ICT4S 2029: What will be the Systems Supporting Sustainability in 15 Years?

Birgit Penzenstadler *(bpenzens@uci.edu)*, Bill Tomlinson *(wmt@uci.edu)*, Eric Baumer *(ericpsb@cornell.edu)*, Marcel Pufal *(mpufal@uci.edu)*, Ankita Raturi *(araturi@uci.edu)*, Debra Richardson *(djr@uci.edu)*, Baki Cakici *(cakici@sics.se)*, Ruzanna Chitchyan *(rc256@leicester.ac.uk)*, Georges Da Costa *(dacosta@irit.fr)*, Lynn Dombrowski *(lynn.dombrowski@uci.edu)*, Malin Picha Edwardsson *(picha@kth.se)*, Elina Eriksson *(elina@kth.se)*, Xavier Franch *(franch@essi.upc.edu)*, Gillian R. Hayes *(gillianrh@ics.uci.edu)*, Christina Herzog *(herzog@irit.fr)*, Wolfgang Lohmann *(wolfgang.lohmann@gmail.com)*, Martin Mahaux *(martin.mahaux@fundp.ac.be)*, Alistair Mavin *(Alistair.Mavin@Rolls-Royce.com)*, Melissa Mazmanian *(mmazmani@uci.edu)*, Sahand Nayebaziz *(snayebaz@uci.edu)*, Juliet Norton *(jnnorton@uci.edu)*, Daniel Pargman *(pargman@kth.se)*, Donald J. Patterson *(djp3@ics.uci.edu)*, Jean-Marc Pierson *(pierson@irit.fr)*, Kristin Roher *(kroher@uci.edu)*, M. Six Silberman *(silberman.six@gmail.com)*, Kevin Simonson *(simonsok@uci.edu)*, Andrew W. Torrance *(torrance@ku.edu)*, André van der Hoek *(andre@ics.uci.edu)*

Department of Informatics
University of California-Irvine, USA

Communication Department &
Information Science Department,
Cornell University, USA

KTH/CSC/Media Technology &
Interaction Design
Royal Inst. of Techn., Stockholm, SE

Department of Computer Science
University of Leicester, UK

IRIT, Université Paul Sabatier
Toulouse, France

Universitat Polytècnica de Catalunya
Barcelona, Spain

Informatics and Sustainability Research
University of Zürich, Switzerland

Faculté d'informatique
University of Namur, Belgium

Rolls-Royce PLC,
Pride Park, Derby, United Kingdom

School of Law
University of Kansas, USA

***Abstract*—Research is often inspired by visions of the future. These visions can take on various narrative forms, and can fall anywhere along the spectrum from utopian to dystopian.**

Even though we recognize the importance of such visions to help us shape research questions and inspire rich design spaces to be explored, the opportunity to discuss them is rarely given in a research context.

Imagine how civilization will have changed in 15 years. What is your vision for systems that will be supporting sustainability in that time? Which transformational changes will have occurred in the mean time that allow for these systems? Is ICT even the right tool or does it contradict sustainability by making our world ever more complex? How can we make systems and our societies more sustainable and resilient by ICT4S?

This paper presents a compilation of fictional abstracts for inspiration and discussion, and provides means to stimulate discussion on future research and contributes to ICT4S community building.

***Index Terms*—sustainability, software systems, vision, fictional, requirements, research challenges**

I. Introduction

At ICT4S 2013, the developing ICT4S research community developed a set of recommendations and list of challenges [1] that was derived from the research results presented and discussed at the conference. Statements that were provided by the speakers before the conference were compiled in a draft document that was then discussed in plenary sessions. These recommendations led to questions on topics including, but certainly not limited to, closure of material cycles to avoid hardware obsolescence, incentives for sustainable behavior, evolution of education for sustainability, and systems for sustainability assessment.

In addition to following recommendations and principles, research is often inspired by the work of others in related domains who have faced similar challenges, and by people who provide visions of the future, for example the SMART 2020 report [2] and the Vision 2050 [3]. The authors of such visions do not necessarily have to be visionaries in the sense of a domain expert in future studies, but instead may well be found within our growing ICT4S research community. Most of the visions in our research evolve somewhat organically, if not implicitly, and therefore a collection of future scenarios or visions to start such an organic evolution may be a good way to kickstart the discussion.

Inspired by 1) a visit of Joseph Tainter [4], 2) a contribution to the alt.chi track in the ACM CHI Conference on Human Factors in Computing Systems [5] and 3) the research questions posed by Kates et al. [6], we sent out a call for fictional abstracts for papers on ICT4S systems that might appear in the ICT4S conference in the year 2029. This call also make the process explicit that the abstracts would be compiled into a paper with the above title and submitted to the regular review process of this year's edition of the ICT4S conference. A time span of 15 years (the fictional context of ICT4S 2029) seemed appropriate to allow for creativity and significant paradigm changes in the future scenarios but not too far in the future to result in abstracts that are totally disconnected from the present. The abstracts were required to be 150 words long, to provide a title for the fictional future paper, and to optionally include an image as well. Abstracts were then selected for inclusion based on their ability to represent a diversity of guiding research visions, their excitatory or provocative potential, and the likelihood of engendering conversations about the future of ICT4S. After the selection, authors of voted-in abstracts were invited to be co-authors of the paper and we performed cross reviews of an earlier version of the paper that were discussed via email within the whole group.

The contributions of this paper are threefold:

1) We present 19 fictional projects that may inspire future research.
2) We offer a way to stimulate discussion at the conference.
3) We contribute to the community building of ICT4S by showing links between topics and by establishing new research collaborations.

The rest of this paper is organized as follows: In Sec. II, we provide underlying definitions and related work. In Sec. III, we provide the compilation of fictional abstracts. And in Sec. V, we conclude the paper with a summary and an appeal for discussion.

II. Background

This section provides the foundations for the concepts presented in the fictional abstracts. It includes definitions as well as related work on visions and challenges.

