Obsolescence Paths: living with aging devices

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***Abstract*—Frequent renewal of digital devices accounts for a large share of their environmental impact because of fabrication environmental costs. This renewal is often attributed to sociocultural phenomena (e.g. presentation of self or persuasive marketing) and to broken hardware (e.g. shattered screens or degraded batteries). We investigate a complementary aspect: how people live with devices as they are gradually becoming obsolete. We present a qualitative interview-based study with 18 participants on the role of software factors on the feeling of smartphone obsolescence. We identify three types of factors pushing for device renewal: upgrade issues, storage issues, and malfunctions. We find that these issues accumulate over time until a threshold is passed leading to renewal: we define this process as an obsolescence path. This threshold is often tied to contextual and social concerns. We also outline the various strategies people use to prolong the life of the almost obsolete devices. Our results show that hardware and software obsolescence are tied, and should be considered together as they trace obsolescence paths. Based on these observations, we identify design opportunities to extend the lifespan of devices.**

***Index Terms*—smartphones, devices, obsolescence, end-of-life, repair, limits, sustainability**

I. Introduction

The environmental impact of ICT is steadily growing [12]. For end-user devices, it can largely be attributed to the manufacturing phase, energy, water and material consumption, impacts on biodiversity as well as populations, the impacts go well beyond CO2 emissions. The end-of-life of devices is also a source of concern but currently harder to assess [25].

Smartphones have become the poster child of these issues: widespread, with a short lifespan, highly-tied to networks and data-centers. They represent what could be called “disposable tech” i.e. devices not meant to be reparable or recyclable but rather replaced.

This can be explained in part by miniaturization efforts but also by manufacturers’ business models. In France in 2019, the average age of smartphones in use was estimated to be around 32 months [2], while a recent study on european consumers estimates that smartphones are replaced after 43 months of use [26]. Various factors influence the discarding or replacement of smartphones, including social and psychological factors [24], [28], as well as broken hardware [26].

Over the past decade, activists and scholars have emphasized the importance of repair, leading to the development of Maintenance & Repair Studies [7]. This scholarship studies the work that goes into maintaining, repairing and caring for things [37]. This sensitivity to maintenance puts breakdowns forward, or as Jackson puts it, develops a *“broken-world thinking”* by paying more attention to the fragility of our technical environment, in which each entity spoils and constantly gets restored [21].

Building on this line of inquiry, rather than looking at maintainers and repairers, we turn to users, focusing on how smartphone aging is experienced and endured. We are less interested in the technical reasons behind aging, but rather on the experiential aspects leading to obsolescence. This experience is not only conditioned by hardware and device factors (broken screen or worn batteries), but also by software-related factors such as slowness, storage saturation and much more. We seek to understand what are these factors, which ones are considered more crucial, how do people cope with issues as they appear and how they are entangled. When and why disposal and replacement decisions happen?

We developed an ad-hoc protocol for recalling issues related to aging and conducted interviews with 18 smartphone users to study the following research questions:

1) What are software obsolescence factors and how are they felt and experienced?
2) How are obsolescence factors entangled?
3) What strategies do users develop in order to prolong their device’s life?

While obsolescence factors have generally been characterized and discussed independently or at least with the idea that one predominates over the others, our main finding is that obsolescence should rather be considered an incremental process that we define as an *obsolescence path*. Our interviews show that in many cases the decision to replace a smartphone is not the result of a single issue, as if a device would suddenly go from working properly to being broken and unusable, but the decision is instead triggered following an entanglement or an accumulation of several obsolescence factors. We identify and describe three key software obsolescence factors: storage, updates and malfunctions, and we explain how they are entangled and eventually trigger a replacement decision. We also identify strategies developed by informants to keep on living with aging devices and to circumvent issues as they appear. Building on our results, we outline design directions that could help prolong the life of the devices.

II. Related Work

1.3 billion smartphones were shipped in 2022 according to estimates from Canalys[1],with shipping numbers slightly decreasing over the past three years. In Western Europe, smartphones have an average lifespan of about 3.5 years [26], they are frequently renewed, handed-over, stored and disposed of. We discuss below studies on replacement, repair, and software obsolescence in respect to smartphones.

A. Replacement and disposal of smartphones

Before smartphone widespread diffusion (in 2007), Huang and Truong investigated replacement and disposal practices of mobile phone owners, showing how factors such as aesthetics, mobile plans, and functionalities are intertwined when attributing value to a used phone, with end of plans strongly influencing replacement behaviors [19]. Looking at larger datasets of smartphone performance, some have questionned whether functional problems play a significant role in replacement [28]. Building on the notion of "functional alibi" developed for luxury products [23], Tamar et al. argue that desire from new products and "mental depreciation" [15] are stronger factors than functional problems [28]. However, as smartphone ownership increases and novelties plateaus, consumption behaviors are evolving with duration of ownership steadily increasing.

A study from the French telecom regulatory body (ARCEP, 2021) showed that in France 28% of old devices are reused either through gifting or reselling [2]. This number has been increasing over the years, despite resistance: more than half of unused devices would still be stored by their owners [2]. Comparing North American and Japanese mobile phone owners, Huang et al. discuss how cultural sensibilities such as privacy can play a role in disposal, giving phones or re-injecting them into second-hand markets [18].

B. Maintenance and repair

Repair has been promoted as the main strategy to avoid early replacement and disposal of smartphone, through e.g. "right to repair" campaigns. This has been translated to various extents in laws in recent years. While in industrial settings, maintenance and its management are discussed as strategic concerns.

Maintenance and repair have been central in social studies of ICT. A wealth of scholarship, especially in Science and Technology Studies, has put maintenance and repair forward and studied them across various domains [7], [37]. They have been looked at primarily in the context of infrastructures e.g. waste, water, streets, networks, e-science platforms, etc. [29], looking at the interplay of technical and social factors, and emphasizing the political aspects of repair [13], [16]. Recently, more attention has been drawn to the broader relationships between maintenance and care [6], [8].

