Cognitively Sustainable ICT with Ubiquitous Mobile Services - Challenges and Opportunities

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Abstract—Information and Communication Technology (ICT) has led to an unprecedented development in almost all areas of human life. It forms the basis for what is called “the cognitive revolution” – a fundamental change in the way we communicate, feel, think and learn based on an extension of individual information processing capacities by communication with other people through technology. This so-called “extended cognition” shapes human relations in a radically new way. It is accompanied by a decrease of shared attention and affective presence within closely related groups. This weakens the deepest and most important bonds, that used to shape human identity. Sustainability, both environmental and social (economic, technological, political and cultural) is one of the most important issues of our time. In connection with “extended cognition” we have identified a new, basic type of social sustainability that everyone takes for granted, and which we claim is in danger due to our changed ways of communication. We base our conclusion on a detailed analysis of the current state of the practice and observed trends. The contribution of our article consists of identifying cognitive sustainability and explaining its central role for all other aspects of sustainability, showing how it relates to the cognitive revolution, its opportunities and challenges. Complex social structures with different degrees of proximity have always functioned as mechanisms behind belongingness and identity. To create a long-term cognitive sustainability, we need to rethink and design new communication technologies that support differentiated and complex social relationships.

Index Terms—Cognitive sustainability, Social sustainability, Sustainable ICT, Cognitive revolution, Privacy, Shared attention, Social cognition, Software engineering for social good.

I. INTRODUCTION

The radical increase and pervasiveness of Information and Communications Technology (ICT) puts our society at the edge of a revolution that has started to change our lives [1].

After the industrial revolution, which essentially extended the human body through mechanical machinery, the beginning of the cognitive revolution extends human minds through computing (information processing) technology.

The cognitive revolution is based on extended cognition/social cognition, which is largely supported by mobile devices and services that are getting ubiquitous [2], [3]. Distributed cognition enabled by ICT is new to humankind and causes substantial changes in the cognitive processes (information acquisition and its processing and storage), which drives long-term and wide scope individual and social changes. Changes brought about by this technological development are acknowledged to have potentially enormous positive effects. We would therefore like to elucidate some challenges that haven’t yet been identified and discussed.

In this paper we focus on how ICT affects different levels of relationships among people. Traditionally, the complex and layered structure of our society was based on different levels of proximity. There is typically a fixed, characteristic number of individuals at each proximity level [4], which increases as a function of the emotional distance [5]. The relationships between our closest relations and more distant ones are rapidly changing with increasing ICT usage.

Up until recently physical distance caused barriers to communication and thus defined closeness. The people who shared the same physical space were the ones with a tight cognitive and emotional bond. Of all relationships, the closest ones are typically heavily dominated by intensity, depth, cognitive and emotional richness and frequency/amount of shared time [6].

With the introduction of ICT this is no longer the case which causes important changes in social relations worldwide – from families to teams, groups, corporations and societies.

In the sphere of closest relationships children are the most vulnerable group and their use of mobile devices is one of society’s greatest concerns. Empirical research has shown that among children and adolescents there are numerous problems related to the overuse of ICT. For example aggressive behavior [7], [8], decreased physical fitness [9], sleep disorders [10], [11], mental problems [10], [11], addiction [12] and lower school grades [10], [11]. In families with extensive gadget use, there are also issues among adults of lack of shared attention and affective presence [13], which also affects children. At the same time, there is increasing societal pressure to diminish the distinction between work- and leisure time. This new phenomenon brings the expectation of being constantly accessible and available for work [14].

