Identifying and Exploring Design Trade-Offs in Human-Centered Design

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ABSTRACT

Human-centered design should not only be grounded in understanding new media and technologies in terms of productivity, efficiency, reliability, and from economic perspectives, but it needs to explore innovative socio-technical environments contributing to human creativity, gratification, enjoyment, and quality of life. It represents a wicked problem with no "correct" solutions or "right" answers; the quality and success of design solutions are not only a question of fact, but a question of value and interests of the involved stakeholders.

Design trade-offs are the most basic characteristics of design. They are universal and they make us aware that there are "no decontextualized sweet spots". In contrast to design guidelines, they widen rather than narrow design spaces by (1) avoiding simple solutions to complex problems and (2) by identifying and exploring interesting new approaches with the objective to synthesize the strengths and reduce the weaknesses of the binary choices defining the trade-offs.

The paper articulates a conceptual framework for human-centered design focused on a design trade-off perspective. The framework is inspired from a brief analysis of design trade-offs in large scale developments (self-driving cars, sharing economy, and big data). Based on our own research activities, it is elaborated with specific design trade-offs (context-aware information delivery, meta-design, and cultures of participation) and further illustrated with the description of the Envisionment and Discovery Collaboratory, a socio-technical environment to frame and solve wicked problems in urban planning.

Author Keywords

design, design trade-offs, human-centered design, transformative frameworks, context-aware information delivery, meta-design, cultures of participation, Envisionment and Discovery Collaboratory

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1. INTRODUCTION

The first phase of research and developments in human computer interaction was focused on concerns about *usability* and *usefulness* [1]. As hardware and software for many applications became readily available, new concerns emerged including design methodologies such as *participatory design* giving all stakeholders a voice [2] and incorporating requirements and insights from *different disciplines* [3]. Human-centered design objectives need to incorporate the findings and practices of these earlier foundations [4], but in addition has to take into account *new requirements* derived from *additional disciplines* (including: behavioral economics [5], creative practices [6], end-user development [7], social production [8], a deeper differentiation of human thinking [9]) to inspire new agendas for theory and practice in computing.

This article analyses the driving forces for articulating and exploring challenges for the future of human-centered design. It is grounded in the problem domains our research has addressed over the last decades (including: urban planning, lifelong learning, creativity, and populations with cognitive disabilities) and for which we have designed, developed, and analyzed *socio-technical environments* [10]. Based on our emphasis on *design* [11], we have focused particularly on identifying *design trade-offs* as the most basic characteristics of design. Trade-offs are universal because there are no best solutions in design. The basic contribution of this paper is to create frames of reference (illustrated with examples drawn from different areas) by exploring and understanding the relevance and the implications of trade-offs for human-centered design.

2. DESIGN AND DESIGN TRADE-OFFS

Design. In contrast to the natural sciences that study "how things are", *design* is concerned with "how things ought to be" [11]. Design problems are wicked, ill-defined, and have no definitive formulation and no stopping rule [12]. The aim of design is not to find truth, but to improve some characteristics of the world.

Design Trade-Offs. Design problems have no "correct" solutions or "right" answers; the rightness or wrongness of a design is not a question of fact (as it is the case in the natural sciences), but a question of value and interests of the involved stakeholders. A huge variety of (1) different objectives, (2) greatly varying problems, (3) different value systems, and (4) different people's need and preferences make d*esign trade-offs one* the most basic characteristics of design. Identifying trade-offs represents a unique challenge to identify, articulate, and assess human-centered perspectives. One particular important opportunity associated with design trade-offs is to spark efforts for *exploring a synthesis* integrating their strengths and premises rather than their weaknesses and perils.

Progress in Science and Technology: Beyond "Can Do It" to "Should it Be Done". Progress in science and technology has contributed to a transformation from *"can not be done"* to *"can be done"* (e.g.: the smart phones in our pockets are more powerful and offer more fundctionality with millions of apps compared to super computers from 20 years ago). These developments bring questions and decisions to the forefront *"should something be done?"* for the social benefits of all humans. Gaining a deeper understanding and more insights into human-centered design will require that the designers of socio-technical environments will explore additional objectives and take the findings of different research disciplines into account (see Figure 1).

