Building Sustainable Smart Homes

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ABSTRACT
The increasing usage of computer technology in our everyday life and especially in our homes and the increasing demand for sustainable life style concepts raise the question of how to combine these two trends. Can we make smart homes sustainable or sustainable homes smart? This paper discusses current trends and challenges arising with these questions and proposes a sustainable smart home approach.

Keywords
Smart and sustainable homes, sustainable living, sustainability.

1. INTRODUCTION
An ever growing awareness of the massive changes that our human societies are causing to our environments and planet Earth, increasingly calls for a fundamental change in our lifestyles. Governments, non-governmental organizations and concerned individuals call for sustainable living and seek ways to transition from our current lifestyle to a more sustainable way. In this context – and especially from an Information and Communication Technologies (ICT) perspective – the home plays a vital role as one of the central points where technology meets life first hand. This work takes a closer look at current development in the smart home area with a special focus on the idea of sustainable smart homes.

The idea of sustainable smart homes arises from two recent trends in the housing market: making homes "smart" and making homes "sustainable". Taking a naive view, creating a smart home means packing the home with Information and Communication Technology (ICT) and electronic equipment, while building a sustainable home usually means reduction and leveraging renewable materials to build resource-efficient houses; two approaches that seem to run diametric to each other. Aiming to combine both approaches leads to the idea of building sustainable smart homes and bears two perspectives to discuss: Can we build sustainable smart homes by …

1. making sustainable homes smart (by using smart home technology to improve sustainability)?
2. making smart homes sustainable (by improving the sustainability of the technology itself)?

We will discuss both perspectives in the following. After giving a working definition of the term 'sustainability' for our needs in the next section, we discuss sustainable homes and show which role ICT can play to address current issues and drawbacks. Afterwards we take a look at different smart homes projects and discuss how we can emphasize sustainability in those approaches. Finally, we propose a holistic view that combines the findings from both perspectives.

2. DEFINING SUSTAINABILITY
The term "sustainable development" was first widely articulated by the Brundtland Commission of the United Nations in 1987 and framed as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" [5]. More than 140 alternative and modified definitions that have emerged since then have been identified by Johnston et al. [34] and this proliferation of alternative definitions of the term "sustainability" has created a situation where this central concept has come to mean many things. At the level of the dictionary definition, sustainability simply implies that a given activity or action is capable of being sustained (i.e. continued indefinitely). This definition however conflicts with the idea of naturally evolving systems that change over time. It is also difficult to apply to the environmental domain, where even highly damaging practices can be sustained within time frames that are seemingly indefinite with respect to a human lifespan. Some people also argue that ecosystems will in time (but maybe too late for the survival of our species) adapt to the changes we inflict upon them. Thus it seems to be difficult to give a direct definition of sustainability or sustainable development and Johnston instead proposes the utilization of four basic principles of sustainability [34] that have been identified by "The Natural Step Framework" [51]:

1. *Substances from the lithosphere*[1] *must not systematically increase in the ecosphere*[2].
2. *Substances produced by society must not systematically increase in the ecosphere.*
3. *The physical basis for the productivity and diversity of Nature must not be systematically deteriorated.*
4. *There should be fair and efficient use of resources with respect to meeting human needs.*

These principles basically demand a minimal human intervention in natural processes (which is almost impossible given the rising human population) or the application of cyclic processes, which eventually give back what has been extracted. The latter is usually reflected in natural systems that are strongly intertwined in adaptive cycles of growth, accumulation, restructuring, and renewal and form an ever evolving eco-system [27]. Scientifically, it has been defined as a panarchy, which is the "*structure in which systems of nature […], of humans […] and combined human-nature systems are interlinked in never-ending*

[1] the Earth's crust

[2] the planetary ecosystems

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adaptive cycles" Holling further identifies this as "*the heart of what we define as sustainability*" [27] and acknowledges: *"We recognize that human behavior and nature's dynamic are linked in an evolving system. We realize that the seeming paradox of change and stability inherent in evolving systems is the essence of sustainable futures."*

Karl-Henrik Robèrt, founder of The Natural Step initiative, argues that *"the only processes that we can rely on indefinitely are cyclical; all linear processes must eventually come to an end"* [50], which gives us another idea about what is sustainable and what is not. He then also observes that our society is continuously processing natural resources in a linear direction, which will eventually reach an end and thus is not sustainable. To ensure our own continued existence, we will have to identify our linear processes and turn them into cycles. This way, we eventually reach a sustainable lifestyle driven by sustainable development and positive evolution.