With respect to smartphones, repair has been widely studied in the context of repair cafes and maker-spaces [31], [33]. These studies show some of the limitations of design or engineering-centered approaches that focus on building and creation at the expense of maintenance and care for existing technical objects[2]. If repair can foster openness and support the development of technical literacy and autonomy, it also has its own limits: often a need for a support network, expertise, and time.

Going beyond fixing by amateurs and technologically literate users, repair shops have been a locus of investigation in countries of the Global South [17], [22] and Global North [30], [33]. Closer to our research, Bloch and Nova studied repair-shops in Switzerland and France [32], showing how they act as informal networks of expertise, producing a form of "silent innovation" through practice-based expertise and knowledge sharing, but also how repair activities can turn into hardware and software customizations: changing smartphone appearance, optimizing speed and storage.

This relates to an often forgotten aspect of discussions on repair: software. Yet, Farman reminds us "it is not simply the physical object that needs repair or maintenance, but the physical object in its relationship with the perpetual software update" [10]. He emphasizes how smartphones are not isolated and pre-determined technological objects, but that their use is tied to networks, servers and APIs availability, Operating System (OS) versions, app availability, etc.

As Gillespie and Jackson further emphasize, repair is not only about fixing, but also about changing the perception of what is working or broken [20]. As we will see in our study, this is particularly the case when looking at software where bugs, connectivity problems and breakdowns abound.

C. Software obsolescence

Software problems could be the source of around 20% of smartphone replacement decisions in France [5]. Magnier and Mugge's survey of European consumers also shows that decrease in performances and software problems are the main factors leading to a perceived loss of value [26].

Obsolescence could be defined as a loss or significant decline in the use value of an object, leading to its replacement. Obsolescence is always observed through use and passage of time. Software should theoretically not suffer from natural wear as does hardware, being able to run endlessly once installed. However, in practice, we see a growing number of empirical examples where high performance requirements, cancelled support and update services, malfunctioning software, new social usage or technical shifts, and other software related problems speed up the obsolescence of otherwise functioning devices.

Software obsolescence has been mostly defined and explored from a technical point of view, as a resource management issue in corporations, or as a security and reliability problem in military, aviation or similar fields (see [34] and [3]). Smartphones rapid hardware and software development cycles, and the quasi duopoly at the OS level, has left no room for standardization and normalization of practices

[1] https://canalys.com/newsroom/global-smartphone-market-2022

[2] See e.g. the NSF project "Reclaiming Repair".

among manufacturers, designers and developers. The world of smartphones is consequently facing a complex interweaving of software and harware obsolescence factors.

There is indeed a very rapid release rate of major smartphone operating systems, coupled with very limited system updates support on already released smartphones. The Android operating system (which holds 75 to 80% of the market), first released in 2008, releases since 2014 a new major version every year, and since 2018, a major version every 6 months[3]. For Apple (20 to 25% of the market) a new version is released every year[4] together with a new device. Meanwhile, devices are rarely updated to the newly released Android system versions: Android versions covers at the most only up to 36% of the device's market share before a new major version comes and the release - update cycle begins again, endlessly. This huge gap between quick update rates and slow adoption rates has not attracted much attention (except for Mahmoudi et al. who show that the majority of changes in Android versions between the official release to the manufacturers flavours could be integrated automatically [27]). As a consequence, functioning smartphones quickly carry an unmaintained system and new versions replace each other before spread, leaving most of devices with old system versions, with neither security updates, nor new features, while applications and websites are always being developed for the newest operating systems and higher hardware performances.

At the same time, economical imperatives, market logics and pressure, end of support decisions and design choices influence the personal use and social practice of smartphones, having a significant impact on their replacement rate, as Guien discusses in chapter four of her book which analyses obsolescence in smartphones [14].

Existing scholarship started showing the importance of software factors on loss of value, smartphone replacement [26], but this has mostly often focused on (OS) upgrades, and loss of performance. In this study, by looking at how users perceive obsolescence and their experience with aging devices, we seek to determine more precisely the software issues that push people to replace their devices, with the objective of identifying strategies to prolong the life of smartphones.

III. Methods

We conducted 18 interviews between August and October 2022. In order to obtain answers to our third research question: "what strategies do users develop in order to prolong their device's life", we chose to focus on people who had, to some extent, tried to prolong the life of their devices.

A. Informants

We interviewed 18 people living in France between 20 and 54 years old (with 4 above 35 years old). 10 of the informants were bachelor, master and PhD students, and 8 were working in different fields : art and design, computer science, education, health. The interviews involved 23 smartphones (see figure 1).

[3]https://en.wikipedia.org/wiki/Android_version_history

[4]https://en.wikipedia.org/wiki/IOS_version_history

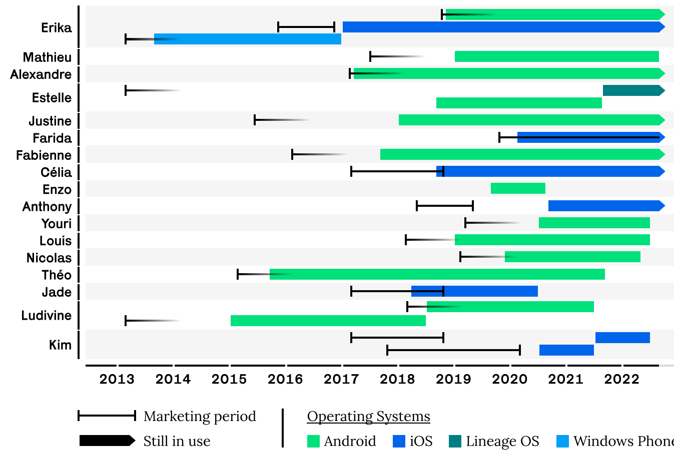

Figure 1. Informants and the smartphones discussed in the interviews, except for Clara who did not know how long she had kept her device.