The attractiveness of ubiquitous ICT makes it difficult for many to find a balance between private and official [15]. All communication tends to become mediated and everybody competes to get our attention, no matter how emotionally distant or how irrelevant the matter is. As cognitive agents...
we have bounded cognitive capacities [4], which means that our capacity to communicate is limited. Time spent using increasingly ubiquitous ICT services is time taken from direct close relationships with other people and with the natural world. The complex network of networks of differentiated levels of proximity in human relationships is becoming more of a flat structure with ad hoc priorities. One side effect is that the stimuli that succeed in catching our attention win. Social structures are built on circles of proximity and the flattening of proximity structures is unsustainable in the long run as it overloads our cognitive systems, which may react by detachment and even desensitization [16]. Moreover, rich cognitive and emotive behaviors, as well as culture and values, are mainly transmitted in close relationships, which get impoverished if they are acquired through long-distance sporadic communication. Chief among these, a rich and nuanced personal relationship between parent and child can never be substituted by ad hoc information coming to the child from the outside world via ICT. Children need our shared attention [17] and affective presence in order to assimilate language, affective behavior, stable value system and the feeling of belonging together [18]. Technology that shapes our behavior can be designed so that it conveys and mediates social cues to make it look and feel different when we communicate with complete strangers or with our closest ones. Software can also be made more sophisticated so that we share more with those that we belong together with and less with people who do not belong to our closest proximity circles. If developers take the challenge of making communication differentiated and shared informational spaces more suggestive of the real world, it might help users get a better grip on reality and make prioritizing between different circles of proximity and and types of communication easier. The underlying idea is to better understand what kind of ICT we should develop and how we should use it for a socially and particularly cognitively sustainable future. We have investigated the effects of ubiquitous ICT usage described in several empirical studies as well as projections for future development. The following are the main contributions of this work.

- We have identified a growing problem of cognitive overload that results in a lack of shared attention and affective presence between closely related groups in society – as presented in Section IV.
- Given human finite cognitive resources, we propose adding cognitive sustainability to the list of already existing social sustainability. This addition acknowledges the insight that techno-social systems should be designed to enhance human cognitive resources and not to deplete, impoverish and exhaust them – see Section V.
- We present concrete examples of how to reduce the effects of dissolving proximity circles. We suggest to differentiating the sharing of information between different circles of proximity based on context-aware computing by representing emotional closeness through the devices’ "look and feel" – see Section VI.

The paper is organised as follows. We begin with definitions in Section II. Section III provides an overview of ubiquitous mobile ICT usage with expected future usage patterns. In Section IV we analyse different effects of ubiquitous mobile service use on social stakeholders. Sustainable development with respect to human cognitive resources and their relationship to ubiquitous ICT is discussed in Section V. In Section VI we analyse how software engineering can contribute cognitive sustainability as a basic aspect of social sustainability. The article finishes with conclusions in Section VII.

II. DEFINITIONS

Sustainable development is, according to the Brundtland Report of the World Commission on Environment and Development [19], defined as:

- development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Environmental sustainability relates to resource consumption (material resources, energy), emissions (greenhouse gas emissions, waste materials), recycling (expectations of environmentally closed life cycles where consumed and emitted materials would ideally be reused), etc.

Social sustainability has been defined to include all other aspects of sustainability – economic, political, technological, ecological and cultural [20]. Social sustainability is studied at the intersection between Software Engineering (SE) and other disciplines such as sociology, economics, ethics, cognitive science, social cognition, interaction design, etc.

Cognitive sustainability is a new aspect that we add to the list of social sustainability aspects. It puts the emphasis on our finite cognitive resources that should not be overexploited and devastated by cognitive overload induced by technology. Cognitive sustainability refers to both rational (“slow thinking”) and emotional (“fast thinking”), as defined by Kahneman [21].

Cognition is in this work defined as embodied cognition, which means it includes information processes such as memory, attention, language, problem solving, and planning that originate from the neo-cortex and are related to rational behavior. It also includes emotions, the spontaneous and irrational quick assessment system that originates from evolutionarily older parts of the brain such as the amygdala. The rational and emotional components of embodied cognition are integrated and intertwined. [22]. When we reason about cognition in this article we take this modern view of embodied cognition, including both thinking and feeling.

Extended cognition or social cognition is the term used to depict networks of cognitive agents exchanging information. Shared attention is defined as a socially distributed cognition occurring when several persons share a common cognitive focus and communicate in the process [17]. This is possible when communication is undisturbed and self-contained.

Affective presence builds on the idea that human cognition is defined by its embodiment, which determines communication in many different modalities, not only visual and auditory. Boehner [23] put forward “model of emotion as interaction:
dynamic, culturally mediated, and socially constructed and experienced ... in its full complexity and ambiguity.” This understanding of cognition as essentially embodied shall inform future ICT in its effort to reach social sustainability.