This idea is picked up by Prof. Braungart and Prof. McDonough with the Cradle-to-Cradle concept [42]. Based on the idea that we should be striving to be part of nature's continuous improvements and a (positive) evolution, it distinguishes two cycles: the technological cycle takes care of feeding our technological resources as nutrients back into new technological cycles and a natural cycle that takes care of feeding our used natural resources back into natural cycles. Both cycles are very carefully separated from one another and aim at keeping their resources in endless circulation.

Sustainability research can thus be described as *the seeking for change and stability in evolving systems and the understanding of cycles and their scales to identify points to trigger positive change and foster resilience with respect to the four basic principles of sustainability*. What this means in detail, however, relates to the field it is applied to and thus is still subject for a final definition in the field of smart and sustainable homes, which we will examine in the remainder of this paper.

3. MAKING SUSTAINABLE HOMES SMART

Based on the above notion of sustainability, we can now look at its application in the field of sustainable homes. We therefore need a definition of sustainable homes and take a look at existing approaches. Afterwards we can analyze technology that can be applied to "improve" sustainable homes and address several identified issues.

3.1 Defining Sustainable Homes

The idea of sustainable buildings and homes is not new and, out of necessity, they have been built embedded into the environment and ready to evolve over time for millennia. Only recently, cheap energy, large glass sheets and air conditioning occurred, transforming the art of building and loosening the relation of the building to its surrounding eco-systems. Buildings are now often enough constructed not only without respect to their environment, but also without respect for their inhabitants [12]. In an earlier attempt to define sustainable homes with respect to these recent developments, Barnett and Browning came up with an eight-point checklist of criteria that a sustainable building has to meet. The list includes the usage of environmental friendly resources for building and living, harvesting water and energy in sustainable self-contained cycles that minimize consumption, the independent growing of organic food, the optimization of ventilation and air flows, and the provisioning of a healthy living environment [43, 48, 54]. Similarly, the Department for Communities and Local Government in the UK provides the "Code for Sustainable Homes" [20], a system of housing quality indicators that provide a framework to measure the sustainability of a home in 9 key areas (largely the same as those above): Energy & CO2 emissions, water, materials, surface water run-off, waste, pollution, health & well-being, management, and ecology. Several case studies of homes complying with the different levels of this code are listed in [3].

Various implementations of these criteria can be found throughout the world. Over 200 sustainable homes opened their doors to over 40,000 people on in September 2011 for Sustainable House Day in Australia [11]. Several projects collect information about sustainable homes and communities and list more than 180 eco-settlements in Germany [1], almost 400 settlements in Europe [53], about 500 eco-villages worldwide mostly outside of Europe [4]. Three selected projects are introduced in the following: a modern home, a continuously improved existing house and a more natural alternative approach.

The Archetype Sustainable House[3] in Canada aims at a modern resource efficient house design with natural and sustainable materials. It is built with wood, cork, bamboo, organic paint and ash based concrete. New insulation methods and solar/gas powered heating as well as solar powered low energy light sources aim at a minimal energy consumption. Waste water is treated directly at the house and rain water is collected and used for toilet flushing. Throughout the construction phase, waste was sorted and recycled on site or sent to facilities, compostable plates and cups were used for lunch and the entire site was powered by solar power trailers.

Figure 1: The Archetype Sustainable House. From http://www.sustainablehouse.ca

In Australia, Michael Mobbs describes his approach to turn his existing home in the middle of Sydney into a "Sustainable House" in his book with the same title [43]. Rainwater is collected, grey and black water tanks have been buried in the garden, which allows the house to be completely decoupled from the city's water system. Solar panels are installed on the roof, food is grown in the garden, organic waste is composted and the house has been tweaked with reusable materials in various corners. It now serves as showcase for the city of Sydney and inspired the city council to start the development of a sustainable neighborhood under the counsel of Mobbs.

