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DOI
10.1080/09544828.2022.2050682

Publication date
2022

Document Version
Final published version

Published in
Journal of Engineering Design

Citation (APA)
Jung, J., Kleinsmann, M., & Snelders, D. (2022). A vision for design in the era of collective computing. *Journal of Engineering Design*, *33*(4), 305-342. https://doi.org/10.1080/09544828.2022.2050682

Journal of Engineering Design

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cjen20

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To cite this article: Jiwon Jung, Maaike Kleinsmann & Dirk Snelders (2022) A vision for design in the era of collective computing, Journal of Engineering Design, 33:4, 305-342, DOI: 10.1080/09544828.2022.2050682

To link to this article: https://doi.org/10.1080/09544828.2022.2050682

Published online: 11 Mar 2022.

JOURNAL OF ENGINEERING DESIGN
2022, VOL. 33, NO. 4, 305–342
https://doi.org/10.1080/09544828.2022.2050682

A vision for design in the era of collective computing

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ABSTRACT
In this study, we envision engineering design activities for collective computing, an upcoming era of complex systems of massive social interaction through a wide variety of connected computing devices. A literature review reveals how collective computing, compared to the previous eras of personal and ubiquitous computing, may lead to new design tasks and design processes, as well as new roles for designers. Based on this review, new design activities for the collective computing era are envisioned, and further revised in an interview study with 24 informants. The result is a vision for design in the collective computing era, with actionable guidance for designers in terms of a coherent set of new design activities proposed in relation to advances in computing.

ARTICLE HISTORY
Received 18 August 2021
Accepted 3 March 2022

KEYWORDS
Industrial design; prescriptive models of the design process; modes of design; system(s) design; design futures

Introduction

Several design researchers have indicated the relationship between the evolution of the design field and developments in computing (Bayazit 2004; Cross 2018; Dubberly 2008). They argue that both design process and designed artifacts have been evolving with respect to developments in modern computing. In their opinion, the connection between computing developments and design became especially prominent during the era of *personal computing* that began in the early 1980s, followed by the current era of *ubiquitous computing* from the 1990s onwards.

Abowd (2016) introduced a new era of modern computing called *collective computing*. This era describes a new stage in modern computing where many people interact with one another through many computing devices, with a prevalent influence on the physical world, and on economic and social values. Based on past and current developments in shareable information systems of collective intelligence (Malone and Bernstein 2015) and combined with recent observations by design scholars (e.g. Chan, Wong, and Kwong 2018; Cooper 2019; Coulton and Lindley 2019; Giaccardi and Redström 2020; Höök and Löwgren 2021) about the new complex forms of computing which designers engage with (e.g. the economic and social structure changes from the various technological development), collective computing can be expected to influence the content and the organisation of the

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design process. Therefore, this article explores the transformations of design activities during collective computing to establish a future vision of the role of design in the collective computing era, with practical and actionable guidance for designers.

Below, we introduce collective computing as a third era of modern computing, followed by two studies. In Study 1, we review the characteristics of design activities for collective computing compared to preceding eras in modern computing, and reflected on by the authors based on their past design work in data-enabled design. Moreover, we develop an initial future vision, describing how the collective computing era is likely to require changes in the activities of designers.

In Study 2, we further review and improve this initial vision, by enriching it through an exploration of the potential guidance for designers to adapt to new challenges posed by the collective computing era. The study was conducted by interviewing 24 informants with expertise on design in relation to computing. Thereafter, we combined the results to produce a comprehensive vision of design activities in the collective computing era, a practical guidance for designers.

The two studies build on a tradition in engineering design research of describing upcoming design activities (including education and research) in relation to advances in computing, either through expert interviews (Spence 1995), or through personal reflection on developments in the design discipline (Andreasen 2011; Cross 2018; Holt 1993). We therefore aim to contribute to an established, yet dynamic discipline (following Duffy 2011) by proactively addressing new challenges and proposing new design activities for engineering design in collective computing.

Three eras of modern computing

Thus far, modern computing has been characterised by reference to three generations of computing eras: mainframe, personal, and ubiquitous computing (Pew 2002; Want 2010). In this section, we discuss the last two eras of personal and ubiquitous computing along with additional literature regarding a predicted future or upcoming era of collective computing. In this context, we excluded the first era of mainframe computing, as we did not find any literature on design processes being directly affected by mainframe computing.

The personal computing (PC) era began in the early 1980s as a consequence of two technological developments (Grudin 2007; Pew 2002). First, technology companies started introducing less expensive but adequately capable mini-computers in the consumer market, e.g. IBM PC 5150 (1981), Xerox Star 8010 (1981), and Apple Lisa (1983). Second, the commercial Internet was released for public use in 1989. With these technologies, programmers as well as ordinary individuals started using computers for entertainment and work. Inevitably, the release of the Internet favoured the development of various Internet-applications such as instant-messaging, music players, and weblog tools. In addition, asynchronous and distant communication such as online discussion and e-mail became widespread and highly popular. Thus, the need for user-friendly computers arose owing to the regular use of PCs by non-experts. Instead of controlling the computers as in the mainframe computing era, PC users interacted with computers through numerous software and Internet-based applications (Ritter, Baxter, and Churchill 2014). Therefore, the further fragmented structure and flow of computer system evolution required the development of intuitive interfaces to ensure that users do not feel frustrated or confused when using

PCs. Thus, superior user-friendliness and intuitiveness became the key selling point for PC vendors (Grudin 2007; Pew 2002), and designers actively collaborated with computer engineers to optimise and evaluate design proposals from a more user-friendly and intuitive mindset (ISO/IEC 1998; Ritter, Baxter, and Churchill 2014).

Ubiquitous computing (or Ubicomp) was initially coined by Weiser (1991) and started to garner increased attention in the 1990s when companies began exploring the potential of portable computer products operating in small networks (Grudin 2007; Pew 2002; Want 2010). As such, the products resulting from these explorations included Apple Newton, EO pad, Palm Pilot, and Sharp Zaurus. Eventually, Ubicomp progressed past its exploratory stage and was adopted by markets in the 2010s (Want 2010). Since then, individual users have increasingly purchased several types of computers such as smartphones, PDAs, and embedded computers, and the miniaturisation of computers has driven the rise of ubiquitous computing. Moreover, cheap sensors, actuators, and convenient programming platforms reduced the barriers to the development of embedded computing applications (Grudin 2012; Pew 2002; Want 2010). Based on these developments, context-awareness and unobtrusiveness became two main characteristics of Ubicomp (Grudin 2012; Pew 2002; Want 2010). Context-awareness signifies that devices can adapt to a specific user context in their operations to provide a more ideal user experience. Developers can create contextual awareness by employing on-platform sensors to detect, for instance, the location of a device, nearby devices, and environmental factors such as sound, motion, and temperature (Grudin 2012; Pew 2002; Want 2010). Unobtrusiveness refers to the seamless integration of computers with common objects such as tables or floor mats (Barton and Kindberg 2001; Kidd et al. 1999). Therefore, the unobtrusive usage of computing devices embedded in the surrounding context is an essential quality of the Ubicomp paradigm (Grudin 2012; Pew 2002; Want 2010). These two characteristics of Ubicomp allowed designers to actively explore new technological possibilities to unobtrusively change user behaviour through the awareness of a user context (Brush 2009; Rogers 2011).

As practice-oriented design researchers and educators, we observe the evolution of complex new forms of computing under active development and design at present, other than those described by ubiquitous computing. These new forms depict many Ubicomp users (individuals possessing multiple computing devices) as interconnected to one another via networks and sharing data widely. Figure 1 visualises the differences between three computational generations. These new forms of computing resemble those described in 'Visions of Design for 2020' by Spence (1995) together with twelve experienced design engineers:

> Underlaying the visions, and with profound implications for data and information handling, was a general acceptance of the personal ownership of huge amounts of data (some gathered by PIGs [(personal information gatherer)] over a number of years), the company ownership of similarly extensive volumes of data concerning such matters as design histories, a worldwide communications network characterised by negligible communication charges, and the ability to plug a personal computing device into the network as easily as one plugs an electrical appliance into a power network. All these factors will lead to more effective information generation and use. (135)

Other recent design scholars have followed this vision while describing the new complex forms of computing with which designers engage. Cooper (2019), Giaccardi and Redström (2020), and Coulton and Lindley (2019) argue that designers face contextual and

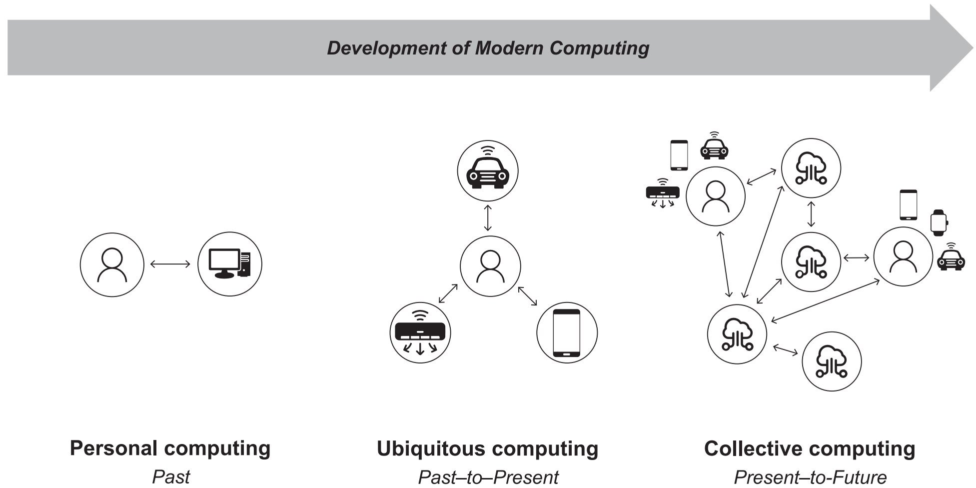

Figure 1. Design-relevant developments in modern computing.

methodological transformation owing to the changes in the economic and social structures made by the advancement in connectedness through Internet of Things technologies, big data, and artificial intelligence (including algorithm and machine learning). Höök and Löwgren (2021) specify the economic and social structural changes from an interaction design perspective: a movement towards a hybrid of physical and digital materials, an emergence of a complex and fluid digital ecology accessible to many, and constant autonomous changes (updating based on the usage behaviour) in the system we design. The recent special issue in the Journal of Engineering Design: 'affective design using big data' introduces various novel approaches of using hugely connected data generated from advanced technologies to capture people's affective needs (Chan, Wong, and Kwong 2018).

