EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

Exploratory Workshop Scheme

Standing Committee for Physical and Engineering Sciences (PESC)

Standing Committee for Social Sciences (SCSS)

ESF Exploratory Workshop on

The Internet of Things for a Sustainable Future

Vielsalm (Belgium), 9-13 May 2011

Convened by:
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SCIENTIFIC REPORT

1. Executive summary.

The past decade an overwhelming amount of evidence has accumulated for the fact that the current organisation of our societies is unmanageable with respect to the available natural resources. In particular our current way of living is seriously damaging biological ecosystems and human living conditions in the short term, which in turn may lead to irreversible climate change in the long term. In order to guarantee our future well-being we fundamentally have to change our lifestyle so that it becomes sustainable, i.e. so that it achieves an ecological balance by avoiding depletion of natural resources. A lot can and must be done from the technological and policy side, and as such sustainability is now a key issue figuring in many a government directive, company slogan and workshop such as the one described here. On the other hand we are still a long way off a global transition in everyday lifestyle, as it is only when people become fully aware of their precarious ecological situation and how this impacts their future living conditions that one can expect the needed behaviour change.

The goal of this workshop was to lay the basis for a research programme which puts the Internet of Things at the service of the sustainability effort. The Internet of Things (IoT) naturally lends itself to many of environmental sustainability's core challenges: monitoring the state of the physical world, managing the direct and indirect impacts of large-scale human enterprises, and informing individuals' personal choices in consumption and behaviour. While a very active domain of research in itself, as reflected in the existence of academic actors focusing on the topic worldwide, the implementation of new and powerful IoT technologies in the sustainability effort is much less explored, in particular in the European research arena. This workshop formed the basis for a European research programme which puts the IoT at the service of the sustainability effort, bringing together the right interdisciplinary expertise to allow for new and better subsequent research actions in this area.

The workshop was an intellectual encounter between quite a heterogeneous group of computer scientists, physicists, designers and geographers, linked by their urge to do something about the sustainability crisis. A total of 19 people participated from 9 countries. To avoid clustering within areas of expertise - which would have been catastrophic for the success of the workshop - we aimed at providing an optimal environment for interaction. Hence we decided upon an informal, community-forming approach, choosing as a venue the former Hotel, now Holiday House Belle Vue in the centre of the picturesque village of Vielsalm, in the Belgian Ardennes. All participants were lodged in private rooms, talks and discussions were held in the hotel lounge, a cook arranged all meals on-site, while the hotel bar, the adjoining lake of Vielsalm, and basement spa made for ample leisure facilities. This balance between private space and communal living provided an excellent team-building habitat, allowing flexible transitions between group research activities on the one hand and leisure time on the other, while at the same time giving participants the opportunity to retreat transparently into their private space whenever desired. This was particularly important because participants typically had not met beforehand. For this reason we wanted to “force” as much interaction as possible without this being apparent to participants, and never without the option of downtime. Though seemingly peripheral, this framework of interactivity contributed largely to the success of the workshop, in that interest was nurtured, communication facilitated, motivation increased, willingness to pursue this topic further heightened.

Transport to Vielsalm was arranged from Brussels by minivan on Monday the 9th at 5pm, and back to Brussels on Friday May 13th at 10am. These minibus trips provided a first get-to-know opportunity, complemented by a joint dinner upon arrival at the workshop venue. The workshop booklet (available on the website), containing abstracts as well as pictures of all participants, was immediately handed out so as to provide an easy tool for participant identification. The workshop itself was spread over the 3 days in between, allowing enough time for all participants to present their work as well as for discussion and brainstorming sessions. Each day breakfast, lunch, dinner and coffee breaks were provided on-site in the dinner area, one table seating all participants. A dedicated workshop website was set up at brussense.be/workshop to collect all information relevant to the workshop and to post news in a blog-like approach. At the workshop itself and as per the suggestion of one of the participants we set up a wiki at enipedia.tudelft.nl/iot (login required, but users can set this up themselves). The wiki was used throughout the workshop to post slides, comments, remarks, questions, links &tc. related to each presentation, and was also used for the brainstorming sessions. All talks were recorded (with permission of participants), though this information has so far not been put online.