III. Ubiquitous Mobile ICT Usage

In order to understand the present state of practice, we start with a historical retrospective. The history of telecommunication shows an ever-increasing usage of ICT devices [24] and they are becoming more and more integrated as a part of ubiquitous computing. While initially web surfing was done on stationary computers connected to a wire-bound network with an Internet connection, Wi-Fi connected laptops, a semi-mobile network topology, were made possible with hotspots supporting the Internet. With the introduction of completely wireless data transfer (3G etc.) a much more radical mobility was achieved allowing people to move freely while remaining constantly connected. From all observed trends, it is generally conceived that total telecommunication usage will radically expand within the next decade. A forecast by Ericsson [2] shows that mobile data usage grows exponentially, see Fig. 1a, with mobile video providing the major growth, see Fig. 1b.

A. Apps

Apps are driving the telecommunication industry of today. The number of apps developed for gadgets is staggering, see Fig. 2. Already in 2009, the cumulative number of downloaded apps surpassed 1 billion ¹. The market for online apps is increasing at a rapid rate, which is evident for both of the major mobile platforms available today; Apple(iOS) and Google (Android). According to Bohmer [39], on average "mobile device users spend almost an hour a day using apps, which is quite high compared to other online activities". As argued by Zhang et al. [40], the introduction of smartphones significantly increased the demand for data communication, and smartphone apps have now increased beyond mobile surfing in terms of usage time.


B. Social Networking Services

Social Networking Services (SNS) online communication tools are often accessed using mobile devices. Examples of such tools are email, LinkedIn, Facebook, Instagram, etc. There is an ever-increasing trend towards using this type of tool, visible from the increase of data stored by Facebook, which is 180 petabytes ($10^{15}$ bytes) per year. As many as 58% of people use SNS ².

C. Computer Games

Mobile devices are used, among other things, for playing games, both by children and by adults. Many parents keep their gaming habits and continue to play games as a recreational activity. Although mobile devices are not the most important platform for game playing, because of their limited computational resources and small screens, there are many games developed for mobile phones and tablets. The habit of mobile game playing is widespread because of availability and ease.

D. Media on Demand

Currently there are many providers for media (music and video) on demand, such as Spotify (music) or Voddler (video), Headweb (video) etc. As stated in market estimations [2], [3], Fig. 1b, streaming video will be the number one driving force for mobile telecommunication within a few years. It will

²www.statisticbrain.com/social-networking-statistics/
further drive the increasing demand for higher bandwidth and newer technologies to support the desired quality levels and increased number of customers, see Fig. 1b.

IV. THE OBSERVED NEGATIVE EFFECTS OF UBQUITOUS ICT ON SOCIAL STAKEHOLDERS

Numerous applications of ICT bring huge positive effects such as simple global communication, efficient navigation, e-learning, information or streaming media available to virtually all, enlarged accurate memory and other data repositories, radically improved computational tools for sciences and technology, government and business – the list is very long. Nevertheless there are observed and poorly understood negative effects such as desensitization, alienation, fragmentation of close groups, lack of shared attention and affective presence that can be attributed to lack of closeness and abundance of long-range communication, Table I. We are facing a situation that is new to humanity. We have "policy vacuums" [43] – lack of experience and strategies for coping with those new technology-induced phenomena.

A. The Private Life Intrusion

In commercial ads many companies present a picture of happy families where each member is engaged with an individual device. In such a picture, direct human communication is replaced by indirect long-range communication with some distant individuals. Human time and attention as well as affective presence are finite resources. Those shared with distant connections are most often not shared within the close group. From the point of view of cognitive well-being of both individual family members as well as a family as a whole, fatigue of shared attention, affective presence and shared time is detrimental and in the long term not socially sustainable. It is hard to predict the effects on the social behavior of children growing up in this type of environment, where shared attention is scarce, as are the results of direct human communication such as shared values, trust and togetherness. Families are not spared from new habits of constant engagement with SNS and other means of long-range communication and ICT-based entertainment. This endangers young children’s early language acquisition capabilities, as expressed in the following statement by Deak et al. [17]:

the tendency for infants and the adults they are communicating with to attend to the same things seems to help infants correctly infer what adults are talking about, and thereby enter the language community.

Without shared attention, the language community loses its foundation as shared meanings and value systems have no way to develop.

B. Overuse by Children

Several news media, institutes and research groups have documented the current status of gadget usage among children, such as described in a report by the GSMA Association [25], where the age of the investigated group ranged between 8–18 years. The key finding is that 70% of children surf on the Internet each day. Bates [26] concludes that children spend too much time in front of gadgets, as those aged two to four spend in average two hours a day, and older children even more.

