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How Interface Design Choices Lead to Indirect Environmental Impacts Through Use Intensification: An Empirical Evaluation of Messaging Apps

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Abstract

In sustainable HCI, the ‘Cornucopian Paradigm’ describes how the expansion of digital services goes hand in hand with the growth of digital infrastructure and its environmental footprint. Yet, the mechanisms driving this paradigm are not well understood at the design level. As a case study, we investigate how messaging apps factor in the cornucopian paradigm by conducting a feature analysis of 17 apps complemented with 12 user interviews. We identify four *scale-up mechanisms* that explain how design contributes to the cornucopian paradigm. These mechanisms all contribute to *use intensification*, i.e., digital practices becoming more intensive and leading to more data intensity, to infrastructure expansion, and indirectly to device obsolescence and replacement. Our analysis of *use intensification* builds upon a set of recurring *cornucopian design patterns* we identified in messaging apps. To mitigate the cornucopian paradigm, we propose a set of moderation heuristics to guide design decisions.

CCS Concepts

• **Human-centered computing** → *Heuristic evaluations; HCI theory, concepts and models; Empirical studies in interaction design; User interface design; Empirical studies in collaborative and social computing*; • **Social and professional topics** → *Sustainability*.

Keywords

Cornucopian paradigm; Design patterns; Indirect effects; Scale-up Mechanisms; Feature analysis; Instant Messaging; SHCI

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1 Introduction

The greenhouse gas (GHG) emissions of the Information and Communication Technology (ICT) sector are estimated to amount to 1.5

to 4 percent of global emissions [6, 11, 12]. In conservative scenarios, this share is expected to reach 7 percent in 2030 and 15 percent in 2040 [6]. Beyond GHG emissions, the sector’s growth trajectory and supply chain also contribute to the crossing of multiple planetary boundaries [57, 64, 65].

To better understand the factors underlying the growth of ICT environmental impacts, a growing body of research emphasizes the importance of the *indirect effects* of technical and design choices [19, 21]. Indirect effects can be understood as “the environmental consequences of an ICT solution’s capacity to change existing consumption and production patterns, taking into account the inter-related socio-economic, cultural, and human-health impacts, both beneficial and adverse” [11]. For example, digital platform design can influence online purchases [26] and commuting habits [30]. Bornes et al. argue that HCI is well equipped to study indirect effects of digital design choices through its position at the interface between technology, design, and uses [15].

Preist et al. have shown that design plays a role in the growing environmental footprint of the digital industry itself [58]. They use the concept of “Cornucopian Paradigm” to describe how the material growth of digital infrastructure is driven by increased user demand, which is itself stimulated by the design of digital services. More precisely, they discuss how common “design principles” [58] such as instantaneity, pervasiveness or high quality, shape user demand in unsustainable ways.

Yet, it is still unclear how specific digital design choices directly and indirectly contribute to the cornucopian paradigm in practice. To tackle this challenge, we conducted a mixed-method study combining a feature analysis [34] with user interviews. We used instant messaging apps as a case study, investigating their UI and UX designs, as well as their evolution over time. We cross-analyzed a selection of 109 features extracted from 17 messaging apps and twelve interviews on messaging practices. The environmental effects of instant messaging apps are usually left unquestioned, and may seem innocuous compared to those of other notoriously data-intensive digital services such as video streaming [59] or AI services [43]. Yet, instant messaging apps are the most widely used type of digital services [38], and their history is long enough to make the chronological evolution of their design worth studying. This makes them an interesting case to study the impact of interface design choices on uses, infrastructural scaling and the corresponding environmental effects. We took a particular interest in group chat features, as an evolution in messaging technology that has deeply impacted online socialization.



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In our empirical analysis, we identified five *cornucopian design patterns* across messaging apps, i.e., pervasive design choices fostering more intensive digital practices. We also identified and characterized four complementary *scale-up mechanisms* that explain how *cornucopian design patterns* lead to more intensive digital practices and eventually to indirect environmental effects. These mechanisms clarify how seemingly unrelated design choices do contribute to the cornucopian paradigm. *Scale-up mechanisms* are the driving forces behind a phenomenon we call *use intensification*, i.e., digital practices becoming more intensive, not only through an increase in data demand but also more computationally intensive and more time-demanding leading over the long run to infrastructural expansion and individual device replacement (Figure 1). As a complement to our results, we propose eight moderation heuristics to guide design towards mitigating *use intensification*.

With this work, we hope to demonstrate how qualitative analysis methods can be used to understand design-driven indirect effects and complement existing HCI environmental evaluation methods.

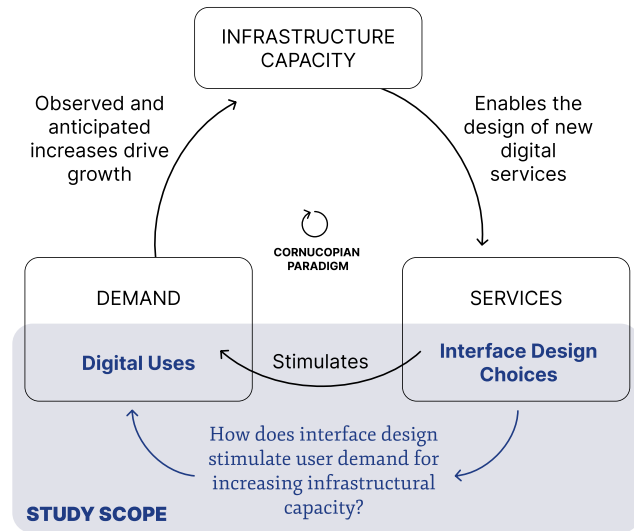


Figure 1: The black loop corresponds to Priest et.al’s cornucopian paradigm diagram. Our study (blue box) focuses on how the design of digital services stimulates uses and demand.

2 Related Work

2.1 The Expansion of the Digital Infrastructure Supporting Messaging Apps

Contributing to the growing body of research on the role of HCI and design in crossing environmental limits [39, 45, 52, 68, 72], Priest et al. proposed the cornucopian paradigm [58] (fig 1). This paradigm explains how the development of digital services drives the growth of digital infrastructure, i.e., the “use of servers, core and edge network equipment, and potentially content creation equipment such as cameras, sensors”, which feeds back into the growth in digital services. The growth in services then leads to a growth in users’ data demand [50].

While efficiency improvements in digital infrastructure are continuously being implemented, the overall carbon footprint of the ICT sector keeps growing. Options that go beyond efficiency, such as inhibiting demand, are rarely considered by digital services providers and policymakers [66]. A recent example of this phenomenon is the wide-scale implementation of generative AI services, concurrent with improvements in the energy performance of data centers [43]. We align with the HCI literature calling for better consideration for data demand, but we extend this concern to Blevis’ material effects of ICT (hardware ownership and the use and replacement of devices) [13] on which the cornucopian paradigm builds upon.

To study how specific design choices directly and indirectly contribute to the cornucopian paradigm, we first categorize the different types of infrastructural and material effects at play in the context of messaging apps. As the initial description of the cornucopian paradigm pertained to cloud-based services, the infrastructural effects presented in the original article did not include individual device-related effects. We chose to include Blevis’s material effects of ICT (hardware ownership and the use and replacement of devices) [13] to build a cohesive list of material and infrastructural effects to consider in our study. In this paper, we therefore take into account the three following effects (Table 1):

- **Infrastructural obsolescence and expansion.** While messaging apps rely on different types of digital infrastructure, they all need data centers to temporarily or permanently store user data, deliver messages and media but also to process account data (logins, profile data, advertising profiles). To prevent breakdowns and malfunctions, data is duplicated and redundancy is also often necessary in the infrastructure. Depending on the service, additional servers are sometimes required to perform data analytics and other algorithmic treatments of user data [1], for security or business reasons. As messaging apps are designed to be used continuously and ubiquitously, they also impact the mobile network infrastructure through signal coverage and bandwidth.
- **Data and compute intensification.** In use, messaging apps foster “infrastructural use” [58], meaning that the practices influence the demand for data transfer, storage and computation, which impacts infrastructural obsolescence and expansion. Data and compute intensification thus depend on how many users interact and how much they do, but also on how much computation is required for a given feature. With recently implemented gen-AI messaging features, compute intensification is particularly worrying [73].
- **Devices replacement and obsolescence.** While the cornucopian paradigm focuses on infrastructural support for digital services, it also builds upon previous work that considered the purchase and replacement of digital products [13]. The design of digital services stimulates the increase of hardware ownership [76], its replacement and obsolescence [51].

INFRASTRUCTURAL EFFECTS	INITIAL FRAMEWORK	EXAMPLE
Data intensification Data-transfer and data storage	Infrastructural use and sharing (Preist et.al, 2016)	Sending video rather than textual contents is more data intensive
Digital infrastructure obsolescence and expansion	Infrastructural expansion and obsolescence (Preist et.al, 2016)	Better quality videos require faster networks and more server storage
Individual hardware renewal and obsolescence	Invention and disposal of new devices Renewal and reuse (Blevins, 2007)	Accessing video contents requires a smartphone

Table 1: Infrastructural and material effects from Preist et. al. and Blevins’s principles adapted to our Messaging apps case study.