Nine smartphones discussed were the informants' current ones, the others being their old ones. Three informants mentionned both their current and previous devices, and one informant talked about a previous device and two currently in use. The smartphones were of various brands (7 iPhones, 4 Samsung, 12 others) and operating systems (14 Android, 7 iOS, 1 Windows, 1 LineageOS). Of the 23 devices discussed, 12 were used or still in use for over 3 years. Six devices had been used or were being used for 2 years or less, of these four were second-hand or reconditioned. It is therefore important to underline that our panel is skewed towards a population motivated to make their devices last, even if this is not the case for every informant.

B. Recruitment and interview procedure

We recruited informants through our extended personal networks, looking for people with a recent replacement or aging devices. The interviews lasted between 20 and 60 minutes and were not compensated. The first and last authors conducted the interviews in French.

We conducted 12 interviews face-to-face, and 6 using the video conferencing service Jitsi. In both cases, we took notes and audio recorded the interviews, except for the first two which were only note-based (Kim and Clara). Eight informants received a custom made comic based on their interview.

We built our interview protocol around the critical incident technique [11]. Informants had to remember specific challenges they had encountered with their devices, sometimes several years ago. Given how such events may be hard to recall without prompts, we structured the interviews as a discussion around a bingo card we designed (see figure 2). Each cell corresponds to a possible issue encountered with a smartphone. Four co-authors worked on listing obsolescence factors based on the literature and their expertise in the area. This list was then structured and consolidated to arrive at a list of 20 issues. As we focused primarily on software, the issues were mostly around software problems (storage, applications, bugs...) although we also added the main hardware problems (breakdowns, worn battery). We left the possibility of adding

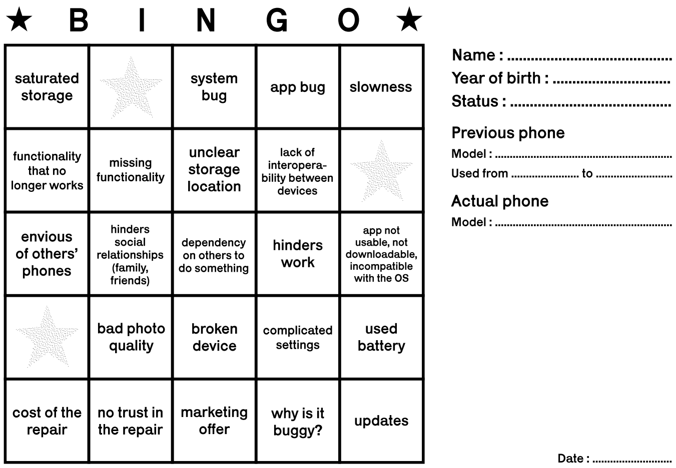

Figure 2. The bingo card. Simplified for readability purposes, filled bingo cards are in the supplementary materials.

more issues thanks to blank "bonus" cells. We iterated on the bingo card six times throughout the interview process. We initially had 5 blank bingo cells, and as the end of the interview process only three.[5]

During the interviews, we invited the informants to take a look at the different cells and share their experiences on all the issues they encountered. In parallel to this bingo, the informant also placed the encountered issues on a timeline, according to the moment when they appeared and the influence they had on the replacement of the device. This medium helped informants to remember as many issues as possible. It also allowed them to avoid limiting themselves to a single/primary reason that may have triggered the replacement of the device.

C. Data analysis

To analyse the data, the primary author created a mapping for each informant where she reported the issues encountered (see figure 3). They are classified according to the order in which they were encountered by the informant and the category of issue (storage, technical capacities, features and applications, social & work, material, manufacturer decisions). The different categories are differentiated by colors. The importance of the issue is represented by its size. Issues that the respondent did not feel had an influence on the feeling of obsolescence of their device are shown in white with only a colored outline. According to the information given by the informant, we added links between the obsolescence factors, as well as verbatims and additional information. The primary author iterated upon the format of the mappings to improve their readability (see supplementary materials).

Based on these first analytical mappings, through various classification exercices in team meetings, we were able to

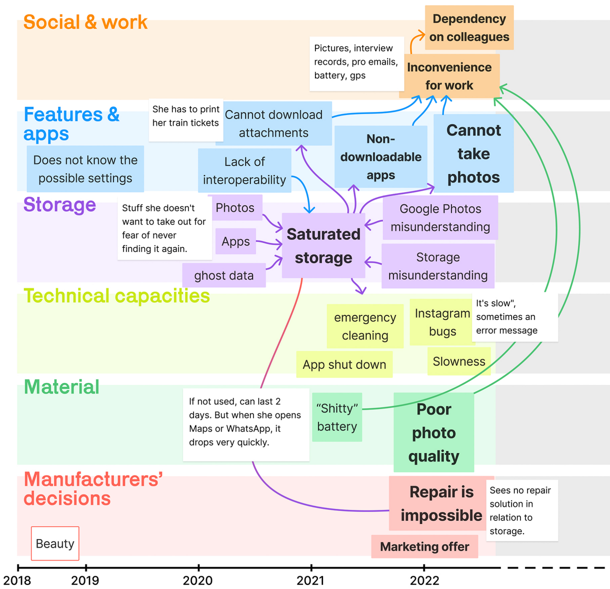

Figure 3. Example of a mapping: the case of Justine. Simplified for readability purposes, all original mappings are in the supplementary materials.

structure the issues encountered by the informants around three themes: saturated storage, issues linked to updates, and malfunctions. Based on this, we created three summary mappings gathering the different causes and consequences expressed by the informants for each of these categories. These mappings were iterated upon by the first and last author as new interview data came in. These mappings helped us structure the interview results: identifying key software obsolescence factors; understanding how they are entangled and how they accumulate; and describing the strategies developed by informants to repair or circumvent them.