Abowd (2016), a well-known ubiquitous computing scholar, proclaimed a highly similar view of connections between many users through interoperable data generated from many computing devices, as a new era of *collective computing*.

> Considering the technological changes across computing's first three generations, how might the next serve humanity? Three critical technologies-the cloud, the crowd, and the shroud of devices connecting the physical and digital worlds-define the fourth generation of collective computing (17). (…) Weiser's vision [of ubiquitous computing] did not really expose the opportunities to enhance interaction across individuals. Our research communities have long recognized computing's importance as a means of supporting human-human interaction. Fourth-generation technologies directly address this gap, recognizing that many people interact with one another through many devices, and vice versa. (19)

Our exploration of new forms of complexity in computing systems is inspired by Abowd's notion of collective computing, and we retain the term throughout the present work. Abowd's concept of collective computing highlights new challenges that thus far have not received much attention in design engineering. More than, for instance, the literature on the design of product-service systems (PSS), collective computing allows for the integration of social aspects in complex technological systems. As Abowd argues, collective computing has been enabled by technological advancements in crowd, cloud, and shroud. Crowd presents a myriad of individuals, complemented by computer algorithms and cooperatively providing their behaviour data and human intelligence (Metcalf, Askay, and Rosenberg 2019; Mulgan 2017). Cloud technology implies massive computational resources, data storage, and access, as well as the integration of various types of data generated through the use of multiple devices (Dillon, Wu, and Chang 2010). Lastly, the shroud describes the large number of connected, highly performing, and small sensing computing devices generating tremendous real-time and real-world data (e.g. 27 billion IoT products in 2025, (Sinha 2021)) (Höök and Löwgren 2021; "Technology and Innovation Report 2021" 2021). Together, the crowd and cloud intelligence establish a new form of omnipresence, supported by a layer of digital technology that Abowd termed the shroud. The shroud connects the physical world to a continuously updated and socially interactive digital system.

In engineering design (and other design disciplines), we see the collective computing context as a major driving force behind the current push for designers to work on complex socio-technical challenges involving multiple different stakeholders and contexts, such as climate change, resource depletion, and healthcare (da Costa Junior, Diehl, and Secomandi 2018; Sevaldson 2009; Van der Bijl-Brouwer and Malcolm 2020). In an upcoming collective computing era, designers face new issues requiring critical decisions, which must inevitably be made with limited knowledge of the context of a massive scale of complex, interconnected community-level data.

Study 1: Exploring transformations of engineering design activities in collective computing era

Abowd and other designer researchers hint at a rough outline of the collective computing concept. However, the understanding of design activities in the collective computing era remains limited, as this is a relatively new concept. Thus, we conducted Study 1 with the following research question:

- What are the aspects of engineering design activities transforming in the prospective era of collective computing compared to the PC and Ubicomp eras?

Research method

In the first part of Study 1, Study 1a, we reviewed the literature on modern computing and design with a focus on design activities and considerations related to computing developments that are currently relevant or that might become relevant in design practice.

For the second part of Study 1, Study 1b, we adopted a constructivist approach (Crotty 1998; Elkind 2005) to explore the future outlook of collective computing in a *designerly* way (Cross 1982; Van Aken and Romme 2012). The inherent interpretation linked to this approach is accounted for by the authors combined perspectives, based on 10–25 years of experience (in various countries in Europe and Asia) with design activities, underlying theories, and methodologies related to various kinds of digital innovation such as websites, 3G/4G devices, smart home appliances, smart health and traffic environments, biometrics, social media, chatbots, and so on. We draw the conclusions presented herein based on knowledge sources from design research, education, and practice on human–computer interaction, collaborative design, strategic design and engineering design. In this part of

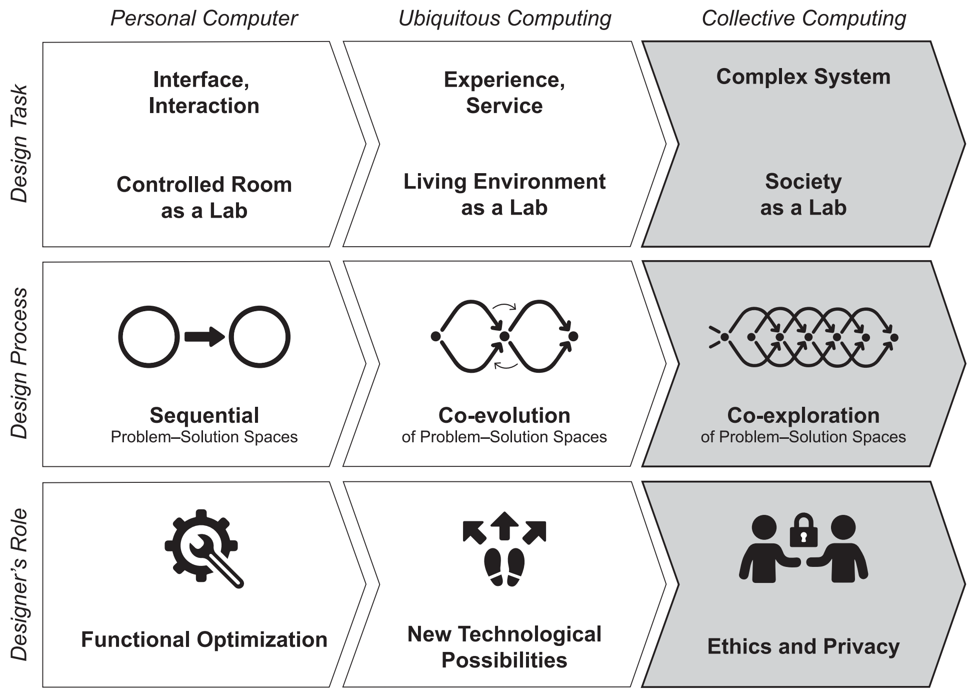

Figure 2. Initial vision on the main design activities across three computing eras.

the study, we constructed our understanding of the literature on modern computing as an initial vision on design activities in collective computing era (Figure 2).

Results

Study 1a consisted of a literature review. The results are summarised in the table presented in Appendix 1 and the text below. The result provides an overview of design activities for the PC, ubiquitous, and collective computing eras where these developments are classified based on the nature of design methods and techniques for a design task, the prevalent design process, and the role of the designer (Dorst 1997, 2016). The overview of the collective computing era is based on our extrapolations from the PC and Ubicomp eras.

During the PC era, designers were actively involved in the design process of interfaces and interactions (Burns et al. 2006; Powell and Cooper 1994; Winograd 1996). This was because the user-friendliness of interface and interaction was an essential factor to attract non-expert PC users (Löwgren 1995; Pew 2002; Shneiderman 1980; Winograd 1996). Also, the design of the webpage was directly related to information retrieval time (Grudin 2007; Pew 2002). Thus, conducting design research in a controlled room was effective enough to explore the user-friendliness and retrieval time for specific moments in computer usage (Hughes et al. 1994; Rogers 2011). As a result, in the PC era, the problem was often already defined and formulated by the software developer in the problem-solving design process (Burns et al. 2006; Jokela et al. 2003; Pew 2002). In this process, the role of designers became one functional optimisation of current practices and evaluation of final design proposals (ISO/IEC 1998; Ritter, Baxter, and Churchill 2014).

During the Ubicomp era, designers have actively expanded their design tasks to enhance the quality of interaction between the user and the product, in terms of experience and service (Desmet and Hekkert 2007; Secomandi and Snelders 2013). Portable computers with low-cost tagging and transmission technologies made the inherent embedment of computers in everyday products possible (Want 2010). Thus, the computing device's contextualised experience and services gained more attention than the computing device itself in isolation (Pine, Joseph, and Gilmore 1998). To explore the users' expanded and overarching experience related to the computing devices designers used the living lab concept (Brush 2009; Dell'Era and Landoni 2014; Feurstein et al. 2008; Rogers 2011; Taylor 2016). The design process in such real-life settings can best be characterised as one of co-evolution, implying that problem and solution spaces cannot be defined at any specific point in the design process but they evolve over time and can be continually modified (Crilly 2021; Dorst and Cross 2001; Hatchuel 2001; Poon and Maher 1997). In this sense, the living lab condition can be seen as influencing the designers' prevalent process towards greater co-evolution of problem-solution spaces. Co-evolution allowed designers to exploring newly emerging technological possibilities in novel interactions and experiences, going beyond simpler optimisation processes (Brush 2009; Rogers 2011).

We extrapolated the design activities of the collective computing era that can be distinctive from ones of the PC and Ubicomp eras. Regarding the *design task* in the collective computing era, advanced technologies have enabled uniquely massive, complex connections between multiple computers and users (Abowd 2016; Höök and Löwgren 2021). Höök and Löwgren (2021) describe this complex context as 'everything is connected to everything else.' Consequently, *complex systems* emerge in which the crowd's physical world blends with a constantly updating digital world (Friedman 2019; Höök and Löwgren 2021; Speed and Oberlander 2016; Verganti, Vendraminelli, and Iansiti 2020). System complexity here is characterised by numerous layers of social, technical, and economic contexts (Friedman 2019) with conflicting agendas between different stakeholders (Höök and Löwgren 2021). These tightly linked systems between the digital and physical world allow data-driven and AI solutions to become a part of our system design, based on autonomous analysis or prediction (Höök and Löwgren 2021; Verganti, Vendraminelli, and Iansiti 2020). Thus, many tech companies deliver their values by using algorithms that connect digital and physical worlds (Iansiti and Lakhani 2020) and deliver users what they want seamlessly (Magistretti, Pham, and Dell'Era 2021). In this context, designers must learn to create designs relating to these more diverse and extensive contexts, which requires a scaling-up of design research (Brown, Bødker, and Höök 2017; Maeda 2018), and an understanding of users not just at personal but also social and societal levels (Gardien et al. 2014; Whitworth et al. 2006). In collective computing, designer research becomes a more constant occupation, and more integrated with the rest of society to allow for a seamless, iterative process (Höök and Löwgren 2021). This development implies a shift from single-contextual research to cross-contextual research, i.e. transiting from one focused context (living labs) towards the crossing multi-contexts-based *society as a lab*. Overall, the design task is now based on rapid iterations between research and development, with users as co-developers, and designers more intensely engaging with their data.