2.2 Understanding ICT’s Indirect Environmental Effects

While it is obvious that the widespread adoption of messaging apps requires building more data centers or expanding network infrastructure, unpacking the different factors that influence the magnitude of their infrastructural effects is a much more complex task. The design of digital services generates indirect effects, which are difficult to estimate and even more difficult to anticipate [19, 30, 35, 36, 71].

While direct effects relate to the use, production, and discarding phases of ICT products and services, indirect effects pertain to the triggers and drivers behind an observed effect. For example, in 2015, Lord et al. [44] investigated how the ownership of tablets and smartphones resulted in the migration of digital practices such as video calls and media consumption to mobile devices, which impacted mobile network development and the fluctuation of data demand at scale. In environmental studies, economists have similarly explored the dynamics behind consumption metrics, which are sometimes presented as rebound or induction mechanisms. In the case of ICT, this consists in qualitatively describing how digital products stimulate unsustainable consumption patterns [40].

Such mechanisms include reconfigurations of time use by technology use [10, 22], interdependencies between non-digital practices and digital uses [70] or practice shifts and impact of consumption motivation [56]. “Induction mechanisms” [40] is a useful umbrella term for what we seek to investigate in this study, referring to how “new options” offered by technology reshape practices and behaviors at different scales. While design is sometimes presented as a factor in the occurrence of indirect effects in ICT [33, 36, 40], we were unable to find studies or models explaining the mechanisms through which digital design choices embedded within products and services lead to indirect environmental effects in the ICT sector.

2.3 Empirical Environmental Evaluation of Infrastructural Effects

HCI has developed many qualitative methods for studying digital uses. These methods have already been used to study the indirect effects of design choices, for instance on users’ attention [48, 49, 67].

Yet few studies in HCI have investigated the digital practices responsible for the environmental effects of ICT. Those that do focus on technology use emphasize the effects on replacement and multiplication of devices. For example, studies have shown that ownership of multiple devices leads to growth in data consumption [76], and that smartphone ownership makes users more reliant on data connection [44]. Such qualitative insights are valuable for our understanding of the quantitative trajectories of the ICT sector’s infrastructural effects. However, to our knowledge, there have been no such studies on the role of interface design in shaping unsustainable digital practices.

Qualitative methods have also seldom been applied to the environmental evaluation of digital systems, although multiple studies have stressed the importance of relying on both quantitative and qualitative data in this effort [19, 61]. HCI researchers have produced tools for “straightforward” [69] environmental evaluations, such as quantitative scores. These popular environmental evaluation tools have been adopted by industrial actors, but the opacity of these scores has been criticized [63]. While they have great pedagogical value, they currently rely on a few arbitrary calculations [19, 27] and mainly focus on direct effects. Remy et al.’s work on sustainability evaluation [61] has highlighted the need to connect metrics with mechanisms that explain the relationship between artifacts and users experiences but also with social or economic outcomes. A mean to evaluate the sustainability of design choices beyond direct effects are value-oriented sets of questions and reflexive activities, such as the Tarot Cards of Tech¹, SusAF Workbook [8], or Nathan et. al.’s strategic envisioning activities [54].

The recent turn to systemic modeling in SHCI [14–16] shows the need to articulate different levels of causal relationships. These approaches currently rely on qualitative data from large-scale studies that document the practices around a product (e.g. studies of consumption trends regarding this type of service). However, during the design process, large-scale transformations might not yet be visible, or might be hard to attribute to a specific type of service. As a complement to these approaches, we propose using a smaller-scale empirical method that is widely used in HCI, i.e. user

¹<https://tarotcardsoftech.artefactgroup.com/>

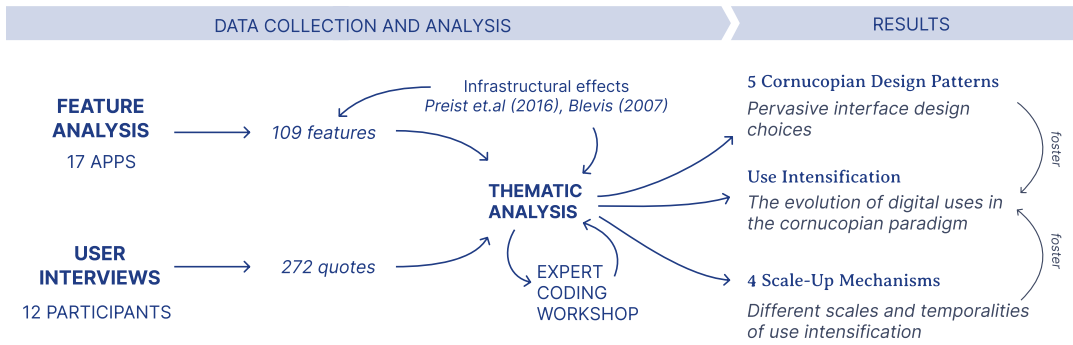


Figure 2: Overview of our mixed-method study and results

interviews, and combine it with a feature analysis to understand how the design of digital features leads to infrastructural effects.

3 Method

Our goal was to identify the different ways in which messaging app features and their design contribute to the cornucopian paradigm. This required identifying 1) features that stimulate user demand; 2) the mechanisms through which they lead to the expansion of the digital infrastructure.

Our study uses a mixed method (figure 2) that builds upon Hasinoff et al.’s *feature analysis method*, whose goal is “to systematically answer questions about how app developers’ design choices reflect existing cultural norms, assumptions, and ideologies” [34]. This method is coherent with our intent to analyse the impact of the growth-oriented mindset of the cornucopian paradigm on the design of messaging apps (Table 1).

We first selected and studied a corpus of 17 messaging apps (Figure 2) and complemented it, as suggested by Hasinoff et. al [34], with 12 interviews of messaging apps’ users. To narrow down the scope of this study, we chose to investigate more specifically features and uses of group discussions, as those may more strongly orient online socialization or user demand.

3.1 Feature Analysis

Selection of a Corpus of Apps. Following the feature analysis method, we started by defining a “problem” [34], an inclusion criterion for determining which digital platforms would be studied. We worded our criteria as follows: “a digital service that enables group conversations”. The corpus selection was performed in 2024 by searching a list of keywords (‘instant messaging’, ‘group chats’, ‘group conversation’, ‘group discussion’) on the Play Store. We excluded results that did not match our initial inclusion criterion and stopped the selection when the store proposed 10 consecutive irrelevant applications, e.g. dating apps, or when group chat features were not displayed on the store’s screenshots. Our corpus therefore features popular mobile apps in our geographical area, i.e. Europe. It also includes social media apps that are largely used as messaging apps for group chat uses, e.g. Instagram and Snapchat. The resulting corpus contains 17 applications (Table 2).

Identifying Potential Cornucopian Features. Our aim was to identify features that potentially contribute to the cornucopian paradigm through infrastructural and/or material effects, i.e. data and compute intensification, digital infrastructure obsolescence and expansion, or individual hardware replacement and obsolescence (Table 1).

Following the feature analysis method [34], we first performed a technical walkthrough, i.e. “a way of engaging directly with an app’s interface to examine its technological mechanisms and embedded cultural references to understand how it guides users and shapes their experiences” [42], on eight representative messaging apps from the initial corpus.

We chose these eight apps because they were representative of the overall corpus in terms of number of active users (see Table 2) and in terms of diversity of advertised uses on companies’ websites (i.e. communication between close friends 🗣️ 🗣️ 🗣️, between family members 👨‍👩‍👧, for larger communities and organizations 🗣️ 🗣️ 🗣️, 🗣️ 🗣️ 🗣️).

For the nine remaining messaging apps, as suggested in the feature analysis method [34], we used the Google Play Store screenshots, geared toward “features that developers think are important enough to entice users to download their apps” [34]. This combination of approaches was particularly relevant in our case. The technical walkthrough allowed us to capture features that are not always advertised by companies, such as pop ups, parameters, or user actions such as group creation, sending files, exporting and deleting messages. The analysis of app store screenshots gave us a sense of intended uses for the app (e.g. very large groups of people), and was also useful for understanding how the apps could be used in coordination with other services or with a desktop version.