Where does all this take us in the future? It is indicative that the GSM Association [25] informs that “children still talk face-to-face with their parents more than they call or message them”. The very possibility that our communication with family members would become dominated by technology seems both disturbing and frightening. Fragmentation of families and close social groups would naturally follow the lack of direct contact.

There is also a trend that children stop playing with other children in the real-world, since they prefer to play alone, with the ICT gadgets. It is doubtful if we can exist as true social beings with all nuances of real-world interactions when we, to an increasing extent, interact with other people only indirectly via ICT-mediated communication channels. Using gadgets as babysitting tools has also been questioned. In pre-gadget time parents used ordinary TV and video while they now utilize gadgets for the same purpose. Ferrari 3 presents an interesting interview with Densmore, concluding that it is most important that adults participate in children’s ICT activities; that they are not left on their own for extended periods of time without adult involvement. Similar to other types of overexposure, even gadget overuse and addiction have several effects on children, according to current research; see Table II for an overview.

C. Work Extension into Leisure Time

Telecommuting is promoted as either replacing or extending working time by working from a remote place using commu-

\[\text{TABLE I: The observed negative effects of ubiquitous ICT on social stakeholders}\]

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<td>Violent computer games</td>
<td>Violent computer games are popular among children and have several side-effects.</td>
<td>[8]</td>
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<td>Privacy and socially responsible behavior is needed even within closely coupled</td>
<td>[31]–[35]</td>
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<td>hanced deviant behaviors</td>
<td>groups of people such as families.</td>
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<td>Gadget addiction</td>
<td>Addiction is fueled by interactivity and quick rewards.</td>
<td>[36]–[38]</td>
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<td>Communication etiquette</td>
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<td>Long-term cognitive overload leads to increased stress levels.</td>
<td>[16]</td>
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3\[31\]–[35]
communication equipment [30] and it is supposed to have beneficial effects on individuals, saving time and environment. However, experiences seem to be different, [29]. According to Noonan and Glass [30]:

(T)Telecommuting appears, instead, to have become instrumental in the general expansion of work hours, facilitating workers needs for additional work time beyond the standard workweek and/or the ability of employers to increase or intensify work demands. The most recent investigation 4 shows that 23% of employees in the US perform at least some work from home. The figures are much higher for people with a bachelor’s degree or above, at 36%. In spite of the belief that telecommunication would reduce traffic, research [29] shows that this is not the case at all. Commuting is actually increasing at an alarming pace. In Stockholm, which has an advanced telecommunication infrastructure, it was estimated that between 2000 and 2015, commuting by mass transit would increase by 33% and 28% by car. The question is thus: how much would commuting increase if there were no telecommuting?

Telecommuting is not only making workload more flexible, but it also makes it possible to take work home. Remote work is not something that will be abolished in the near future, as up to 85% [14] of workers are more likely to stay with current employer if they have flexible work time. This, in its turn, brings increased pressure on family shared time (called “leisure time”) and consequently on sustainability of existing social forms. It is an urgent priority to think those issues through, from the point of view of society, business, families and individuals as stakeholders. Is it good to be online and reachable all the time? Is it possible to partition the day between working time and private time? Mathiesen [15] found that people want to be able to communicate with other people at any time, but do not want to be reached at all times, which is contradictory in nature. To some extent, email communication gets close to this ideal, while the expectation of being contactable on Skype puts very high demand on traditionally private time in late afternoons and evenings (and sometimes even at night, due to time differences). Regarding work time 5:

A full-time worker in the OECD ... devotes 62% of the day on average, or close to 15 hours, to personal care (sleeping, eating, etc.) and leisure (socialising with friends and family, hobbies, games, computer and television use, etc.).

If we take into account a minimum of eight hours of sleep and two hours for eating and other “self-maintenance”, plus one hour for transportation activities, there seem to be four waking hours daily available for private human needs, including family, shopping, paying bills, sport activities, friends, etc. It should be pointed out that individual variations are large. Since current research shows indications that total working hours are increasing, this is something we need to understand. Nevertheless, some people claim: “If I Want to I Can Always Turn It Off” [15]. Will it really be acceptable that employees switch off their company owned mobile phones [30]? The main problem is not that the working hours increase, rather it is the expectation that one will be on standby for work at all times. That extra cognitive load of never being able to relax and completely dedicate shared time to one’s closest relations produces chronic stress which makes this habit of a life constantly online socially unsustainable [44].