The low impact woodland home of Simon Dale in Wales takes minimalism and eco-friendly almost to the extreme. Build from natural material found on site and recycled components it provides 60sq meters of living space and blends in with the surrounding nature. It combines a wood burner for heating, a fridge that is cooled by air coming underground through the

[3] http://www.sustainablehouse.ca/

foundations, solar panels for lighting, music and computing, water coming from a nearby spring, a compost toilet, and a pond in the garden to collect rain water from the roof.

Figure 2: The Woodland Home in Wales. From http://simondale.net/house

Based on the evaluation of over 20 sustainable home projects, including the three described above, we can note that the main topics with respect to our definition of sustainability are the usage of natural and renewable building material, efficient usage and collection/creation of water and energy, and the utilization of land for agriculture. Additionally, recycling and minimizing pollution, trash and wastewater play a major role. All approaches address the four basic principles of sustainability to different degrees. Well being of the inhabitants plays an important role too and cycles can often be found, e.g. in water recycling or gardening and composting approaches. Some approaches then emphasize comfort where others put a stronger focus on eco-friendliness and closeness to nature. Another strong difference between the approaches is the building and living cost. Massively optimized as in the Woodland Home, the building cost can be as low as £3000 and the cost of living can be largely reduced by gardening and on site food and energy production. While a minimalist approach in terms of resource usage, cost and comfort can often be found in the more natural approaches, commercial approaches usually aim at a maximum comfort with a minimized ecological impact.

Many of today's sustainable homes are still experiments of their owners, pioneering the path to a more sustainable living through inventing, experimenting, testing as well as stabilizing, conserving and often publishing their findings. Their organization in the larger context of sustainable neighborhoods aims at increased self-sufficiency, which can hardly be achieved in a single household. Some limitations that have been described are the acquisition of building materials, solar collectors that generate a surplus during the day, but require buying additional energy at night or gas that is often still needed for cooking and warm water. Often aiming at self-sufficiency, growing some food and owning animals are part of sustainable lifestyles, but inhabitants usually still have to acquire additional food as well as clothing and other necessities from external sources and the anticipated low ecological impact often comes with less comfort for the inhabitants. While this has been reported as not entailing less happiness of the inhabitants [43], it seems to be a major entry barrier for the masses.

3.2 Technology for Sustainable Homes

Technology plays different roles in different approaches to sustainable homes. The three examples in the previous section nicely illustrate the different levels of technology integration. The Woodland Home has a minimal technology integration but still provides electrical lighting, music and computing facilities. The Home of Michael Mobbs is equipped with a computer, a fridge, electric lights, stereo, etc, but aims at using low power devices. Similarly, the Archetype Sustainable House provides standard appliance with a low energy intake, but also uses high-tech products to reduce the daily ecological footprint of the house. This includes a zoned air conditioning system, utilizing a heat pump and a generator, space heating, electrical power generation and hot water, smart meters, and home energy display monitors for temperature control. The different concepts provide different levels of comfort for the inhabitants, which is reflected by the amount of high-tech products utilized in the homes.

In addition to the increasing level of comfort, smart home technology aims at the facilitation of more sustainable ways of living and can be a feasible way to tweak existing buildings. This ranges from increasingly efficient household appliances, cars, computers, etc. to new building materials and production processes and computer-based optimization. The Bluff Homestead[4] in New Zealand, utilizes a micro-processor that controls various pumps to move water around different tanks to make optimal use of solar heat and an additional stove and ensure that all guests have uninterrupted access to hot water (as the author personally experienced). The owners also run an automatic watering system for their vegetable garden and plan to make increasing use of alternative energy sources. To gain efficiency, this could even be extended through the use of moisture sensors in the ground or the weather forecast from the Internet [59]. The latter falls into the category of optimization through extended information and prediction, where information from the Internet and extended sensor networks allow better control of appliances and utilities. Other examples in this category are the weather and sun angle based control of blinds or solar panels as well as presence based scenarios, e.g. the control of lights, blinds or multimedia devices based on the users presence, activity (e.g. sleep detection), or even planned activities derived from a digital calendar system. Similarly, temperature surveillance, air quality and indoor climate monitoring can be used for optimization purposes [33].