Following the walkthrough method guidelines [34, 42], we considered *how* messaging apps features would orient uses towards infrastructure growth. Indeed, we understand digital features as shaping users’ actions in different ways, some of which more strongly “push, pull, enable, and constrain” [23] digital uses with high infrastructural effects. To better understand the “environments of expected use” [42] that were envisioned for each app, we also read promotional websites of platform providers and specialized press articles. The investigation of apps was broken down into 6 categories in order to systematically explore features associated with these tasks surrounding group messaging: (1) group creation and

Messaging app	Initial Release	Monthly active users	Distinctive characteristics
Downloading and manually "walking through" apps (Technical walkthrough method, Light et.al., 2018)			
WhatsApp	2009	2 billion (2020)	World leader
Instagram	2010	2 billion (2021)*	Integrated social media chat
Messenger	2011	988 million (2022)	Standalone social media chat
Telegram	2013	900 million (2024)	Competition with Meta
Snapchat	2011	557 million (2022)	Social media, photo sharing
Discord	2015	150 million (2021)	Historical gaming platform
Signal	2014	40 million (2021)	Privacy, No adds
GroupMe	2010	12 million (2021)	Microsoft-owned
Collecting app stores' screenshots (Screenshots method, Hasinoff and Bivens, 2021)			
WeChat	2011	1.263 billion (2022)	China's leader, "super-app"
Google Chat	2013*	500 million (2020)*	Office suite chat
Google Messages	2018	500 million (2020)*	Installed by default on Android
Microsoft Teams	2017	280 million (2023)	Office suite chat
Rakuten Viber	2010	260 million (2019)	Popular in eastern Europe & western and southern Asia
Skype	2003	200 million (2020)	Early telecommunication app
Line	2012	169 million (2020)	'Super-app': news, music streaming
Slack	2013	12 million (2019)	Office chat
Rocket.Chat	2015	12 million (2022)	Privacy, Intended for Institutions

* Data related to the entire platform, not only to the use of messaging features

Table 2: Summary of our app corpus divided by investigation method: the technical walkthrough and the app stores' screenshots method.

invites; (2) message exchange and notification; (3) sending files and media; (4) inter-relatedness of features; (5) deleting and leaving. This resulted in the identification of 110 unique messaging app features and related affordances that we documented in a database, including screenshots and indicating the year of release when we could find the information.

3.2 Semi-structured Interviews with Messaging Apps Users

We conducted 12 interviews concurrently to the feature analysis, to complement our understanding of the influence of messaging apps features on users' digital practices. We wanted to better understand how practices might interact with affordances and intended use cases. We conducted these semi-directed user interviews in person, aiming for as broad a range of interviewees as possible in terms of age, socioeconomic status, digital literacy and messaging app uses (personal, school, professional...) (Table 3). The study was approved by our university IRB board.

Recruitment. We recruited participants partly using the snowballing method, and partly by posting a message on a public Facebook group for a large city. We selected participants to ensure varied socio-professional profiles. Digital literacy was self-assessed during the interviews (see details in next paragraph). Overall, the

participants used seven different apps that were all in our corpus. The messaging apps used by participants reflect the current oligopoly, with the three apps most used by the participants all owned by Meta: all but one used WhatsApp, nine used Messenger and eight used Instagram. Some participants also used Snapchat (4), Microsoft Teams (3), Telegram (2) and Discord (1). One participant in our panel (P9) did not have a smartphone and used the apps' desktop versions.

Interview Sessions. The interviews lasted one to two hours. Participants were first asked about their demographics (age and occupation). We then assessed their digital literacy by asking them how comfortable they felt in their ordinary digital practices (e.g. 'I don't feel comfortable, I am scared of doing things wrong' (P11), and asked them to describe the last time they encountered an issue with digital technology (e.g. 'I struggled with the remote installation of the XLStat software because it was lagging' (P9)). The scale on table 3 reflects the authors' interpretation of participants' self-reported data. Our scale is meant as a broad indicator, as digital literacy is a multifaceted and context-dependant phenomenon.

Participants were asked to present the different messaging apps they were using. They then chose two apps and, using a pre-made template, produced a hand-drawn data-visualization of their degree of commitment to each of the different group chats they were in.

Participant ID	Occupation	Age	Digital literacy Self-reported	Messaging apps installed From the most to the least used
P1	Designer, student	22	++	📷 🗣️ 📧 📧
P2	Designer	24	++	📷 🗣️ 📧 📧 📧
P3	Industrial Engineer	24	++	📷 🗣️ 📧 📧 📧
P4	Scenographer, student	24	+	📷 📧
P5	Illustrator	54	-	📷 🗣️
P6	Math teacher	34	++	📷 📷 🗣️
P7	Special needs teacher, Unemployed	25	+	📷 📧 📧
P8	Health executive	60	--	📷 🗣️ 🗣️
P9	Sociologist, PhD Student	27	++	🗣️ 🗣️ 🗣️
P10	Call center employee	29	-	📷 📧
P11	Cleaning worker	35	-	📷 🗣️ 📧
P12	Project manager	59	+	🗣️ 📷

Table 3: Participants’ occupation, age, digital literacy and messaging apps used. Digital literacy is presented on a basic scale, from (- -) : participants who were both insecure regarding their digital skills and met non-technical issues with generic digital manipulations (e.g. deleting a file, P.8); to (++) : participants who describe themselves as confident with their digital skills, and who had issues that were related to bugs or expert manipulations.

They captioned their visualization either with suggested options, e.g. ‘*this group is very important to me*’, ‘*I keep this group just in case*’, or by creating captions of their own, e.g. ‘*muted group*’ (P1, P3, P5, P7) ‘*perished group*’ (P3), ‘*videos*’ (P6). This design boundary object [7] facilitated discussion between the researcher and the respondents and allowed participants to address past discussions with a reflexive lens. While creating the visualization, we asked participants questions about their media and file-sharing practices, their involvement in each group chat, their reason for choosing a particular platform to interact with these people and their data deletion practices. When unlisted features were mentioned during an interview, they were added to the database, e.g. video messages.

The interviews were audio-recorded and transcribed locally using the software Whisper. We extracted all quotes (n=272) that were relevant to messaging apps design in terms of infrastructural and material effects (Table 1) and added them to our database.

3.3 Data Analysis

Among the different qualitative analysis methods (grounded theory, inductive content analysis), we chose to perform a thematic analysis [18].

Indeed, inductive analysis methods do not allow for the inclusion of established knowledge of infrastructural effects. Thematic analysis is more suited for incorporating top-down (theories and existing knowledge) and bottom up (inductive analysis) analyses. In our case, we wanted to consider infrastructural effects already discussed in the literature in the analysis of our corpus.

We cross-analyzed the two data sources through the lens of the cornucopian paradigm [58] and the related infrastructural and material effects (Table 1) to understand the mechanisms through which messaging apps features and related practices contribute to

the cornucopian paradigm. In the paper, the authors provide questions aimed at triggering reflexivity on infrastructural expansion and material obsolescence, e.g. “*Does the design cause the disposal of physical material, directly or indirectly and even if the primary material of the design is digital material?*” [13]; “*Does the design encourage increased infrastructural use?*” [58].

For each feature identified during the walkthrough and app store selection methods, we coded their relevant infrastructural effects and described how the affordances of features shaped users actions. As suggested in the feature analysis methodology [34], we relied on Davis’ affordance theory to identify correspondences between features and intended or observed use outcomes. At that point in the analysis, codes included e.g. ‘diversification of uses leading to infrastructural growth’, ‘increase dependency’, ‘encourages spamming’.

We conducted the interviews after a first round of feature analysis coding, these codes therefore influenced the interviews and their subsequent thematic analysis. We did a first coding pass on the interview dataset while reviewing the transcripts with the corresponding audio file. Codes were related to environmental effects (‘equipment replacement’, ‘increased data exchange’, etc), to social dynamics (‘social norms’, ‘cultural obsolescence’, etc), or user behaviors (‘refusing’, ‘fear of missing out’, ‘no cleaning’, etc), symptoms (‘increase of storage’, ‘multiplication of devices’, etc) and interface characteristics (‘by default’, ‘subtle integration of AI’, etc).

We iterated successively on codes and themes, i.e. “conceptual patterns” [18]. After this first coding pass performed by the first author, we conducted a workshop with 8 HCI researchers (5 of whom were not involved as authors) to visually map, cluster and discuss codes. This helped us converge towards interrelated themes

in the form of a phenomenon, mechanisms and patterns which the authors then discussed and expanded upon in the writing process.

4 Results

Our analysis of the design and uses of messaging apps led us to identify interconnected mechanisms that show how digital practices are affected by design choices. We identified *use intensification* as the design-driven phenomenon explaining how demand growth is stimulated within the cornucopian paradigm (Figure 3). In other words, interface design choices lead users to spend more time within messaging apps and to use more intensive features.

In the following, we further unpack how design influences digital practices directly and indirectly. We explain how *use intensification* derives from what we call *scale-up mechanisms*: Fostering feature intensification (see 4.2), Contributing to platform dependency (see 4.3), Contributing to device dependency (see 4.4), and Normalizing higher expectations (see 4.5). As Remy et al. argued, in HCI environmental evaluation, “identifying mechanisms is critical for understanding the relationships between an artefact and its complex environment”. *Scale-up mechanisms* aim to describe the ways design choices shape digital practices across different temporalities (i.e. short-term, mid-term, long-term), and across different social scales (i.e. the user, the users’ social circle, and society) (Figure 4).

For the sake of our analysis, we disentangled the different scale-up mechanisms we identified. In the following sections, we describe them one after the other but readers should note that they mutually reinforce each other and are highly intertwined in practice, as illustrated in figure 4. Like any qualitative analysis, our goal was to identify phenomena and describe their relationships, not to measure their importance quantitatively. To support the appropriation of our findings by designers, we also propose a set of heuristics to guide design decisions aiming at indirect effects mitigation. We call them *moderation heuristics* because they complement Widdicks’ work on moderate uses [77].