A. Definitions

This subsection provides definitions of the most important terms that are used throughout the abstracts and require a common understanding for the discussion of concepts for future research: sustainability, collapse, and resilience.

1) Sustainability: In general, sustainability is the "capacity to endure," but interpreting this concept requires context. A popular definition of sustainable development was given by the UN as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [7]. Although it is not actionable, it is the most cited definition currently in use. Ultimately, sustainability depends on the population at large, so common conceptions of sustainability must be acknowledged. People sustain what they value, which can only derive from what they know [8]. For that purpose, Joseph Tainter has suggested that it is useful to pose the four questions with regard to sustainability:

1) Sustain what?
2) For whom?
3) How long?
4) At what cost? [4]

To understand the sustainability implications of ICT systems as well as other systems, it is useful to consider not only first order effects but also second and third order effects [9]. *First order* effects are direct effects of a system on its environment; in the case of a software system, first order effects would include energy usage, e-waste production, emissions caused by required infrastructure, etc. *Second order* effects are indirect effects or induction effects; in the case of software systems, second order effects could include changes in users' resource consumption or consumer behavior. *Third order* effects are broader scale societal changes including rebound effects; a rebound effect would occur if the increased efficiency of systems tends to make us use even more systems which, in total, consume even more energy. All of these types of effect should be considered in an encompassing approach to supporting sustainability [10].

Tainter [8] draws seven lessons from his various studies linking social complexity to sustainability:

1) Sustainability is an active condition of problem solving, not a passive consequence of consuming less.
2) Complexity is a primary problem-solving tool, including problems of sustainability.
3) Complexity in problem solving is an economic function, and can reach diminishing returns and become ineffective.
4) Complexity in problem solving does its damage subtly, unpredictably, and cumulatively over the long term. Sustainability must therefore be a historical science.
5) Sustainability may require greater consumption of resources rather than less. One must be able to afford sustainability.
6) The members of an institution may resort to resiliency as a strategy of continuity only when the option of sustainability is foreclosed.
7) A society or other institution can be destroyed by the cost of sustaining itself. [8]

Ostrom points out that we need a general common framework to be able to organize findings and knowledge with regard to analyzing the sustainability of social-ecological systems, because isolated knowledge does not accumulate, and proposes such a framework in [11].

2) Collapse: Collapse has been defined as "a lower degree of stratification and social differentiation; less economic and occupational specialization, of individuals, groups, and territories; less centralized control; that is, less regulation and integration of diverse economic and political groups by elites; less behavioral control and regimentation; less investment in the epiphenomena of complexity, those elements that define the concept of 'civilization': monumental architecture, artistic and literary achievements, and the like; less flow of information between individuals, between political and economic groups, and between a center and its periphery; less sharing, trading, and redistribution of resources; less overall coordination and organization of individuals and groups; a smaller territory integrated within a single political unit" by [12, p. 4]. Rapid and powerful events such as nuclear attacks may cause events to unfold in a way that merits the term "apocalypse"; however, while various "tipping point" phenomena (according to [13], [14]) may cause non-linear changes to occur very rapidly (as is common in ecosystems), sustainability scientist Tainter [12], geographer Jared Diamond [13], and others note that collapse frequently occurs more gradually.

The concept of "collapse informatics" has been proposed as encompassing the "the study, design, and development of sociotechnical systems in the abundant present for use in a future of scarcity" [15]. If collapse is a potential outcome of industrial civilization's "business as usual," then collapse informatics could become part of the purview of ICT4S.

3) Resilience: While sustainability is the capacity to continue a desired condition or process, social or ecological, resilience can be defined as "the ability of a system to adjust its configuration and function under disturbance" [8, p. 92]. In social systems, resilience can mean abandoning sustainability goals and the values that underlie them. Consequently, sustainability and resilience can conflict [16].

Stokols et al. [17] suggest that taking into account the different types of capital — the material resources of economic, natural, human-made environmental, and technological capital as well as the human resources of social, human and moral capital — might be the solution to enhancing the resilience of human-environment systems.

B. Visions

There are a few vision papers worth mentioning that may be considered as related work, although they fundamentally differ in their approach to presenting visions and are more in-depth reports. However, they also have some commonalities: all visions require the research community as well as the overall population of the planet to substantially change their life styles. They demonstrate that a lot of effort is required to solve our current challenges for climate and resources. Furthermore, they outline a constructive approach and a feasible solution roadmap (as opposed to dystopian visions).

1) SMART 2020: The SMART 2020 report [2] outlines the transition to the low carbon economy in the information age. Half-way into the teens of this millennium, we should already be substantially further in implementing this roadmap, but it may still serve as reminder of what needs to be accomplished.

2) Vision 2050: In their Vision 2050 [3], the World Business Council for Sustainable Development (WBCSD) envisions a pathway with nine key areas of action: peoples' values, human development, economy, agriculture, forests, energy and power, buildings, mobility, and materials. After the 'turbulent teens' (2010-20), each of these key areas has to go through a transformation in order to achieve the vision of a sustainable world in which 9 billion people can live well, and within the limits of the planet, by 2050.

3) Transition Engineering: More visions for the future are brought by an emerging discipline called Transition Engineering [18] that seeks to enable change from existing unsustainable systems to more sustainable ones by adaptation and filtering of demand to declining supply.

4) Resilient Citizens in the Information Society: Cameron [19] makes the case that sustainability presupposes the requirement for sustainability and, more concrete, that the "concept of a 'sustainable' Information Society incorporates the requirement for ICT (Information and Communication Technology) to support and promote viable communities of citizens" [19, Sec. 1]. She provides a framework with best practices for governments and for organizations aiming to support resilient citizens, but also for the citizens themselves who need to take over responsibility, including a failure survival strategy.

C. Challenges

The challenges presented in this section are intended to serve as background information and related work. Not all of them are addressed by the fictional abstracts, but we consider it important to provide them as context for the discussion on where research should pick its topics for investigation.