Along with having society as a lab, developments in sensor and computing algorithm technologies (i.e. machine learning, neural networks, artificial intelligence) are also affecting the *design process*. These technologies facilitate the acquisition, analysis, and synthesis of extensive amounts of user data across various usage contexts of use by designers in real-time (Gorkovenko et al. 2019), and without any scale-limitation (Verganti, Vendraminelli, and Iansiti 2020). Sensors embedded in products and services (e.g. smartphones) collect countless behavioural and location data almost real-time (Höök and Löwgren 2021; Van Kollenburg et al. 2018) from their actual use in the wild (Churchill 2017). The use of an algorithm, such as of machine learning, implies that a system will evolve by the collection of continuous streams of data (Verganti, Vendraminelli, and Iansiti 2020). Höök and Löwgren (2021) argue that this design process will always be 'a work in progress' or 'perpetual beta' through continuous evolvement. Giaccardi and Redström (2020) add that the design process no longer happens before production; instead, development and deployment processes are becoming intertwined – technologies we designed learn while in use and change and adapt over time. This 'constant becoming' (Giaccardi and Redström 2020) implies that the problem and solution spaces in the design process not only co-evolve in conjunction (Dorst and Cross 2001), but can also be simultaneously explored while these new digital technologies are being used (Magistretti, Pham, and Dell'Era 2021). Stienstra, Bogers, and Frens (2015) coined the term '*co-exploration*' for this process.

In terms of the *role of designers* in building collective computing systems, designers can assume to have much less control over the consequences of their design (and thus, over its meaning and value) as arising with time and use within society (e.g. the offensive tweet controversy involving the Microsoft AI chatbot Tay (Lee 2016; Wolf, Miller, and Grodzinsky 2017)). This suggests that designers should examine their natural optimism regarding the desirability of their solutions and more appropriately review projects for unexpected and unwanted consequences, particularly considering *ethical and privacy issues* (Benton, Miller, and Reid 2018; Bourgeois and Kortuem 2019; Giaccardi and Redström 2020; Lazar et al. 2016; Nelson and Stolterman 2014). The ethical issues that collective computing should address include privacy issues, but they are broader than that due to its societal involvement. Thus, designer may also need to reflect more than before on issues of freedom and human rights (Ibiricu and Van der Made 2020). Other scholars are exploring how responsible innovation can be realised in data-enabled devices, focusing on ethical concerns to design IoT products such as (Bourgeois and Kortuem 2019), (Boenink and Kudina 2020), and (Wehrens et al. 2021).

In Study 1b we constructed Figure 2 as the initial vision for the collective computing era, based on those distinctively transformed design activities identified in the literature and summarised in Appendix 1. The figure lists the crucial distinctions of collective computing activities compared to those in the PC and Ubicomp eras. Similar to Appendix 1, the horizontal axis in Figure 2 distinguishes the three computing generations (Abowd 2012, 2016; Weiser 1991), and the vertical axis lists the three groups of design activities (Dorst 1997, 2016). Figure 2 was also used as input for Study 2, as a help in discussing developments in design activities in relation to advances in modern computing, and as starting point in constructing a vision on collective computing.

Study 2: Building a vision of engineering design activities for the collective computing era

Study 2 also consists of two parts. In the first part, Study 2a, we interviewed and analysed the answers to the following research questions from 24 informants:

- What improvements do the informants see in the initial vision (Figure 2) to reflect past, current, and future design activities in relation to advances in computing?
- What is the potential guidance for designers managing the transformations in the near future of (collective) computing in terms of the design task, process, and designer's role?

In the second part, Study 2b, we constructed our vision of collective computing, based on our interpretation of the analysis result of the interviews (see Figure 4). Consequently, our vision was the outcome of our reading of the literature on design activities in relation to modern computing (in Study 1), and on sharing and discussing our initial findings with key informants.

Study 2a: Interview study

Research method

Sampling and Interview Strategy. Twenty-four informants were recruited per a key informant sampling strategy (Patton 1980), and they had a range of experience in design from industry and academia (see Table 1). Informants were approached through various channels, including e-mail requests, recommendations by other informants, and face-to-face approaches at conferences (i.e. CHI 2019, ICED 2019, IASDR 2019).

The interview was open and consisted of three sections, including comments on the initial vision, forces that enable new design activities for collective computing, and guidance for developing new design activities for the collective computing era. The interview guides (with the indicated sections) developed before the interview allowed to slightly deviate and reformulate the way and order in which the questions were asked to investigate the relevant issues accordingly (Blessing and Chakrabarti 2009; Patton 1980). The guide allowed us to cover the same topics for all interviews. We also conducted six pilot interviews before Study 2; we learned to change the initial vision (interview stimuli) to be a simple visual (fewer details) and form the interview to be an open interview. Audio of the interview was recorded with the consent of the informants.

Interview Analysis. We followed the procedure of inductive qualitative data coding from (Patton 2014), (Miles, Huberman, and Saldana 2014), and (Blessing and Chakrabarti 2009). This is a stepwise procedure (Figure 3) and double coding.[1] Involvement of the two other authors who are highly experienced senior design researchers, and a highly qualified senior design practitioner in the analysis procedure helped reduce interpretation bias as they were not a part of the interview process (Miles, Huberman, and Saldana 2014). This analysis extracted the topics and themes of informants' answers and comments to our research questions.

We conducted five steps to extract the final themes as described in Figure 3. Also, Table 2 describes a typical instance of this procedure with an actual interview excerpt. The first

Table 1. Details of the key informants for Study 2.

	Informant Details		Interview Details	
Infor-mant	Job Title (years of experience)	Affiliation	Venue	Duration (approx. min)
Inf 1	Principal Design Manager (25)	Technology Company, Multinational	CHI	60
Inf 2	Professor (21)	University, America	CHI	60
Inf 3	Design Technologist (20)	Technology Company, Multinational	CHI	60
Inf 4	Assistant Professor (8)	Design School, Asia	CHI	60
Inf 5	Professor (19)	Technical University, Asia	CHI	60
Inf 6	Professor (17)	Technical University, Asia	CHI	30
Inf 7	Design Research Lead (15)	Electronics Company, Asia	CHI	30
Inf 8	UX researcher (13)	Digital Company, America	CHI	30
Inf 9	Associate Professor (10)	Technical University, Asia	CHI	30
Inf 10	Senior Designer (5)	Consumer Electronics Company, Multinational	CHI	30
Inf 11	Assistant Professor (5)	University, Europe	University	60
Inf 12	Professor (22)	University, America	ICED	30
Inf 13	Assistant Professor (4)	University, America	ICED	30
Inf 14	Assistant Professor (11)	Polytechnic, Asia	IASDR	30
Inf 15	Senior Innovation Specialist (4)	Management Consultancy, Multinational	IASDR	30
Inf 16	Professor (40)	University, Europe	Online	60
Inf 17	Assistant Professor (2)	University, Europe	Online	60
Inf 18	Strategy Advisor (9)	Digital Platform Agency, Multinational	Company	60
Inf 19	Senior Designer (6)	Consumer Electronics Company, Multinational	Online	60
Inf 20	Service Design Lead (4)	Consultancy in-housed Design Agency, Multinational	Company	30
Inf 21	Senior Service Designer (4)	Consultancy in-housed Design Agency, Multinational	Company	60
Inf 22	Assistant Professor (14)	Technical University, Europe	University	60
Inf 23	(ex-) Senior Director (35)	(ex-) Healthcare Device Company, Multinational	Online	60
Inf 24	Professor Emeritus (54)	University, America	Online	60

Note: Years of experience of informants is counted from their final academic degree acquisition (most often Ph.D.). The order follows the date of interview.

step was separating sections in each interview. Each interview text was divided into three sections, namely, the issues of interview: comments on the initial vision on collective computing (Section 1), forces that call for new design activities in this upcoming era of collective computing (Section 2), and guidance for developing new design activities for the upcoming era of collective computing (Section 3). The following steps were separately performed for each section.

The second step was interpreting individual interview using descriptive coding. Within a section of each interview, the first author recited the interview text and segmented it in order of flow of various episodes. In addition, all the episodes were marked with a unique descriptive code (Miles, Huberman, and Saldana 2014).

The third step was the sub-categorisation of descriptive code into a topic category, typically related to particular interview questions. It was to have some structural and conceptual order to help the coding process and determine the breadth of data (Blessing and Chakrabarti 2009; Miles, Huberman, and Saldana 2014). The column headers listed in Tables 3, 4, and 5 (under columns of 'Step 3 & 4'), are the topic categories we used for each section.

Table 2. An Example of the analysis of the interviews (Step 1–5).

Step 1		Step 2	Step 3	Step 4	Step 5
Section	Interview Quote	Descriptive code	Topic Category	Topic	Theme
Guidance	Designers are imperialists. They are the dictators. The designers go into a little village in South Korea. They look and send the ethnographers in, who study what's going on. Then you (designer) go back and do your ideation, prototyping, and testing. Then you (designer) go back to the people and say, 'here is a solution to the problem you (user) didn't even know you had'. 'Here's what you want.' It doesn't work. So, what we are saying is that we have to move towards community-based design, where the community knows their issues. They don't need to do ethnography; they live there. Designers have to change. They (designers) have to be mentors and facilitators, but not somebody who comes in and says, 'here's what you need'. (Informant 24)	Designers should not be the one who provides the solution. The community itself needs to be the one who knows their issue and creates the solution.	Description of the guidance	A community by itself needs to act as the researcher. Designers should not provide the solution but be facilitators in aiding the community to realise their own problems and create solutions.	A community drives design
	In this community work, I still follow the principles of human-centered design but are implemented differently. You still want to know as much as you can about the people you're working with and use all the clues. But again, the real change is we are not telling people (community), but we're trying to work with them and help them shape their ideas. We don't take their ideas and just use them because most of the time, the ideas are not going to be complete at any point designers are leaving the project. (Informant 24)	Designers help the community shape its ideas and not just take its ideas because the designer's ideas won't be completed at any point of project.			
	In management, there's a well-known philosophy: if you want to convince somebody about your idea, the best way is to make them think it's their idea. Design is all about changing behaviour. Those are things that will change behaviour. But we want to do it more in a collaborative way. And especially with these complex social problems. (Informant 4)	Make community think design idea is their idea to deal with complex problems.			