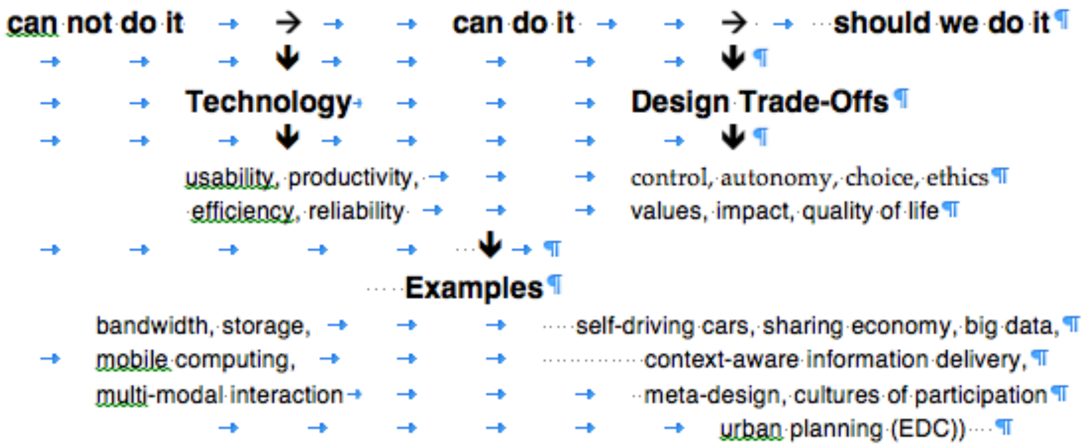

Figure 1: Beyond "Can Do It"

Contributions of Design Trade-Offs for Enriching Human-Centered Design. Some of the specific contributions of a design trade-off framework that we have explored are:

- *avoiding oversimplified solutions* by ignoring important facets of complex problems (e.g.: because our world is complex (i.e.: "reality is not user friendly"), our tools and systems need to reflect this reality);
- *uncovering unknown alternatives* and identifying the truly limiting factors that underlie problems (e.g.: the "real" problem underlying the design challenge for "Mobility of the Future" may not be gas versus electric engine versus hybrid engines or human-driven versus self-driving cars, but a much more elaborated framework integrating different modes of transportation; see section below);
- *transcending one-sided views and group think* by overcoming the hype or underestimation associated with many technological developments (e.g.: we live in an increasingly polarized world and echo chambers, filter bubbles, and personalized systems makes it less likely that we encounter opposing viewpoints);
- *appreciating the complexity and richness of human experience* (e.g.: to reduce our understanding to an economic view by only asking "how much" or to a technological view by only asking "can it be done?" and not "should it be done?"; see Figure 1);
- *considering ambiguity as an opening* for insight and reflections, rather than a bug to be fixed (e.g.: design trade-offs avoid a exclusive focus on one of the choices but encourage the exploration of the tension inherent in opposing views);
- *providing evidence* that *decontextualized sweet spots do not exist* for wicked design problems (e.g.: for simple problems like hitting tennis balls, sweet spots exist; for complex problems such as (1) whether MOOCs can or should replace residential education and to which extent [13] or (2) whether people need or want to have a personal car (the decision to this issue is very different whether they live in a big city or in a rural area); an important function of a design trade-offs analysis will help to define and explore specific contexts in which certain decisions are better than others or specific tools are more useful than others).

3. DESIGN TRADE-OFF PERSPECTIVES FOR MAJOR NEW DEVELOPMENTS IN INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT)

To illustrate the broad scope of a design trade-off framework, three current examples of major developments will be briefly discussed and analyzed.