1) Limits to Growth: The book "Limits to Growth" by Donella Meadows et al. [20] and the Club of Rome[1] has been around since 1972, and presents the computer modeling of exponential economic and population growth with finite resource supplies. The book was updated 20 and 30 years later. Most scenarios resulted in an ongoing growth of population and of the economy until to a turning point around 2030. 40 years later, the Club of Rome noted that "Only drastic measures for environmental protection proved to be suitable to change this systems behaviour, and only under these circumstances, scenarios could be calculated in which both world population and wealth could remain at a constant level. However, so far the necessary political measures were not taken." [21]

2) Central Research Questions for Sustainability Science: Kates et al. [6] offers seven central research questions for sustainability science that in part inspired the fictional abstracts presented in the paper at hand:

1) How can the dynamic interactions between nature and society — including lags and inertia — be better incorporated into emerging models and conceptualizations that integrate the Earth system, human development, and sustainability?
2) How are long-term trends in environment and development, including consumption and population, reshaping nature-society interactions in ways relevant to sustainability?
3) What determines the vulnerability or resilience of the nature-society system in particular kinds of places and for particular types of ecosystems and human livelihoods?

[1] www.clubofrome.org

4) Can scientifically meaningful "limits" or "boundaries" be defined that would provide effective warning of conditions beyond which the nature-society systems incur a significantly increased risk of serious degradation?
5) What systems of incentive structures — including markets, rules, norms, and scientific information — can most effectively improve social capacity to guide interactions between nature and society toward more sustainable trajectories?
6) How can today's operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition toward sustainability?
7) How can today's relatively independent activities of research planning, monitoring, assessment, and decision support be better integrated into systems for adaptive management and societal learning? [6]

Like other use-inspired sciences, sustainability science includes "significant fundamental and applied knowledge components, and commitment to moving such knowledge into societal action" [22].

3) EROI: Energy continues to be one of our most important resources, while recent history seems to indicate that we have at least reached declining returns from our reliance on fossil fuels [12]. Due to increases in energy demands, we are now facing increasing energy costs as a result of the increased costs of producing energy.

The EROI (Energy Returned on Energy Invested) formula illustrates this phenomenon [23]:

$$EROI = \frac{Energy\ gained}{Energy\ required\ to\ gain\ that\ energy} \quad (1)$$

Put into simpler terms, as oil becomes more difficult to access, it costs more to retrieve it for energy production. Preliminary investigations of EROI for oil and gas have been reported on by [24] and a long-term assessment of oil and gas in the US has been provided in [25].

III. Visions of the Future: ICT4S'2029

Here we present 19 fictional abstracts selected from those submitted in response to the open call. The abstracts were selected for inclusion based on their ability to represent a diversity of guiding research visions, their excitatory or provocative potential, and the likelihood of engendering conversations about the future of ICT4S. The selection was performed via a vote held by the first five authors of this paper, who initiated the call for abstracts. Some of the systems outlined in the abstracts may not even be achievable by 2029, and some might appear significantly before then. We present them clustered according to four major aspects that revealed themselves as themes: infrastructure, society, food, and waste. This is not the only possible categorization but it provides a simple classification to allow for an overview, as depicted in Fig. 1.

Infrastructure Abstracts

A. Let's get into space!

Georges Da Costa, Christina Herzog, Jean-Marc Pierson

Infrastructure	Society
Data Centers in Space Corporate Accountability Resilient Computing Civilization-level Collapse Policy Perspective	Paradigm Shift Currencies Participatory Info. Diffusion Autonomous Vehicles Sustainable Lifestyles Beneficial Corporations Smart Prosumers
Food	**Waste**
Food Network Topologies Local Food Production Intelligent Food Security Sustainable Food in Space	Self-Recycling Systems Adapting Legacy Hardware Neo-Benthamite Initiatives Wearable Impact Analysis

Fig. 1. Overview of Abstract Collection

Earth is surrounded by the cold and (almost) unused outer space, while on earth we face global warming and limited space. We believe that space would be an alternative for activities currently done on earth and causing problems to our environment. The cooling of data centers is getting more problematic and even "green" solutions for cooling like using water or constructing data centers in cool regions of the earth are not acceptable for the environment.

Having storage for data in outer space might be a solution for the future as the expansion of our living space into outer space has already begun and is not causing huge difficulties any more. The aim of our paper is to show that cooling in outer space is an alternative to the polluting current way on earth. Additionally, a solution for energy problems will be investigated as running data centers in outer space may include the usage of solar energy to power them.

B. Open (re)Source: An anonymous clearinghouse for sustainability-related corporate information

Bill Tomlinson, Debra Richardson, Ankita Raturi

The flows of materials and energy through industrial processes have profound environmental implications. Trade secrets have typically prevented disclosure of information on these flows, and prevented knowledge of them from being taken into account in consumer decision making, thereby hampering consumer efforts to make environmentally-informed decisions. Over the past decade, though, the Open (re)Source system has enabled broad scale disclosure of this information.

Created and maintained by the online collective 6AnonymousB, Open (re)Source is an online database of corporate information anonymously leaked by employees. This paper presents an ethnographic analysis of the Open (re)Source community, revealing two types of contributors: first, a group that are concerned about privacy and lawfulness, but believe that environmental impact data needs to be transparent; and second, a group that is disgruntled about corporate structures, and post information as retaliation.

C. Computing for all: A sustainable infrastructure in a time of need

Daniel Pargman

With unemployment numbers exploding after the Potemkin-Aramco scandal of 2018, the 2020 Hindsight (great oil reserves) Writedown and the global flash-crash of 2023, the emergence of a “lost generation” has profoundly shaken all Western countries. These developments have had a profound effect on the ICT sector both in terms of usage patterns and R&D orientation (and budgets) in the 2020s. This paper outlines a broad research agenda for the development of a low-tech, low-cost and ultra low-energy computing infrastructure that can meet the computing needs of the swelling ranks of un- or underemployed consumers, while simultaneously decreasing the energy/CO2 footprint of our computing infrastructure by an estimated 68%.