Since there was little backbone of research to rely on, attendees came from varied disciplines, and participants were often new to the group as a whole, it was crucial to set up a common knowledge base from the very start. Scientific interaction required first and foremost that each participant introduced their own research, keeping in mind the common framework of sustainability. While the latter was highlighted through keynote talks, the former was achieved by giving each participant a slot in which to present his or her work to others. In this way we gave participants a forum to present their body of work and to delineate its place within the domain context. Keynote talks dealt with more broader, visionary or review topics, and were placed at the start of the day to give participants food for thought for the rest of the day (the second keynote talk, on May 11th, was placed in the afternoon because of the speaker's virtual participation from the Boston time zone). Research talks were grouped into sessions as per the contents of each talk. Keynote talks were loosely coupled to the presentation sessions for the same day.

The first day of the workshop (May 10th) was all about gathering data about and by people. The first keynote talk by Christian Nold about the Internet of People was followed by sessions on participatory sensing and on applications of IoT technology to the areas of energy, transport and health. The second day of the workshop (May 11th) focused on more societal aspects of the IoT in general. Sessions on social aspects and privacy considerations were complemented by a keynote talk by Jennifer Dunnam of the SENSEable City Lab at MIT. Day 2 was closed of with a team-building activity: paint-balling in the forests of the Ardennes. All but one participant joined the game, which was a lot of fun and clearly eased interactions between participants afterwards. The third and last day of the workshop (May 12th) consisted of half a day of talks on environmental sensing and half a day of brainstorming. As a result of generally excellent keynote and research talks, as well as ample informal interaction, participants were as ready as they could get for brainstorming sessions. For these we followed a diverge-converge structured social process to arrive at a shared understanding of issues, tools and possible projects around IoT for Sustainability. Brainstorming proved successful first in that all groups managed fluent communication, which was not trivial considering the variation of skills within each group and the fact that group members had not collaborated previously. On top of this, common notions emerged from all groups, which strengthens our case and ensures that we are on the right track.

The workshop concluded in style with an excellent dinner and lots of discussion. All participants were extremely enthusiastic about the workshop, which was generally considered a success. Concrete ideas for follow-up actions were proposed, in particular a joint paper and project proposal. Within the boundaries of a three-day workshop, we achieved the common insight that this is valuable and necessary research, and the willingness to pursue the development of the IoT for sustainability.

2. Scientific content.

The three-day workshop covered different areas which deal with or are foraging grounds for IoT for sustainability. Each day featured a longer keynote talk, wherein speakers had the liberty to broaden and deepen their presentation topic, and which served as food for thought for the rest of the day's programme. We scheduled each day's talks to that they were broadly oriented around a particular theme, while sessions within each day grouped talks more concretely per topic. We discuss each of these themes and its composing sessions in more detail below. We refer to Sec.4 for the exact programme of the workshop, and to the workshop wiki (enipedia.tudelft.nl/iot) for a full listing of comments and slides for each talk.

Day 1. The first day of the workshop (May 10th) was all about gathering data about (and by) people.

- The keynote talk by Christian Nold about the Internet of People stressed the importance of a top-down evolution towards an IoT reshaping of public space, putting people's ideas, wishes, opinions, habits… directly into the loop. This vision is one of a community-built network which is both local and global and which provides the tools and infrastructure of daily life. To build this we need to develop a range of social standards, embedding the social qualities of that we want into future technologies.
  Comments. The topic of this talk was a recurrent theme in the workshop, and one that everybody agreed on: we need more dialogue between and co-evolution of technology/data and people/opinions. The awareness of this was very acute, even though there were only two (part-)sociologists in the crowd. Other examples of successful situations were brought forward, as well as frustrations due to the lack of such interaction.

- This was followed by a session on participatory sensing , i.e. crowd-sourcing through mobile phones and the like, an approach with active participation of citizens and thus inherent awareness-building features.
  - The first talk in this session was that of Muki Haklay advocating extreme citizen science, i.e. involving citizens at all levels in defining problems, envisioning possible projects and analysing subsequent results. Indeed the general public can (and should) participate in any discussion about data they have collected, and are often best placed to analyse that data. One example of extreme citizen science is that of the Mbendjele pygmies, using simple pictograms on a smartphone to catalogue trees in their environment, thus working with tree loggers for a more sustainable environment.
    Comments. The last slide listed some of the core challenges and was the origin of much of the discussion. The challenges mentioned are: quantity of measurements vs. accuracy of instruments and procedure - patterns of engagement (spatially and temporally, and designing for this) - motivations, incentives, longevity of engagement, empowerment etc. - human error models to understand when and how errors happen and how to deal with them - environmental models that assume such input data. In particular modelling incentives was discussed,

and how philosophical arguments such as methodological individualism play an important role therein.