Self-driving cars. Ten years ago, self-driving cars seemed to be more a topic for science fiction than becoming a reality in the near future. As rapid progress is made at the technological level ("it can be done (soon)"), the design trade-offs associated with "should we do it" (see Figure 1) take center stage. The *proponents* of self-driving cars [14] argue for their following desirable contributions: (1) independence for people who cannot drive (based on impairments such as age or blindness), (2) fewer accidents (no more drunk driving, no more distracted driving), (3) fewer cars (based on the reduced need for owning a car), (4) better use of existing cars (more than 90 percent of all cars are not driven at a particular moment), and (5) spending more time on personally preferred activities (e.g.: reading a book or sleeping instead of driving). The arguments of the *opponents* are centered on: (1) loss of control (for many people driving is fun and engaging); (2)

major unresolved consequences such as: (a) loss of jobs in driving (truck drivers, taxi drivers), (b) loss in jobs in the car industry (as substantially fewer cars are needed), and (c) unclear responsibilities if something goes wrong.

Beyond the two endpoints of "no technological support" and "complete automation", numerous *driver assistant systems* have been developed and more are becoming available in the cars of today including: adaptive cruise control, collision avoidance system, parking assistants, and car-to-car communication [15].

Sharing economy. The sharing economy has emerged as an alternative model in several domains (e.g.: Uber in transportation, Airbnb in accommodation) by providing consumers with alternative, convenient, and cost efficient access to resources and services. Many stakeholders stress the *positive* impact of the sharing economy on human-centered design: (1) consumers see it as a way to (sometimes) get cheaper and more readily available services, (2) drivers and renters earn some additional money, and (3) the companies supporting these services have become some of the most valued ones. Others experience the *negative* impact of the sharing economy: (1) taxi companies and hotels are driven into bankruptcy, (2) professional drivers and hotel employees loose their jobs, (3) taxes are not paid, and (4) safety may be at risk [16]. The sharing economy is facilitated and supported by ICT developments and researchers and practitioners in human-centered design and related fields will be responsible in shaping these developments impacting the quality of life of many people.

Big data. Some of the assumptions behind our ability to gather huge amount of data are [17]: everything that can be measured should be measured and data is a transparent and reliable lens to make informed decisions, analyze the behavior of learners (e.g. with learning analytics), illuminate patterns of behavior and functions that we are unable to observe and analyze. Some of the *positive* impacts of big data on different human-centered design dimensions are: (1) reduce information overload via personalization and making information relevant to the task at hand [18]; (2) give feedback on activities with FitBit-like devices and apps; (3) help to be environmentally responsible (e.g.: with smart grids and smart meters); and (4) expose when our intuitive view of reality is wrong. A trade-off analysis of big data uncovers many of the *negative* consequences: (1) privacy violations [19], (2) the elimination of the positive aspects of forgetting [20]; and (3) the narrowing of our exposure to a variety of different themes based on personalization creating filter bubbles [21].

4. DESIGN TRADE-OFFS EXPLORED IN OUR RESEARCH

Table 1 provides an overview of three themes relevant for the future of human-centered design that we have analyzed and explored from a design trade-off perspective.

Context-Aware Information Delivery. Humans (workers, learners, citizens, decision makers) are supported in today's world with *high-functionality environments* (including: software reuse libraries, MS-Office, Apps on Smart Phones, MOOCs courses available on the Internet, etc.). There are two basic approaches to cope with and incrementally learn such systems: information access and information delivery.

Table 1: Overview of Design Trade-Offs (Positive and Negative Consequences)

Development	Objectives	Positive Expectations	Negative Consequences	References
context-aware information delivery	personalization, user modeling, task modeling	reducing information overload	loss of serendipity, group think	[21]; [18]
meta-design	design for designers, end-user development	putting owners of problems in charge; creating evolvable designs	participation overload	[5]; [22]
cultures of participation	means to contribute actively in personally meaningful problems	social production; coping with complex systemic problems	required engagement in personally irrelevant activities	[23]; [24]

Information access systems ("pull-systems") in which users initiate the search process with browsing and search methods are designed under the assumption that users are aware of their information needs and that they know how to ask for it. The major *limitation* of information access systems is: if a user does not know that something exists, they are unable search for it.

