Market-Based User Innovation in the Internet of Things

Gerd Kortuem, Fahim Kawsar
School of Computing and Communications
Lancaster University
Lancaster, UK
{kortuem,kawsar}@comp.lancs.ac.uk

Abstract— **The importance of user innovation is widely accepted, but the development of the Internet of Things is primarily driven by large commercial players. Using an innovation perspective, this paper identifies how user innovation and market-based innovation can be combined in the Internet of Things (IoT). A survey of tools for user/developers in the IoT space uncovers a rich set of tools for creation of hardware, software and data but reveals poor support for distribution and sharing of such artifacts. To address this shortcoming we propose *connected marketplaces* as a way to provide users/developers with rich opportunities for sharing and trading of artifacts, and to enable effective user innovation in the IoT.**

Keywords: user innovation, Internet of Things, smart buildings, digital markets

I. Introduction

The iPhone and the iPhone App Store have unleashed a wave of innovation in the mobile space comparable to the breakthrough of the Web in late 1990s. Not only has the iPhone given consumers seamless access to a vast number of mobile phone applications, it has also enabled individuals with a minimum of programming skills to reach a mass audience for their applications. As a result, the iPhone (and increasingly other mobile platforms such as Android, …) has created a long-tail of mobile applications, that has brought about applications, for example, for social activism [1], citizen science [2,3,4], and citizen journalism [5]. The development of the Internet of Things, in contrast, has primarily been driven by concerns of large industrial players and resulting technologies and solutions narrowly focus on business relevant aspects. A recent report on "Vision and Challenges for Realising the Internet of Things" [6] by the Cluster of European Research Projects on the Internet of Things (CERP-IoT) is heavily industry focused and fails to mention the role of end-users and small independent developers in shaping the future Internet of Things. There is a danger that this exclusive focus on industry concerns and commercial applications seriously limits the innovation potential in the IoT space and that, as a result, the Internet of Things falls short of its potentials [7,8]. As we are working towards the realization of the Internet of Things (IoT), we are faced with the question of how to ensure that the IoT supports user-led innovation and empowers ordinary people, citizens and non-commercial entities in the same way the iPhone has done in the mobile space.

It has long been recognized that users are an important source of innovation [9]. von Hippel and Katz's observed that by providing users with adequate toolkits it is possible to shift innovation from companies to end users [10]. In line with these observations, researchers are starting to stress the active role of end-users in shaping the IoT. For example Michahelles [11] argued that giving end-users the tools to create and invent IoT applications is a way to ensure that people's concerns will be adequately addressed, Kawsar [12] has demonstrated how empowering end-users in building smart objects in a Do-it-Yourself fashion can elevate users' experiences, and the Do-it-Yourself Smart Experiences project (DiYSE) [13] explores approaches for mass creativity and DIY service provisioning in the Internet of Things [14,15]. Innovation is a multi-stage process that involves not just *invention*, the creation of novel ideas or products, but also *diffusion*, the process through which novel ideas or products are communicated among potential users [16]. Development tools merely address the creation aspect. If we want to ensure that users/developers are capable of producing *and* disseminating innovations in the IoT space we need to move beyond development tools and need to ensure that they can effectively communicate and distribute their ideas, artifacts and products. The iPhone example has shown how market-based mechanism can play a key role in achieving this goal[1].

Regarding the Internet of Things the question then is: How can we give ordinary citizens a voice, not just as commentators of ongoing IoT developments, but as innovators and shapers of technology? How can we ensure that the Internet of Things allows for user-led innovation (in addition to company-driven innovation)? How can we create or encourage innovation mechanisms for the Internet of Things similar to the market-based mechanisms employed in the mobile space? In this paper we make first steps towards addressing these questions. In particular, this paper makes three contributions: (1) we outline the case for the importance for user innovation for the future development of the IoT. (2) We provide a survey of end-user tools in the Iot space and investigate current innovation activities associated with these tools. (3) We propose *connected*

[1] For simplicity we focus on Apple and the iPhone, even though increasingly other mobile vendors such as Nokia, Google, Microsoft, Palm and RIM replicate elements of the iPhone ecosystem.

marketplaces as a novel way to enable users and independent developers to become effective innovators. We start this paper with a general discussion of user innovation.