- The second talk in this session was by co-convenor Matthias Stevens about the NoiseTube project, a participatory sensing framework for noise pollution (this is research carried out together with convenor Ellie D'Hondt). The different components of this framework were covered: mobile application, server software gathering and visualising all data, approach to and quality of sound measurements. An experiment with up to 20 volunteers mapping an area in Antwerp and the results thereof were presented, comparing this approach with the official maps of the region (which are based on simulation techniques).
  Comments. A lot of questions were asked about official techniques for noise mapping, because many people are not aware of European norms and practices to tackle this issue. The idea of having few precise sensors around seemed absurd to some participants, but of course one should understand this within a simulation framework, where only few but very precise initialisation input values are required.

- The afternoon of day 1 focused on several application areas of IoT technology, starting of with a session on the use of IoT for energy analysis & management.
  - Alan Smeaton headed of the session with a presentation of the Clarity Centre where he is based, zooming in on household energy monitoring experiments. "We found the same as everyone else ... initial enthusiasm gives way to bad habits - need to continuously inform." Current experiments are focusing on the unexpected role of energy monitoring for lifestyle analysis, as some obvious correlations between energy usage patterns and lifestyle were observed.
    Comments. The idea of captology spurred a lot of interest: it is the use of technology as a persuasive tool for behaviour change.
  - Next talk was by Markus Weiss on the work of the Bits to Energy Lab: combining information technology and behavioral sciences to promote energy conservation and efficiency. The lab conducts research on consumption feedback, customer engagement, and data analytics – with an emphasis on economically attractive deployment and advocating automatic procedures wherever possible.
    Comments. Large energy expensive appliances have heavily increased their energy efficiency, but the large number of small appliances are now starting to dominate the energy use. Discussion centered around the question: does IoT's constructive contribution to sustainability compare to its destructive contributions? We should always shy away from gadgetry for gadgetry, in a sustainability setting one should never increase net carbon footprint by introducing new technology.
  - Final talk in this session was Adrian Friday about an experiment carried out at 4 of the University of Lancaster's shared campus residences to determine personal energy practices using low-cost off-the-shelf sensor technology (the kitchen stove was monitored by an overhead camera, the hobcam) and interviews.
    Comments. It is all about changing what people are doing right now. However, it is more difficult to change people's preferences than to just give them feedback on use. Some obvious energy-evils are: boys with toys, senseos, xboxes…

- The final session of the day featured applications of IoT to transport and health.
  - The first talk by David Evans dealt with the TIME project, a pragmatic approach to help users with tactical and strategic decisions about transport relying on existing data only. There is already a lot of infrastructure there: bus times are monitored, traffic cameras are present… This data is used as input through a middleware approach into a decision algorithm and presented visually to the user. Problems are scale (multitude of bus positions!), organisation boundaries and privacy.

Comments. There is other middleware like this one (AgentScape, i2maps), how does it compare? On the whole, the idea of using data already out there is great. But how do organisations cope in practice?

- The second talk by Elisabetta Farella was about using body sensor/actuator networks for healthcare and rehabilitation. Sustainability in the health domain is a social, reusability and energy perspective challenge. Concretely an experiment using audio feedback to inform the patient on his stability during mobility exercises was explained. This requires not only sensing but also actuating, and in these experiments energy requirements were very strictly taken into account (harvesting, &tc.).
  Comments. At first sight off-topic, this talk was very good in helping people realise that the health industry also crucially needs to be made sustainable. The economics of sustainable health is such that we have to let elder people sustain themselves or their care will not be sustainable. Another pertinent remark: greening IoT equipment could very well come out of e-health apps, which have stricter requirements due to dealing with elder people (low to no maintenance, transparent use ...). These developments can feed back into more general IoT apps.

Day 2. The second day of the workshop (May 11th) focused on more societal aspects of the IoT in general. The keynote talk was placed in the afternoon due to the fact that the speaker's presence was virtual and from the Boston time zone.