We draw on previous studies of marginalized groups’ use of ICT in affluent societies (immigrants, the young, the poor, the unemployed) as well as studies of reverse technology transfer from underdeveloped to formerly-affluent societies (the “counter-ICT4D” movement). We conclude by suggesting an offensive strategy for the radical simplification of hardware, software and networking and propose the Freeternet — a “future-proofed” resilient low-cost, low-energy, limited-bandwidth Internet infrastructure.

D. ICT Development in light of looming civilization-level collapse

Debra Richardson, Bill Tomlinson, Birgit Penzenstadler, André van der Hoek, Ankita Raturi

ICT development is changing rapidly as the global economic crisis deepens and the potential for civilization-level collapse is upon us. This paper describes a qualitative study of how civilizational contraction has affected ICT development over the past decade.

We find that: (a) ICT system development has changed dramatically in balance from a focus on functionality first (assuming resources are available) to a focus on key system properties such as sustainability and resilience first followed by the development of functionality in that context, and (b) the methods by which ICT systems are developed have correspondingly changed, to explicitly guide developers in making choices related to sustainability and resilience in usage process modeling, human computer interaction design, and system architecture design. We find serious shortcomings, however, in current processes and methods should the world experience further deepening of the crisis foreboding collapse, and recommend transformational changes to account for these issues.

E. A policy perspective on emission reductions through heating, lighting and electricity quotas

Daniel Pargman, Baki Cakici

In this age of great hardship, there is a great need for 1) protecting the integrity of national borders in the face of mounting immigration pressure from “flipped” climate zones and failed states (c.f. Garrett Hardin’s (1974) Lifeboat ethics) and 2) to strongly incentivize citizens to do their utmost in husbanding energy and other scarce resources. The first challenge has essentially been met through the development of third-gen drone-mounted search & purge technologies (e.g. OctoSurv). While Swedish CO2 emissions have decreased by 56% compared to the 2010 level of 10 tons CO2e/capita, much is left to do to before reaching the 1 ton/capita goal by 2050.

In the face of inertia in citizen compliance with previous emission reduction plans, we propose a radical three-pronged plan for further emission reductions: 1) the introduction of a strict quota system for subsistence-level heating outside of city centers, 2) a general prohibition of lighting in both private and public spaces during non-productive hours and 3) a strict smartgrid-enforced 200 Watt ceiling on electricity usage per household during said hours.

Society Abstracts

F. ECOin

Ankita Raturi, Bill Tomlinson, Donald J. Patterson

The early 2010s saw a rise in the popularity of peer-to-peer digital currencies with the cryptocurrency Bitcoin leading the charge. Bitcoin was instrumental in revolutionizing the nature of e-commerce after it stabilized at around 42 US Dollars to 1 Bitcoin in 2020. This led to Bitcoin outlasting copycat currencies like Coinye (peaked at 69US$ to 1CYe) and Dogecoin (0.01USD to 1DeC).

The ECOin (see Fig. 2) was the first currency to function as a hedge against continued environmental damage. The ECOin stored a person’s environmental value by capturing the externalities of their actions. Leaps in resource tracking and the quantified self movement, have meant that we now know the environmental impact of each person. The better they are at being sustainable the higher the value of their ECOin. This paper is a retrospective on the role of the ECOin in the extreme rise in global sustainable behaviours, its effects on the economy, and rate of collapse.

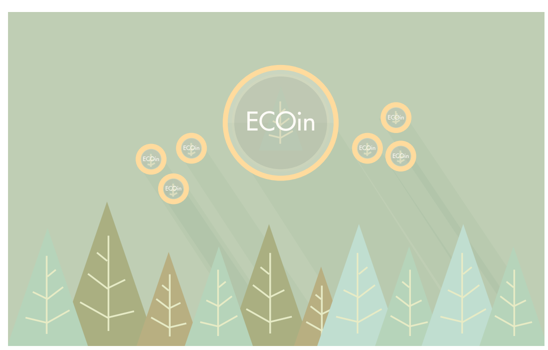

Fig. 2. ECOin: cryptocurrency against environmental damage

G. Together now — a study on participatory information diffusion and the media industry

Malin Picha Edwardsson, Elina Eriksson

With heavy rainfall and flooding, drought and new records of cold weather, we are living in an era where climate change no longer is a possibility — it is here. In this study we are evaluating the new collaboration portal on "Task Force on Mediated Climate Information", where governmental agencies, the media industry and the public can meet and collaborate in order to make information on mitigation and adaption plans easier to grasp and diffuse.

The portal is a multimodal, virtual ICT-platform, where different stakeholders can work together in a participatory process to make local solutions from global knowledge. In particular, this study will look at the media industry's role in transmogrifying complex issues (climate data, regulations, research findings) into understandable presentations for distribution in different ICT channels. The results from this study show that the participatory aspect is of utmost importance for success, as citizens need to engage in this process.

H. Social aspects of autonomous and electric cars in Germany

Wolfgang Lohmann

The mantra of electric cars to stabilize smart grids and to reduce the CO2 emissions is still in vogue. Repeatedly, ICT is declared as key to logistics optimization. During the last decade the share of electric cars has increased dramatically, as well as the number of autonomous cars in the last five years.

First, we show the increase of life quality during the last decade. The positive effects to health of both, the improved air quality and the decreased noise level, are now statistically evident. The amount of city space regained from removed parking space due to the success of concepts like 'car from the moving cloud' is amazing.

Second, we show that due to the optimized logistics, too few electric cars stand idle and, therefore, cannot provide their battery as buffer for the smart grid. We suggest an explanation why the energy for the cars is still coming from coal. More importantly, we argue that the trend to replace truck drivers by autonomous cars will likely continue. In Germany alone the number of truck drivers has been decreased from about 803 000 to 227 000 within a decade. Together with similar effects of ICT in areas such as automated shops this potentially imposes dramatic societal instability.