Besides these automation purposes, information from sensors and the Internet can also be provided directly to the user to facilitate better decision making and the integration into local and global communities. Aiming at allowing informed users to make informed decisions [40], environmental information systems are available on the web, ranging from pigeons blogging about local air pollution [17] over encouraging individuals to make changes in their energy footprint through social networks [39], modeling long-term consequences for sustainability of decisions regarding urban transportation and land use [14], to supporting cultural change through informal networks, pre-existing institutional structures, and formal organizations [44]. Such web-based technology can help bringing the relevant information closer to where it is needed, making information about sustainable products available in the home or on the mobile phone while shopping or incorporating personalized sustainability related adverts into interactive TV streams.

Under economic view points, the increasing awareness about environmental problems our society is facing offers a variety of possibilities for new products and services. Sustainable services are on the advance as by September 2012, [2] lists 461 new eco and sustainability business ideas since 2003. Sustainability related ideas make up more than 10% out of a total of 4225 listed concepts. The direct integration of services and information into the home becomes a serious business case, while well established web sites like couchsurfing.org gain sustainable competitors like the recently launched sustainablecouchsurfing.org. Sustainability

[4] http://www.bluffhomestead.co.nz

(while to date often only addressed by PR relevant actions) becomes an important factor for established businesses [52].

The discussed projects all aim at facilitating a more sustainable lifestyle by making sustainable and eco-friendly behavior easier and acceptable for the masses. However, they bear the danger of waiting for a technological solution for a problem that requires major changes in consumption and behavior pattern to be solved and they all face the problem of the inherent sustainability of the underlying technology itself. The latter often drives sustainable living entrepreneurs to reduce technology in their homes to the bare minimum perceived as necessary or inevitably. Being part of the complex eco-system of a home, introducing one partial solution (e.g. automatic light switching) might even introduce more problems (e.g. old people spending even more time without getting up from the TV chair) than they solve in the long run.

4. MAKING SMART HOMES SUSTAINABLE

After analyzing sustainable homes and technological "improvements" in the previous section, we now jump to different perspective and take a closer look at smart homes and the idea of making smart homes more sustainable.

4.1 Smart Homes

In contrast to sustainable homes, which continuously gain momentum, holistic approaches to realize smart homes, although under development for decades now, have barely made it out of the research labs. Originally termed by the American Association of House Builders in the year 1984, the term "smart home" today mainly addresses the integration of ICT into domestic buildings, but has a long history and various definitions. One simple but well accepted definition has been developed by the DTI Smart Homes Project: "*A dwelling incorporating a communication network that connects the key electrical appliances and services, and allows them to be remotely controlled, monitored or accessed.*" [37]. While this definition works for most smart home scenarios that usually contain interacting and connected appliances, it rather focuses on automation and control aspects of the home and lacks a direct relation to the term "smart". Smart homes in turn can be described as acting autonomously and being proactively based on artificial intelligence. A problem with the term "smart" in this case is the lack of measurements for the smartness of a system.

The idea of smart homes comes from the earlier work on home automation in the 1970s and thus various approaches, aiming at home automation, focus on different aspects. Main areas are e.g. temperature surveillance, air quality and indoor climate monitoring [33], air, heating, lighting, ventilation, and water heating control to minimize energy consumption [45]. The MavHome project [16] aims at maximizing comfort, while minimizing operation cost. It predicts the actions of its inhabitants and automatically turns on and off heaters, lights and coffee machines in the morning, sprinkles the lawn, places grocery orders, and prepares hot tubs for its inhabitants. More recent projects like the Amigo Project [23] and the Service Centric Home [9] aim at the development of middleware that integrates heterogeneous systems and appliances to achieve interoperability between services and devices. This then forms the basis for interaction between the devices or remote control by another smart entity to optimize resource usage, comfort, and operation costs. One innovative approach by Intille in the scope of the House_n project of the Massachusetts Institute of Technology presents a concept to empower people by providing information when and where decisions and actions can be made instead of aiming for the automation of tasks [31].