- The first session of the day was about social aspects of the IoT, both in its use as well as as those that surfaced as a result of investigations through IoT technology.
  - An Jacobs headed off the day with a talk about her experiences with data collection and analysis in an IoT world. Technology should be an ideal 19th century servant: invisible, easily localised, and controlled. This underlines the need for putting the user into the design loop (the Internet of People, again), but also in the operational loop, giving the user control over and information about what is happening. Much could be learned from DiY culture in organising this approach. One should also take the roles of users into account: typically 90% of users in Web2.0 systems are lurkers, 9% contribute a little, 1% account for almost all the action. (this is from a paper from 2008 - it has gotten worse by 2011, with 0,1% accounting for all of the action).
    Comments. The speaker was the only sociologist pur-sang present at the workshop, as a result the insights given were very enlightening to other participants who were typically more science/technology-oriented. The importance of invisibility (also explicit in Weiser's vision of ubiquitous computing) and of user roles were brought to the foreground. The Internet of People idea caught on even more with this talk.
  - The second talk of this session was by Igor Nikolic on agent-based modelling for engineering large-scale socio-technical systems (long lifespan, high investment, e.g. harbours, waterway networks, industry…). These are complex adaptive systems (they evolve, no centralised control…), which can be modeled through agents. Agent-based modelling steers the coevolution of such systems in terms of semantic linked open data on technical design, social processes, formalised knowledge and collected facts. Note that the enipedia site, which was also used for this workshop, is the front for a database used actively in this type of research. IoT is important since it can extend the underlying data set significantly.
    Comments. Related work mentioned was the idea of post-normal science (a methodology of inquiry that is appropriate for cases where facts are uncertain, values in dispute, stakes high and decisions urgent) and the work of environmental scientist-attorney Braden Allenby (in particular that on convergence and

technological evolution). There is potential in engaging with existing communities of interest, which could add facts of a different type to the database.

- The session was closed by Vittorio Loreto on agent-based modelling of the social phenomena of collective behaviour and opinion shifts in user-contributed systems. Agent behaviour relies heavily on ideas from (statistical) physics.
  Comments. The main lesson learned by participants is that experimental data is almost never there in a massive way... and the web is one place to obtain this data, in particular in bottom-up user-generated content (e.g. delicious). So the web should be seen as an experimental avenue to test out these social modelling approaches.

- A second session dealt with privacy considerations, an often overlooked aspect of IoT practices which is extremely important if we want to achieve broad uptake of IoT technologies. Two talks made up this session.
  - Pavlos Efraimidis acted in part as a proxy of colleague Ioannis Athanasiadis, who could not make it to the workshop himself. The talk thus existed of two parts: the first dealing with the lab's experience with proper software development for eco-informatics. While data capture and end-user apps work fine (though there is a serious imbalance between data coming from developed and developing countries), data processing and software development tools are lacking or not properly used in sustainability. The second part dealt with the privacy-enabling architecture Polis, which was tested in e-shop, social network and content-management-system contexts.
    Comments. How can the IoT help in the data bottleneck, i.e. making sense of all the data gathered - i.e. how does the sustainable software development package proposed tie in to this new technology? Smart, context-dependent end-user software could do part of the job. This framework presents a middleware approach. A wild idea is that of applying algorithmic game theory ideas, in particular Nash equilibria, for achieving balanced emission trading and incentivise users of participatory applications.
  - Hedda R. Schmidtke presented some of the projects at TecO: mobile app for activity recognition, taking the machine learning specialist out of the loop; vibration sensor networks to localise problems in industrial settings; RFID tags for chemical storage management; production of cheap small printed nodes, with printed batteries and the aim to make them biodegradable. These projects were presented within the philosophy of the Internet by Things, rather than of Things, and this is also the link with privacy. The idea is to put more control with the IoT components, letting them set up their own networks of computation and even reasoning; this abolishes the need for unique addressing and thus solves a number of privacy issues.
    Comments. This idea of putting control with the things themselves rather than having a centralised organising unit is very interesting – it is really the amorphous computing vision of the end of the nineties, now finally becoming a reality and forgotten by many.

- The above sessions were complemented by a keynote talk by Jennifer Dunnam of the SENSEable City Lab at MIT. This is one of the larger labs in the USA, where research on citizen-oriented IoT is further advanced than in Europe. The goal of this keynote was to obtain an insight in such a larger lab's place within the world and its experiences drawn from the many projects carried out. For technical reasons the bulk of the talk was a recorded talk of the lab's director Carlo Ratti (at the see conference#6), while the intro and questions afterwards where in real-time. Projects covered were trash&track, the Copenhagen wheel, visualising networks all around the world, Zaragoza's water curtain installation.

Comments. The overview given resulted in much discussion, both on- and offline, in particular due to the lab's heavy focus on visualisation while most of us where interested in the underlying data and what one can learn from it. Another red flag for gadgetry!

Day 3. The third and last day of the workshop (May 12th) consisted of half a day of talks focused on environmental (in particular air quality) monitoring and half a day of brainstorming.