4.1 Cornucopian Design Patterns

In our analysis, we found that *scale-up mechanisms* are taking place in messaging apps because they are enabled by specific features and/or by the design of such features. Across the 110 messaging app features we identified, we found recurring feature designs leading to *use intensification* across apps, and chose to structure and summarize them as cornucopian design patterns. *Cornucopian design patterns* are design patterns i.e. pervasive design choices [31], that capture how the ten design principles of the cornucopian paradigm [58], (i.e. (1) personal, (2) variety, (3) instant, (4) shareable, (5) high quality, (6) pervasive, (7) continuous access, (8) eternal, (9) ephemeral, (10) rich, cross-modal and ubiquitous), are concretely embedded in the design of messaging apps. While Preist et al.’s initial design principles are generic and high-level, the cornucopian design patterns show how they are embodied in interface elements.

- (1) Features allowing exchanges of heavier files (Figure 5)
- (2) Features encouraging new chat modalities (Figure 7)
- (3) Features favoring AI use (Figure 8)
- (4) Features demanding social media engagement (Figure 9)
- (5) Features discouraging data deletion (Figure 10)

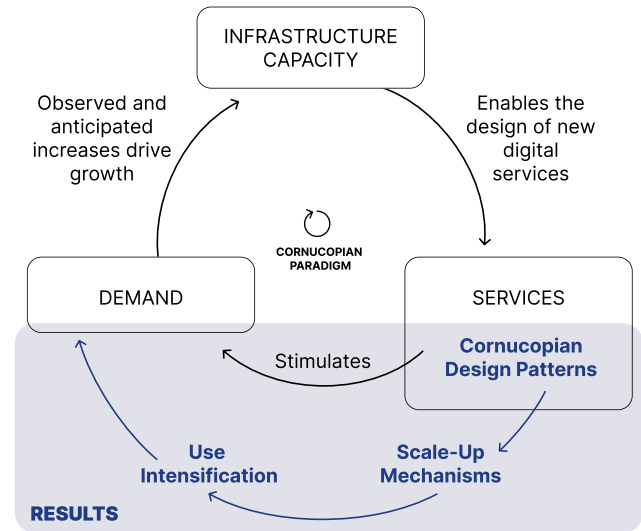


Figure 3: Summarized view of the results showing how services introduce cornucopian design patterns which, mediated through scale-up mechanisms, stimulate use intensification.

Taken individually and in the short term, each *cornucopian design pattern* might not have a significant environmental impact. While the use of any feature involves data-transfer or computation, it is through scale-up mechanisms that cornucopian design patterns transform digital practices and result in infrastructural effects. The cornucopian design patterns we discuss in this article can be understood as systemic deceptive patterns, contributing to a deceptive infrastructure in Westin’s sense [75], meaning that it is through cumulative effects and through the context in which the features exist that they end out having negative outcomes.

It was challenging to summarize and communicate the common affordances that we identified across apps and through the interviews: messaging apps are familiar interfaces and individual database screenshots do not allow to explain how features co-exist and together shape unsustainable users actions.

Therefore, we chose to present these patterns as mockups and in action in the corresponding *scale-up mechanism* sections to describe how design choices end up sustaining the growth dynamic of the cornucopian paradigm through *use intensification*.

4.2 Scale-up mechanism 1: Fostering Feature Intensification

The most evident and direct scale-up mechanism driving use intensification is design’s role in *fostering feature intensification*. This describes the tendency to design features that require more resources, and to encourage users to adopt these features.

Feature intensification of messaging apps occurs through technical choices, e.g., increased maximum file size, but is also conditioned by design. In the case of messaging apps, this evolution results in orienting digital practices towards data and compute intensity (data transfer, data storage, computation). While the intensity of features

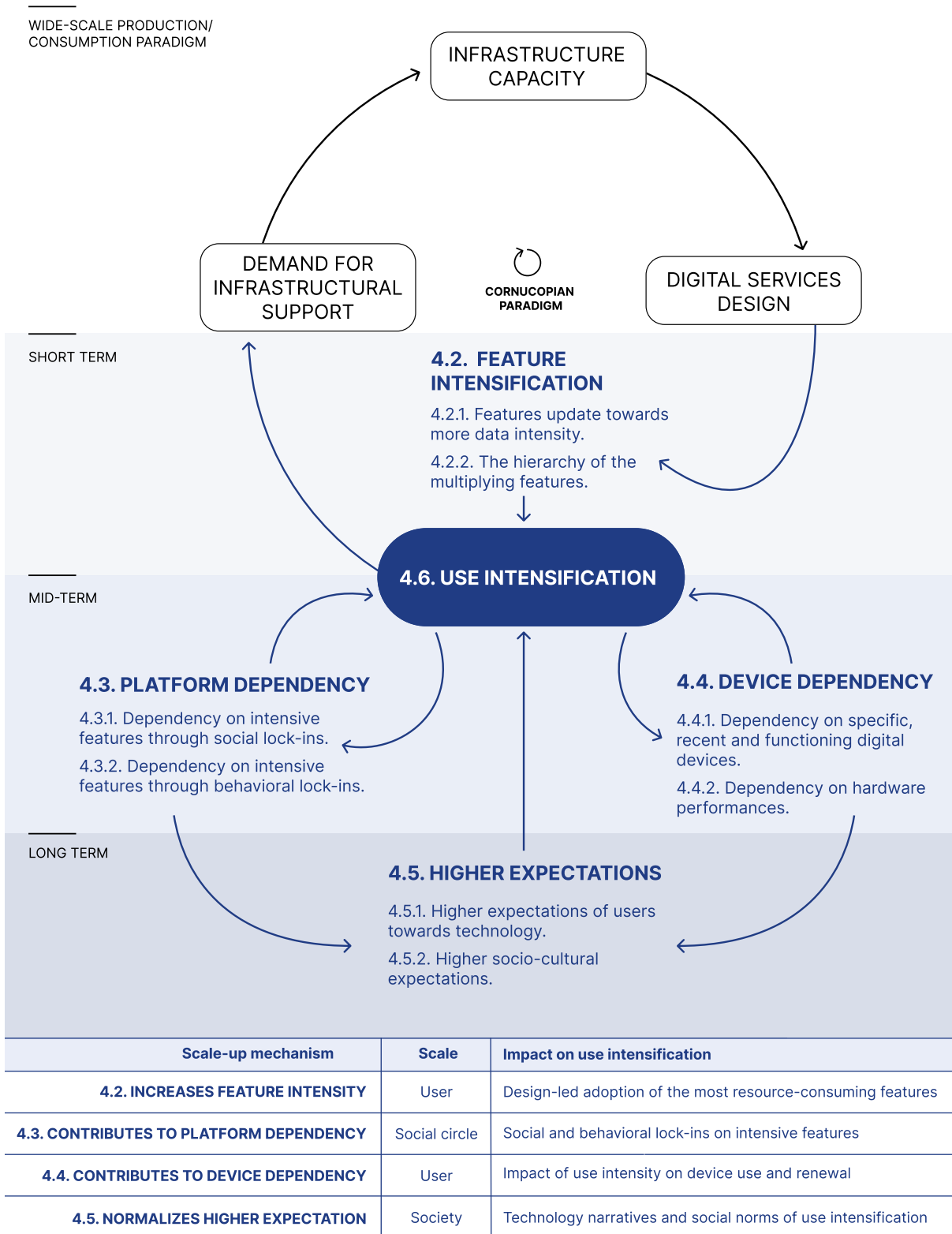


Figure 4: The four scale-up mechanisms interact at different scales and time-frames with use intensification, and reinforce the cornucopian paradigm.

is usually considered a technical element, the design of these features also impacts data and compute intensity, and at scale, the expansion of the digital infrastructure. The technical evolution of features combined with their design thus influences the degree to which users contribute to the cornucopian paradigm through *use intensification*.

We identified two distinct forms of feature intensification on messaging apps: newer features tend to become more intensive (4.2.1), and the most intensive features are favored on the user interface (4.2.2).

4.2.1 Features are becoming increasingly data-intensive. An example is maximum file size that can be sent by users increased over time for all applications on which we could find data (Table 4). In 2022, the maximum file size on Messenger went from 25 MB to 100MB ($\times 4$), while Whatsapp increased by a factor of 20 the maximum size for file upload in 2022. The impact of this technical evolution on the amount of data transferred nevertheless depends on users practices: if users are allowed to share larger files, will they do so?

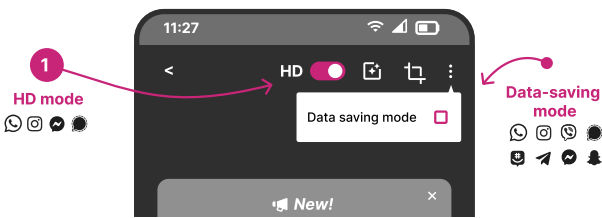


Figure 5: Cornucopian Design Pattern 1: Summary mock-up of features related to file size management on messaging apps.