Smart homes still mostly aim at the simplification of daily routines and processes and at making life easier and more comfortable for the inhabitants. Developed technologies often target elderly or disabled people and address the need to live independently in their own environment. Additionally, they aim at controlling and optimizing resource usage and safety, entertainment, and communication. Sustainability is still not addressed as a core area, but treated as a nice to have feature. Thus, smart homes often incorporate hard-to-recycle or -reuse materials, are energy hungry, and require continuous maintenance, updates and replacements. They also still face a large number of technical, social and economic challenges.

A major critique is that current home automation approaches consume more energy than they save [24]. In [26], Hilty et al. discuss the potential risks of pervasive computing technology (which is applied in smart homes), stating that there are various unexplored issues related to health, social effects and environmental issues. Mankoff et al. also argue that ICT is facing the key challenges of growing energy consumption and electronic waste [38]. In North America 38% of the energy was consumed by households in 2009. Furthermore, the share of residential electricity used by appliances and electronics in U.S. homes has nearly doubled from 17 percent to 31 percent in the last three decades [8]. Computational energy consumption has been reported to be responsible for 2% of the world emissions in 2007 already [25]. The increasing usage of electronics and computer technology also creates a massive problem of (largely toxic) electronic waste, which is difficult to reuse, recycle or even to store [55]. It is becoming a significant component of waste streams, increasing at a rate of 5% per annum [19]. In 2007, a study by the United Nations University found that the world generates around 40 million tons of electronic waste every year with a lot of it being shipped to developing countries [29].

In terms of inhabitants, Intille describes that homeowners often believe that computer devices make life more complex and frustrating rather than easier and more relaxing and that they are wary of the aesthetic, financial, and cognitive challenges that come with new technologies [32]. He also argues that technology should not make people useless but require human effort in ways that keep life mentally and physically challenging. Davidoff at al. argue that developers have to be careful not to remove tasks that are vital to our identities [18]. It is important to allow the integration of technology into different habits and "workflows" of the family. Requiring the family to adapt to technology is very likely to fail quickly [18]. Yamazaki identified the extension of human activity support beyond the home to the scope of communities, towns, and cities as a crucial aspect [57].

Energy consumption, electronic waste, user frustration, over automation, information overload, a lack of focus on human needs, and toxic contents in products, etc will all have to be addressed in an attempt to make smart homes sustainable. While there does not seem to be an overall concept to address all these issues yet, most of them are already being worked on.

4.2 Sustainability for Smart Homes

The Climate Group of the Global Sustainability Initiative found that in 2008, better building design, management and automation could save 15% of North America's buildings emissions and 1.68 $GtCO_2$ worldwide [25]. The US Department of Energy found that homes are contributing about 38% of the nearly 3,741 billion kilowatt hours that North America consumed in 2009 [7] and the electricity used by electronics was up to 31% and growing in 2010. While consuming energy is not a negative thing in itself, the way we currently produce most of our energy is not sustainable, making the usage especially of high amounts of energy unsustainable as well. The reduction of energy usage and the shift of load to avoid peak times to reduce the need for high production capacities have been identified as keys for energy efficiency [36].

Approaches to address these issues are already under development. [13] describes a web application for supply chain transparency that is likely to be able to help with the acquisition of sustainable products and building material. In the sustainable computing area, new solutions are coming e.g. in form of heterogeneous chip multiprocessors that can achieve four to six times energy savings per instruction, supercomputing programming paradigms for a modified cell processor that can achieve up to 100 better energy efficiency, intelligent routing protocols that ensure the use of minimum energy routes, a reduced need for new computers by using grid computing, modular chips or components that make it possible to replace a single part instead of an entire system [56]. IBM [30] presents a visionary approach where smart home intelligence is provided via a cloud computing system, limiting the intelligence the actual devices in smart homes have to provide. In combination with modular chips this could be an upcoming possibility to address the lifespan of our current electronic products that usually ranges from months to a few years only, where houses and homes are built to last for decades and centuries. It thus seems strongly required to design for longer life spans and dynamic change and provide open system that can dynamically evolve over time (in contrast to current fixed systems that need continuous replacements) [18]. While we need to understand consumer behavior, periodic changes, exceptions and improvisation to do so, there are also growing possibilities to construct new and modify existing behaviors [18]. Expanding the lifespan of current products, unfortunately, interferes with economic goals to raise ever increasing demands and keep consumption at a maximum, but new recycling technologies, compostable computers and environmentally friendly materials might be able to help in resolving these contradictions. The Cradle-to-Cradle concept [42] suggests to keep the ownership of the raw-material with the producing manufacturer, to encourage recycling and reuse efforts and create new, more sustainable business models.