Our results are qualitative and our goal was to understand the experience of obsolescence, not to quantify factors, frequency or importance. In the results section, we name or count the informants as an indication of how much an issue was common among our panel, but it should not be interpreted as representative of the broader population.

As a complement to this analytical work and in order to provide more concrete representations of each person's story, we also transcribed some of the most relevant parts of the interviews into comic strips. These allowed us to share the results to a wider audience, and make the informants' experience more tangible.

Bingo grids, timelines and mappings are available as supplementary material: https://doi.org/10.57745/HX81CK

IV. Results

We organize our results following our three research questions: (1) What are software obsolescence factors and how are they felt and experienced? (2) How are obsolescence factors entangled? (3) What strategies do informants develop in order to prolong their device's life?

[5]List of changes to the bingo grid:

V2	Split: "missing feature" and "feature that does not work anymore";
V3	Added: "dependency to others" and "cost of repair";
V4	Removed "lack of data synchronization"
V5	Merged: "non usable app" and "non dowloadable app"; Added: "no trust in repair".

A. Key obsolescence factors: storage, updates and malfunctions

We identified three main obsolescence factors perceived by the informants: saturated storage, issues linked to updates and malfunctions. In this section, we focus on these factors separately, explaining how each is perceived by the informants as well as their origins and effects. In the following section, we explain how they are entangled, building what we call as obsolescence paths.

1) Storage saturation: One of the most clearly indentified factor by the informants was storage saturation. They identified the accumulation of files (created and downloaded), generally photos and videos but also songs and podcasts, as a source of saturation. Célia, Théo and Alexandre also mentionned the software imposed by device manufacturers: the ever growing OS, unoptimized applications as well as bloatwares. To these different saturation sources, we can add hard-to-identify data, represented as "system data" on iOS or as "other" on Android, called "ghost data" by Célia: data that are hard to grasp, not knowing where they come from, where they are stored, what purpose they serve and how to get rid of them.

This saturation is worsened by informants' lack of understanding of storage. Regarding "ghost data" for example, Clara wanted to free up memory to download an application so she deleted another one, calculating that it would free up enough space for the new one. However, after the deletion, her storage was still unsufficient, even after she had deleted "the cache, cookies and stuff" and she could not even re-download the application she had just deleted. The most common source of confusion for informants was the storage architecture: it was hard to understand whether data was stored on the internal memory, on an SD card or in the cloud, making it difficult to free up space. Fabienne and Justine were afraid to remove files because they did not know whether that would also delete them in their cloud backup.

Design choices also led to confusion and impede storage management: Jade for example regularly received warning notifications about her iCloud storage but she simply did not know how to clean it. This led to suspicion towards manufacturers whose messages suggest buying more storage space and is felt as too insisting (Jade, Kim).

Storage saturation had effects on the use of the smartphones. It led to unusable or dysfunctioning applications, sometimes making it impossible to dowload and use even "daily life" ones (music, mobility...) as in Justine's case. Lack of storage also blocked application updates and eventually caused them to stop functioning. For example, Théo lost access to his train application: when launching the app, he could only see a message asking him to update it.

Saturated storage also blocked some functionalities: downloading attachments and taking photos (Justine), editing photos (Fabienne). In these cases, a notification clearly explained it was tied to a lack of storage. In other cases, the connection was less obvious and uncertain, such as Fabienne who could not receive calls and messages.

Lastly, Clara, Justine and Alexandre also thought that saturated storage led to malfunctions and especially slowndowns. Justine, for example, made the connection between storage and malfunctions because of the incessant notifications asking her to free up space. That connection was not made by all: Jade had both problems but did not connect them.

2) Update issues: A second key issue was related to updates, whether they affected individual applications or, more commonly, the whole OS. Updates can be unavailable on what manufacturers deem old smartphone models, and OS are sometimes completely abandonned: Windows Phone is not supported since 2017 and Erika was forced to replace her smartphone because application creators had lost any incentive to develop new or even maintain existing applications on this OS. As we have seen, lack of storage space is also a key factor as new OS versions inevitably ask for more space. For example, Célia had to do a "great cleaning" on her iPhone to be able to update from iOS13 to iOS15 as the newer version required 2 GB more. Even when they could install them, 4 informants were also wary of updates. Jade for example explained that she "did not necessarily want to update" because she had heard that "it made devices obsolete".

The impossibility to update mainly led the inability to use applications (because of apps no longer downloadable or updatable). Erika decided to change her phone when WhatsApp stopped being supported on her Windows Phone. Farida and Mathieu also regretted not being able to access new features, e.g. using the new dark mode for Mathieu.

Critical problems could also come from an update. Right after installing an OS update, a malfunction appeared on Nicolas' phone. It started shutting down from time to time, and then as soon as he unplugged it. This led him to change his phone after several months (figure 4).

While Nicolas was able to ascribe the issue to the OS update, the connection was not always obvious. Célia started noticing bugs after updating her phone: it randomly displayed the shutting down interface but she was not sure whether the two events were connected. Updates could also cause more common malfunctions. For example, one of the applications

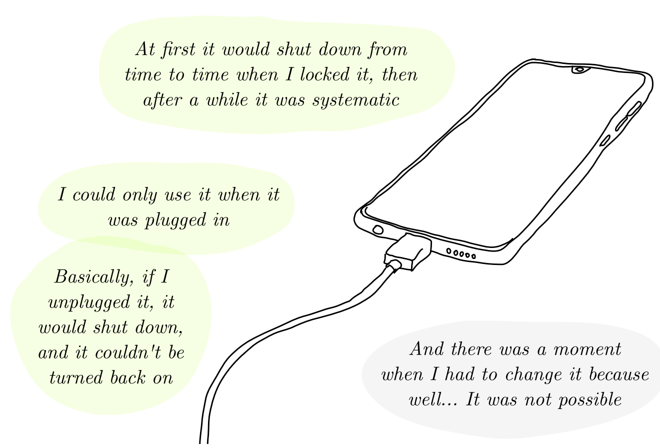

Figure 4. Excerpt from Nicolas' interview.

that Estelle was using could not be launched after she updated it. Her colleagues who also used the application albeit with newer phone could still launch it, but it took time. In that case, the application was likely designed for newer more powerful phones and failed to support old ones. In Estelle's case the application was not crucial and the issue was resolved after another application update. Kim and Jade also wondered whether updates caused a more general performance loss, but this was not a shared opinion accross all informants: Théo had disabled all updates but his phone still dropped in performance, leading him to conclude that updates were not the cause.