(*continued*).

Table 2. Continued.

Step 1		Step 2	Step 3	Step 4	Step 5
Section	Interview Quote	Descriptive code	Topic Category	Topic	Theme
	I agree that with the vision that you're putting forward under collective computing. We need more sort of producers and maintainers if you want to have a distributed vision of computing in collective computing. It's not just enough to facilitate imagination. We need somebody from them, maybe from the community, to take these ideas forward, do prototyping, and maybe see how it works and maintain the system. (Informant 4)	Someone from the community should take the ideas forward to maintain and build the system.			
	…	…	Importance to accept the guidance	Unless the solution is derived from the community itself, the community would not sustainably comply with the solution provided by the designers. …	
	…	…	Strategies to execute the guidance	Be sensitive to the diverse cultures of each community. … .	
	…	…	Challenges to accept the guidance	The community would not recognise the underlying problem and will tend to solve just the symptoms. … .	

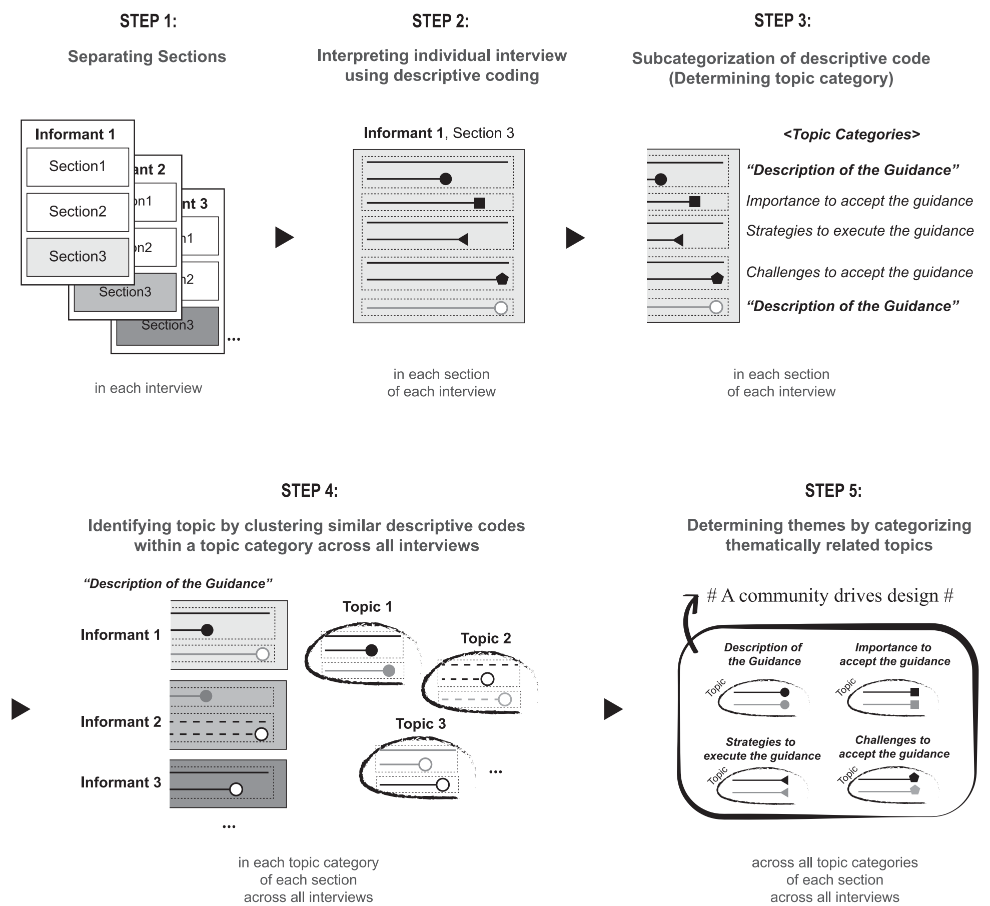

Figure 3. Procedure for structuring the information derived from the interviews by the first author.

The fourth step was searching and clustering similar descriptive codes within a particular topic category to identify and organise topics across all interviews of each section. The clustering of similar codes across all interviews was a challenging task, especially for Section 3, which had multitudes of unique descriptive codes. Thus, filtering similar codes only within a specific topic category provided an outline to the author to navigate and effectively locate similar codes. Subsequently, the author labelled each cluster with a small narrative (Miles, Huberman, and Saldana 2014) and considered it as a topic. In Table 2, the first topic in 'Step 4' column describes an example of deriving such a narrative topic by combining four descriptive codes. Moreover, the complete results of Step 4 are reported in Tables 3, 4, and 5, under the column 'Step 3 & 4'. Other two authors, who are highly experienced senior design researchers, also reviewed and provided feedback on the logical consistency and codes in the second cycle of this step.

The last step was determining themes by categorising thematically related topics. The first author thematically categorised the narratives of related topics across all topic categories of all interviews (within a Section) to determine the final themes. Subsequently, the first author labelled them with initial thematic phrases. In the second cycle, the two

Table 3. Comments on initial vision (modifications based on Figure 2).

Step 5	Step 3 & 4 (*Inf* denotes informant)	
Themes of Changes	Description of suggested change	Reasons for change
Continuum of design activities	Presenting the distinct design activities between various computing eras as a continuum that induces co-existence instead of a sequential development: 'just like fractal' and 'multi-levels rather than timeline.' *Inf 5, 9, 13, 20*	Previous design activities were not forbidden. The low-level design activities (e.g. interface, interaction, or experience) should still occur as fundamental tasks to execute the high- level changes (e.g. system). *Inf 9,13*
Accountable Implementation (alternative to 'ethics and privacy' in initial vision, Figure 2)	Designers face a more considerable challenge than 'ethics and privacy' in the collective computing era: understanding the implementation of the design in the user's context without naively thinking that implementation will occur anyway. *Inf 1,2, 21*	The 'ethics and privacy' constitute a part of 'implementation concern,' but it does not cover all the concerns. Designers in collective computing face difficulty in realising various products with other discipline experts from the early design stage. *Inf 1, 2, 21*

other authors and a senior design practitioner co-developed the final labelling of themes together on which we all agreed together, as presented in the first column (i.e. Step 5) of Tables 3, 4, and 5.

Result of interview Study 2a

Tables 3, 4, and 5 present the results of Study 2a. Table 3 presents the comments on the initial vision. First, multiple informants recommended presenting the design activities as a continuum between various computing eras because the characteristics of the previous era do not disappear but co-exist with successive eras. Second, informants recognised ethics and privacy concerns in the role of design as a component of a broader 'accountable implementation' for designs of collective computing.

Table 4 reports the enabling forces, with the informants mentioned, that will trigger the origination of new design activities. The first theme is 'data as a part of society at large' owing to the multiple and daily-life connections between humans and computers. The generated data can provide a rich understanding of people's actual (and unconscious) behaviour. The second force is 'hyper-connection' within the system that exists by reason of the connectedness and openness of the collective computing system and allows for new combinations of relations, functions and contexts. The third force is 'continuous reconfiguration' that originates as a result of continuous and iterative system updates. Continuous reconfiguration leads to new versions of software and the addition of new functionality and services over the system's lifetime.

Finally, Table 5 describes the eight themes of guidance mentioned by the informants to approach the design activity changes in collective computing. The representative quotes of each theme provide by the informants are shared in Appendix 2. The first theme of guidance is to make the community drive their design themselves; unless the community themselves drives the solution, the community would not sustainably comply with the solution given by designers. Second, designers can have flexible combinations and analyses; designers can analyse the meaning of the data into multiple different values and opportunities, including values and opportunities that depart from the original purpose of data collection. Third, designers need to use mixed data to supplement each data for accuracy and biases. Fourth,

Table 4. Forces Enabling Changes in Design Activities toward Collective Computing Era

Step 5	Step 3 & 4 (*Inf* denotes informant)		
Themes of Forces	Description of force	Importance of accepting the force	Challenges against accepting the force
Data as a part of the society at large	A large quantity of computing is embedded and connected to all the contexts and diverse societal aspects of people's lives, thereby generating high accessibility to data. *Inf 1, 5, 14, 17*	There is already abundant data aggregated for people's behaviour; moreover, people are unaware of their own behaviour in a holistic view. *Inf 1, 12, 17*	Only large companies possess complete access to the data, as they have tracked it with their existing services. *Inf 10*
Hyper-connection	The advanced intelligence of computing (each computer can collect as well as analyse data on its own without communicating to a central computer) allows connectedness and openness between contexts and connection to various subsystems and extensions. *Inf 15, 16, 22*	Computing is already well-embedded in society and has established its relationship with the society, e.g. collective computing tracks people's behaviour (through smart objects) and decides on its own the actions required in a related context. *Inf 16*	A nonlinear, complicated user journey (multiple entry and exit points) is created. Thus, only certain corporations with enormous database can correctly predict the complicated user journey. *Inf 15*
Continuous reconfiguration	The system is iteratively and continuously reconfiguring over a single human lifetime by adding several contexts and versions to each other. *Inf 9, 16*	Software aspect is emphasised in collective computing. Companies do not create new products, but they produce new versions or extensions of the existing products or services. *Inf 2, 13*	This continuous reconfiguration may continuously pose the designers with novel risks and responsibilities as compared to that at current disposal. *Inf 1*

the informants also recommended designers to be comfortable in re-designing societal transformative forces without focusing on the single-user or single-issue problems. Fifth, designers would develop multiple soft launches with a modular design. It helps to have a constant loop between learning-from-users and development. Sixth, the implementation should happen in an actual living context of users – to allow them to experience a potential future (technological) situation that is difficult to imagine or has quite not happened yet. Seventh, informants mentioned exploring and being careful about unintended consequences. There are constant new risks and responsibilities owing to the complexly interrelated contexts, real-time changes, and the systemic nature of collective computing. Eighth, designers need a transdisciplinary vision of the value and control of the design output. This means to adapt various approaches/perspectives from various disciplines, such as extracting meaningful information, identifying valuable data resources, dealing with ethics or privacy issues.