Information delivery systems ("push-systems") provide information to users without explicit requests. Many information delivery systems (e.g.: Microsoft's "Tip of the Day", recommender systems) suffer from the problem that concepts get thrown at users in a decontextualized way. Despite the possibility for interesting serendipitous encounters of information, most users find this feature more annoying than helpful. To overcome the information overload with personally irrelevant information in delivery systems, we have developed *context-aware information delivery systems* [18].

While these promises of context-aware information delivery systems contribute *positively* to human-centered design, some important *pitfalls* of context-aware systems should not be overlooked. As web companies exploit context awareness to tailor their services (including news and search results) to people's inferred personal preferences and tastes, there is a unintended consequence: recipients get trapped in *"filter bubbles"* [21], a unique universe of information computed by algorithms exploiting context awareness based on users' previous actions and behaviors. By not getting exposed to information that could challenge or broaden worldviews and by suppressing unexpected encounters with different topics and opinions, filter bubbles may lead to *group think* [25] with a loss of individual creativity and independent thinking, as well as a tendency to minimize conflict and reach a consensus decision without critical evaluation of alternative ideas or viewpoints.

Human-centered design objectives are to find the right balance between *serendipity* [26] and *making information relevant to the task at hand* [27] by designing interaction mechanisms allowing users to select their own personal, situation- and time-dependent *best mixes* of this design trade-off.

Meta-Design. Meta-design (focused on "design for designers" [28]) is a theoretical framework to conceptualize and to cope in unique ways with design problems. In a world that is not predictable, improvisation, evolution, and innovation are more than luxuries: they are necessities. The challenge of design is not a matter of getting rid of the emergent, but rather of including it and making it an opportunity for more creative and more adequate solutions to problems [7]. Many design approaches force all the design intelligence to the earliest part of the design process, when everyone knows the least about what is really needed. Meta-design extends the traditional notion of system design beyond the original development of a system by supporting users as *co-designers*. It is grounded in the basic assumption that future uses and problems cannot be completely anticipated at design time, when a system is developed. Users, at use time, will discover mismatches between their needs and the support that an existing system can provide for them. These mismatches will lead to breakdowns that serve as potential sources of new insights, new knowledge, and new understanding. Meta-designers use their own creativity to produce socio-technical environments [10] in which other people can be creative and they define the technical and social conditions for broad participation in design activities.

Computational environments model systems existing in the world. As these real-world systems change, the corresponding computational environments need to change requiring open and evolvable systems. In our research, we have used a design trade-off analysis [29] to gain a deeper understanding to identify the strengths and weaknesses of: (1) a*daptive systems*, which automatically alter their behavior based on models of users, tasks, and contexts, and (2) *adaptable systems*, which are modified by users in response to breakdowns and missing functionality experienced during the use of the system.

Adaptive systems (a simple but illustrative examples is *Auto-Correct* in MS-Word) automatically make changes without putting a burden on users. They have a negative effect in situations where these changes are not welcome or hated by users. *Adaptable systems* (supported with end-user modifiability and meta-design) put users in charge. The price to be paid of being in control, however, is that adaptable systems require knowledge and effort on the part of users. Table 2 compares some of the major differences between adaptive and adaptable systems.

Table 2: Comparing Different Dimensions of Adaptive and Adaptable Systems

	Adaptive: System Infers Context	Adaptable: Users Articulate Context
Definition	dynamic adaptation by the system itself to current task and current user	user changes the functionality of the system
Knowledge	contained in the system; projected in different ways	knowledge is extended beyond the original system
Strengths	little (or no) effort by the user; no special knowledge of the user is required	user is in control; user knows her/his task best
Weaknesses	user has difficulty developing a coherent model of the system; loss of control	systems become incompatible; user must do substantial work; complexity is increased (user needs to learn the adaptation component)
Mechanisms Required	models of users, tasks, and dialogs; incremental update of models	support for meta-design
Application Domains	active help systems, critiquing systems, recommender systems	end-user modifiability, tailorability, definition of filters, design in use

The goal of making systems modifiable by users does not imply transferring the responsibility of good system design to the user. End users will in general not build tools of the quality a professional designer would; they are not concerned with the tool, per se, but in doing their work. However, if the tool does not satisfy the needs or the tastes of the users (which they know best themselves [7]) then users should be empowered to adapt the system without being dependent on developers.