Our interviews suggest that beyond technical intensification, the design of these features is an important factor driving the adoption of more intensive practices. As users do not face constraints or incentives for compressing media files, they end up sending most media with the app's default settings, regardless of how much they value the content shared, be it a beloved family picture or a spontaneous photo to 'illustrate' (P5) the text of a message. None of the interviewees in our panel reduce the default size of the files and media they send, unless the interface prompts them to (Figure 5). For example, P8 generally uploads files on Teams without paying attention to their size. However, she explained that, occasionally, she is prompted by a pop-up to reduce the size of the documents she uploads, and thus takes this opportunity to compress her files. In this case, the pop-up is users' main tool to control file quality, beyond the initial compression that is sometimes performed by default, but on which users have no input. Instead, several apps offer the option to bypass this compression thanks to an HD toggle 1.

In this context, feature intensification lies in the increased data transfer capabilities, but also in the way interface design is making users adopt more intensive features mostly without friction, without even noticing, and without this increased data transfer being only applied to specific and meaningful user actions.

Moderation heuristic: Limit feature intensification. In a context of systematic upgrades, designers should prevent data intensification and digital infrastructure growth by limiting the intensity of new and existing features, especially when users are already accustomed to limitations and live well with them. New or redesigned features can maintain existing data consumption thresholds and/or restrict increased data consumption to specified and bounded use cases.

4.2.2 Feature hierarchy on the interface tend to favor more intensive uses. Departing from text-based messaging, all messaging apps have gradually introduced new and ever more data-intensive communication features involving images, sound and video (Figure 7). Newer communication modalities tend to be more data-intensive (Figure 6), e.g. sharing a story requires more infrastructural capacity than a text message.

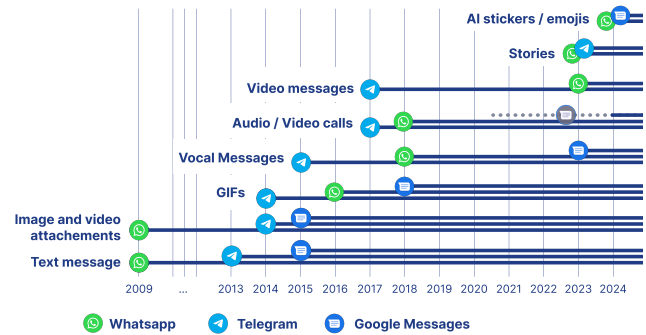


Figure 6: Chronological accumulation of message modalities for WhatsApp, Telegram and Google Messages

Moreover, the new and intensive communication modalities are presented to users in a way that encourages their adoption. The evolution of the send button to integrate new modalities is a very good example of how the presentation of a feature can shape conversation modalities. In the first versions of messaging apps, transferring an audio file would have required recording it independently on another software or app, and then adding the audio as a file in the conversation². The recipient would have had to download the file and maybe open it in a separate app to listen. The audio recording button, positioned next to the text input bar, made audio recording more accessible. This design choice led our participants to use audio to express themselves on messaging apps when they are in a rush, 'tired of writing' (P10) or 'to share a specific emotion' (P3).

This audio recording feature has recently been replaced or supplemented on some apps by the video messages feature 2. In 2024, three platforms offer the video equivalent of the voice messages feature: 'video bubbles' 1, 'clips' 2 and 'video messages' 3 (Figure 7). While video interactions already existed on these apps through synchronous calls or by sending videos as files, the position of the video messages button provides another opportunity for video

²For example see the 2010 version of WhatsApp: <https://web.archive.org/web/20250514235516/https://www.webdesignmuseum.org/gallery/whatsapp-in-2010>

Messaging app	Upgrade of file size limit	Multiplying coefficient	Year of upgrade
Telegram	1,5 to 2GB	1.3	2020
Microsoft Teams	100 to 250GB	2.5	2021
WhatsApp	100mb to 2GB	20	2022
Messenger	25 to 100MB	4	2023
Discord	8mb to 25mb to 10MB	1.25	2023

Table 4: Evolution of file size limit on five messaging apps, based on the documentation available on tech blogs and companies' communications. The year of upgrade corresponds to the date found on companies' communication websites.

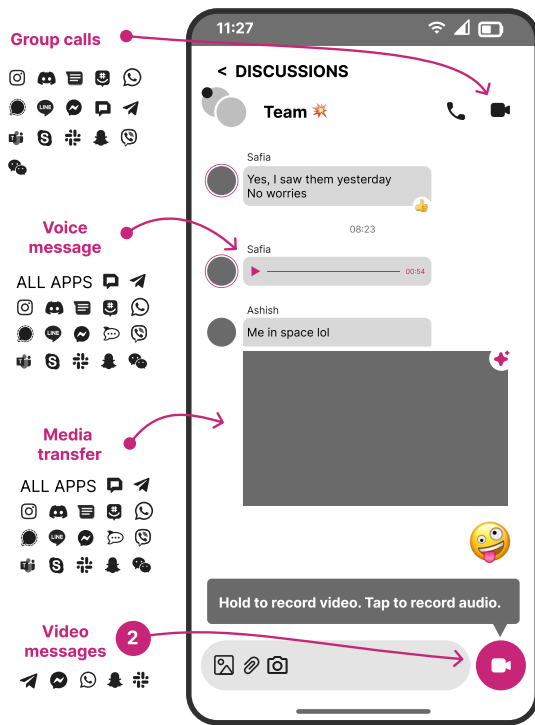


Figure 7: Cornucopian Design Pattern 2: Summary mock-up of features that encourage new chat modalities.

transfer and consumption. It is positioned in between other discussion modalities in a way that frames video sharing not as a file to be stored, but as a message in an ongoing conversation. P2, an early adopter of this feature on her family group chat explains that video messages are intended for *“more instantaneous uses”*.

We observed a similar role of interface hierarchy in the proliferation of gen-AI features which began in 2024, for example as a way to support text production (3), but also as a way to summarize unread conversations (4) (Figure 8). We have shown in a previous study that AI-based features are often visually highlighted in platforms beyond messaging apps, we found that they are also put forward in messaging apps with similar strategies [5]. By showcasing a feature that requests a high degree of computational power and requires

new types of data centers [43], designers encourage users to engage with features that are extremely intensive in infrastructural resources.

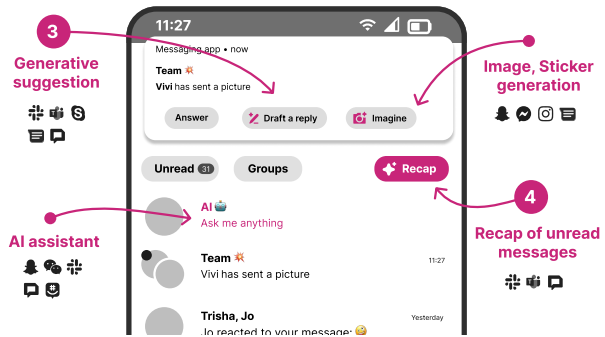


Figure 8: Cornucopian Design Pattern 3: Summary mockup of features that favour AI use

In these two examples, *feature intensification* lies in the way features work together as a system that structures users' actions [37]. Hierarchies, colors and animations hint at expected user behaviors. The intensity of a feature can be understood relatively to the other ways in which users can perform a similar action. A given feature can also become more intensive just by changing its presentation on the interface, and without changing its technical metrics.

Moderation heuristic: Promote less intensive features on the interface. In the current paradigm, newer features tend to be more intensive. Because new features are often highlighted, older and often less intensive features can appear as second choices to users. Designers should always promote the least data-intensive feature for a given use case (e.g. sending a message) on the interface and make it the default option. More intensive features should be limited to specific contexts and use cases.

4.3 Scale-up mechanism 2: Contributing to Platform Dependency.

Use intensification can be sustained in indirect ways. One key mechanism here is how the design of messaging apps *contributes to platform dependency*, i.e., digital platforms and their most intensive features being perceived and experienced as unavoidable or inescapable. Dependence on intensive features gradually increases

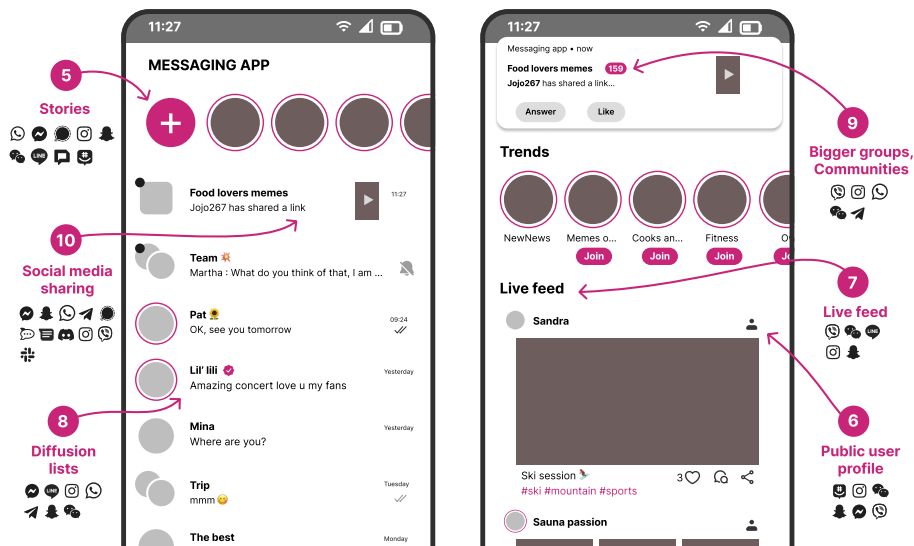


Figure 9: Cornucopian Design Pattern 4: Summary mockup of features that demand social media engagement

as users become more involved with the platform over time, as they build relationships, skills [22] and habits [70]. Dependency is a temporal mechanism, where the use of intensive features is encouraged and then sustained because of social lock-ins (4.3.1) and behavioral lock-ins (4.3.2). These long-lasting, intensive digital uses, in turn, contribute to infrastructural expansion because higher data intensity needs to be sustained permanently.