- This day started with a keynote talk by Silvia Santini reviewing 10 years of work on wireless sensor networks for environmental monitoring. Over these 10 years data delivery efficiency went from 30% to 98% and WSNs augmented in size from a few nodes to 100s of nodes. Communication protocols went from isolated, closed approaches to internet protocol approaches that are also compatible with other types of networks. Typical requirements for WSNs are context-dependent, though communication should always be minimised. E.g. for bridge monitoring one cannot afford to lose any packets at all , and the configuration of long arrays of nodes on a bridge demands different communication algorithms; requirements may also differ at the level of lifetime, typical number of nodes, difficulty of accessing the nodes… Really large-scale deployments (1000s of nodes, typically with small nodes called smart dust) are now considered unfeasible by the research community.
  Comments. This review talk came with many questions on how these projects were implemented, and was very educational for all of us. One lesson learned is that the gap with IoT approaches such as mobiles sensing is really closing in. Concrete links: WSN protocols can be seen as the network layers and the fundamental protocols for IoT; smart dust is almost equal to RFID tags; large WSNs typically rely on smart dust for the monitoring of large areas, which is now considered to be more feasible via mobile sensing.

- Next was a session of research talks on aspects of environmental monitoring
  - The first talk by Hans Scholten was about the opportunistic use of mobile phones for environmental monitoring and, more generally, disaster management. Flocks of phones are put to use in a vision of context-aware opportunistic sensor networks which inform users when needed in realtime.
    Comments. This nice vision begs many questions, as the reality of IoT software development is one of heterogeneity and incompatibility.
  - The following talk was presented by Jan Theunis, and dealt mostly with the performance aspect of environmental sensor equipment. The conclusion is that air quality sensing is not yet ready for pervasive applications/crowd sourcing, as performance widely varies and it is not even always clear what these sensors measure (many pollutants are correlated). A combination of low-cost sensors, more sophisticated sensors, air quality models and contextual information (human sensors) is advocated. Sensor arrays are also put forward as a way to construct better sensor values.
    Comments. This talk was very valuable for learning about the realities of sensor equipment for air pollution, which most participants were not aware of. From the workshop wiki: "This talk is raising serious points about the limits of citizen science (costs, skills) and shows the need for collaboration between experts and participants".
  - The final research talk of the workshop was given by Michael Bruse on the topic of agent-based modelling techniques for estimating the microclimate (temperature) and pollutant exposure in urban structures. The environmental model is a mix of system dynamics and computational fluid dynamics (ENVI-met) with pedestrian agents walking through it (Botworld). Parameters are: wind field, air temperature (less important than one may think), radiative temperature (artificial

field embodying influence of solar radiation), and humidity. On the other hand each agent can have its own “personality” such as preferences or goals as well as his/her own perception and assessment of the environment. A substantial difficulty is that agents are not stationary and that agent exposure assessment depends on the history of climate conditions the assessing individual was exposed to before.

Comments. An application such as Mappiness , which asks people personal questions at different time intervals to improve subjective information, may be relevant. What about directly applying this framework to the steering of city design through agent comfort?

The final afternoon of the workshop was devoted to a brainstorming session. Beforehand we gathered key topics, related projects and project calls on the wiki to use as a starting point. Participants were divided into four groups and given large poster paper, coloured pens, and the wiki as tools for brainstorming. A short introduction on the process to be used was given by Igor Nikolic. Concretely, we followed a 3-tiered 3x30-minute diverge-converge structured social process to arrive at a shared understanding of issues, tools and potential projects around IoT for Sustainability. The result was a 6 step process, as follows.

The first divergence-convergence was on issues/problems. Each group diverged to create a list of questions/issues/problems in IoT for Sustainability. Then all groups converged through information exchange, i.e. by reading other groups' ideas on the wiki and cross-pollinating these with their own. Each group made a short summary of their findings.

The second divergence-convergence is on tools/approaches. These include mathematical methods, computer simulation, useful theories, whatever the participants have to offer or know about. The same process as above is used.

The third divergence-convergence is on projects (or work packages). This is the step in which the lists created in the first two steps are brought together to develop actual combinations of issues and tools that are practical. This is also where the issues and tools are brought together into the final report.