Reflection on the result of interview (Study 2a)

Of the 24 informants, 11 from academia and six from industry contributed new insights over and above those already found in the existing literature in Study 1. Thus, we conclude that the empirical part of Study 2 contributes to the existing literature, and perhaps a little more as a new field for academic exploration than as a sufficiently matured design practice in industry. An example of new insight is that design activities gradually change over the different eras, with new activities growing out of older, more established activities. This view diverges from the literature that portrays *changes in design activities* without pointing to how *old and new design activities are related*. This insight will be used in Study 2a to improve the initial vision.

Reflecting on the particular contributions of those who added novel insights, we could not clearly distinguish between academic and industry informants. No persistent differences arose between the two groups, and the likely reason is that most informants held positions that allowed for considerable access to insights from both fields. Finally, we note that all the informants accepted the central tenet of our initial vision. They agree that there is a new upcoming era in modern computing that is relevant for designers, and that the initial vision of collective computing (Figure 2) is an appropriate starting point for discussing upcoming changes in design activities.

Study 2b: Constructing a vision (based on the interview results)

Research method

As in Study 1b, we created a vision based on a constructivist mindset, with the same accounts for this approach's inherent interpretation as before (see Study1b). The goal of Study 2b was to create a vision of design activities in relation to collective computing, based on the interviews with informants (Study 2a). For this purpose, we interpreted and synthesised the themes from the interviews, and created Figure 3 with the vision, as an improved and more complete version of the initial vision of Figure 2.

We compiled the results of the interview study into the vision on which we co-reflected with experts from academia ($N = 2$) and industry ($N = 3$), seen by their peers as frontrunners in the field to validate our interpretations. These design experts had not been informants in the interviews in Study 2a, nor were they involved in the analysis of the interviews.

Table 5. Guidance for the design changes in collective computing era.

Step 5	Step 3 & 4 (*Inf* denotes informant)			
Themes of guidance	Description of guidance	Importance of accepting the guidance	Strategies to execute the guidance	Challenges against accepting the guidance
A community drives design	A community by itself needs to act as a researcher. Designers should not provide the solution but be facilitators in aiding the community to realise their own problems and create solutions. *Inf 4, 23, 24*	Unless the solution is derived from the community itself, the community would not sustainably comply with the solution provided by the designers. The system continuously reconfigures so is never completed with the designer's solution at any instance. Therefore, the community itself needs to know to build the system by continuously exploring itself. *Inf 23, 24*	Be sensitive to the diverse cultures of each community. Designers are required to design the platform that will be used by the community to design the process on its own. *Inf 5, 13, 24,*	The community would not recognise the underlying problem and will tend to solve just the symptoms. The community can comprise billions of individuals, where each individual follows unique cultural/social norms. *Inf 24*
Flexible combination and analysis	Be aware that the perceived meaning of data can be utilised for multiple, different values and opportunities in comparison to the original purpose for which it was collected. *Inf 2,17*	Data can explain the users as well as the surrounding contexts. This provides a new approach that the designers are unable to formulate on their own. *Inf 2, 4*	Story-telling and inferencing skills assist designers in flexibly interpreting data. This is less fixated on user-centeredness. Data can be used to represent and be used by an individual other from the source of data. *Inf 2, 14*	– –
Use mixed data	Presence of constant combination loops between qualitative and quantitative data. *Inf 12, 14,15,21*	Be less biased or determine the root cause of deviation/variation to supplement each data with accuracy and target the most impactful opportunities. *Inf 2,12, 21*	Use quantitative data for identifying anomalous patterns, and use qualitative data for exploring the driving cause of the pattern. *Inf 2, 12*	The data format is often not formatted in a way that designers would prefer to use, because the data was usually collected for a different purpose. Decisions made on the selection of data sources can be biased as well. *Inf 21*

(*continued*).

Table 5. Continued.

Step 5	Step 3 & 4 (*Inf* denotes informant)			
Themes of guidance	Description of guidance	Importance of accepting the guidance	Strategies to execute the guidance	Challenges against accepting the guidance
Work on social forces at a system level	Be comfortable with changes in high levels of problems without focusing on the individual-level of user problems to create transformations in the society, e.g. Re-arrange stakeholders – identify the benefits of various stakeholders and discover the stakeholders with hidden potential. e.g. Consider policy with a higher priority in the design process. The policy effectively triggers a large-scale change and poses a direct influence on the user behaviour. *Inf 2, 5, 23*	Current design issues are broader and more complex than designers consideration. Therefore, designers are required to work on the most impactful area to modify that complex issue for best results. *Inf 2, 5, 24*	Hypothesise the greatest risk situation during the design process, e.g. lacking properties at the industry, high product cost, or policy problem. Outline the system by focusing more on interaction than users, such as capturing values in data flows between stakeholders, intangible values, and experience. The alterations in this complex system are never achieved only through the designers' efforts. Thus, interacting with other disciplines is necessary, such as policymaker. *Inf 2, 20, 21*	– –
Develop multiple soft launches with modular designs.	Designers dissect a design project into various granularity levels that continuously expand to new levels (modular design) during implementing minimum viable products and constantly develops its design in its course (soft launch). *Inf 2, 17, 21, 24*	Provides constant chances for testing assumptions and determining the correct design rationale with continuous exposure to new problems for resolution. Designers are relieved from attempting considerable risk (a small negative change does not account significantly in the end). Provides adequate time for learning and building the trust with clients by demonstrating continuous progress toward completing a huge system design. *Inf 21*	Start from the most impactful or short-term future problem and continuously explore in terms of completeness of design (e.g. function), number of the target group, types of stakeholders involved. Establish a seamless connection between the generative question pertaining to user behaviour and building the prototypes. *Inf 15,20, 21*	Determining the finishing mark of the current step and transmission to the following stage is challenging. *Inf 20*

(*continued*).

Table 5. Continued.

Step 5	Step 3 & 4 (*Inf* denotes informant)			
Themes of guidance	Description of guidance	Importance of accepting the guidance	Strategies to execute the guidance	Challenges against accepting the guidance
An experiment in users' living environment.	Implementing the prototypes in users' living environment to be constantly interactive between users' feedback and design development. *Inf 1,9, 16, 21*	To allow users experience and opine on the potential future technological situation that has 'quite not happened yet,' as users often cannot adequately describe an experience that they are yet to experience. To identify the interdependencies and unexpected problems of the system that are too complex to easily imagine, such as an emotional relationship in a family. Convenience and openness to releasing high-fidelity prototypes with reasonable costs. *Inf 1,5,16, 22*	Establish the appropriate KPI of each experience moment to measure the reflection on the technological vision. *Inf 21*	Characterisation of performance with appropriate KPIs – the corporation often requires to modify its original methods of measuring the performance, which is extremely difficult to adjust with. *Inf 21*
Transdisciplinary vision on the value & control of the design output	Integrate the working approaches from various disciplines, industries, and companies at the most fundamental stage to realise the design; adapt various approaches from alternative domains on the values and control of design output. e.g. extract meaningful information or design opportunity, identify valuable data resources, and communicate the reasons influencing the decision. One discipline, industry, or company cannot solve entire aspects of the systems. *Inf 1, 2, 20, 21, 24*	The design realisation of this complex system is not achieved only through the designers' efforts or one industry/company. Various stakeholders require different values (being aware of the distinct challenges) to implement a new design variation, e.g. the designer is aware of the people's needs/desires, whereas data scientists are aware of the information that can be extracted from the data. For instance, both economic growth and social prosperity are required to be simultaneously explored for building a new city. *Inf 2, 20, 23*	Manage all concessions between the various disciplines and industries involved in the scenario. Be flexible and constantly negotiate to modify ideas according to the claim of each other's domains, e.g. negotiation with policymakers to promote adequate regulations regarding the design task. Build trust among various stakeholders by showing that they are working on the same project in different parts and scales. *Inf 2, 5, 21*	– –

(*continued*).

Table 5. Continued.

Step 5	Step 3 & 4 (*Inf* denotes informant)			
Themes of guidance	Description of guidance	Importance of accepting the guidance	Strategies to execute the guidance	Challenges against accepting the guidance
Explore and be wary regarding unintended consequences	Traversing from utopian perspectives to be willing to explore unintended consequence: thinking about the appropriateness of the designers' selection for building and being careful regarding unintended consequences and manage unanticipated situations.	Technological companies are currently asked to be more careful (owing to AI development) regarding respecting people's privacy, e.g. users have even started questioning the purpose of data acquisition and are concerned regarding the personnel managing the user information, such that privacy is respected. Design research constitutes the final task for people, in which designers should not impose negative influence by conducting design research.	Employ a speculative design approach to visualise ultimate futures that is currently more accepted in many technological companies. Start questioning the ethical consequence of the designers' creation. Raise the correct question during the design process, prior to focusing on the development of the artifact.	–
	Inf 1, 2	*Inf 1, 4, 14*	*Inf 12, 17, 22*	–

They were a vice president and two senior directors of the design sector of a front-runner company in design methodology (a multinational major health technology company with more than 400 design employees), and two professors of a computing-driven design lab in Europe and a social innovation design lab in Asia.

Results of Study 2b

Synthesised themes of guidance. The first synthesised guidance included 'addressing a community by engaging with their data,' which results from rephrasing a guidance interview theme: 'A community drives design.' This was executed to express the designers' need to incorporate direct and extensive community involvement in design processes more appropriately. As several informants suggested, unless the need for design is derived from the community itself, the community would not sustainably comply with the solution provided by the designers. Further, the community requires its own information regarding the continuous redesign of the system, because systems in the collective computing era are never completed at any instance of the solution delivered by the designers. However, we rephrased this as designers 'engaging with community data,' instead of letting all the community members directly drive a design process, as the ideal of certain informants – to let a complete community drive a design process – might pose an insurmountable challenge and neglect the fact that community-level data are already becoming publicly available and abundant for designers to work with. As an example, members of an online community can publish their opinions or data traces on online social platforms, reflecting the entire digital presence of the community. In such circumstances, designers can act as the creators of information systems that continuously self-learn and self-analyse based on data that communities publish in digital spaces. Accordingly, communities can self-define their problems and independently develop solutions with such systems in a continuous manner.