D. Violent Computer Games

One of the earliest detected problems was violence in games. Grossman performed early research [8] on violent computer gaming (VCG) habits as early as 1996. He argued that computer games have demonstrated real-life effects and illustrates his claim with the use of computer games in preparing soldiers for war. A recent literature survey by Statens Medieråd [41] in Sweden from 2011 concludes that, out of 106 publications, it is not scientifically possible to draw any conclusions as to whether VCG causes violent behavior or if violent people are drawn to VCG. One possible conclusion is that there is a positive feedback loop between the two. Even though the discussion continues, one literature review [7] shows that there are negative effects to extensive gaming, in the form of aggression and asocial behavior.

E. Facilitated and Enhanced Deviant Behaviors

Mobile devices can be used for different kinds of deviant behaviors, such as cyberstalking and cyberbullying. Cyberstalking is the use of the Internet or other electronic means to stalk or harass an individual, a group, or an organization. 6 Cyberbullying is the use of information technology to harm or harass other people in a deliberate, repeated, and

<table>
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<td>Sleep disorders after excessive game play.</td>
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<td>Cognitive problems</td>
<td>Low self-esteem, depression, anxiety, alienation, discontent, etc.</td>
<td>[12]</td>
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<td>Gadget addiction</td>
<td>Addiction to the feedback mechanism provided by interconnected gadgets.</td>
<td></td>
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<td>[10], [11]</td>
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<td>Poor physical fitness</td>
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<td>[9]</td>
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5www.oecdbetterlifeindex.org/topics/work-life-balance/
F. Facilitated Tracking

Modern devices (including computers and mobile phones owned by employers) are carrying more and more of individual personal information in the form of private pictures, videos, documents etc., which is both private and valuable for owners. There are many apps that can report position etc. [31] which can also be considered as private information. Access to such data conflicts with the right to online privacy [32], i.e. the user’s right to communicate, without third-party monitoring. Additionally, it is possible to gather vast amounts of user data in an automatic manner such as described in [33]. In this particular case the data is used for research purposes, but can be used for other purposes as well. An interesting topic is tracking within close groups such as family, studied in [34] who emphasizes that privacy does not mean independence from society, but it allows social freedom. It is realized by involvement in a variety of associations that present “safe spaces for self-expression”, where we communicate with different degrees of closeness.

By restricting access to the ones outside those spaces, privacy enables us to relate in meaningful ways to the ones inside. In other words, privacy is deeply socially embedded and so too is privacy violation, which, therefore, is not without social consequences.

Even though sharing and a sense of mutual dependence and closeness is typically high within families, tracking within a family can easily lead to privacy violation, as it can “bypass the system of boundaries set up within family contracts to modulate and maintain relationships, exposing them to undesirable states.” In a family setting there is often “reciprocity between trackers and tracked: participants play both roles or both the point of view of the tracker and the tracked are taken into account.” Tracking of family members can make people feel both comfortable and safe but also frustrated, with a feeling of loss of freedom. So context-aware services that would provide extensive information shared by family members should be carefully designed with a variety of personalised settings capabilities. There is also a new trend to add context-aware services to SNS [35]. The idea is to use contextual information to provide a more tailored service for the user, for example during a meeting it is possible to automatically map participants to a special SNS group.

This type of automatic functionality will of course require an extensive privacy investigation.

G. Gadget Addiction

Gadgets supply unprecedented communication capacity coupled with easy data access [36]. Quick and easy rewards make gadgets attractive for most people [37]. The effect of gadget over-usage is apparent. People cannot stop updating their Facebook accounts or repeatedly looking at new posts being afraid that they will miss something important [38]. The study by Salehan and Negahban [36] indicates that using interconnected SNS increases the risk of addiction. Research by Billieux [37] confirms the link between gadget overuse and addictive behavior. The level of addiction is related to stimuli frequency and network size. Children also react to their parents’ excessive use of ICT. As many as 33% of Swedish children are asking for more parental attention [28].

H. Communication Etiquette

It has also been observed that there has been a complete change in the attitudes towards communication etiquette. Katz [38] describes how during meetings nowadays it is often acceptable to check emails or communicate on social sites, read articles, surf, etc. The introduction of worldwide telecommunication coverage together with the always-online mentality increases the phenomenon of constant usage of SNS. This affects the results of a presentation when a majority of the “listeners” pays only partial attention to their actual context. The essential cognitive resource of shared attention is becoming alarmingly scarce in direct social communication.