I. Green lifestyle lessons: learning from green lead users

Daniel Pargman

With increasing acceptance of the assertion that we live in an age of decreasing returns of increasing societal complexity (Tainter 1988), we urgently need to look for examples that can help us transition to simpler, more sustainable, low-energy "green" models of consumption. This paper summarizes lessons learned from the decade-long research project "Green lifestyles for reduced energy consumption" (Pargman, Eriksson & Katzeff 2026).

More specifically, we discuss 1) the results of early studies of "lead users" (primarily members of eight Transition Town initiatives in three different countries) who voluntarily and proactively chose to simplify their lifestyles (with an emphasis on attitudes, actions, computing habits and everyday energy consumption), 2) the design and development of concepts, prototypes and products that embody lead users' best-of-breed computing and energy-saving behaviors and 3) the resulting services and products that were developed and marketed by project partner and global retail chain IKEA. We conclude the paper by enumerating the five most promising areas for wide scale energy and computing lifestyle changes.

J. Participatory simulations: sustainability and the legal rules of corporate governance

Bill Tomlinson, M. Six Silberman, Andrew W. Torrance

The structures of many existing institutions predate sustainability discourse, and may constrain people to engage in activity that impedes progress toward sustainability goals. Corporations are one instance of this class of institutions.

We conducted a series of interactive computational simulations to investigate possible effects of different rules to govern corporate behavior on sustainability outcomes. In particular we examined the potential role of the benefit corporation, a legal entity similar to a for-profit corporation, but with an explicit goal of have a positive societal and/or environmental impact.

In addition, we envisioned and implemented several other models for corporate activity, including the zero-sum corporation (which must document how its growth is offset by the shrinkage of some other corporation) and the anti-growth corporation (which is funded via a subscription model, and uses its resources to cause particular sectors of industry to shrink). These models of corporate behavior present a range of potential outcomes that do not perpetuate "business as usual."

K. The Open Revolution: Lessons learned from the era in which technology united humankind

Martin Mahaux, Alistair Mavin, with contributions from the Open Interdisciplinary Welfare Research Group — The Wiki-University

Breakthroughs in communication technologies have always been central to major historical changes. The Open Revolution followed this pattern, but could easily have failed. The power of capitalism could have destroyed the planet and seemed impossible to break down. However, Goliath ignored David: thousands of skilled citizens, spread over the world, who believed in open, participative and sustainable innovation. They influenced millions, empowered them, allowing them to change from dumb consumers into smart prosumers.

People naturally switched from competition to collaboration, enabled by frictionless knowledge sharing infrastructures. This eliminated corruption, private life violations, technology lock-in, lack of interoperability, obsolescence and many other evils. Collaboration made us feel part of a single world, which raised levels of respect for both people and the planet.

We analyse how those ingredients were crucial in finally leading the Open Revolution to destroy and replace the growth-based capitalist economy and representative democracy (see Fig. 3).

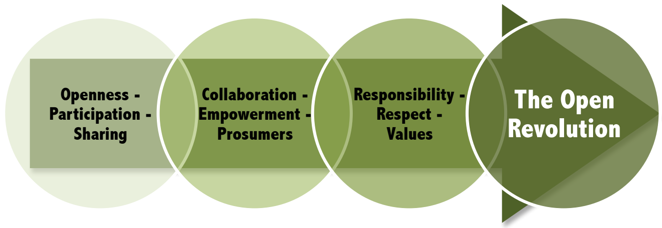

Fig. 3. The Open Revolution

Waste Abstracts

L. EverGreen: An MDD-based approach for generating self-recycling cyber-physical systems

Xavier Franch

The automated support to the produce - use - retire cycle in cyber-physical system has been an object of attention in the last decade. Approaches including those by James Disposal and Henry Waste at 50th ICSE have advocated for the use of MDD techniques but are still subject to limitations, remarkably the inability to automatically retire all the components that conform the system. This paper presents EverGreen, a model-based development (MDD) approach that, starting from a UML6.5 specification, is able to generate adequate software and hardware components that apply the correct technique to every type of component in order to retire them.

In the case of physical components, we use the TotalPrint last generation 3D printer to generate mechanical artefacts. Total print also offers chemical compounds able to destroy those components with minimal environmental impact according to the ISO/IEC 84320 Sustainability Quality Model. The approach has been validated through a multi-case study conducted at the premises of the Dharma Initiative.

M. A general theory for implementing interactive systems on legacy hardware

Bill Tomlinson, Donald J. Patterson, Debra Richardson

The recent convergence of developing nations and collapsing nations has led to profound shifts in resource availability around the globe. For example, the non-renewable resources needed to manufacture post-post-modern ICT systems (e.g., metals such as rhenium, ytterbium, and manganese) are largely located in landfills in developing nations, as a result of decades of e-waste exportation from nations that are now collapsing. Shortages of these resources in collapsing nations, coupled with continuing demand for ICTs to support communication, commerce, coordination and other human activities, has led to a new trend in which modern functionality is adapted to operate on hardware that significantly predates it.

We introduce a general theory for layering new interactions on legacy platforms. This theory accounts for the development of IVOR (Interactive Video Over Radio) and TVSL (Twitter Via Signal Lamp) and presents other transformational changes in technologies that may support human wellbeing in the context of growing resource scarcity.

N. Mother Svea Vigilant: Lessons learned from a nation-wide anti-waste initiative

Baki Cakici, Daniel Pargman

In this paper, we analyze the widely acclaimed "Mother Svea Vigilant" initiative aimed at eliminating wasteful consumption in Sweden. The initiative was funded by the Swedish state between 2021 and 2026 to recognize and classify consumption acts by automatically monitoring commercial transaction logs from all Swedish households and combining them with data submitted by citizens' smart-ID implants. From a technical perspective, we argue that automatic advisory methods such as scheduled comparisons of recycled mass versus the total mass of purchases in a given time period have created new possibilities of ensuring enthusiastic public commitment to monthly recycling quotas.

We also analyze the success of social aspects of the Mother Svea initiative such as the "See some waste, tell with haste!" program and the community-enhancing "tell (on) your neighbor" campaign. We conclude that Mother Svea and other comparable neo-Benthamite national ICT initiatives this far provide the only scientifically proven methods to stem CO2 emission through the combination of powerful technical and social motivators.