Cultures of Participation. A large number of new media are designed to see humans only as *consumers*. Television is the most obvious medium that promotes this mindset and behavior. Educational institutions often treat students as consumers, creating a mindset of consumerism for the rest of their lives [30]. Citizens often feel left out of the decisions by policy makers and professional planers, denying them opportunities to take an active role in urban planning (this example is elaborated below in the discussion of the Envisionment and Discovery Collaboratory).

For a couple of decades the rise of digital media has been providing new powers for the *individual* and the world's networks are providing now enormous unexplored opportunities for *groups and communities* [8]. Providing all citizens with the means to become co-creators of new ideas, knowledge, and products in *personally meaningful activities* presents one of the most exciting innovations and transformations, with profound implications in the years to come. The rise in *social computing* has facilitated a shift from *consumer cultures* (in which people passively consume finished goods) to *cultures of participation* [23, 24]. *Cultures of participation* are facilitated by the participatory Web contributing to the aims of engaging diverse audiences, enhancing creativity, sharing information, and fostering the collaboration among users.

They democratize design and innovation [7] by shifting power and control towards the users, supporting them to act as both designers and consumers of the system and allowing that systems are shaped through real-time use.

The traditional notions of developer and user are unable to reflect the fact that many socio-technical environments nowadays are developed with the participation of many people with varied interests and capabilities (Wikipedia and open source software being prime examples). Social production and mass collaboration [8] require contributors with diverse background knowledge who require different support and who value different ways of participating. The "reader to leader" framework of [31]) illustrates a rich ecology of participation by postulating different roles. As participants become more engaged, the complexity of the tasks that they do and the demand for how much they have to learn is increasing. To accept these additional efforts participants must consider these tasks as *personally meaningful* and the migration paths need to be supported by gentle slope systems in which the transitions from one level to another level are smooth.

The impact of cultures of participation on human-centered design creates the following *design trade-off* [24]:

- on the one hand cultures of participation may force people to act as active participants in *personally irrelevant* activities where they would be prefer to be consumers because they find these activities not interesting, do not want to spend time working on them, and experience a lack of challenges. Simple examples that we identified are: (1) checking out groceries by customers themselves, (2) filling out an infinite number of questionnaires about the quality of services, or (3) coping with constant requests to download new version of systems and apps — all of these requirements leading to a *participation overload*;
- on the other hand, people are forced into consumer roles with no control in *personally meaningful situations* in which they would like to have the power to change a system to their needs without being dependent on "high-tech scribes". Meta-design represent developments to enrich control by the owners of problem by providing them with the support needed to successfully act as participants.

5. THE ENVISIONMENT AND DISCOVERY COLLABORATORY: AN INSPIRATIONAL PROTOTYPE FOR IDENTIFYING AND EXPLORING DESIGN TRADE-OFFS

The Envisionment and Discovery Collaboratory (EDC) [32] is a long-term research platform exploring design trade-offs in which stakeholders can collaboratively frame and solve wicked problems and discuss and make decisions in a variety of application domains and different disciplines. The knowledge to understand, frame, and solve these problems does not already exist, but is constructed and evolves in ongoing interactions and collaborations among stakeholders coming from different disciplines providing a unique and challenging environment to study, foster and support human-centered design, design, creativity, and learning.

At the *social* level, the EDC is focused on the collaborative construction of artifacts rather than the sharing of individually constructed items. It brings individuals together in face-to-face meetings, encouraging and supporting them to engage, individually and collectively, in action and reflection. At the *technological* level, the EDC integrates tabletop computing environments, tangible objects, sketching, visualizations, and simulation support, geographic information systems, and external tools.