I. Cognitive Overload and Virtual Desensitization

The combination of finite cognitive resources with increasing informational flows results in cognitive overload. The consequence of long-term exhaustion and saturation of cognitive resources is a chronic stress. Individual cognitive resources that are connected in social cognition produce culture, with language, arts and everyday cultural habits that are transmitted to children. It is not difficult to imagine a cognitively exhausted and impoverished culture where knowledge is transferred indirectly from parents to children, without the close embodied relationship of shared attention and affective presence. Additionally, repeated exposure to the same situations within virtual reality may lead to desensitization in the real world [16] causing ordinary reaction to gradually diminish because of habituation. Thus, experiences from virtual worlds such as extreme violence affect reactions in the real world, such as higher tolerance for violence.

Interesting in this context is the fact that our brain receives 11 million bits/sec input data from our senses, while conscious processes are capable of handling 60 bits/sec in the form of language/symbols. [48] That means that a huge part of the information processing that our relation to the real-world builds on is done without conscious control, based on massive amounts of sensory data. Reducing this rich communication with present-level digital communication is to deplete human

cognitive resources. This will slowly integrate into culture with unforeseeable consequences, and therefore should be taken seriously as a question of cognitive- and eventually social sustainability.

V. SOCIAL SUSTAINABILITY STRUCTURES AND MECHANISMS

In order to elucidate the character of cognitive sustainability as a basis of social sustainability, in this section we will present an analysis of the mechanisms of social sustainability and their corresponding structures, see Table III. In their study Magee et al. [20] propose characterizing social sustainability through its different aspects: economic, political, technological, ecological and cultural. As a consequence of preceding discussions, we propose adding a new aspect: cognitive sustainability, which acknowledges that our cognitive resources are finite and can be depleted. Our (finite) cognitive resources are central to our ability to relate to both society and nature, to make balanced and well-reasoned decisions, to communicate, learn, memorize – and pretty much everything else we do. Being constantly bombarded by information designed to catch our attention and not having automatic mechanisms to filter out irrelevant and useless information, can lead to problems such as addictive behavior, loss of sense of reality, desensitization, aggression, etc. Social sustainability is based on the cognitive resources of its stakeholders, individuals and groups building complex networked structures. If human cognitive resources gradually get depleted because of overexposure to information, which has little relevance to core aspects of real life, that will negatively affect all other aspects of social sustainability which builds on sound human cognitive capacities, both as individuals and as constituent parts of extended (social) cognition. Findings in Section IV regarding privacy issues, children’s overuse of technology, intrusion of work into private life, tracking issues, addiction, cognitive overload and desensitization suggest that from the perspectives of individuals, families, working organizations and from a societal perspective, the present state of development and practice is not socially sustainable, as it does not meet some of the fundamental human needs, especially when it comes to new generations who have grown up with ICT.

A. Circles of Privacy (Proximity) and Shared Attention

Privacy is a human right guaranteed by Article 12. of The Universal Declaration of Human Rights 8.

In spite of that, there are pessimists who, extrapolating from current trends, predict the end of privacy [45]. We will argue that it is crucial not to give up privacy as a human right, as it is essential for the whole of human existence – from the feeling of identity and community to our ability to make sense of the world based on autonomous access to reality, free from purposeful manipulations. As with technology in general, ICT systems shape the way we think, and the way we behave [46]. The process we are witnessing globally is that, instead of a clear distinction between different circles of privacy as shown in Fig. 3, we get mutually connected with the same ease with complete strangers as with family members. Despite physical proximity of family members, each of them can nowadays be active on their own Facebook, Google+, Twitter, Instagram, Blogger, etc. Cognitive engagement is fragmented, shared attention and affective presence nonexistent. This changes the very basis of human relationships, with the potential to radically negatively impact future generations.