The second element of synthesised guidance is that designers should progress toward the 'flexible combination and analysis of mixed data,' which results from combining the two interview themes: 'flexible combination and analysis of data,' and 'use of mixed data.' The integration of these interview themes provides concrete and integrated guidance that designers can simultaneously execute within a design process. Moreover, designers are reminded of the various possibilities of data, other than the original purpose for which it was collected, and potentially for other users than those providing the original data. At the same time, designers can be reminded to use various data types to boost data accuracy and reduce unwanted biases in the data interpretation.

The third synthesised guidance theme is that designers must 'work on social forces at a system level,' instead of merely focusing on individual users' problems. Currently, designers address complex collective computing systems that are hyper-connected to widely diverse parts of the society. As suggested by (Van der Bijl-Brouwer and Malcolm 2020), a societal impactful force cannot be addressed by a single design effort, i.e. designers cannot create an entirely new world. This indicates that designers should be comfortable with the notion of executing small adaptational steps of redesigning system parts, such as working with policymakers to realise system changes for effectively influencing society.

The fourth synthesised guidance theme specifies that designers in collective computing should start 'developing multiple soft launches with modular designs.' Two interview themes are combined in this: 'an experiment in users' living environments,' and 'developing multiple soft launches with modular designs.' It is because soft launches already mean

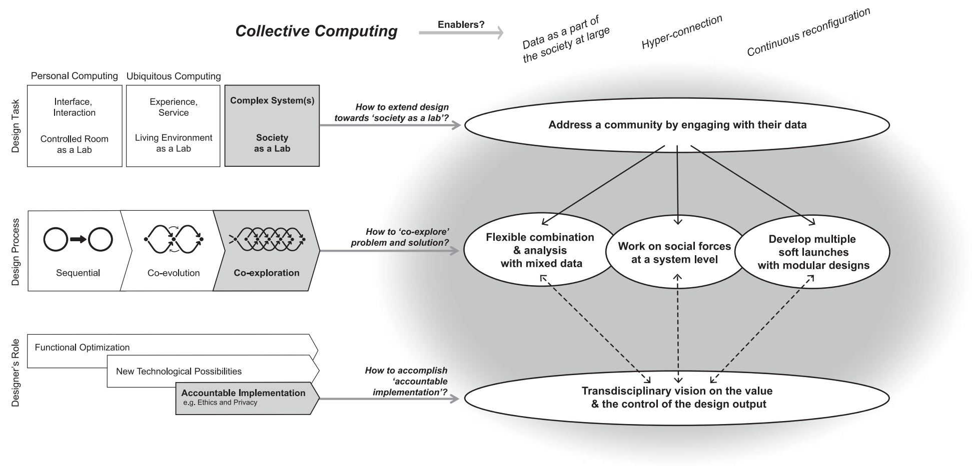

Figure 4. A vision of design activities in collective computing era.

to continuously release and implement new updated versions in a living social context. Moreover, 'modular design' signifies that designers will gradually progress toward more complete designs in collaboration with larger networks. As the design and development process would decompose into numerous small steps, learning from small failures (as a powerful learning mode) could therefore become a more acceptable and tenable option.

The fifth synthesised guiding item is about a 'transdisciplinary vision of the value and control of the design output,' which is the result of a larger interpretation of the interview theme under the same name, together with another interview theme, 'explore and be careful about unintended consequences.' This second interview theme can be seen as a component of displaying a transdisciplinary vision on the control of design output. Such a vision implies the acceptance of various approaches and perspectives from various domains of expertise, learning to speak the languages of these different domains more fluently to extract meaningful information, identifying valuable data channels, and managing implementation issues such as ethics or privacy concerns. In contrast to the more utopian perspectives on the contribution of design in past eras of personal and ubiquitous computing, our vision considers the degree of control over design outputs as a matter of debate, with an open mind toward the unintended consequences of design and a more critical stance towards the appropriateness of design considerations. In collective computing, there are constant new risks and responsibilities arising from the complexity of interrelated contexts and real-time group dynamics of using new designs. In other words, no one specific industry or discipline can work alone to make a completely working collective computing systems, but rather, widely varying groups must work together to varying extents to operate productively in the new environment.

Establishing a vision figure. The vision of design activities in the collective computing era is presented in Figure 4. It yields a comprehensive overview of the design activities to be carried out in the collective computing era.

The left-hand side of Figure 4 is the modified version of the initial vision from Study 1 (Figure 2), portraying the design activity changes over three computing eras. Based on the interviewee's comments on Figure 2, modifications were conducted to organise the design activities between different computing eras in a continuum. In addition, the designer's role in the collective computing era is currently indicated as 'accountable implementation' (ethics and privacy concerns being only one aspect of accountability).

The right-hand side of Figure 4 shows the identified enabling forces (top) and the five synthesised guidance themes (white ovals) driving design activity changes toward the collective computing era. The five guiding themes were assigned to the corresponding design activity related to the design task, the design process, and the designer's role.

In addition, we explored the impact of the synthesised five guiding items (white ovals, guidance) on one another and indicated the influence flow using black arrows between the guidance themes presented in Figure 4. As observed, the guidance on design tasks influenced the execution of the design process, which consequently influenced the designer's role and vice versa.

Finally, the relationship between the left- (design activity changes) and right-hand sides (guidance) was indicated using driving questions on the application of the renewed design activities in the collective computing era.

Contribution to design practices and methods: applying the vision to a design project

We tested if the vision could be supportive for designers, and if the guidance it provided was actionable. We asked a graduate (master) student to design a new digital healthcare system while using our vision of collective computing for inspiration and guidance. The aim of this project was to design a system that promotes the physical activities of children with congenital heart defects (CHD). The student found the solution to this problem in co-creation with medical experts from a Dutch university-level hospital. Figure 5 illustrates the storyboard and shows the system map of the solution. It consists of an activity tracker for the child, a chatbot for parents with which they can talk to medical experts in case of concerns or emergency, and a dashboard for the medical experts. By sharing data about the conditions of the child, it is possible to generate a better understanding regarding the condition and share responsibility between the caregivers and the medical staff regarding the children's safety boundaries.

The actionable guidance of the vision that the student mainly applied while designing the collective computing system was based on the guide items: 'address a community by engaging with their data', 'work on social forces at a system level', and 'develop multiple soft launches with modular designs'. The student's strategy to address the community was to analyse hundreds of online parental stories from various social platforms used by patients (using text mining techniques) and extract the parents' behaviour towards their children given a timeframe. This analysis defined fundamental issues regarding parents' overprotective behaviour; the student found that parents constantly and restlessly looked for symptoms. The student worked on how the responsibility of parents, who are worried about themselves being unaware of the symptoms, can be addressed (addressing a community), and shared (social forces at the system level). The student then divided the system into three levels: modules, sub-modules, and functions (as described in Appendix 3) and

Figure 5. Storyboard and system map of the first sub-module on which the vision is applied (created by the student).

soft-launched one sub-module in six CHD children's families (sub-module titled 'real-time worry line' and as described in Figure 5). The project is currently in progress, with new iterations and soft launches on various sub-modules. One added sub-module is illustrated in Figure 6; clinical researchers support the medical staff decision making through bio data-driven prognostic models, while the CHD children (parents) provide valuable health and activity data for child exercise activity studies. Eight other sub-modules are described in Appendix 3.

The student stated that the experience of using this vision was inspirational, by reminding and reinforcing herself on becoming a successful system designer throughout her design process. Applying the vision and guidance brought new directions to the existing design processes in multiple ways. First, the designer (student) could identify the collective needs and challenges and compare them with those of individual patients (going beyond the inclusion of only a limited number of users in a conventional design practice). Second, the insights from community-level data allowed solutions at a system level

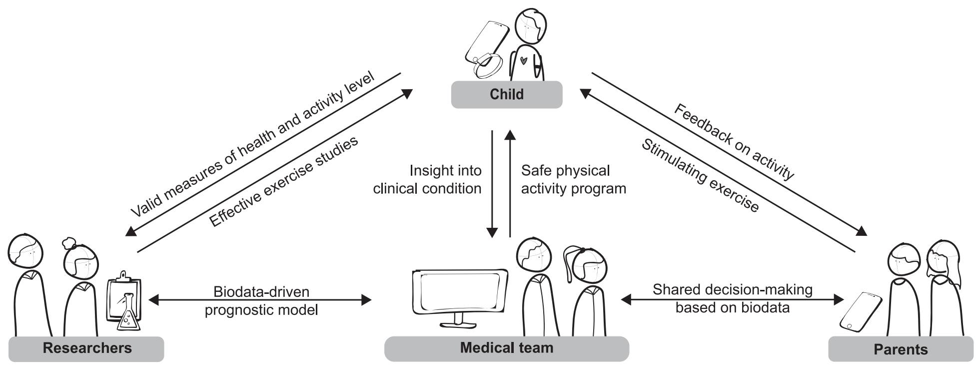

Figure 6. System map of the second sub-module on which the vision is applied.

because these data indicate a broader perspective on users' challenges and needs. This allowed the designer to involve a new stakeholder group (i.e. clinical researchers) and assign an additional role to them. In this way, the vision helped the designer expand her approach to improving the system and information value for a broader 'collective' of patients, parents, the medical team and clinical researchers. It is different from designing more user-friendly interactions and experiences between the already selected stakeholders of the first sub-module (i.e. parents, child, and medical experts). Third, the modularity approach provides the designer continuous resources (e.g. sharing the implementation result of the first sub-module awarded the project a grant and attracted other experts to join the project). Moreover, it provided the designer with a manageable workload and a better-defined set of responsibilities than when she would be designing a complete system at once (e.g. while receiving the clinical research approval, defining potential risks that may raise to the patients within the limited context was more accessible than exploring them in the complete design).