The EDC integrates the development of artifacts and scenarios that were developed to provide inspiration for human-centered design. It is not focused on technologies in search of a purpose but on the development of systems supporting stakeholders to explore personally meaningful problems.

The Architecture of the EDC. Figure 2 depicts the EDC in use by a group of stakeholders (including city planners, transportation specialists, and neighborhood representatives engaged in a planning and decision making session) to improve public transportation by establishing a new bus route through a neighborhood. The conceptual architecture of the EDC instantiates Schön's conceptualization [33] of "reflection-in-action" and "reflection-on-action" as a framework for decision making and conflict resolution.

The horizontal tabletop environment in the foreground is an interactive surface coupled with a projected display of a computational information environment using geographic information systems (GIS) and other contextual information. Tangible interaction with the environment takes place by the stakeholders moving the computationally enhanced physical objects that are sensed by the interactive table. The horizontal tabletop represents the "action space," supporting participants to make decisions and undertake design actions in a collaborative space. The face-to-face configuration allows all participants in creating externalizations of their ideas and objectives, using the pieces to emphasize their convictions behind the associated actions. Thus, the tacit knowledge of each individual is externalized and made explicit allowing for the development of informed compromises that form the basis of the shared understanding necessary for the resolution of conflict in the solution of design problems.

Figure 2: A Global View of the EDC

In the background of Figure 2 are two vertical interactive whiteboards serving as "reflection spaces" that provide extended information related to activities taking place, including: argumentation contextualized by the actions and visualizations of designs constructed in the action space

Design Trade-Off: Closed versus Open Systems. Given the open ended nature of ill-defined, wicked problems, the research and developments with the EDC have explored architectures and substrates for open systems in which changes can be made with a reasonable effort. As participants contribute new ideas or want to explore new domains, the system must be able to capture these changes. One of the reasons why the simulation game SimCity is not well suited for urban planning is because it is incapable of allowing participants to engage in authentic and personally meaningful design problems. For example: In SimCity when too much crime occurs in a city, the designers can increase the police force to fight crime — but there will be no possibility for them to pursue an alternative strategy to increase social services in order to prevent crime.

Without being able to capture (or react to) information contributed by participants, closed tools are limited in their ability to capture dynamic open-ended collaborations. By being open, the EDC allows participants to pursue design alternatives by exploring a set of possible worlds.

By transcending the functionality and content of existing systems, control is distributed among all stakeholders in the design process and it erodes monopoly positions held by expert professionals. Empirical evidence gathered in the context of the different design activities [34] indicates that these possibilities are less successful when users are brought into the process late (thereby denying them ownership) and when participants are "misused" to fix problems and to address weaknesses of systems that the developers did not fix themselves. To create environments in which people can be supported to contribute in whatever ways are appropriate represents the design requirement that we have pursued with meta-design. The distributed control avoids that technical experts will be the sole gatekeepers in the EDC giving participants no control.

Design Trade-Offs in Creating and Revising Bus Routes and Placing Bus Stops. The rational for this design activity got started that the company operating public transportation noticed that the ridership in a bus route through one outlying area of town was much lower than expected. Transportation planners then decided to try to change the existing route and its bus stops to better serve the needs of the neighborhood and encourage the residents to use the bus more often. The objectives of the redesign were to (1) maintain a commercially viable and lively downtown area, (2) decrease the use of private car transportation, (3) improve the connection to a Park & Ride station connecting the region through regional bus lines, and in doing so also addressing environmental and energy concerns of the region.

Rather than focusing solely on the technical planning aspects of the problem and developing a top-down design, the planning team wanted to understand what behavioral and social issues were responsible for the choices of the residents regarding their transportation needs and they hoped to cultivate greater participation from the residents in the planning of public transportation at the urban and regional levels.