4.3.1 Dependency on intensive features through social lock-ins. When digital platforms are used in social contexts, using certain apps or features over others cannot be considered as an individual choice. Griggio et. al [32] suggest that the network effects driving messaging apps' adoption and market segmentation depends not only on the number of users, but also on the nature and intensity of social ties. We call these effects social lock-ins. The design of messaging apps shapes online socialization. Social lock-ins lead to use intensification by producing and accentuating user engagement and network effects. For example, we identified features in our corpus that bring emblematic social media features to messaging apps, e.g. stories 5, or public user profiles 6 (Figure 9). We also found equivalents to live feeds 7 under different names, e.g. 'discover' or 'trends', which means that users have access to much more content. Group chats are becoming more diverse, and sometimes resemble mailing lists or forums 8, billed as 'spaces' or 'communities' 9. These features encourage interaction with large numbers of people, especially strangers. All participants were on group chats with classmates, colleagues or relatives, and some also participated in bigger groups on the scale of their village (P5), their city (P4) or internationally around a common activity, like streaming sports on Telegram (P9). Checking up on what is happening on the different conversations has become a driver for coming back to a given app or discussion, described as a form of social 'FOMO' by P1. This expression especially resonates with the

common practice among participants (P7, P1, P3, P6 and P11) of sharing social media content 10 on their friends' group chats.

Participants and their contacts influence each other in adopting new messaging apps and keeping unwanted ones due to affective links and social and professional obligations. Due to contacts being split between apps [32] and the lack of interoperability between messaging apps, users end up having to manage an ever-increasing number of conversations. For example, P1, P3, P4, P5, P6 and P7 stay in certain groups not to take part in the conversation, or even to read the messages, but simply to be reachable 'just in case' or to be able to reach the contacts in this social circle.

These social lock-ins are not inherently data-intensive, but they make it harder for users to adopt more moderate uses, even if they wanted to. Increased dependency legitimizes the expansion of the digital infrastructure (e.g. network coverage) [74], and device ownership, as social obligations multiply and require features that rely on ever-more intensive technologies.

Moderation heuristic: Orient social influence towards less intensive uses. Digital systems are intertwined with social practices. The design of features and their affordances steer user behavior as much as people influence each other in using more intensive features more intensively.

To combat use intensification in digital services, designers should give users means to agree on shared use intensity limitations. Interoperability across services could also allow users to maintain groups and social relations independently of the platforms and thus decouple basic social features (group chat and contact management) from other engagement-heavy features that foster use intensification.

4.3.2 Dependency on intensive features through behavioral lock-ins. The repeated use of messaging apps leads to the development of specific habits and feature-related skills, i.e. *behavioral lock-ins* [3]. The consequences of design's influence over users' cognition and

behavior are usually discussed in the context of dark or deceptive patterns [31], but behavioral lock-ins are rarely considered in the environmental evaluation of digital systems. Beyond the time spent on apps as a result of attention-grabbing mechanisms, behavioral lock-ins can foster intensive uses on platforms.

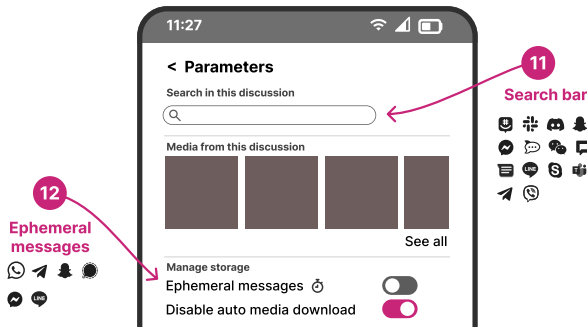


Figure 10: Cornucopian Design Pattern 5: Summary mock-up of messaging apps' features that discourage content deletion

In the case of messaging apps, we found that participants tend to rely on past conversations as repositories, navigating them thanks to their contextual memories. Messaging apps interfaces become gateways for accessing information, filtering and sorting it through search bars, filters, pinned messages and gallery views 11 (Figure 10). Thanks to these features, participants avoid the tedious work of cleaning up and organizing their message repositories. This results in participants using messaging apps to store and manage personal data sent through these channels: *'This [inactive] group, I am going to keep it, because there are photos there.'* (P9). The availability of these features contribute to participants deliberately keeping their messaging data in apps. For example, P2 stores and retrieves administrative documents sent by her mom directly on their family group chat 1.

The messaging apps we studied make it easier for users to accumulate messages, media, files or accounts than to delete them. For example, except in Snapchat, ephemeral messages 12 are disabled by default when the option exists. We observed that most participants did not care about the long-term storage of their data. P1, P2 and P3 never think about deleting data: *'They never tell me that my messaging inbox is full, so I never need to care'* (P2). However, P11 for example is bothered by the accumulation of images downloaded automatically from her chats, and she deletes images when she comes across them *'while scrolling'*. The reduction of the cognitive load associated with saving and retrieving leads to the accumulation of data stored on platforms servers or locally on users' phones, as sorting or deleting data is not a requirement for retrieving valuable content in the future.

Moderation heuristic: Align behavioral costs with feature and use intensity. The effects of a given feature's intensity can be multiplied by frictionless interfaces that encourage its use, especially because behavioral lock-ins favor more comfortable options. In order to mitigate use intensification due to intensive defaults, habits, or behavioral lock-ins, designers should ensure that features

encouraging moderation are straightforward to use and can be incorporated as habits, while the features that drive use intensification should require more effort.

4.4 Scale-up Mechanism 3: Contributing to Device Dependency

Device dependency focuses on the indirect influence of design choices on the lifespan and ownership of devices. This mechanism describes the dependency on material artifacts such as recently released digital devices, equipment or sensors (4.3.1) and on hardware performance (4.3.2). Design choices contributing to device dependency are a cause of premature device replacement (Table 1), which accounts for a significant share of ICTs global emissions [28], among other environmental effects.

4.4.1 Dependency on specific, recent and functioning digital devices. This mechanism corresponds to messaging apps encouraging the need for recent devices (smartphones in our case) with specific sensors and connectivity capacities. The multiplication of media modalities (Figure 7) puts more pressure on required phone functionalities, e.g., a sufficient camera performance to use messaging app features properly. P12 for example, mentioned that he and his colleagues use a back-up smartphone to make sure they can connect to audio on professional video calls because they *'regularly'* experienced issues in connecting with his computer microphone. P9 no longer wants to own a smartphone and initially had his family switch to Telegram so that he could talk to them from his computer. A few years later, however, he was no longer able to use the platform because an update required him to log in by scanning a QR code using a smartphone. The addition of a single feature minimized device compatibility. The fact that users are socially dependent on messaging apps means that those with incompatible devices will have to find complex workarounds if they do not want to replace these devices.

Moderation heuristic: Identify and maintain device-preserving features. Maximizing compatibility with older devices is a well-established good practice in sustainable IT development. Designers also should make sure not to disadvantage users of older devices by identifying and preserving features upon which users rely to extend their devices' lifespan.

4.4.2 Dependency on hardware performances. This mechanism describes how messaging apps contribute to increased expectations on minimum hardware requirements and performances. Use intensification can further exacerbate the discomfort experienced when using an inadequate device, e.g., a device that appears to be too slow for the software will be less tolerable with repeated use, which will motivate the replacement of the device.

With messaging apps, the automatic download of media from conversations often leads to local storage saturation, especially as messaging platforms gradually increase the maximum size shareable (Table 4). P4 replaced her phone because the growing size of files and apps stored on her smartphone saturated her local storage, which prevented her from downloading new apps. P8's phone storage was saturated with media received on WhatsApp, so she transferred everything to her Teams cloud storage (which later also became full) to be able to continue downloading files.

The tendency of software makers to constantly increase the number of features on offer, historically referred to as software bloat [47] also leads to applications that require more storage space to be installed and increasingly powerful devices to run smoothly. All participants had to accommodate at least two messaging apps on their phones and because of *platform dependency*, they could not delete them easily to free up storage space. This is an example of what Mosezzo et al. describe as “software obsolescence paths” [51], where “obsolescence [is] considered an incremental process” and storage saturation is one of its main causes. Messaging apps alone do not trigger device replacement, but they certainly contribute, along with other apps, to the saturation of local storage that encourages it. In addition to storage saturation, exchanging messages affects the battery life of smartphones, i.e., when the next charge is needed, proportionately to the number of messages sent and received [60].