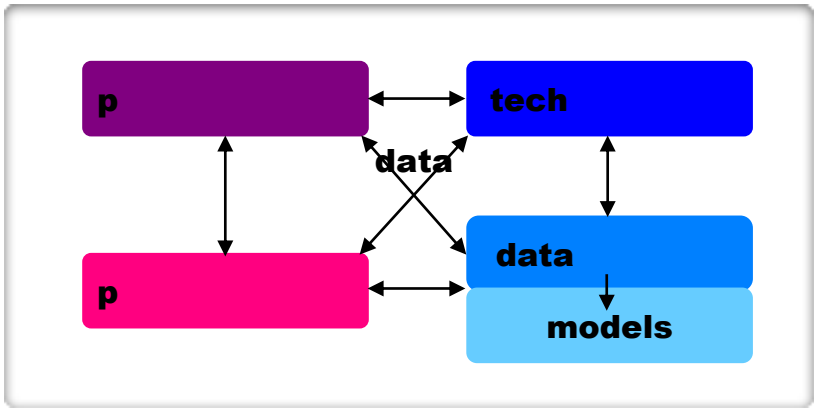
After the three steps a group session was held in which each group presented their project ideas and plans for future actions were discussed. We note that due to the swift turnover (each converge step is 20 minutes, each diverge step 10 minutes) this was a relatively short but dense brainstorming exercise, which is aimed at obtaining fast, intuitive ideas and capturing gut-feelings for potential avenues of research rather than at delivering polished outcomes. Instead of providing the raw list of projects and ideas that came out of this brainstorming session, we felt it was more useful to carry out a synopsis and distillation step first, so as to obtain a more useful digest of the collective output of the brainstorming session. The latter may be found in the following section, which deals with workshop outcomes.

3. Assessment of results, contribution to the future direction of the field, outcome

3.1 Outcomes

The brainstorming session turned up a partially converged compilation of each of the four group’s listings of issues, tools and projects, respectively. We list here the most obviously recurring themes and constructive ideas from those compilations. All of these can be situated along the nodes or vertices of the diagram below. We loosely fol-

low a counterclockwise ordering, starting from the technology box, in the listings that follow.



Issues.

In everything we do, we should always remember the following motto: no gadgetry for gadgetry!! Cool things are allowed, but only if they contribute to long term goals, behaviour change, and they improve on overall sustainability (i.e.also taking the carbon footprint of the technology used into account).

How do we better connect IoT technology to people? IoT can be very technical, even cold - about things talking to themselves. Instead it should be centered around people, their interaction with the physical and virtual world and with each other, and extend human senses and capabilities.

How do we use IoT technology to steer policy? We do not want to end up with technologies that are just proof of concepts. We want to develop new technologies and tools that are to be part of long-term policy making and action in society.

How do you turn heaps of data into something meaningful? How do we translate sensor data to information to knowledge to insight? Note the discontinuity between the little sensors and the large world: the local vs. the global, the high resolution, small-scale approach of sensing vs. the large-scale implications and models running that we expect to derive from the sensor data, which run on much longer timescales.

How do we turn awareness into action? If we act local, does this mean we think global? We need to break down the awareness aspect, as it consists of a number of different things. Do people have no idea what is going on ? Is this even an issue ? People might even know what is going on, but not what to do about it.

Related to the previous, what are the different roles of IoT users, and how can we put this knowledge into the system? As a very concrete example, there are powerful unelected actors (e.g. kitchen advisors) while consumers are disempowered. We need an ethnography of people who can make powerful long lasting impact on our lives.

Tools & Theories.

Technology development, software and hardware: autonomous systems, sensor fusion, edible batteries, micro-controllers, energy harvesting, object tracking, prototyping, software and hardware support for better integration.

Data gathering by human & machine, from most to least autonomous: crowd-sourcing - distributed computing - opportunistic sensing - participatory sensing - extreme citizen science, all of these using sensors, tagging, surveys, ...

From data to models for the physical world, social interactions, and the evolution of organisations: through data integration, (collaborative) filtering, compression, management, mining, representation (ontologies, metadata…), visualisation; using statistics, environmental science, complex systems theory, fluid-social-opinion dynamics, dynamical systems theory, game theory, logics, knowledge representation, algorithms, numerical models, machine learning.

Designing for people, with people, using: graphic design, community-based science, interaction design, participatory design, social process design, community memories, (cryptographic) tools for privacy preservation, visualisation.

From awareness to action, individual, communal, organisational by: challenging assumptions, being contrary, looking at the long tale, sharing of commons, micromanagement of commons, community-building activities, deploying systems in the real world, public infrastructures, serious games/games with a purpose; taking into account the theories of the management of the commons (E. Ostrom), critical theories of technology (A. Borgmann on device paradigms, A. Feenberg on democratisation of technology) and grassroots movement theories.

Projects.

The material which came out of the brainstorming sessions can be digested into the two following project proposals.