While we already presented some home automation approaches in the previous section, Mattern et al [41] and others [32] noticed that automation and optimization alone are not enough and might raise more problems than they solve. We will need a change in behavior and consumption patterns to "save the planet" and ICT can play a major role in facilitating this transition and empowering the user instead. In a recent study, Froehlich et al. found more than 130 papers reporting about eco-feedback [22] and the monitoring of consumption (water, energy, air, waste, …) has the potential to make users aware of the hidden details of their current behavior as well as about a greater impact or how he compares to other community members. We can't manage what we can't measure and the described technologies provide solutions that enable us to 'see' our consumption and could provide the means for optimizing systems and processes to make them more efficient [25]. New interfaces allow users to better control their usage and unobtrusively inform them of the actions of their peers, which provides increased social awareness in the household and immediate feedback in an unobtrusive design [58, 31, 39]. Besides energy monitoring, which is probably the most obvious and vastly researched theme, Water Monitoring, [35, 10], temperature surveillance, air quality and indoor climate monitoring [33], a "robotic plants" as feedback on waste disposal [28] or observation of the bandwidth-usage of individual devices [15] have been developed. Selected examples include Karlgreen et al., who designed the "Socially Aware Tea Kettle" that shows how home appliances might be enhanced to improve user awareness of energy usage. Yun presents a study that shows how a minimal in-home energy consumption display encouraged users to reduce energy consumption by identifying high-power devices in their home and by playfully setting conservation goals [58]. Mankoff et al. propose to utilize social web pages to deliver personalized eco-related information and show how well individuals and their social networks are reducing their ecological footprints [39]. Holstius et al. present the utilization of "robotic plants" as feedback on waste disposal in a trash or a recycling container [28]. Outside information can similarly be integrated into the home ambient, e.g. by signaling pollution levels by influencing the mood of music playlists [21], or by displaying health information about distant living relatives [46]. Woodruff and Mankoff discuss how pervasive computing can help addressing environmental challenges by supporting monitoring the state of the physical world, managing the impacts of human enterprises and informing individuals' personal choices in consumption and behavior [56].

In summary, technology as described above allows us to reconnect people with their environment. Enriched by sensors, the environment can actually start expressing itself and creating competitive situations that reward sustainable behavior without denouncing individuals or families can motivate certain behaviors. Furthermore, the effect of "Dematerialisation", i.e. the substitution of environmental expensive products and activities with eco-friendly alternatives (e.g. replacing face-to-face meetings with videoconferencing, or paper with e-billing) can help to save important resources [25] and the possibility to help optimizing processes and routines, allows utilizing computers as very efficient tools. While [49] claims that the use of real-time feedback presents an opportunity to decrease energy consumption by 10%-20%, others found that feedback gadgets alone are unlikely to maximize energy savings [6] and fear that tracking home electricity use will not "become a national hobby" and the novelty will likely wear off quickly [47]. Similarly, a study in Switzerland showed that current home automation approaches consume 35% - 55% more energy than standard homes [24]. Finally, side effects of current approaches are not widely studied. Similarly to the shortage of food raised by bio fuel, automating too much might have negative effects too.

5. SUSTAINABLE SMART HOMES

We have examined the idea of sustainable smart homes from two different perspectives in the previous sections and can now derive some conclusions to give initial ideas how the concept of a sustainable smart home can be implemented.

Two main starting positions can be distinguished: Building a new home from scratch provides the possibility to start from scratch and gives room for fresh considerations. However, improving existing homes is probably even more important as from a global perspective it is absolutely unsustainable to tear down existing homes to build more sustainable ones.