Discussion and conclusion

The present work contributes to the existing historical and visionary literature on disruptive changes in *what we design* (see e.g. DesignX (Norman and Stappers 2015), fourth generation design (Jones 2014), the fourth order of design (Buchanan 2001)), and it does so in connection to another, more ongoing discussion on how modern computing continues to change *our way of designing* (see e.g. Andreasen 2011; Cooper 2019; Cross 1999, 2018; Liddament 1999). Regarding the latest developments in modern computing, several design researchers and practitioners have noted that disruptive modifications are taking place that challenge the way we design. Hence, in Study 1 we developed our initial vision on advised changes in design activities for the collective computing era, and thereafter, tested and revised this vision in Study 2. In the envisaged collective computing era, we argue that designers use 'society as a lab' by addressing communities and engaging with their data. Moreover, designers can 'co-explore' design problems and solutions almost simultaneously by considering the flexible combination and analysis of mixed data, working on social forces at a system level, and developing multiple soft launches with a modular design. Finally, designers act to ensure an 'accountable implementation' by incorporating a transdisciplinary vision on the value and control of the design output. The potential of this vision to inspire designers was accurately gauged by presenting the vision to several decision-makers in design fields.

A potential weakness of our approach may be a degree of what Manzini (2016) (Manzini 2016) termed as 'solutionism.' The limitation of the constructivist mindset might be that it solely focuses on the functional and/or practical benefits of an approach, and thus that it is lacking in depth and unable to motivate participants or inform a social conversation with all affected, regarding the designed future of computational systems. While we see this limitation in our approach, we have tried to remedy this by initiating open discussions in Study 2 through the interviews with key informants. This helped to further explore and validate our vision, and consequently, we compiled their advice as a single model of guidance. We also found that all the informants were keen to remain within our framing of collective computing, even when we invited them to widen the discussion and go beyond this framing. Further, the potential of this vision to inspire designers was accurately gauged by several decision-makers in design fields – both at industrial organisations and academic institutions, including a leading company in design methodology (a major multinational health technology company), a computing-driven design lab in Europe, and a social innovation design lab in Asia. They confirmed the conceptual clarity and novelty of the vision, and were ready to accept this vision and adapt it according to their practices. From a constructivist perspective, we could express that the vision is 'a house built with many borrowed bricks.' Thus, we believe that our constructivist mind has been open to debate and criticism, allowing us to create a firm vision of a future of design in relation to upcoming computing developments.

In addition, our results have significant implications and potential in social design, which focuses on solving social challenges. According to Manzini, 'social innovation' is a new design stimulus and objective, different from technical innovations from the past (Manzini 2015). Presently, designers incorporate positive social changes such as sustainability (Manzini 2014). Irwin et al. argued that 'transition design' can design for a societal transition toward more sustainable futures by addressing grave problems such as climate change, loss of biodiversity, depletion of natural resources, and the widening economic inequality (Irwin 2015; Irwin, Kossoff, and Tonkinwise 2015; Tonkinwise 2015). However, in the concept of collective computing, these social challenges are prevalent in a world where many individuals interact with many others through multiple computing devices. Thus, the designers' attempts to solve societal challenges should inevitably consider the technology-embeddedness of society. We believe that our research can act as the conceptual bridge between technology-driven and social design; it further allows us to explore the meaning of 'society' from a technology-oriented perspective and that of 'technology' from a perspective rooted in social innovation design.

Our future research focus is to develop and validate design tools that support designers in the era of collective computing, to *co-explore* with *community-level data* while designing *complex systems* in healthcare. The next step will be applying the vision and its actionable guidance in design settings that are broader than a student project. In addition, we will explore how technological solutions such as machine learning (including text mining and artificial intelligence) can benefit from the application of the vision to design practice. Lastly, we will further explore how community-level data can be combined with individual-level data to design collective computing systems. For example, how can we effectively combine highly private medical data (e.g. bio-data) with publicly available community-level data (e.g. online stories).

To conclude, we believe that the vision of the upcoming design activities of the collective computing era formulated herein can inspire both industry and academic designers with guidance that actively promotes design at the leading edge of the collective computing era.

Note

1. Double coding means to have a time delay in between two iterative cycles of coding process by same person or coded by two independent researchers for higher reliability of the coding results (Blessing and Chakrabarti 2009).

Acknowledgement

We appreciate Hosana Morales for using the vision in her master graduation project and for sharing her experience, as described in the contribution section. Also, we express gratitude to all the informants who share their vision in Study 2.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendices

Appendix 1. Design activities for the personal, ubiquitous and collective computing eras.

	Personal Computing (PC)-relevant design activities	Ubiquitous computing (Ubicomp)-relevant design activities	Collective computing-new design activities (extrapolated)
Key technological issue	Competition on the user-friendliness of computer systems and development of the Internet (Grudin 2007; Pew 2002)	Portable computers with low-cost tagging and transmission technologies (Want 2010)	Cloud computing and digitalised behaviour of crowd through advanced Ubicomp devices (Abowd 2016)
Task (design object)	Interfaces and interaction (Burns et al. 2006; Powell and Cooper 1994; Winograd 1996)	Experience and service (Desmet and Hekkert 2007; Secomandi and Snelders 2013)	Complex systems (Buchanan 2001; Jones 2014; Norman and Stappers 2015)
Underlying reasoning	Interface and interaction designers considered human factors (Löwgren 1995; Pew 2002; Shneiderman 1980; Winograd 1996). The design of webpages or software applications is directly related to information retrieval time (Grudin 2007; Pew 2002). Internet applications such as World Wide Web, e-mail, and online games changed the ways users (including designers) work, communicate, and entertain themselves (Grudin 2007; March 1994; Pew 2002; Rodgers and Huxor 2000; Zimmerman, Forlizzi, and Evenson 2007).	Devices carry less significance than the experience they provide; extensive user journey included before and after using the computing devices, instead of exploring only the specific moments of use (Pine, Joseph, and Gilmore 1998) Inherent embedment of computers in everyday practices increased the degrees of freedom in the design (Want 2010)	Advanced technologies have enabled unique massive connections between multiple computers and users (Abowd 2016; Höök and Löwgren 2021). The physical world of people blends with a constantly updating digital world (Friedman 2019; Höök and Löwgren 2021; Speed and Oberlander 2016; Verganti, Vendraminelli, and Iansiti 2020). Involves multiple layers of social and economic contexts sourced from the crowd (Friedman 2019) with conflicting agendas between different stakeholders (Höök and Löwgren 2021). System with autonomous analysis and prediction (Höök and Löwgren 2021; Verganti, Vendraminelli, and Iansiti 2020).
Task (design research)	Controlled Room (Hughes et al. 1994; Rogers 2011), e.g. effectiveness of the interface design for construction information sharing multimedia system (Powell and Newland 1994), virtual window on media space (Gaver, Smets, and Overbeeke 1995), meaningful gestures for HCI (Hummels and Stappers 1998), age factors in layered user interface (Rama, de Ridder, and Bouma 2001).	Living Lab (Brush 2009; Dell'Era and Landoni 2014; Feurstein et al. 2008; Rogers 2011; Taylor 2016), e.g. Aware Home (Kidd et al. 1999), Cooltown project (Barton and Kindberg 2001), Projects from ENoLL (Dell'Era and Landoni 2014).	Society as a Lab (Baek et al. 2018; Baek, Meroni, and Manzini 2015; Gardien et al. 2014; Hummels and Frens 2008, 2009), e.g. Lighthouse project (Van Galen, den Ouden, and Morisson 2020), The Box ("The Box" 2020), SynchroniCity ("SynchroniCity" 2020).

(*continued*).

Appendix 1. Continued.

	Personal Computing (PC)-relevant design activities	Ubiquitous computing (Ubicomp)-relevant design activities	Collective computing-new design activities (extrapolated)
Underlying reasoning	Explore certain moments in computer usage, e.g. the moment of locating the menu button on screen (Mayhew 1999). Retain users' attention from being distracted or from anything else that could confound the user testing results, such as family assistance (Rogers 2011)	Explore such overarching user behaviour (Brush 2009).	Issues pertaining to scaling up (Brown, Bødker, and Höök 2017; Maeda 2018). Design a complex system that requires both societal and personal understanding of users (Gardien et al. 2014; Whitworth et al. 2006); research in design becomes a more constant occupation, and more integrated with the rest of the society to allow for a seamless and iterative process (Höök and Löwgren 2021).
Prevalent Design Process	Problem-solving process (Shneiderman 1980) -term is from (Simon 1988) Problem definition is independent from the delivery of solution spaces in the design process, and can therefore, be handled sequentially, e.g. Virtual window on media space (Gaver, Smets, and Overbeeke 1995), GUI for laboratory instruments (Herman and Aburdene 1991)	Co-evolution of problem and solution- term is from (Dorst and Cross 2001) Problem and solution spaces constantly change and influence each other, e.g. Smart rehabilitation shirt (Ten Bhömer et al. 2013).	Co-exploration of problem and solution (Giaccardi and Redström 2020; Höök and Löwgren 2021; Hummels and Frens 2008, 2009; Stienstra, Bogers, and Frens 2015) Analyse the problem and implement the solution in overlapping processes. The problem space and solution space are extensively merged and became increasingly coupled, e.g. Connected bottle project (Van Kollenburg et al. 2018).
Underlying reasoning	Problem space frequently formulated by software developers as a form of user-requirements & usability efficiency (Burns et al. 2006; Jokela et al. 2003; Pew 2002).	Extensive user journey explored in living lab indicated that the design problem cannot be defined at a certain point of the design process, but it continually evolves and modifies based on the results (Dorst 2006; Hatchuel 2001).	New developments in sensor and computing algorithm technologies facilitate the acquisition, analysis, and synthesis of extensive amounts of user data across various usage contexts of use by designers in real-time (Gorkovenko et al. 2019), and without any scale-limitation (Verganti, Vendraminelli, and Iansiti 2020). Sensors embedded in products and services (e.g. smartphones) collect countless behavioural and location data in real-time (Höök and Löwgren 2021) from their actual use in the wild (Churchill 2017). The use of an algorithm, such as machine learning, implies that a system will evolve by the collection of continuous streams of data (Verganti, Vendraminelli, and Iansiti 2020).

(*continued*).

Appendix 1. Continued.