Using the IoT for environmental impact management. Rely on practices for management of the commons, participatory sensing, community memories, visualisation, and environmental campaigning, to bridge the divide between low-level sensor data and collective action for sustainability, what we call the "fast data - slow models - slower policy" problem.

Use a bottom-up approach for actions, involving and empowering citizens at all levels.

Use a top-down approach for data collection, always asking oneself: what is the essential data and technology to create a more sustainable world? How do we get meaningful data to the people who need it?

Create different ways to collect and organise data into information that is directly useful for decision-making processes at the policy level. Develop methodologies that enable integrating fast data into models/policy. Once models/policy his into place, go back to the data to see how one can improve/evolve policy and models.

Create an observatory for studying the impact of our actions on the environment/for resource-commons management. Use this observatory to give people a sense of the consequence of their actions, i.e. we have observed you behave such and such, and under different future scenarios, you will have affected the world such and such.

Contextual affordances to support the Internet of People. Using the new concept of contextual affordances, i.e. smart context-sensitive derivation of what a user wants technology to do and in what way in terms of data collection, autonomy, behaviour, in order to develop a person-centric, local and interactive Internet of Things and develop policy-replacing applications thereof.

By smart we mean in a local way which is oblivious to the user, instead of the centralised way in which context is obtained now, i.e. by explicit interaction with the user or through the web.

Recommendations for user-centric relevant actions based on data streams constructed as per the user's context (locality, the user's current role, the available technology, …). A kindergarten example: inform users of energy costs of their actions and the savings obtained from doing them locally. A strong effort into context-aware software development would be required.

Mediating socially afforded interactions. A kindergarten example: phone behaviour depending on context (in a meeting, at home,…). This would require an encoding of socially acceptable interactions in terms of logical models.

3.2 Guidelines for the future direction of the field.

The workshop as a whole and brainstorming session in particular turned up a number of guidelines which can help direct developments of the IoT for a more sustainable future.

Decrease carbon footprint, a.k.a. the law against gadgetry: never introduce technology when the net result of its introduction is an increase in carbon footprint.

Quality. Collect data at as high a quality as possible, work with data only if you know what its quality is.

Behavioural inertia and damping. Never assume that people will adopt technology without incentives, and always assume incentives wear off. Remember that different people may have different roles in using technology.

Completeness. Target all citizens at all levels, go for extreme citizen science.

Decentralise, invert control. We need an Internet by Things with delocalised control, not an Internet of Things with centralised control.

Homogenise. Work towards transparent boundaries between organisations, policies, people, data and technology.

3.3 Future actions

The workshop created an initial European network of researchers interested in wielding IoT technology for a more sustainable future, with a willingness to collaborate further and a number of concrete plans for future actions.

We plan to publish our vision for the domain of IoT for Sustainability in an article for a broad audience in (a venue such as) Futures Magazine. An alternative version thereof will be submitted to Brussels Studies, an electronic magazine for research in Brussels.

There is a coming EU Call for environmental actions (planned for this summer/autumn) which is very relevant to our workshop and for which we expect to submit a proposal. The pertaining section is ENV.2012.6.5-1: Developing community-based environmental monitoring and information systems using innovative and novel earth observation applications. The funding scheme is that of SME-targeted Collaborative Projects, so we would need to tailor our consortium so that at least 30% of the funding goes to SMEs. Discussions are currently underway.

There were suggestions for a Special Issue on the topic of the workshop. We are still determining a suitable venue.

4. Final Programme.

Monday 9 May 2011

17:30	Minibus departure from Brussels Airport/Brussels Midi Train Station
19:00	Arrival in Holiday Home Belle Vue, Vielsalm
20:00 - 22:00	Opening reception

Tuesday 10 May 2011

8:30 - 9:30	Breakfast
9:30 - 9:45	Meeting introduction
9:45 - 10:00	Presentation of the European Science Foundation (ESF)
10:00 - 11:00	Christian Nold: The Internet of People for a post-oil world *(Keynote talk)*
	Coffee break
	Session 1: Participatory sensing
11:30 - 12:00	Muki Haklay: Extreme Citizen Science and the Internet of Things - participatory sensing and sense making
12:00 - 12:30	Matthias Stevens: NoiseTube & beyond: a participatory approach for pollution mapping
	Lunch
	Session 2: Applications - Energy
14:00 - 14:30	Alan F. Smeaton: Unexpected applications of sensors: home energy and lifestyle analysis
14:30 - 15:00	Markus Weiss: Leveraging residential energy management through the Internet of Things
15:00 - 15:30	Adrian Friday: Understanding personal energy practices in shared campus residences using ubiquitous sensing