3) Malfunctions: A third type of software related issues was also very commonly perceived by informants: malfunctions. These issues were diverse, both in terms of perceived causes and effects, but they all had in common to result in abnormal functioning.

Some malfunctions happened throughout everyday use: slowness, randomly closing applications, frozen screens, random phone shutdowns. Others were specific to some functionalities such as Bluetooth, photo edition features but also sometimes more crucial features such as sending and receiving SMS and calls (Fabienne), hanging up (Théo), taking pictures with a black screen (Estelle) or even receiving notifications (Enzo, Estelle, Louis).

Informants mentionned hardware reasons to explain these malfunctions: worn battery, broken sensor, or low computation capacities, with sometimes very specific reasons like loss of RAM (Random Access Memory) due to "cells that are no more usable" (Théo). They also mentionned software reasons such as non-optimized apps (Théo), energy-consumption while booting (Mathieu), a non-official OS (Estelle) or update issues, as we have already discussed. Overall, informants were confused and did not have a clear explanation for the malfunctions. Some just did not know what caused the malfunction and their guesses were very abstract, blaming planned obsolescence (Jade) or their mobile phone being too old (Kim, Louis) or of poor quality (Enzo). Even tech-savvy informants doubted their diagnosis when it came to explain specific malfunctions.

One of the most common effects of malfunctions was that they forced informants to use some applications less: camera, messaging or social media. These effects were sometimes perceived negatively but also positively. For notification issues, despite the social awkwardness that ensued, it was also perceived positively, allowing them to use their phone less and regain some control over their attention (Estelle, Ludivine). In other cases, applications became completely unusable, especially resource-intensive applications such as games, location-based apps or banking.

B. Obsolescence Paths: the entanglement of factors

Our interviews suggest that in many cases the decision to change smartphone is not the result of a single cause but is instead caused by an entanglement or an accumulation of several factors.

We call these specific entanglements obsolescence paths: the ways in which different obsolescence factors build onto one another and eventually lead to the replacement of the device, sometimes after several months or even years. Importantly, we found that obsolescence paths incorporate technical issues but are also affected by social and contextual factors. Direct effects (unusable functionalities or applications, etc.) generally have second order social consequences (inconvenience for work and social relations, dependency on others). We saw previously that a saturated storage can make a device slower or prevent it from being updated, or that an update can lead to malfunctions. This shows how software issues are interconnected and that this chain of issues, more than any single identified one, is what pushes users to change mobile phones. Hence, it is generally the accumulation of diverse issues that pushed informants to change phones, like in Théo's case, who had storage issues but also a cracked screen inducing touch issues and a non-functioning physical button.

1) Connections between material and software obsolescence factors: Our interviews and the notion of obsolescence path call into question the frontier between software and material obsolescence factors. For example, storage is constrained by material factors but is also greatly affected by software aspects when it comes to storage management. Moreover, software issues can lead to material issues and vice versa. For example, during the 2022 heatwave, Alexandre explained that his phone was overheating. To mitigate the issue, he removed his phone case but a while after, because it was unprotected, one of the mobile phone's physical buttons broke. These events built on top of already existing issues and brought the device closer to its replacement date. In Mathieu's case, his device was going off when he was using power-intensive applications, so he changed the battery but the issue remained, although mitigated. This result allowed him to narrow down his diagnosis: "this is also what convinced me that the problem is not only the battery, there is also a system problem". We see that if a used battery is a material problem, it also depends on software as it could last longer if applications were less energy-demanding. Also, if material and software issues are entangled, it is sometimes difficult to identify the origin of the encountered malfunction, and hence to tackle it.

2) Connections between obsolescence factors and contextual and social issues: Mobile phone replacement happens when smartphone use is impeded, particularly when important functionalities are affected (such as unlocking) or when they lead to effects on social relationships that they generally support. Indeed, direct effects such as unusable functionality generally have social second order effects that usually happen towards the end of obsolescence paths (see e.g. figure 5).

Our interviews provided numerous examples of this. Louis had to code a drawing application in the context of a class assignement. However, his phone with limited computing power was affecting his prototype: "when you drew a stroke, you could feel it struggling and therefore all strokes were jerking". This problem put him in a stressful situation at school and participated in convincing him that he had to change it.

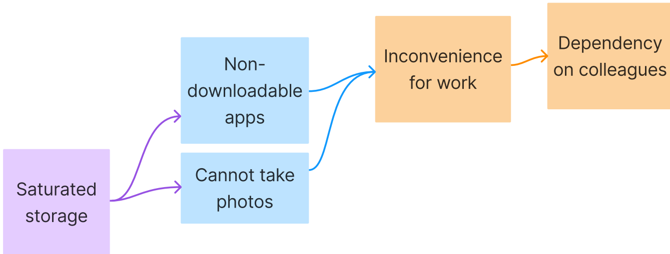

Figure 5. Example of Justine's obsolescence path.

For Justine, the inability to use some features was all the more inconvenient because she needed them for work. Often working outside the office, she needed to upload her itinerary, contact her colleagues, take pictures, but her saturated storage prevented her from doing so. These examples show the very concrete implications that software issues can have, pushing people to replace their phones less because of the technical issue itself, and rather because of its impact on social life.