To address these objectives, the transportation planning team developed a set of scenarios to support a series of meeting with residents to explore possible alternatives, understand the interests and motivations of different stakeholders, and analyze the impacts and benefits of different transportation choices.

A trade-off that emerged in one of the design sessions was that adding to may stops to the bus route added to much travel time for the bus. The stakeholders agreed that there was enough time in the schedule for changes of 5 to 10 minutes and they identified which streets are wide enough for the buses to drive on. This factual information gave the participating residents an idea about how much they can change the route without requiring extra buses or significant additional funding for infrastructure changes. The bus route could be changed, provided it met the constraints described.

Neighbors are encouraged via public announcements and neighborhood fliers to participate in the route design activities and make recommendations to the planners on path of the route and the location of bus stops.

Design Trade-Offs in Locating Bus. To explore the location of bus stops required a design trade-off analysis between the requests of people living in different locations along the bus route under consideration. We developed a system component to illustrate walking distances that allowed participants to understand the interactions among their personal preferences and their willingness for walking a certain distance to catch the bus. Having indicated where they live with placing a house on the map (see Figure 3), participants could articulate their choices as to how far they were willing to walk, indicating different distances for "good weather" (the large circles around houses) and for "bad weather" (the small circles around houses). After specifying this information, the system created colored circles around the house icons of the individual participants. The representation shown in Figure 3 provided an emerging insight (which did not exist in the individual minds of the participants at the start) and which helped them to create a rational foundation for the analysis and validity of their respective opinion and desired objectives.

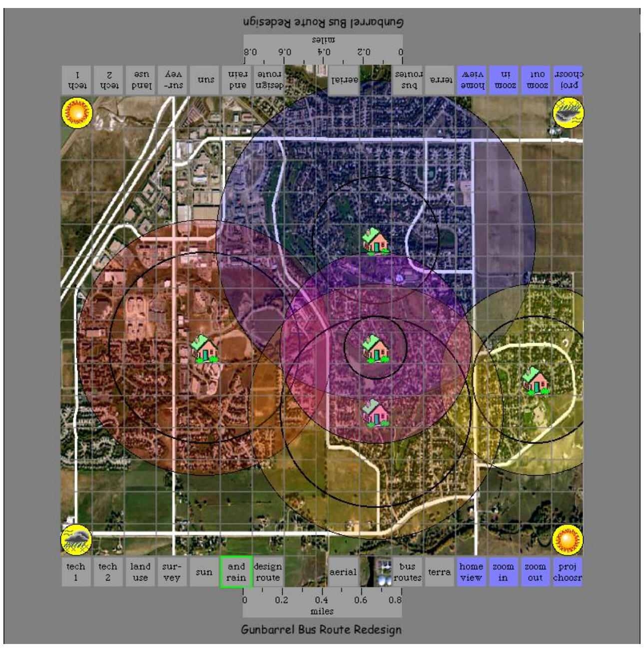

Figure 3: Exploring Design Trade-Offs for the Location of Bus Stops

Design Trade-Offs Related to the Impact of Building Heights. The EDC allows stakeholders to sketch new buildings, associate a height with them, and analyze their impact on the surroundings (e.g.: do they block a neighbor's view of the mountains — one of the most controversial issues in the City of Boulder that has led to extensive rules about height limitations). The ability to change perspective views in urban planning projects is an obvious necessity to understand visual impacts of different development actions. The sketching support provided by the EDC requires a small effort to create crude new building structure by depicting a floor plan and associate a height with it. The visualization in Figure 4 shows the impact that a building of a certain height has from a specific location. The ability of stakeholders to picture the impact of new buildings in their minds is at best very difficult if not impossible. This system component also provided support to analyze the different aspect of the design trade-offs associated with building heights/

