in living' (Marres, 2012) that they formulate infrastructural hopes (Reeves, 2017). Both sustainability experiments and alternative phones face the same challenge that infrastructures have to be transparent and work reliably. For example, users trying to achieve renewable independence through installing solar cells and batteries will in most cases still require the backup of a stable power grid, which then corresponds to the 'daily driver'. Yet, the explicit goal in both the case of alternative mobile phones and in experiments with more sustainable infrastructures is to gradually phase in new 'daily drivers', that is, new infrastructures of daily life.

We saw that in the case of the phones, user-driven infrastructuring was addressed by all participants as a community effort. The process of *collective* experimenting enabled many parallel trials, whose outcomes were communicated and collected through dedicated infrastructures that users built to support each other. The most usual form of collective experimenting and, at the same time, the lowest hanging fruit of user involvement in infrastructuring found in the empirical material was collective 'debugging', that is, the search for the reasons of failures and malfunctions and their fix. There is no reason to assume that this form of experimentation in the service of repair is exclusive to the special kind of users studied here. Everyday experimentation, according to Giddens (1996: 11f), is a fundamental mode of being in post-traditional societies. According to him, it is part of a 'displacement and reappropriation of expertise', that is, a reaction of users to the 'intrusiveness of abstract systems', which devalue their everyday expertise (Giddens, 1996). Both users of alternative mobile phones and 'regular' users can be expected to at least sporadically 'reappropriate' expertise about their infrastructures in this form of infrastructuring. However, judging from the comparison of the users observed here and

'regular' mobile phone users, a central difference is that alternative phone users engage in dedicated communities that are built around collective repair and maintenance. Again, a parallel exists to experimentation with more sustainable infrastructures, for example, when energy users organise collective learning and action in low-carbon and energy communities (Heiskanen et al., 2010; Seyfang et al., 2014).

Third, as we have seen, infrastructures as object of knowledge feature prominently in both morally motivated material adoption and collective maintenance and repair. Learning through collective experimentation played a privileged role among the users of alternative phones but we have also encountered users who were eager to learn about different modes of infrastructure development ('How do you guys do it?') and their implications for use. In the tradition of studies of creative appropriation of media and technology, Sørensen (2006) describes learning how to use a technology as one of three dimensions of its domestication. Moving from device to infrastructure, we see that since infrastructures reach beyond a specific site and use case – Star and Ruhleder (1996) call this 'reach and scope' – learning about them will lead to insights into more general traits of socio-technical systems. Every instance of adaptation of phones, as well as the collective experimentation and the learning happened in the context of high dependence on larger infrastructures outside the control of users. The cases presented above showed that users negotiated their entanglements, always weighing convenience against their infrastructural hopes. These processes, as we have seen in the case of the PinePhone, can lead to the decision not to proceed with user-driven infrastructuring. Extending the scope from expert users to 'regular' users, this point at which experimentation becomes too costly will be reached much earlier.

Because of the hidden character of infrastructural relations and users' moral motivations, infrastructures as object of knowledge can quickly take a conspiratorial turn. The often-derided 'tinfoil hat' in this sense is a form of user-driven infrastructuring, which is based on the users' 'research' into wireless infrastructures. Despite this similarity, the material analysed here did not show any traces of conspiracy theories and it is reasonable to assume that not every instance of morally motivated user-driven infrastructuring performed by 'regular' users is doomed to resort to knowledge about 'dark and hidden forces'. In this context, as Vine and Carey (2017) have shown, it is important to analyse how the 'infrastructural doubt' is performed individually and collectively. In addition, some infrastructural connections are in fact hidden and not available to democratic scrutiny, be it because companies hide their intellectual property or because states prefer to clandestinely monitor their citizens.

The question of knowability of infrastructures leads us to the topic of relations between infrastructural design and user-driven infrastructuring. A universal right to engage in infrastructuring would mean to fundamentally rethink what infrastructures are and should be (Jimenez, 2014). Here, the distinction between an 'engineering ethos' of open-source development and 'corporate interests' made by LineageOS users is instructive. The alternative mobile phone users preferred the former, which they saw as more in line with their own interests. In his classic text on the politics of artefacts, Winner (1980) contrasts decentralised, renewable energy production, which corresponds to decentralised systems of governance, with nuclear power, which demands stronger central authority. Looking for a mode of infrastructure development that lends itself to user-driven infrastructuring, the cases discussed here point towards an open-source model of development, which includes but goes beyond decentralisation. It is indeed difficult to imagine how a user of

an iPhone, which in all respects is even less open to user modification than a regular Android phone, would in any way be able to engage in user-driven infrastructuring of the kind observed here. Rethinking infrastructures as positioned on a spectrum between enabling user-driven infrastructuring and blocking it directs our attention to how far they can be materially adapted, how far they support and demand the users' maintenance and repair, and to which degree they enable their users to learn about how their inner workings. Whether all infrastructures should be turned into 'open infrastructural beings: sources for ongoing compossibilities' (Jimenez, 2014: 359), which enable – but also demand – far-reaching user-driven infrastructuring, is ultimately a political question in a world which is profoundly dependent on global socio-technical infrastructures.

An overarching lesson for *infrastructure studies* is that users indeed can engage with infrastructures with their hopes and moral judgements, they are able to collectively experiment with repair and improvement, and some are eager to learn about the larger socio-technical systems on which our world is built. As we have seen, how infrastructures are designed creates different shades of grey between the black and white of the exclusion and inclusion of users from infrastructuring. Open standards enable users to establish their own infrastructures on top of the material base of today's large-scale infrastructures that Hesmondhalgh (2021) reminds us of. Where standards are not open, users engage in collective reverse engineering of embedded rules and standards. In this sense, user-driven infrastructuring is a 'focal entity' (Lee and Schmidt, 2018) that exists because it is supported by existing infrastructures. But at the same time, it is the practice of creating alternative infrastructures on top of the existing ones driven by the hope to transform and eventually replace what they depend on.

For studies of the creative appropriation of media and technology, the main lesson is that the stakes are not only different (Berker, forthcoming) but also higher when users engage actively with infrastructures instead of devices: the users encountered here understood this very well and they approached the domestication of global mobile phone infrastructures skilfully by creating communities and material support structures. User-driven infrastructuring starts when the technical devices, which saturate everyday life, are turned into objects of concern because of their infrastructural connections. While this infrastructural doubt easily can ossify into the backbone of conspiracy theories (Vine and Carey, 2017), in user-driven infrastructuring, it is turned into practices performing infrastructural hope.

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