O. Carbon Glass: Reducing your carbon footprint

Kristin Roher, Debra Richardson

Over the past decade, researchers have begun realizing the full potential of image processing and computer vision advances and also the ability of carbon tracking algorithms to accurately report environmental impact. These advances have led to our development of Carbon Glass, an application running on Google Glass that tracks the wearer's resource usage (see Fig. 4). Carbon Glass performs carbon footprint analysis, and based on observed behaviors, provides users with recommendations for ways to cut resource usage and reduce one's carbon footprint — all uploaded to a personalized webpage. Together with each recommendation is an explanation and further background as to how the recommended behavior will affect one's carbon footprint. Further, if an impactful, immediate change in behavior is recommended, Carbon Glass suggests it via the Google Glass voice response. This paper discusses the requirements elicitation for this product, particularly concerning the following features and the design tensions between them: feedback, control, privacy, information access, and avoiding interruptions. The design tension between privacy concerns and the need for information access to make the product functional is discussed in detail.

Food Abstracts

P. Food Packets: Network graphs for food distribution

Donald J. Patterson, Bill Tomlinson, Gillian R. Hayes, Melissa Mazmanian, Lynn Dombrowski

Various food distribution mechanisms exhibit different network structures. For example, food systems may use peer-to-peer structures (where individuals engage in many small exchanges across different locations), hub-and-spoke structures

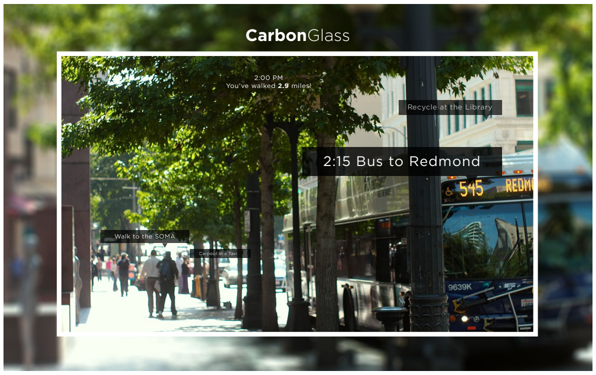

Fig. 4. Carbon Glass: Reducing your carbon footprint

(where many individuals collect from a single distribution center), and hub-and-tree structures (where there is a centralized distribution point from which one or more distribution trees arise). Each of these structures is appropriate for different kinds of exchange, and would benefit from different kinds of ICT support.

We have developed an ICT application, informed by ethnographic analysis, that supports the process of local food distribution by matching the characteristics of the system to an appropriate network topology. Our research describes how ICT can most effectively support the distribution of 'food packets' in a local food system. Given the different stakeholders and their food distribution structures, such an approach creates new understandings of local food systems (Fig. 5). For example, it may expose food distribution bottlenecks and opportunities, and help local governments and communities understand the resiliency of their food system.

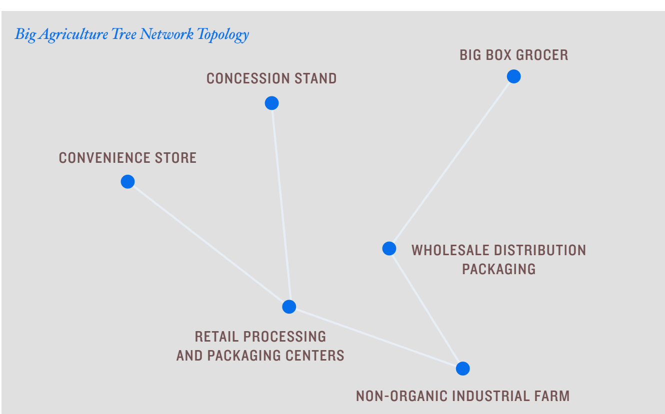

Fig. 5. Local Food Production

Q. Evolving optimal ICT systems for local food production

Bill Tomlinson, Juliet Norton, Kevin Simonson, Debra Richardson

Over the past half century, ICT systems have gradually become integral to most local and industrial food production processes (e.g., computer-controlled watering systems, chemical sensors for aquaponics, online harvesting reminders). Until now, the systems that supported local food production have relied on the expertise of the teams creating and deploying them to be successful (e.g., a gardener programs the seasonal water schedule of a watering system).

In the last decade, a considerable amount of data has been generated around key performance indicators (KPIs) of agricultural systems (e.g., species specific water requirement per unit of yield). Such data can be used to automate menial tasks and aid in the execution of complex tasks. This paper describes a new model for agricultural ICT support systems that takes KPIs as inputs to evolve ICT-based control systems that maximize utility of the food system.

R. Enabling sustainable farming through FarmWell

Ruzanna Chitchyan

The need to ensure continuity of secure food production in the face of mounting environmental change and population growth is one of the biggest challenges of our time. This paper demonstrates how the widespread use of FarmWell systems helps to drastically reduce the negative environmental impacts of food production, as well as raise yields and increase the efficiency of input use.

A number of studies of the system use are discussed, showing that the best results are obtained where all (sensors, autonomous learning, and social networking) components of the system are deployed. Yet, we observe that the use of the integrated knowledge base on sustainable farming techniques, location-specific climate-motivated farming transition pathways, and economic return guidance built into the social networking module has the largest return from the FarmWell adaption. Thus, we aim at even closer integration of agricultural, climate, and economics research into future releases of the system.

S. Sustainable food production in space

Juliet Norton, Bill Tomlinson, Marcel Pufal, Donald J. Patterson

Since the advent of NASA's first space garden in early 2016, ICT has played an important role of monitoring and informing researchers and the public of the potential to "off-planet" some of our food production. Although they serve as preparation for distant future emergencies or significant population growth scenarios, most of the experimental lunar food production efforts thus far have been of an industrial mindset.