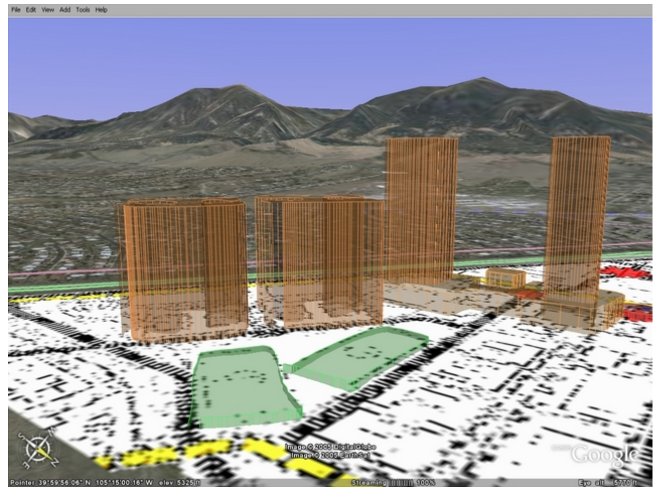

Figure 4: The visual impacts of high building shown in Google Earth

Design Trade-Offs between Individual and Collaborative Activities. Design by a community has both individual and social aspects [35, 36]: *individual* design activities inspire and drive collective design activities, and *collective* design activities provide the distributed intelligence context that cultivates and triggers further individual activity. Design by a community does not necessarily require that all members always participate in design activities with the same engagement at the same place and the same time. Depending on the nature of the task, some actions and reflections are better done individually, whereas others are better done collectively. The challenge is to provide multiple devices and interaction spaces that can sustain the continuity of action and reflection from the individual to the collective and vice versa [36].

In open-ended systemic problems such as urban planning tasks all the stakeholders want to devise their "best" ideas and need to discus and negotiate with each other to create mutually agreeable design plans. Individual reflections and group discussions often happen in parallel: some participants individually try to come up with their own ideas, and other participants collectively evaluate existing plans.

Caretta [37] used the inspiration of the EDC to intertwine and integrate personal and shared computational environments for participants. To explore the design trade-offs for achieving a smooth integration of individual and social creativity, Caretta allows pretesting a solution in stakeholder's own private space (e.g. with a personal digital assistant (PDA)) before applying it to the tabletop thereby supporting stakeholders in devising their "best" idea.

The development of Caretta was driven by the objective to explore the design trade-offs between individual and social creativity. The focus of the EDC on social creativity does not imply that *individual creativity* should be considered irrelevant. Social creativity does not necessitate the development of environments in which the interests of the many inevitably supersede those of the individual. Creative individuals, such as movie directors, champions of sports teams, and leading scientists and politicians can make a huge difference, as analyzed and shown by Gardner in exemplary cases [38]. Organizations get their strength to a large extent from the creativity and engagement of their individual members [36]. Appropriate socio-technical settings can amplify the creative outcome of a group of people by both augmenting individual creativity and multiplying it, rather than by simply summing up individuals' creativities.

In Summary. The EDC research explored a number of design trade-offs in specific settings thereby providing a deeper understanding and requirements for human-centered design:

- empowering *cultures of participation* [24] that put the owners of problems in charge by allowing them to act as active contributors at use time— a design trade-off compared to providing closed systems designed by professionals at design time;
- *supporting meta-design* [22] by offering functionality for tailorability, customization, and user-driven adaptation — a design trade-off compared to systems that can not be modified and evolved by end-users);
- offering mechanisms for *intertwining individual and social creativity* [36] so that the contribution of each member can be channeled back into the common design workspace to influence subsequent design actions — a design trade-off compared to systems which are exclusively target either to individuals or teams).

6. CONCLUSIONS

To make further progress in human-centered design will require exploring and supporting the co-evolutionary processes between fundamental human activities and their relationships and interdependencies with new media. This will require a deeper understanding of design trade-offs.

Design trade-offs are important because the future is not out there to be discovered but is has to be designed. As researchers we need to explore and understand the implications of design trade-offs and engage multiple voices in constructive controversies. As teachers, educators, and members of scientific communities we need to encourage and support learners of all ages in exploring human-centered design and provide opportunities in nurturing mindsets for thinking, reflecting, and acting in an informed way by considering design trade-offs in all areas of human life.

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