Sometimes, this impact is experienced more strongly when the informant's life situation becomes less stable. For instance, Ludivine had to push her SIM card inside the phone to receive her messages, but it did not bother them: "since I was well settled in my student life [...] I did not care". But at the end of her bachelor, as she applied for masters, she missed important calls. She also planned to travel for several months and needed her phone to make her "as autonomous as possible" so she bought a new one.

What is considered abnormal is socially situated: it is when comparing with others that informants realized their devices were obsolete, even if they personally did not mind. It was particularly the case with slowness. Informants had become accustomed to it, like Célia: "slowness and bugs are becoming my normality". They usually realized how slow their phone was by comparing it to newer, faster ones.

Obsolescence paths reveal the intricacies of obsolescence issues. They can also help us identify blocking factors to act upon, in order to prolong mobile phones lifespan.

C. Strategies to extend device lifespan

Obsolescence paths invite us to understand how people put up with ever occuring issues. At the end of obsolescence paths, even if the decision to replace one's phone becomes inevitable, the majority of informants tried to postpone it for several months or even years. They used diverse means to make their devices last, for economical reasons but also political ones as a few informants (Estelle, Alexandre, Célia) were proud to be able to use an old phone. Two informants were also trying to preserve features they could not find on more recent phones such as the jack socket (Célia) or the small size of the device (Mathieu). In our analysis, we identified four types of prolongation strategies: repair and maintenance, bypassing, extension, and giving up.

1) Repair and maintenance: We observed both repair and maintenance strategies. Repairing is an action triggered after a breakdown to bring the device back to its previous state. Maintenance, on the other hand, tries to prevent breakdowns by maintaining the device in a stable functioning state [9].

In terms of repairing practices, we can distinguish material and software ones. Among the 18 informants, 3 explained that they had physically repaired their phone and only one with success (Erika). Several obstacles to physical repairing were expressed by informants: it can appear as too costly, but informants also expressed a lack of trust regarding data protection (Alexandre) or fear that the repair would take too long (Ludivine). Sometimes, they also could not directly establish a connection between issues and what to repair. For example, Jade did not connect the bugs she was experiencing to her otherwise failing battery. Overall, even when physical repair was technically doable, informants did not consider it because they had already accumulated many problems of different kinds: "changing a battery when there already are bugs, it is not worth it" (Jade).

We observed more software repair attempts. Rebooting one's phone was used to fix several issues such as frozen screens (Estelle, Enzo, Jade), unlockable phone (Théo), unlaunchable camera (Enzo), calls and SMS that could not be sent or received (Fabienne). Rebooting was used a bit as a "miracle remedy" as informants could not always understand its mechanism. It was however a temporary fix and sometimes a constraining one as for Enzo who very often had to reboot his phone when he wanted to take a picture.

Some parametrization could be seen as software repairing hacks. Such parameters, can at times fix issues coming from hardware. For example, Théo deactivated his screen turning off during calls to compensate for a broken proximity sensor even if "it was a bit hidden". Cleaning up files was another type of repair, especially the irregular cleaning practices. They were triggered by a critical situation such as the fear of not being able to pay the rent (Célia), to take a picture (Célia), to download an app (Estelle). These situations led informants to make a "great cleaning" (of pictures, musics), for example to get enough storage space to download the OS update Célia needed.

We also observed maintenance practices: regular cleaning, data storage management activities or organizing of one's device to fit one's use. Enzo and Célia maintained cleaning routines; twice a year, Enzo sorts his pictures and keeps only the most important ones (120 pictures in 2 years). Three informants reported using applications to help them do this maintenance work: cleaning RAM (Louis) and registers, emptying caches (Youri), emptying storage (Estelle). However, their efficiency was nuanced by informants because they mostly only had a short-term effect: "it was helpful, but really after a while, whatever you do, it's just that the phone is dead" (Louis). It was generally hard for informants to estimate the efficiency of these practices because when maintenance is digilently done, "nothing happens" [9].

Cleaning practices, both for maintenance and repair, are also impeded by a lack of understanding of smartphones inner-workings. For example: Fabienne's internal storage was full while her SD card was almost empty, she thought that data would automatically be saved on her SD card when her internal storage was full. This confusion relates to how data is visualized and communicated, especially as storage on mobile devices tends to work differently from computers. For example, Fabienne again was trying to organize her photos, but did not understand why when she deleted a picture in the "Camera" section, it was also deleted from the album she had put the picture in. Some data are also difficult or even impossible to delete. It is especially the case with "ghost data" that cannot be deleted because it cannot be accessed.Other limiting factors include lack of interoperability that makes it hard to move files from one device to another (Justine) or lack of time to sort out thousands of pictures (Alexandre).

2) Bypassing: Bypassing strategies consist in circumventing issues, to enable *normally* unusable functions. Bypassing malfunctions was possible through software. Louis for example was able to use an application that gave him the possibility to install Netflix through an .apk file as the application was not officially downloadable because his phone was too old. Théo used an application to display virtual buttons that replaced the physically broken ones (see figure 6). We notice again some entanglement between hardware and software.

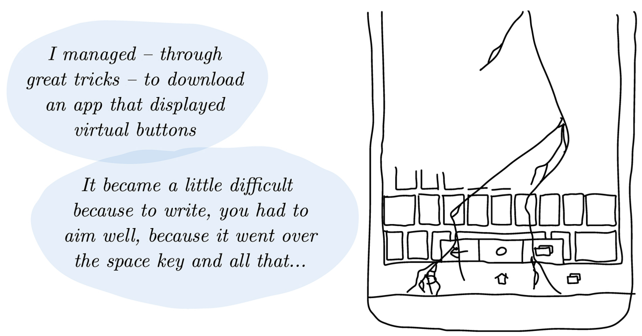

Figure 6. Excerpt from Théo's interview.