Moderation heuristic: Preserve device performance. New or updated features should not require increased performance. Designers should ensure that user experience is maintained over time, e.g., by minimizing battery drain, ensuring storage is not saturated, or by containing the requirements on CPU/GPU. Designers should pay attention to and anticipate accumulative effects.

4.5 Scale-up Mechanism 4: Normalizing Higher Expectations

This last mechanism describes how digital practices built around more intensive features and uses become social norms that further drive their adoption in new contexts or by new demographics. Conversely, the normalization of higher expectations leads to a marginalization of sufficient digital uses [65]. It becomes increasingly costly for users to resist adopting more intensive practices. This mechanism is crucial because it sustains and reinforces the other ones through social and cultural changes.

This mechanism challenges what is perceived as users’ demand or expectations of a digital service. Here, we understand normativity as “a set of references for conduct” [25], and we point at how the design of features and dependency mechanisms result not only in practices, but also in shaping shared expectations of technology use.

4.5.1 Higher expectations of users towards technology. This mechanism describes how users develop expectations towards technology and digital services, associating them with unlimited use. For instance, participants’ lack of concern for their accumulating digital data on platforms’ servers (4.2) hints at the largely accepted idea that digital technologies are limitless in terms of data transfer and storage. Design largely contributes to this perception of messaging apps as limitless, as data deletion is not part of the natural user flow on messaging apps.

Participants also developed an understanding of which technological platforms, uses and devices should be used. P4 and P6, for example, downloaded Instagram and Whatsapp not because they wanted to connect with specific contacts, but rather because they thought that it is socially expected to have an account on these applications. This also leads them to devalue their older messaging apps, e.g. Messenger which they perceive as no longer ‘modern’ enough (P8).

In professional contexts, the pervasive and instantaneous nature of messaging apps has changed perceptions of what a “normal” communication channel is. E-mails are becoming a channel for administrative information, while other platforms like Teams (P8) or WhatsApp (P11, P12) can be used for more trivial or urgent matters. For example in the call-center company where P11 works, a WhatsApp group is used ‘to facilitate communication between [employees] and [their] managers’, and e-mails ‘when it becomes official’.

Large-scale and long term-use of digital systems changes what is considered as normal or constraining technology use. The evolution of design features devalues certain uses and makes them more difficult to sustain, not for practical reasons, but for cultural ones. The rapidity, modernity or usefulness of digital features is, of course, context-dependent. However, the emphasis on the modernity, fluidity or instantaneousness of a feature is not usually directed towards moderate use.

Moderation heuristic: Challenge growth-oriented metaphors and meanings embedded in interface design. Design plays a role in shaping meanings and cultures around technology use. It contributes to a common understanding of what a *lot* of data is, what a *good* internet connection is or what an *old* app or smartphone is. Designers should present less intensive features in a way that challenges growth-oriented metaphors. Less intensive features can also be *fast*, *convenient* or *instantaneous*, as these terms rely on users’ perception and experience.

4.5.2 Higher socio-cultural expectations. This mechanism describes how users develop higher expectations towards other people, for example in terms of availability on a platform or message response speed [74] thus reinforcing use intensification.

In interviews discussing personal chats, participants described how messaging apps were driving expectations related to participation in conversations. A recurring example is the practice of sharing photos and videos as a way of keeping in touch and strengthening friendly and family bonds, as P8 described, alternating between ‘posting photos’ on her family group chat when she hosts her grand children and ‘hearting photos’ when they are away. P9 was the only participant who was not part of a family group chat. He chose to give up using a smartphone for ethical reasons and doesn’t mind missing on family news and discussions because ‘there isn’t really a lot of indispensable information’ (P9), and also because his mother relays important family updates in phone calls. However, opting out in this way might not be possible, desirable or comfortable for everyone.

We observed that professional environments were particularly susceptible to the rapid and large-scale normalization of more intensive digital uses. For example, the COVID-19 pandemic reconfigured what we collectively expect from professional communication software and from workers [2]. In P8’s hospital ward, meetings are now systematically held on Microsoft Teams regardless of whether employees are physically on site. Tools that were implemented out of necessity during the peak pandemic are now being sustained through managerial actions. P12, manager, said that it was his role to make sure his team is reactive on Teams.

These examples highlight the importance of social relations in the adoption of intensified uses. People act as information relays,

as early adopters, as enforcers of new practices and contribute to pressuring others to adopt more intensive uses.

Moderation heuristic: Design for the full scope of user engagement. Taking into account the social drivers that orient users towards more intensive features and more frequent use, designers should design features and systems that accommodate users who are less invested in the system, and even non-users. Designers should enable the coexistence of different levels of user engagement and digital availability.

4.6 Use Intensification

The four *scale-up mechanisms* presented above all reinforce the cornucopian paradigm. They describe how design choices lead to increases in demand, and consequently to infrastructure growth. We propose to call this phenomenon *use intensification*. We illustrated how, in the context of messaging practices, use intensification is influenced by the design of features of messaging apps.

In previous research, the evolution of practices and demand has most often been framed in terms of “data demand”, i.e., “the levels of traffic required to deliver digital services” [50]. However, our analysis shows that the evolutions of digital practices encompass not only this increase in data demand or computation demand, but also infrastructure expansion and individual device replacement (see messaging apps’ infrastructural and material effects presented in Table 1). As we have seen with the scale-up mechanisms, the factors behind use intensification are manifold (social, economic, political, behavioral, etc), and act on various time scales, but our analysis highlights the key role of interface design as a driver of this phenomenon.

5 Discussion and Future Work

5.1 Extending the Cornucopian Paradigm

This study extends the cornucopian paradigm [58] by more precisely describing the role played by design in this reinforcing loop. Our results show how the high-level design principles proposed by Preist et al. [58] are instantiated in specific UI designs. The scale-up mechanisms we propose explain the complementary ways in which interface design stimulates demand and ends up driving infrastructure growth, i.e. use intensification. In this sense, scale-up mechanisms are to be considered as *induction mechanisms* triggered by digital design, where UI and UX design frame unsustainable “consumption options” of digital contents and devices [40].

In its original description, the cornucopian paradigm features an unidirectional link showing how services influence user demand. Our results also hint at an opposite direction. Indeed, demand might also drive the design of increasingly intensive features through perceived user feedback. For example, we empirically observed, through the chronological accumulation of similar message modalities across apps (Figure 6), how applications tend to all add features that have proven successful on competing services.

Normalization mechanisms also influence the demand for specific technologies, which means that what is described as “demand” in the cornucopian paradigm is often less a genuine interest in more intensive features but rather a socially induced pressure to adopt certain uses that require intensive features or devices. In economic

terms, this is referred to as induced demand [17], which begs for a better integration of this literature in SHCI.

While this study highlights the key role of design, services stimulate demand not only through design choices but also through marketing, advertisement, and financial incentives. To extend the cornucopian paradigm, these other aspects and their combination require further examination. HCI scholars could also reflect on how their work contributes to shaping demand through work on appropriation, adoption, and the general focus of the discipline on need finding, which is often aligned to commercial developments and the development of markets for new products and services.

Study Limitations. Our focus on messaging apps limited the number and types of cornucopian design patterns and scale-up mechanisms we could identify. Even in the context of messaging apps, new patterns can emerge, like the *favoring AI* design pattern which appeared during this study. Conducting a similar study on another digital domain might also help identify more cornucopian design patterns and scale-up mechanisms. To focus on mechanisms that foster indirect effects, we chose to study messaging apps because their direct effects alone are limited in comparison to the services usually studied in SHCI.

Scale-up mechanisms identified in this study are therefore likely to be at play in more intensive domains as well. However, more research is needed to understand to what extent the cornucopian design patterns and scale-up mechanisms we identified could be readily applied to other digital domains.

In this study, we only focused on identifying mechanisms and patterns that contribute to the cornucopian paradigm but future work should also investigate the mechanisms and patterns that lead to positive indirect effects. Indeed, we encountered a few features that were oriented towards mitigating use intensification. For example, GroupMe has an “SMS only” feature which lets users create a group with people who do not have the app on their phone. This feature is a good example of how design choices can challenge *platform dependency* and reduce *feature intensification*.

5.2 Systemic Drivers of Design Choices in the Cornucopian Paradigm

Reflecting on the mechanisms we evidenced, we identified several systemic drivers, i.e., cultural and socio-economic factors that favor digital design choices that end up contributing to infrastructural expansion, rather than fostering a sufficient digital infrastructure.

- (1) The fierce competition between platforms in the messaging app sector motivates companies to outbid each other so as not to be ‘outdone’ by their competitors, and therefore to either design new distinctive features or to copy emerging ones.
- (2) The two main economic models of messaging apps also sustain the cornucopian paradigm. Digital platforms with a “free” model need to maximize the production of user data and exposure to advertising [53], and digital platforms with “freemium” models are incentivized to develop ever more “powerful” or “intensive” features as a way to recruit paying users.