	Personal Computing (PC)-relevant design activities	Ubiquitous computing (Ubicomp)-relevant design activities	Collective computing-new design activities (extrapolated)
Role of the Designer	Functional optimisation of current practices and evaluation of final design proposals (ISO/IEC 1998; Ritter, Baxter, and Churchill 2014), e.g. The Eight Golden Rules of Interface Design (Shneiderman 1997), Criteria for effective interaction design (Alben 1996).	Exploring new technological possibilities that can alter and disrupt user behaviour (Brush 2009; Rogers 2011), e.g. Research through Design Projects (Stappers and Giaccardi 2017).	Consider the ethical and privacy issues to address unintended misuse (Benton, Miller, and Reid 2018; Bourgeois and Kortuem 2019; Giaccardi and Redström 2020; Lazar et al. 2016; Nelson and Stolterman 2014), e.g. Ethical tools for designers (Gispen 2019), IDEO's Ethical AI Card and Principles (Sampson and Champman 2019).
Underlying reasoning	Design standards, structured principles, and guidelines were often developed to guide other designers (Ritter, Baxter, and Churchill 2014; Shneiderman 1980).	Technological development such as actuators, sensors, and easy-programming tools (Grudin 2012; Pew 2002; Want 2010). More attention on novel interactions and experiences of emerging technologies in design practice (Brush 2009). The emergence of speculative design – design is provocative rather than predictive or prescriptive (Dunne and Raby 2013).	Changes to complex systems that can impact society (Jones 2014; Norman and Stappers 2015). Design constantly learns user behaviour and updates/changes its form through its embed learning system (Friedman 2019; Speed and Oberlander 2016) Designers decides on changing product design without complete knowledge or certainty (Nelson and Stolterman 2014).

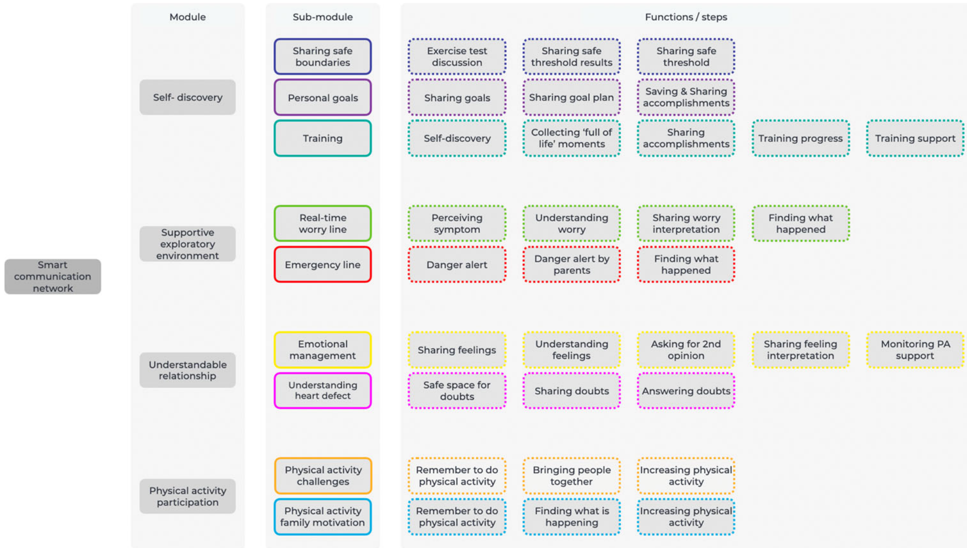
Appendix 2. Representative Example Excerpts from the Interviews for Each Theme of Guidance (Study 2a).

Themes of Guidance	Representative Example Quotes from Informants
A community drives design	'Unless the community buys into the argument and understand-and-accept this is what we've been talking about, they won't accept it. They won't use it. … But again, the real change is we (designers) are not telling people (community), but we're trying to work with them and help them shape their ideas. We don't take their ideas and just use them because most of the time, the ideas are not going to be complete at any point designers are leaving the project.' - Informant 24 'End-users nowadays design and create their own things or even systems but they are not design experts. So, the designers' role would be designing the platform for them. Building such a platform is closely related to the current design researcher's role: the design researchers develop design methods for research. It seems that the design practice level is gradually becoming closely connected to the design research. Designers are needed to design a platform for co-exploration and co-evolution for a community- end users. These days, there is a lot of studies about social innovation and community-driven innovation because it is easier to get societal and communal insights.' - Informant 5
Flexible combination and analysis	'With user cantered design, we only considered with users' needs. We were fixated. The users use emails but they do not tell designers 'oh email is resource.' But designers need to further think about 'what can I do with this?' … Because it is a sort of reversing your perspective looking out to say what are my possibilities in the other direction and to start looking at (the data) resources … There is a core dependency of data. If you do not have data, you cannot build a data model. So, when you do upfront research, you need to be sensitive for seeing data. We need to be less fixated on users. … But we still keep the user at the centre; when we are fluid, we have to let it go. Because when you make a discovery out of data, it's almost never about the user. It's about everybody that is not the user that is creating data. That's probably valuable for someone else.' – Informant 2
Use mixed data	'Now in collective computing era, you can actually combine qualitative data and quantitative data. So, it is much easier to persuade your client. You can start with the user behaviour data and find the reasons behind the data. … The qualitative data helps you to understand where to look; these are 20 problems or opportunities that have found. Then, by using quantitative data, we find out which problem or opportunity impacts people or organisations the most. So, by combining the qualitative and quantitative data, I've got these three the most important ones among these 20 opportunities. Then, we go back to qualitative to contextualise further these three problems today and deep into them again. So, it's like a constant loop of putting qualitative and quantitative data next to each other to see where there is overlap. … It makes you far more effective as a designer in choosing what problems to tackle because you have all of the sudden access to this huge amount of data. You will not have the time to research the entire context of all the stakeholders of all the interactions in the complete ecosystem. But mapping those ecosystems allows you to understand where to deep dive in.' – Informant 21
Work on social forces at a system level	'In these times, we also are sending and receiving data. We were also going through a co-evolution process of users and companies. Because we see the implications of data now, we suddenly have to zoom out of the personal level to a societal level. Because we can see also the impact on society through data.' – informant 20 'We have this very formal manufacturing point of view; how do I resolve what the design is … This is not what we do anymore (in collective computing era). Because we're trying to fundamentally make a system. So, we need to look and say what is the thing that will kill my system. … You sort of need to see which the big forces are sort of locked into a functional ecosystem. How would I rearrange those to be disruptive? But, I don't actually need to go super down when I'm trying to get into the individual behaviour of a person. I don't need the detail of the whole system. … But then there are almost always policy approaches that are just going to be way more effective at triggering large scale change. … We are moving to a new place where we will design things and policy at the same time. Because in some cases, rules are more effective than things. … Often, it's the intersection of the two that actually get us where we want to be.' - Informant 2

(*continued*).

Appendix 2. Continued.

Themes of Guidance	Representative Example Quotes from Informants
Develop multiple soft launches with modular designs.	'So, you might start with a very small problem. You're trying to understand and make a few artifacts which help you understand that problem. It is also called as 'world-building' because you can then keep adding pieces on. If that raises a new problem or a new issue you can make another artifact expand it and expand it. It's never going to be a virtual simulation of the world. You can grow from that focused context to a slightly larger one over time.'- informant 17 'The next project will take the learnings from the first one and slowly understand what that means.' – informant 23 '[T]ry not to go overly deep in your first few iterations. We start to do something quite simple first and to test. We can never be sure until we visit to more people. So increasingly as we move from smaller experiments and tasks to a larger group. We try to then increase the resolutions of each of the prototype to make it more and more real.' – informant 15
An experiment in users' living environment.	'Implementing in real world is not a different method than what we have used before. But it's more applicable in collective computing era because you can start to think about the interconnections that might occur. People can't imagine. It's very difficult to imagine all the different levels of interconnections and also the levels of security breaches, the ethics issues, the trust issues and the privacy issues. Then, you start with a system of interconnected to which objects in the space. … What we're doing is experimental. I mean, you have to set up the experiment in order to understand the different inter-dependencies. So, the living room of the future we actually had three exhibitions where we put the lab in the Tate Modern in London. The visitors come to the museum into the lab and we were extracting their reactions to it. Their reactions on privacy, ethics, trust, the whole thing. That's why we came to be thinking about designing.' – Informant 16
Transdisciplinary vision on the value & control of the design output	Now the world is so complex that you cannot know everything. So, you need to know how to pair up or team up with different expertise. Different people guard different parts. – informant 20 Starting to understand how other disciplines think and work is needed to designers - involving in your facilitation skills. People work in entirely different ways and have a different way of thinking. You need to understand why they do their job, what their secret agenda is, or what they are trying to achieve. … Make sure your idea is desirable to the people, the stakeholders in the ecosystem. It's a constant conversation with people who bring other expertise. – informant 21 Designers have to be careful that they don't think that they can you do it all. There's been a sense where social scientific design think they own the issue of AI ethics. But actually, it's our legal team and our sales force that who've also done some really deep thinking-brought a different perspective on thinking about ethics. I think you also have to be more humble about thinking about what the roles are. Kind of triumvirate of engineering, design, and social science, what the roles are for these other disciplines that bring kind of different perspectives. So again, it asks a lot of designers in terms of collaboration to learn to engage with. – informant 1
Explore and be wary regarding unintended consequences	'Most technological companies like (Name of Major Tech Company) have been quite utopian about what our technology in the past will make. These kinds of corporate videos had very slick and have everything work seamlessly in this imagined world which technology is doing amazing things. I think one thing that collective computing era or AI has pushed us to do is to think about the consequences. It means that certain design approaches like thinking about speculative design, which are really about saying about ultimate futures are more acceptable. Those have always sat outside of companies like (Name of Major Tech Company) a little bit and been seen as kind of strange- they're a little bit alien, a bit unapproachable; a bit difficult to digest. But now I think companies like (Name of Major Tech Company) are more willing to say well we do want to explore that unintended consequences. We are willing to take a lesson utopian view around the technology. … (Name of Major Tech Company) like most technology companies was quite incautious about the research done we did in the past. Appropriately we're being asked to be a lot more careful about respecting people's privacy and thinking about the roles and what they do here.' – informant 1



Appendix 1. Designing a system in modularity (created by the student).