Beyond specific applications, using a different OS system (LineageOS) allowed Estelle to upgrade her Samsung Galaxy S4 which was stuck on Android 5 because of the manufacturer lack of update. This allowed her to download a more recent OS but also led to frequent bugs because it was not an official version. This hack was only performed by Estelle who was an expert user, while other informants thought that it was too risky to be tried: "I'm not really an expert in Android, and if that fails and I screw up my phone, well then my phone is screwed" (Mathieu).

Bypassing malfunctions was also possible through source code modification. Inspired by an existing application, Théo directly modified the source code of his smartphone to be able to unlock it with the volume buttons instead of his broken power button.

Bypassing was also possible by diverting applications from their primary use. Farida and Justine shared files between their smartphone and computer using messaging applications when interoperability between devices was defective. Estelle's camera was malfunctioning and she could only take pictures via the front camera on Snapchat, which became her default way to take pictures.

3) Extension: Extension strategies consist in adding external objects to the device to fill the gap left by a malfunction and to keep on using the phone as usual.

We observed that storage extensions in the form of memory cards and online storage were used not only as a way to circumvent storage capacity limitations as in the case of Estelle, who used an SD card to install her most heavy apps, but also to secure data (Anthony), or facilitate file transfers across devices (Mathieu). However, online storage, because it promises large or unlimited space, could discourage from organizing one's pictures and lead to store even more data, like Farida who had 52,520 photos and 8,000 videos online.

We also observed battery extensions in diverse forms: portable batteries, everpresent chargers, multiplugs, to counter limited battery life.

4) Giving up: The last strategy deployed by informants to put up with their aging devices was to live with the issue and give up some functionalities. This strategy was observed when informants saw value in their devices and were ready to compromise to make them last longer despite the issues.

Giving up specific features and applications Informants kept on using their damaged phones by permantently renouncing to specific functionalities like manual locking (Alexandre) or notifications (Enzo). Sometimes giving up was also temporary. Justine explained that when she needs to follow an itinerary and has little remaining battery, she does a screen capture and quits the application, for her phone to last longer.

Giving up features or applications sometimes impacted informant life habits, requiring anticipation and extra organization (Alexandre, Justine).

Decline in overall usage Six informants explained that they used their smartphone less because of the malfunctions, such as Enzo who chose not to use computation intensive applications. The fact that a performance drop induces slowness and eventually limits mobile phone use was seen positively by Louis and Estelle: "I was keeping it because I saw that I was using it less" (Louis). For Clara, it was a good way to separate a professional and personal life as her phone was too slow for work tasks.

Smartphone abandonment We also observed that three informants were not really attached to having a smartphone (Clara, Nicolas, Enzo). They explained that they would rather only use a dumbphone, either because they did not need all the functionalities offered by a smartphone, or as a way to limit their use. However, this desire was generally put away because of existing dependencies: messaging apps (Nicolas) and GPS (Clara) are generally only available on smartphones. Among all informants, Enzo was the only one who completely gave up his phone for 6 months, and was globally happy with the situation except that he could not purchase online, have access to train tickets and make emergency calls.

Transfering use to other devices As informants reduced the use of their smartphone, voluntarily or not, this increased to dependencies towards other devices and people. This was the case for more than half of informants. Contrary to the "extending" strategy that we observed, the "transfering" strategy appeared in parallel to reduced use.

This transfer was first and foremost directed towards computers. It did not necessarily led to an increase in usage time, but rather to a greater diversity of uses as Enzo put it: "I'm always on my laptop anyway, but I was using it for more things". However, this new dependency could be perceived as annoying and not convenient (Justine). This transfer also directed towards other devices, like Alexandre who used a 4G router, a computer as well as a game console. This new distribution of digital uses supports the extension of smartphone life by reducing its use to essential functions, but can also multiply dependencies to other digital devices. In rare cases, informants also reported shifting towards non-digital means: Justine printed her train tickets, while Estelle reported using a letter from the bank for remote purchases.

Dependence on others When a functionality was not available anymore, informants also turned to their family, friends and colleagues. Six explained that they asked others to take photos. This dependency was perceived as problematic at work (Justine). The resulting lack of autonomy could create a certain pressure (Clara) and could also have long-lasting consequences for the person on whom they depend (Kim). Estelle seemed to have a more balanced experience in a personnal context: "it's a rather shared use [...] we went on a road-trip and we used my phone to listen to music or to do internet searches, and her phone was for photos and maps." If that kind of organization can lead to long lasting phones, it does require a collective agreement for how uses and responsabilities are to be shared.

Giving one's phone to someone One last way to make a phone last longer was to give it to someone who required less of it. For example, Youri gave his phone to his father. It could work because he only used it minimally (banking and messaging apps). However he would have tried to keep his phone longer if his father did not need one. If phone circulation can make them last longer, it also induces new buys.

V. Designing with obsolescence paths in mind

Obsolescence builds up over time. Rather than a single problem leading to replacement, we captured the strategies informants developed to continue *living with their aging devices*, sometimes over years, as issues, breakdowns or simply wear appear. Strategies mobilized by users to postpone device replacement as well as the various limits they encountered revealed blocking points that could be leveraged to prolong the lifespan of devices.

We identify two main design directions. The most obvious one is to prevent obsolescence altogether, by avoiding breakdowns, slow-downs or aging from occurring. The other consists in better supporting people living with devices that present signs of obsolescence such as a saturated storage, an old OS version, a cracked screen, a worn battery, or any other issue we identified.

These strategies and the efforts they require depend directly on design choices: what actions can be performed and how easily they can be performed. We believe that it could be possible to imagine *by design* ways to live with aging devices. Designers could anticipate the inevitable aging of software and hardware and offer possibilities to continue using them even in a depreciated way. Based on our results, we worked together and came up with four different design principles to support living with obsolete devices: facilitating repair and maintenance; supporting multi-availability; designing for sobriety and supporting shared use.