So for a new home, sustainability starts with the early planning and construction phase. Besides making appropriate use of the land and using renewable, natural and non-toxic materials, limiting the usage of energy and water as well as the production of trash should be a major goal throughout the whole planning – building – running – maintenance life-cycle. Additionally, even the deconstruction phase should be considered at the very beginning of the process, to be able to optimally recycle and reduce material and feed it back into existing resource cycles.

A sustainable home should then ideally be capable of harvesting the water and energy it needs to provide a comfortable living environment for its inhabitants. Various technologies can be used to harvest the required energy and insulation and the usage of low energy devices can help to reduce the energy needs. Different technologies like a wood burner, solar hot water, geothermal energy or heat from a compost pile can be combined to provide warm water. Water should be harvested and treated locally and ideally be continuously recycled on site. This has to be supported by the utilization of natural and unharmful products for dishwashing, showering, laundry and cleaning.

To facilitate a better usage of additional resources, some gardening and food production are highly recommended. This can be coupled with some food swapping in the neighborhood to address as many needs as possible with local products. Systems like permaculture principles can be used to reduce the effort to run the food production. A compost pile and grey water from the house can help to provide the nutrients needed for a garden.

The home should be comfortable and inspiring for the inhabitants. It should provide a healthy environment, stimulating the productivity of the inhabitants and allow the integration into (local) economies and communities. Last but not least, it has to provide the necessary security and safety for its inhabitants.

As discussed above, computer technology can be applied in different areas. Starting with the planning and building phase, ICT can make the underlying processes more efficient and deliver better planning and building results. During and after the building phase, monitoring the energy consumption, informing the user about it and automating different processes to use the energy more efficiently is another main area. It can help monitoring and managing the supply of hot water, provide security systems and make life comfortable through entertainment systems and domestic appliances. Besides automation, which currently still consumes more energy than it saves, the main role of ICT seems to be – as the name implies – the information and communication facilitation. The smartest part of the sustainable smart home still seems to be the inhabitant. He more or less consciously chooses his activities and consumption patterns and is thus the main influence and the last instance for any decision. Informing the inhabitant about influences his decisions have on the environment, guiding gently to reduce energy consumption, networking communities and making the environment speak appear to be the fields that ICT is best at. It can make a difference in facilitating the transition to a more sustainable lifestyle and in making sustainable living acceptable and even desirable for the masses, but within the process it will have to face its own inherent unsustainability. Recycling and long product lifespans are not yet the qualities of the products of the ICT industry. The ecological footprint of the overall lifecycle from production of the artifacts over deployment and usage to their final disposal or recycling will have to be considered to finally judge the sustainability of a product. Devices are built from toxic material, designed to be obsolete or outdated after a very short time and difficult or almost impossible to reuse or recycle. Finally, the ICT sector also tends to be quick to find new technologies to address any kind of problem, where sometimes low tech approaches and intelligent overall design may be as (or even more) effective. While new approaches are on the horizon to address these issues, they are not yet sufficiently addressed and thus ICT, at its current state, might not be capable of being the main driver for sustainability in the long run.

6. CONCLUSION

Coming back to the definition of sustainable smart homes we will have to come up with a more dynamic and changeable design, which needs to incorporate cycles of various scales in different areas. Technology has the potential to facilitate a transition to more sustainable lifestyles by making devices more efficiently and ICT can play a major role in making processes more transparent, observable and manageable. It allows informing and connecting people but currently still faces its own inherent unsustainability, which will have to be addressed with technological approaches as well as with changing business models and best practices. Since many scientist believe that we are beyond the state where being sustainable is enough. We are in need of corrective rather than preserving methods and behavior. We will have to restore our resources rather than just abstain from consuming and wasting them and this will have to go hand in hand with the definition of a sustainable lifestyle over 7 billion people. What is taken out of the environment will have to be given back and to reach any corrective effects, it will have to be given back in a better state that it was before. Sustainable smart homes will have to trigger positive change and foster resilience with respect to the four basic principles of sustainability. The utilized ICT systems – hardware and software – as well as the building itself will need to be able to evolve over time and to adapt to changing needs. The whole building and all its components must be created by using only natural resources (ideally renewable) that don't harm any life and can be returned to other cycles and technological resources that can be recycled with the final deconstruction of the building. Finally, sustainable thinking and behavior have to become core parts of our lives again.

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