Fig. 3 illustrates the relationships between circles of closeness as defined for different types of relationships – family, friends, colleagues, acquaintances and others. The Dunbar number [4] indicates that approximately 5 individuals are located in the closest relationship, increasing [5] by a factor of 3 for each new level, resulting in roughly 150 for the total number of connections one can practically manage. The effortless and intense ICT connections between all circles, irrespective of

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<td>Shared attention</td>
<td>Enables common cognitive framework.</td>
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<td>Community and belongingness</td>
<td>There is a fundamental need for humans to belong to a close group.</td>
<td>[18]</td>
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<td>Affective presence</td>
<td>Enables empathy and provides a social glue.</td>
<td>[23]</td>
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TABLE III: Cognitive aspects of social sustainability

![Fig. 3: Levels of communication with ranges of proximity. Numbers indicate typical amount of connections [4]](image-url)
distance, contribute to the blurring of the distinction between private life and work/public life. Complex social structures that used to function as indicators of closeness, attachment and affiliation are dissolving. Individuals in a social unit such as a family form different circles of proximity when they are separately exposed to different virtual worlds instead of having shared experience, Fig. 3. In a modern family, for example, children spend extensive unsupervised time [26], [27] on their gadgets while their parents are using their own online devices [28]. Each family member acquires his or her own experience. They often do not share the same friends and their friends do not know each other – thus, an important social reinforcement mechanism is getting lost. This will lead to differentiated behavioral patterns in situations where we traditionally had a shared behavior within the social group. What are the effects on a family when members no longer share the same values, experiences, memories, interests and behavioral patterns? One of the effects of extensive online communication is that levels of privacy get compressed. The vast increase in long-range at the expense of short-range communication threatens to turn global social network of networks with different degrees of cohesion into network of cognitively equally loosely bound nodes – with strangers getting closer while the previously closest social groups such as families drift apart. It is interesting to notice that Aristotle, in his work De Anima, presents a hierarchy of the senses, where sight is the highest of the senses, followed by hearing, smell, touch and taste. Those can be seen as levels of privacy – with taste as the most private level that demands closest proximity and sight as the least private one. The members of the closest group one can see, hear, smell and even taste. With members of the general public, we communicate through sight and speech. Loss of privacy leads to loss of ability to distinguish between belonging to different types of groups – from closest to the most distant. Our near relationships are characterised by the sense of community which, according to [47], has four elements: 1. membership, the feeling of belonging and relatedness; 2. influence, a sense of making a difference; 3. reinforcement, fulfillment of needs and support; and 4. shared emotional connection, "the commitment and belief that members have shared and will share history, common places, time together, and similar experiences." The lack of community/belongingness can cause several negative side-effects as there is a fundamental need for long-term close interpersonal relations [18].

B. Circles of Proximity and Social Sustainability

What can be done to mitigate this development that endangers the very foundation of social sustainability? The first step is to understand the radical change in communication patterns and its consequences for social structures – and thus to identify the problem. The way to positively influence the development is by Value Sensitive Design, [49] taking insights from Human Computer Interaction, Ethics, Information Design and Requirement Engineering to design future software products, services and devices. The Value Sensitive Design of new ubiquitous mobile devices should enable and encourage users in social groups to interact and experience their informational environment together in different circles of proximity, instead of only individually, as is typically the case.

VI. SOFTWARE ENGINEERING FOR SOCIAL SUSTAINABILITY

According to Lago et al. [50] the current understanding of sustainable software includes two different interpretations of sustainability – relative and absolute, where relative sustainability implies that a function shall sustain over a specific time, while absolute sustainability implies that a software product or service will “contribute to preserving environmental and human well-being.” Thus our present analysis is done with absolute sustainability in mind. Ultimately, a high-level analysis must "break down the definition of sustainability so that it can be applied to SE." For software engineering, Lago et al. [50] identify the future challenges for requirements, design and quality of software.

The contribution this paper consists in identification of cognitive sustainability as a new aspect of social sustainability for ICT, which will have an impact on the requirements for the development of future software. Cognitive sustainability builds on close relationships that support and relieve the burden of cognitive overload, which depend essentially on the possibility of privacy and preserved integrity.

A. Examples of Software Engineering for Privacy Protection

As far back as 1993 Bellotti and Sellen [51] proposed a solution to the problem of design for privacy in ubiquitous computing environments. Thomas et al. [52] presents an example on the method of distilling privacy requirements for mobile applications. The authors explain:

Eliciting mobile privacy requirements is challenging, largely due to the fact that mobile privacy issues are so dependent on the physical and socio-cultural context of the users. This means that only data that captures the nuances of these contextual factors and variations can adequately inform the development of privacy requirements for privacy-aware mobile applications.