A. Facilitating repair and maintenance

Many studies have already pointed out the importance reparability and maintenance. Our interviews confirm the importance of supporting care and replacement (ease of repair, availability of parts, etc.) They also suggest that software and design are essential elements in supporting repair and maintenance, or reducing overall friction. **Extending parameterization possibilities** to modify button functions or to add one when the touch screen is broken as seen with Théo or proposed in [35]. It can also provide ways for the interface to adapt so that the damaged parts do not interfere with reading or interaction (moving the status bar, scrolling, virtual buttons...) This way, hardware issues could be compensated by software-based solutions and vice versa.

Designing interfaces with more **transparency and intelligibility** could help users better understand the reasons of a malfunction, saturation or slowdown, as mentionned in interviews with Théo, Mathieu and Estelle. For example, revealing the data produced and stored, giving an easier access to the storage architecture could support users or more experienced third parties when they want to delete files and clean the device. We also saw how important it is to make the storage location of data more explicit – as the confusion (between internal and external memory like SD card or cloud storage) came up several times in the interviews – and to facilitate the management of these different locations.

B. Supporting multi-availability

Providing several ways to access a function or a service, or even means to do without the service, is another strategy for better resilience to breakdowns. Several informants mentioned their dependency on messaging, banking and travel applications that can only run on smartphones. Old devices may not support these applications, installing or updating them can be a problem due to a lack of storage or because the currently installed OS is deemed too old.

There is a need to provide an access to services on old devices and to people who do not own smartphones. For example, Beignon investigated the digitization of public services in Sweden [4], and proposed an alternative to the official public transportation app by imagining an SMS-based service that provides access to routes and lets users buy tickets from a dumbphone. Of course, regulation should play a role by forcing services to make their data and functionalities through various means, paper based or through a browser rather an app for example. Currently, some services such as online banking are only available through their official applications and therefore create strong dependencies on newer smartphones. We can also mention ticketing services such as DICE that do not let users download their tickets, or WhatsApp that prevents users from accessing their messages from a computer if the application has not been installed on a smartphone beforehand.

C. Designing for sobriety

Creating more data-, performance-, or feature-intensive software increases the required capabilities of devices, and makes them slower through additional updates. More frugal software design would lead to longer-lasting devices. We can think for example of creating applications that work on smaller screens and not necessarily touchscreens; or with lower energy demands. Today "Lite" versions of applications[6] sometimes exist but are generally only available in the Global South. Deeper changes in the way designers think about their applications today are needed, by rethinking the metrics against which contemporary design is evaluated. This also relates to inclusion challenges, as new high-end phones are often considered the norm by developers and designers. However, old phones are much more widespread, and the cost of new high-end phones reserves them to a small proportion of the population.

D. Supporting shared use

Although smartphones are generally thought as individual objects, our interviews revealed interesting cases of collective and shared uses to compensate temporary or persistent lack of functionality. For example, it was easier for Estelle to live without GPS as she could rely on her partner. In the meantime, her smartphone was used for music and web searches, supporting a shared use of both devices. Encouraging this kind of usage would reduce the production of new devices and help reduce frictions when using a depreciated device. Shared use could be better supported and more advertised features such as user sessions on a shared device already exist but are not used. There are also existing ways to separate professional and personal uses on smartphones but they are rarely used. And we could imagine support for sharing practices on a larger scale (among groups of friends, within companies or communities).

E. Regulatory directions to support design solutions

Designers and developers can support people willing to keep on living with their aging devices in numerous ways. However, many propositions will hardly come into being without stronger regulations, for manufacturers and designers to extend the lifespan of devices. The European Union is already working in this direction [36]. Among other initiatives, France has recently developed and enforced a reparability index which will soon be followed by a durability index [1]. We can also mention the law to decrease the environmental footprint of digital technologies [7] that defines software obsolescence as one specific element of planned obsolescence, forcing sellers to provide information about updates and maintenance advices to limit the decrease in performance. However, regulations could go further by extending the legal warranty period for devices, by making repair economically advantageous, or by requiring more interoperability between devices.

[6]Such as Instagram Lite

[7]https://labo.societenumerique.gouv.fr/en/articles/adoption-of-the-law-to-reduce-the-environmental-footprint-of-digital/

VI. Study Limitations

Our study is only a first step towards a better understanding of the experience of obsolescence. It needs to be complemented with more comprehensive studies, both observational and quantitative ones. Our informants were not representative of the general population as most explained to us how they wanted to make their devices last longer but could afford to change their devices when they could not endure it anymore. Understanding people who cannot afford to buy a new smartphone as well as people who always have the most recent smartphones would also critical to provide a more comprehensive view of smartphone obsolescence.

Our study focused initially on software obsolescence as it has been an under-researched source of obsolescence. In doing so we surfaced the relations between hardware and software obsolescence, but have little insights on their respective importance and influence. Future studies could quantitatively investigate the relative importance of software and hardware factors in the obsolescence paths of devices. We mainly relied on informants' perception of obsolescence. Large-scale quantitative analysis of software bloat and/or software updates practices could put our results into perspective with external quantified data.

We did not focus on security issues. The availability of updates is often tied to security at various level of the software and hardware. Informants lack of interest for security concerns, especially in regard to upgrades is in line with previous work on the topic [38]. This aspect would also deserve further investigation particulary to understand device obsolescence in professional settings.

VII. Conclusion

Our study of living aging smartphones shows how storage and malfunctions are important causes of device replacement, as well as lack of updates. It is often an accumulation of issues, software and hardware ones, but also contextual and social factors, forming what we define in this paper as obsolescence paths, that trigger the decision to get another smartphone. Our results suggest that the frontier between hardware and software obsolescence is a very blurry one, hardware issues can be triggered but also sometimes repaired or circumvented by software-related actions.

Many informants were trying to extend the life of their devices, developing diverse strategies. Even if they were held back by a number of design choices that impeded their repair abilities. Our work invites developers and designers to take into account and support users as they live with aging devices. We also outline directions in which extra regulation would be beneficial.

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