This paper describes the need for "off-planet" food production to originate from a sustainable model and suggests how "lunar" adjustments can be made to existing ICTs that support sustainable food production on Earth in effort to make such technology also applicable to the moon. In particular, this paper addresses issues relating to the moon's low gravity environment, its different circadian and annual cycles, and the chemical composition of lunar soil.

IV. Initiating Discussion

Several ways to structure the discussion of this collection of fictional abstracts arose while drafting this paper:

- Synthesis of the abstracts in a summarizing vision, for example in a story of the future
  - Utopian story: Mary wakes up, puts on her Google Glass, stocks up online on her fair trade coffee with 2 ECOins, and walks out into her farmwell-supported garden to harvest breakfast from her aquaponic food forest.
  - Dystopian story: Mary is woken up by the Mother Svea Vigilant alarm after being "told on" by her neighbor but was able to avoid arrest due to collapse of the police telecommunication infrastructure.
- Further classification of the abstracts
  - Further or not so far into the future (assumes many vs. few scientific breakthroughs in the next 15 years)
  - Assumes continued economic growth vs steady-state/shrinking economy
  - Utopian vs dystopian
  - According to the challenges listed in Sec. II
- Solution elements: How exactly does ICT contribute to solving sustainability challenges in the future?
- Success factors: What assumptions are made for the scenarios to become true?
- Analysis of change and continuity via three perspectives: technological, economic, and social.

While all of these possibilities are worth exploring, we limit ourselves to the last three for a brief discussion and leave further consideration to the conference participants.

A. Solution Elements

The elements that ICT needs to provide in order to contribute to solving sustainability challenges in the future can be classified into:

- Monitoring (e.g., of resource requirements, food/plant growth)
- Controlling (e.g., energy consumption, irrigation of crops)
- Information sharing (e.g., on research, climate change, techniques of farming)
- Consulting (e.g., on adjusting individual behavior, optimizing business processes)

This categorization can be used to gather general requirements on these types of systems and provide a framework for more efficient elicitation for domain-specific instances.

B. Success Factors and Assumptions

For the scenarios behind the fictional abstracts to become true by 2029, several assumptions need to be fulfilled for each scenario. For example, many abstracts suggest that individuals are the driving force with ICT supporting them in collaboration. Other abstracts suggest that the priorities are to be changed towards working "bottom up" from local communities and thereby strengthening resilience.

We can see a spectrum of actions aimed at:

- Individual level (optimization of resource consumption, self management)
- Community level, either in local communities (collaborative consumption, carpooling, etc.) or by building up topic-specific communities (open collaboration, open research)
- Global level (social movements, paradigm changes)

Our projection is that parts of the utopian scenarios as well as parts of the dystopian scenarios will manifest themselves on several of these levels.

C. Analysis of Change and Continuity

An important component of the genius behind the writings of Jules Verne and H. G. Wells emerge from their ability to envision futures not only in which submarines take us beneath the sea and we travel through time but also in which men still wear neckties [26], [27], [28]. Similarly, in thinking through these abstracts, one fruitful approach may be considering both what the authors suggest will have changed and what will implicitly have remained the same. This can be done along at least three dimensions: technological, economic, and social.

Several of the abstracts, including those dealing with utilizing outer space, augmented reality, electric cars, and others, present distinct visions of what will become technologically possible within 15 years. Others make interesting implications about the persistence of particular technologies. For example, the need for implementing TVSL (Twitter via signal lamp) suggests that Twitter still exists 15 years from now. Still others, such as Mother Svea Vigilant, could, technologically speaking, potentially be implemented today. Of importance here is considering how these differing technological visions influence what counts as an important technological advancement in today's research.

A number of economic shifts are also proposed. For example, ECOin implies some (potentially radical) changes to world economies. Similarly, alternative food production and distribution systems imply potential concomitant shifts in economic practices. On the other hand, entities such as IKEA are suggested to continue to play central roles in consumer products. Also, Open (re)Source suggests not only that corporations still exist as powerful and important entities, but it also perpetuates a mode of environmental activism through capitalist consumption.

This point draws attention to broader social implications. The Open Revolution, as well as the "Task Force on Mediated Climate Information," both suggest some fundamental changes to the organization of society, labor, and information. Mother Svea Vigilant, with its "tell (on) your neighbor" campaign, presents a powerful, if potentially somewhat dark, vision of how societies might adapt to handle problems of waste reduction. the civilization-level collapse occurring implicitly or explicitly in many of the abstracts certainly suggests major societal-level changes. On the other hand, lead "green" users have existed for some time now [29], and locavores have long advocated the value of locally-based food production and distribution systems.

This section is meant neither as praise nor as critique for any particular abstract. Rather, we seek to point out patterns that may be informative with respect to thinking through how these future visions may shape current research.

V. Conclusion

"Think globally, act locally!" goes back to 1915, when the town planner and social activist Patrick Geddes wrote that "*Local character* is thus no mere accidental old-world quaintness, as its mimics think and say. It is attained only in course of adequate grasp and treatment of the whole environment, and in active sympathy with the essential and characteristic life of the place concerned" [30, p. 397]. Yet, it is still unsolved whether and how we will answer the need for changing our lifestyles towards more sustainability and resilience, and thereby avoid superfluous complexity and the potential for collapse.

This paper presented a set of fictional abstracts that could appear at ICT4S in 2029 around the concepts of sustainability, complexity, collapse, and resilience of ICT systems. We hope that by providing this collection together with the set of referenced definitions and background from the various related disciplines we are able to (1) inspire future research, (2) stimulate discussion at the conference, and (3) contribute to building the ICT4S research community.

Acknowledgments

This material is based in part upon work supported by the DFG (project EnviroSiSE, grant number PE2044/1-1) and the National Science Foundation under Grant No. 0644415. We would like to thank Joseph Tainter and Lorenz Hilty for valuable feedback and discussions as well as Reviewer 2 for helpful comments that made the rooting of the paper more explicit.