The distillation tool enables requirements analysts to use qualitative empirical data and refine them systematically in accordance with users’ privacy needs. Obviously, design for socially sustainable ICT demands more than the technical solution of the different types of communication in different circles of privacy. The question is not only how to prevent intrusions but also how to promote a sense of togetherness and group affiliation and especially how to design informational environments for children that will support shared cognition and affective presence of parents.

B. Software Engineering for Cognitive Sustainability

Cognitive sustainability is fundamentally determined and regulated by preservation of differentiated circles of proximity. It requires technological solutions that would indicate
closeness between closely related people who could share more, and in a different way. However, not all solutions can be provided by technology alone. In a socio-technological system, the relationship to technology is a part of culture. As a culture we still lack insight about the value of shared attention and affective presence. Sensible use of technology is not only a question of technology, but also of culture. SE design can improve social sustainability through better privacy management by providing a means to understand relational distance to other users [18]. When using a gadget to communicate with a person, their closeness could be suggested by the "look and feel" of the interface, helping the caller to distinguish closely related people from strangers. Currently there are some initial attempts to achieve this in Google Circles, VIP people and family sharing in Apple products. During the design and development of new gadgets, products and services, the SE community can contribute by integrating functionality to understand long- and short-range as well as close and distant relationships. Knowing the relational and physical distance will help people to make a cognitively sustainable integration of their virtual – real-world and private – official role in society.

**VII. Conclusions**

Globally, we are undergoing a cognitive revolution, which is causing radical changes in our habits. The changes are driven by ICT that is becoming a ubiquitous part of our culture and civilization. All trends are pointing towards further development in the form of cloud computing, Internet of things, cognitive computing, ambient intelligence, etc. Our cognition has developed through a process of evolution, dominated by real-world physical interactions. Currently, in a very short period of time, cognition is becoming increasingly based on computer-mediated information, and both our relation to nature and our social relationships are forming through communication via ICT. Even our closest relationships, such as those with our children, have recently become, to a significant degree, mediated by technological devices. Some aspects of this development give us reasons to worry about social sustainability, and more specifically about the cognitive sustainability of present communication forms. There are empirical studies indicating problematic social effects resulting from increasing mobile ICT use, as we have shown in the paper. For example privacy intrusion, tracking, addiction, desensitization, lack of shared attention and affective presence in closely related groups. We point out that it is important that the vast positive consequences of increased ICT usage for enhanced distributed cognition on the social level, be in balance with the individual need for privacy, closeness, shared attention and affective presence. Combining the preservation of the tightest bounds in the closest groups can reduce the negative effects of ICT by providing feelings of security and belongingness. Moreover, it is necessary to create spaces for children to meet in the real world instead of spending all their time online or playing computer games alone, as human embodied cognition needs rich variety of real world experiences to fully develop.

There is still research to be done about how different levels of proximity regulate information flows and provide social cohesion. We should understand the consequences of different models of social organization. Given modern simulation tools, such studies are possible. Even anthropological comparative studies of different social organizations can help us to understand what happens in a complex social structure compared to the flat structure where every node in the network is an equally important source of information for every other node.

Value sensitive design can help to develop the new generation of context sensitive devices that will reduce the desensitization effect by making gadget users aware of the relationships in the space of circles of proximity/privacy/publicity – reality/virtuality. Making distinctions in the look and feel of the user interface for ubiquitous mobile devices, depending on the levels of proximity, is both possible and desirable. Relational distance indicators can provide support to manage different levels of closeness, which in turn can allow the user to share various amounts and types of information, depending on the type of relationship. Such new technology, more human-centric and cognitively noninvasive, may contribute to the social sustainability of the global ICT-based society. The flattening of complex network of networks of social relationships without differentiating between distant and close communication is unsustainable and should be avoided by new and better technical solutions.

As an engineering community, we aim to constructively contribute to the sustainable development of society by designing and constructing devices that will better reflect our cognitive, social, emotional and informational needs. So, what kind of computers are needed to support our basic human cognitive needs? That is an important question for cognitive scientists, sociologists, psychologists, ethicists and interaction designers. Software engineers who design and program ICT devices and form their functionality based on a variety of functional and nonfunctional requirements have an important role in the future development. As a conclusion, we emphasize that ICT provides both tools and building blocks for the cognitive revolution. We want to embrace the cognitive revolution while being socially sustainable by securing the cognitive well-being of individuals in their private and working lives. We have a long way to go, but the first step is to identify the problems and propose possible routes to cognitively sustainable solutions.

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