	Coffee break
	Session 3: Applications - Transport & Health
16:00 - 16:30	David Evans: Using data to inform tactical and strategic decisions about transport
16:30 - 17:00	Elisabetta Farella: Body sensor/actuator networks for healthcare and rehabilitation: ICT for a sustainable Health
20:00 - 22:00	Dinner & Bar discussion

Wednesday 11 May 2011

8:30 - 9:30	Breakfast
	Session 4: Social aspects
9:30 - 10:30	An Jacobs: Sense it yourself : social aspects of data collection and analysis in an Internet of Things world
10:00 - 10:30	Igor Nikolic: Agent-based modelling of large-scale socio-technical systems coevolution using semantic linked open data
10:30 - 11:00	Vittorio Loreto: New perspectives for the investigation of collective behaviour and opinion shifts
	Coffee break
	Session 4: Privacy
11:30 - 12:00	Pavlos Efraimidis: Semantics and privacy issues for environmental software
12:00 - 12:30	Hedda R. Schmidtke: Privacy, address, and resources - key challenges for future IoT developments
	Lunch
14:00 - 14:40	Jennifer Dunnam: SENSEable City Lab *(Keynote talk)*
	Coffee break
15:30 - 19:00	Team building façon Ardennes: Paintball
20:00 - 22:00	Dinner & Bar Discussion

Thursday 12 May 2011

8:30 - 9:30	Breakfast
9:30 - 10:30	Silvia Santini: Wireless sensor networks for environmental monitoring: a 10-year retrospective *(Keynote talk)*
	Coffee break
	Session 6: Environmental sensing
11:00 - 11:30	Hans Scholten: Flocks of phones, or why mobile phones are the next big thing for opportunistic sensing
11:30 - 12:00	Jan Theunis: The potential of community sensing for outdoor air quality monitoring
12:00 - 12:30	Michael Bruse: Thermal sensation and pollutant exposure in urban structures assessed with multi-agents
	Lunch
	Session 7: Planning future research actions
14:00 - 14:30	Ellie D'Hondt: Synthesis of previous sessions & Task force setup
14:30 - 15:30	Brainstorming session for each of the key issues identified. Split-up of working groups depending on the number and nature of such issues
	Coffee break
16:00 - 17:30	Synopsis & Future Planning
20:00 - 22:00	Dinner & Bar Discussion

Friday 13 May 2011

8:30 - 9:30	Breakfast
10:00	Minibus departure from Holiday Home Belle-Vue, Vielsalm
12:00	Arrival in Brussels Airport/Brussels South Train Station

5. Final list of participants.

Compared to the original application for this workshop a number of shifts occurred in the participant list. There were 4 cancellations where no replacement could be found (Alan Chamberlain, Jonna Häkkilä, Valerie Parker, Wolfgang Reitberger). There were 10 situations of conflicting schedules, even though the dates of the workshop were communicated well in advance. However these were all solved by finding excellent replacements, of which 7 of the same lab (Pavlos Efraimidis, David Evans, Elisabetta Farella, Igor Nikolic, Hedda Schmidtke, Jan Theunis, Markus Weiss, though the latter is currently not at ETH Zurich but visiting researcher at MIT). Christian Nold replaced Usman Haque as the keynote speaker to bridge the gap between research, real-world (urban) projects, and art. Jennifer Dunnam was our final choice for representative of one of the American labs, which are longer-running in this type of research. It proved very difficult to secure presence of one of the more senior researchers, though nearly all of them were contacted and replied enthusiastically. The reason for this is that our timing clashed severely with teaching terms and SIGCHI, one of the main conferences in our domain. Finally, we replaced Yann-Aël Le Borgne with Silvia Santini as per his (excellent) suggestion, as he is no longer working on the topic of the workshop. We also added a number of new participants whom we identified between the writing of the workshop proposal and the actual workshop (An Jacobs, Hans Scholten).

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6. Statistical information on participants.

Total number of participants	19	Country of residence	
		Belgium	**4**
Sex		**Germany**	**2**
Male	**13**	**Greece**	**1**
Female	**6**	**Ireland**	**1**
Age		**Italy**	**2**
Junior researchers (pre-doc)	**4**	**Netherlands**	**2**
Post-doctoral researchers	**6**	**Switzerland**	**1**
Senior researchers	**9**	**UK**	**4**
		USA	**2**