References

[1] Participants and Speakers of the First International Conference on ICT for Sustainability, Zurich, February 14-16, 2013, "Conference Recommendations: How to Improve the Contribution of ICT to Sustainability," http://2013.ict4s.org/wp-content/uploads/ICT4S_Conference_Recommendations.pdf, 2013.

[2] The Climate Group, "Smart 2020: Enabling the low carbon economy in the information age," http://www.smart2020.org/publications/, 2008.

[3] World Business Council for Sustainable Development, "Vision 2050: A New Agenda for Business," http://www.wbcsd.org/WEB/PROJECTS/BZROLE/VISION2050-FULLREPORT_FINAL.PDF, 2010.

[4] J. Tainter, "Sustainability," Personal communication, February 14, 2014.

[5] E. P. S. Baumer, J. Ahn, M. Bie, B. Bonsignore, A. Borutecene, O. T. Buruk, T. Clegg, A. Druin, F. Echtler, D. Gruen, M. L. Guha, C. Hordatt, A. Kruger, S. Maidenbaum, M. Muller, L. Norooz, J. Norton, O. Ozcan, D. Patterson, A. Riener, S. Ross, K. Rust, J. Schoening, S. Silberman, B. Tomlinson, and J. Yip, "CHI 2039: Speculative Research Visions," in *Proceedings of alt.CHI of the ACM CHI Conference on Human Factors in Computing Systems*, 2014.

[6] R.W. Kates, W.C. Clark, R. Corell, J.M. Hall, C.C. Jaeger, I. Lowe, J.J. McCarthy, H.J. Schellnhuber, B. Bolin, N.M. Dickson, S. Faucheux, G.C. Gallopin, A. Grbler, B. Huntley, J. JŁger, N.S. Jodha, R.E. Kasperson, A. Mabogunje, P. Matson, H. Mooney, B. Moore III, T. ORiordan, and U. Svedlin, "Sustainability science," *Science*, vol. vol. 292, no. no. 5517, pp. pp. 641–642, 27 April 2001.

[7] United Nations, "Report: Our Common Future," in *Conference on Environment and Development*, 1987. [Online]. Available: http://www.un-documents.net/wced-ocf.htm

[8] J. Tainter, "Social complexity and sustainability," *Journal of Ecological Complexity*, vol. 3, pp. 91–103, 2006.

[9] Lorenz Hilty et al., "The relevance of information and communication technologies for environmental sustainability," *Environm. Modelling & Software*, vol. 21, no. 11, pp. 1618 – 1629, 2006. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1364815206001204

[10] B. Penzenstadler, A. Raturi, D. Richardson, and B. Tomlinson, "Safety, security, now sustainability: The non-functional requirement of the 21st century," *IEEE Software Special Issue on Green Software*, 2014.

[11] E. Ostrom, "A general framework for analyzing sustainability of social-ecological systems," in *Proc. R. Soc. London Ser. B*, vol. 274, 2007, p. 1931.

[12] J. A. Tainter, *The Collapse of Complex Societies*. Cambridge University Press, 1990.

[13] J. Diamond, *Collapse: How Societies Choose to Fail or Succeed*. Viking, 2004.

[14] J. Lovelock, *The Vanishing Face of Gaia: A Final Warning*. Basic Books, 2009.

[15] B. Tomlinson, E. Blevis, B. Nardi, D. J. Patterson, M. S. Silberman, and Y. Pan, "Collapse informatics and practice: Theory, method, and design," *ACM Transactions on Computer-Human Interaction*, vol. Vol. 20, no. No. 1, 2013.

[16] T. F. Allen, J. A. Tainter, and T. W. Hoekstra, *Supply-side sustainability*. Columbia University Press, 2003.

[17] D. Stokols, R. P. Lejano, and J. Hipp, "Enhancing the resilience of human-environment systems: a social ecological perspective." *Ecology & Society*, vol. 18, no. 1, 2013.

[18] S. Krumdieck, "The Survival Spectrum: The key to Transition Engineering of complex systems," in *Proceedings of the ASME International Mechanical Engineering Congress & Exposition*, 2011.

[19] J. Cameron, "Resilient Citizens in the Information Society," http://ifipwg92.org/resilient-citizens-in-the-information-society/, 2011, For the IFIP WG9.2 & WG 9.9 Joint Workshop, Milan, June 2011, Social Accountability & Sustainability in the Information Society: Perspectives on Long-Term Responsibility.

[20] D. Meadows, *The limits to growth*. Signet, 1972.

[21] The Club of Rome, "40 years 'limits to growth'," http://www.clubofrome.org/?p=326, 2012.

[22] R. W. Kates, "What kind of a science is sustainability science?" *Proceedings of the National Academy of Sciences*, vol. 108, no. 49, pp. 19 449–19 450, 2011.

[23] D. J. Murphy and C. A. S. Hall, "Year in review eroi or energy return on (energy) invested," *Annals of the New York Academy of Sciences*, vol. 1185, no. 1, pp. 102–118, 2010. [Online]. Available: http://dx.doi.org/10.1111/j.1749-6632.2009.05282.x

[24] N. Gagnon, C. A. Hall, and L. Brinker, "A preliminary investigation of energy return on energy investment for global oil and gas production," *Energies*, vol. 2, no. 3, pp. 490–503, 2009.

[25] M. C. Guilford, C. A. Hall, P. OConnor, and C. J. Cleveland, "A new long term assessment of energy return on investment (eroi) for us oil and gas discovery and production," *Sustainability*, vol. 3, no. 10, pp. 1866–1887, 2011.

[26] J. Verne, *Twenty thousand leagues under the sea*. Oxford University Press, 1998.

[27] H. G. Wells, "The time machine. 1895," *New York: Berkley, nd*, 2005.

[28] J. Verne, "From the earth to the moon. 1865," *Translated by J. and R. Baldick. Dutton, New York*, 1970.

[29] A. Woodruff, J. Hasbrouck, and S. Augustin, "A bright green perspective on sustainable choices," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2008, pp. 313–322.

[30] P. Geddes, *Cities in Evolution*. London: Williams, 1915.