- (3) As the success of digital platforms is largely measured through user engagement [24], platforms develop design strategies for increasing users' engagement and loyalty to the platform, such as "*Supporting Social Connectedness*" or "*Promoting Repeated Use*" [24]. This focus on engagement largely drives "*use intensification*". While this systemic driver emerged and was largely documented in the social media sector, our study shows that it is also now at play within the messaging app sector.

We need further investigation to understand how cultural and socio-economic factors are driving design decisions in practice, and how to mitigate them. We also need to understand to what extent it is possible for apps to refuse adopting cornucopian design patterns without losing users or market shares. Further work could investigate the conflicts that designers face in various types of organisations, and whether they already identify and try to mitigate use intensification and scale-up mechanisms. A recent study on the South-Korean digital industry indicates that designers and developers are not conscious of rebound and indirect effects when trying to advocate for sustainable interventions [41]. This study also highlights other social, psychological or knowledge-related barriers to implementing SHCI principles in practitioners work. This demonstrates the importance of professional culture and business models in successfully applying sustainability guidelines in 'real-world' settings. It also highlights the need for more qualitative studies to document geographical, political, regulatory, and other contextual disparities regarding the integration of sustainability in tech environments.

5.3 Opportunities and Challenges for Qualitative Environmental Evaluation

Our study is a qualitative analysis of factors driving ICT environmental impacts in a domain where quantitative approaches are generally favored. It proposes approaching environmental evaluation in sensible and designerly ways, as a response to the impossibility to quantify and anticipate all types of environmental effects, especially indirect ones. As our study shows, some design choices have impacts that cannot be measured through quantitative approaches (e.g. normalization, dependency) but that indirectly influence energy and resource consumption by shaping end-users' practices at scale. In that sense, our study is in line with recent HCI work that has attempted to qualitatively connect design choices and indirect effects [15], and contributes to recommendations to further use qualitative approaches in complement to quantitative approaches in environmental evaluation methods [29, 61].

For now, environmental evaluation methods that include indirect effects have mostly used high-level qualitative data (e.g. press articles [16], already documented large-scale economic, political and social mechanisms [61]), relied on prospective scenario-making [4, 8, 9], or on experts' interviews [9]. With this study, we show how a small-scale empirical analysis can link design choices to increased demand and its infrastructural effects. We think that empirical data on *use intensification* could also integrate well with systemic modeling methods, in which a data collection phase precedes and feeds the systemic modeling of the digital service's indirect effects [16].

Qualitative evidence of use intensification could be complemented with quantitative methodologies, for example to establish which cornucopian pattern leads to the most use intensification. Conversely, quantitative measures could leverage qualitative evaluations to refine interpretation. However, for this to happen, researchers need a much broader access to quantitative data from digital platforms. Such data is currently unavailable, making it impossible to fully assess *feature intensification* mechanisms. For this reason, we are for instance unable to understand how media compression is impacting the global amount of data transferred in messaging apps (see Table 4). The extreme opacity of most digital platforms and their perpetual evolution make them hard to study and thus limit our capacity to cross our qualitative data with quantitative metrics.

The development of methods that better estimate indirect effects of digital services is also crucial as EU digital regulations have begun encouraging environmental reporting in the digital sector, e.g. with the Corporate Sustainability Reporting Directive³, or with the AI Act⁴.

Using qualitative data in environmental evaluation does not completely solve the issues that designers face in measuring indirect effects. We suggest that qualitative data could bring light on matters that would otherwise be overlooked, but the misinterpretation of the effects of digital practices at scale could lead to unsustainable design choices or rebound effects. For example, if designers minimize users' time spent on their app, they do not control the supplementary activities they engage in thanks to the time they saved (e.g. driving to visit relatives instead of having a video call). Similarly, our moderation heuristic 4.3.1, which advocates for interoperability, is intended to minimize indirect effects caused by social lock-ins, but could also increase direct effects because of data-redundancy across services.

5.4 Implications for Design Practice

Previous SHCI studies have called for a diversification of evaluation methods [61]. For example, Silbeman and Tomlinson have made the case for developing HCI environmental evaluation tools in three categories: indices, heuristics and principles (e.g. patterns or anti-patterns) [69]. These tools are particularly useful to evaluate design at early development stages. We suggest that they could be used to disseminate SHCI research about indirect effects in professional contexts where project timelines and short-term deliverables make it hard to follow the impact of digital features in the long run [62].

Developing qualitative assessments to tackle the indirect effects of design decisions. Eco-design practices in the European industry are currently centered on the direct reduction of CO2 metrics, based on estimates [27]. Framing the decision-making process around *use intensification* instead of relying solely on technical and quantitative metrics might help designers take indirect effects into account. As such, *use intensification*, *cornucopian design patterns* and *scale-up mechanisms* contribute to the creation of a shared vocabulary that

³https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

⁴<https://eur-lex.europa.eu/eli/reg/2024/1689/oj/eng>

articulates and explains [61] how design choices lead to infrastructural effects through the evolution of digital practices at different scales.

More specifically, cornucopian design patterns could work in complement to existing quantitative indices. Dark or deceptive design patterns offer a concise mean of presenting negative effects of design choices [31]. They have received widespread attention, and are now integrated in the vocabulary of design practitioners⁵ because they help them describe issues, and reflect upon them. Cornucopian design patterns could be similarly leveraged to discuss design choices, and support designers in challenging the status quo in their organization by articulating why some design choices can have detrimental environmental effects. Beyond their use in the design process or for advocacy within organizations, cornucopian design patterns could, as deceptive patterns have done, play a role in influencing digital regulations that better protect users [20]. Our hope is that such patterns could help support the implementation of needed regulation of software and hardware obsolescence.

The benefits and limitations of heuristics as ready-made design resources. The heuristics we propose to mitigate scale-up mechanisms aim to support designers in looking at feature design with different levels of design-led indirect effects in mind. Heuristics are useful tools for disseminating research results in professional environments [69], as they become intuitive over time, but can also be used as a common ground to facilitate discussion on “what is good or bad about the interface” [55].

Our heuristics could be used by designers in complement to existing ecodesign heuristics such as the Web Sustainability Guidelines⁶. Our moderation heuristics are co-dependent with knowledge of the practices surrounding the digital product, which we hope would prompt design teams to be attentive to use intensification when being in contact with users or when looking at users’ data. This can represent a significant shift for design user researchers, as using moderation heuristics requires studying digital practices with an attention to use intensification, rather than to usability or user satisfaction.

Nonetheless, heuristics, like any evaluation tool, have weaknesses. They are often criticized because they lead to focus on very specific aspects of problems that are usually much larger and complex, and the risk is to overlook issues that are beyond their scope [46]. The *moderation heuristics* we proposed should therefore be considered alongside others (usability, accessibility, etc.) and would be best combined with other types of environmental evaluation methods, e.g. quantitative impact assessment. The moderation heuristics could also integrate existing systemic design artifacts and methods that help to model and envision design effects across dimensions, time-frames, or levels of stakeholder engagement [9, 54].

Exploring the generative potential of scale-up mechanisms through heuristics. Moderation heuristics also have the potential to support the ideation of features that mitigate use intensification. For example, we observed in our study that social lock-ins prevented users from deleting inactive or irrelevant conversations because they would lose distant contacts in the process. A feature enabling to

convert a group discussion into a group of contacts might facilitate the decision to clear up data rather than to mute groups.

While these study results are articulated in forms that are already familiar to designers, our next step is to explore whether and how design practitioners manage to integrate them in their existing workflows, and to what extent they actually support designers in identifying indirect effects and design against *Use Intensification*.

6 Conclusion

Building on the Cornucopian Paradigm framework, this article has developed a mixed-method analysis to understand how specific design choices, in the context of messaging apps, lead to increased demand, and indirectly to material and infrastructural effects. These effects carry an environmental cost. We first identified features that stimulate user demand and conceptualized them as cornucopian design patterns. We then identified the mechanisms through which these patterns lead to the expansion of the digital infrastructure. More specifically, we found that interface design is fostering a phenomenon we call *use intensification* and which describes how digital practices become more intensive, not only in terms of data demand, but also through infrastructural expansion and device replacement. Our analysis shows that *use intensification* happens through four complementary *scale-up mechanisms*: fostering feature intensification (1), contributing to platform (2) and device (3) dependency, normalizing higher expectations (4).

To complement these findings and support their appropriation by designers, we have presented a set of heuristics based on the different *scale-up mechanisms* to better tackle indirect effects during the design phase.

Cornucopian design patterns and *scale-up mechanisms* call for “*re-designing*” or “*undesigning*” [68] conventional design features by highlighting their role in fostering detrimental indirect effects that contribute to the cornucopian paradigm. Beyond this case study, we call for more research to investigate whether this theoretical framework can provide a practitioner-friendly tool to document and analyze how interface design choices drive the cornucopian paradigm.

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⁵<https://webdesignerdepot.com/deceptive-design-patterns/>

⁶<https://w3c.github.io/sustainableweb-wsg/>

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