II. IoT Innovation By Users, For Users

The Internet of Things is seen as the next revolution in IT. While related paradigms such as mobile computing, ubiquitous computing and pervasive computing have pushed the notion of *anytime*, *any place* connectivity for *anyone,* the term Internet of Things is used to conjure visions of a world of connected objects and items, i.e. connectivity for *anything.* [17,18,19,20,21,22,23,24]. Until fairly recently the Internet of Things was almost exclusively associated with RFID technology and industrial applications. The success of these applications - and the commercial drivers behind them [25,26] - has created a huge momentum that has pushed technical developments and public discourse in one direction.

In recent years we have witnessed efforts to open up the Internet of Things and to make its development more inclusive. Under the label 'Web of Things' [27], universities and commercial players alike are working on open protocols that connect objects to the Web, for example by exploring RESTful web service infrastructures for embedded devices and objects [28,29]. The end goal of these efforts is to create an open infrastructure and platform, which level the playing field and on top of which innovative IoT services and products can be developed.

Some of the most interesting ideas in the IoT space currently emerge from "innovation communities" of artists, designers, hobbyists, researchers, and small technology firms dedicated to creating and oftentimes sharing innovations (examples include ThingM [30], Tinker [31] and Berg London [32]). An important aspect of this global community is the development of open source hardware and software platforms for unrestricted prototyping and experimentation (for example, Arduino [33]). The cooperative, community-minded spirit of open source projects is also extending to data aspects of the IoT [34]. The existence of these communities and their collective output indicate that bottom up and user-led innovation can play an important part for the IoT. User-led innovation occurs when users play an active part in the development of new or improved products and services. Users, who are often best placed to identify what they need, frequently have innovative ideas that can lead to new and improved products or services, provided they are able to design, build and distribute their own solutions. The web as a space for social collaboration and the ever-increasing proliferation of digital tools has produced a wave of user-led innovation in hardware, software and web services: "The clear divisions that used to exist between firms and consumers or firms and suppliers are increasingly blurred: we're all (potential) innovators now" [9, p4].

Markets As Enablers of User Innovation. The open community spirit exemplified by the open source and open hardware movements, which is based on social collaboration, is not the only model for user innovation. In contrast, the iPhone example demonstrates how user innovation can be fostered by open markets[2] and market-based mechanism. By combining programming tools, application platform and distribution channel, Apple has created an environment that effectively supports user innovation networks [35], in which innovation development, production, distribution and consumption are performed by users (or more precisely by user/developers and micro software firms). von Hippel proposes that "user innovation networks can function entirely independently of manufacturers when (1) at least some users have sufficient incentive to innovate, (2) at least some users have an incentive to voluntarily reveal their innovations, and (3) diffusion of innovations by users is low cost and can compete with commercial production and distribution." [35, p.3]. The user innovation network supported by the iPhone ecosystem is horizontal, where innovation – in the form of iPhone apps – is created by and for users. In contrast to von Hippel's original notion, which refers to open-source development and the ability to replicate and adapt a product, the iPhone innovation network does not compel users to make their innovations openly accessible to other users. Instead, transfer of innovation among users is facilitated by a two-sided market (realized by the App Store), with user/developers on the one side and users-only on the other[3]. The network effects realized by this market enable the effective transfer of ideas (in the form of applications) and the effective recruitment of users for application that require large user populations to become successful (for example, crowd sourcing and participatory sensing applications). Even though the iPhone ecosystem has been a boon to commercial software developers and primarily has been created to benefit Apple, it has "democratized innovation" [36] and paved the way for user-led innovation[4]. The democratization of innovation is significant since it has led to the development and adoption of applications for social activism [1], citizen science [2,3,4], and citizen journalism [5]. It is unlikely that these application would have emerged if innovation were purely industry and commercially driven. It is this potential to create innovation that fall outside the commercial realm what makes user innovation so important for the emerging IoT.

In the next two sections we investigate current support for user innovation in the Internet of Things. First we survey the tools that are currently available in the IoT space and discuss to what extent they are being used for innovation. Second, we propose how market-based user innovation can be applied to the IoT.

III. A Survey of the IoT Tool Hierachy

There is a large variety of tools for creating hardware, software and data in the IoT space. These tools can be envisioned as a stack with hardware at the bottom, software in the middle and data on the top (Figure 1). We divide tools into

[2] The iPhone marketplace is open in the sense that entry barriers for developers are low.

[3] The term 'market' does not imply commercial transactions – indeed the majority of iPhone software downloads involve free software (the ratio of paid/free apps is 1.8 to 7 [65]).

[4] User-led innovation complements traditional company-led innovation.

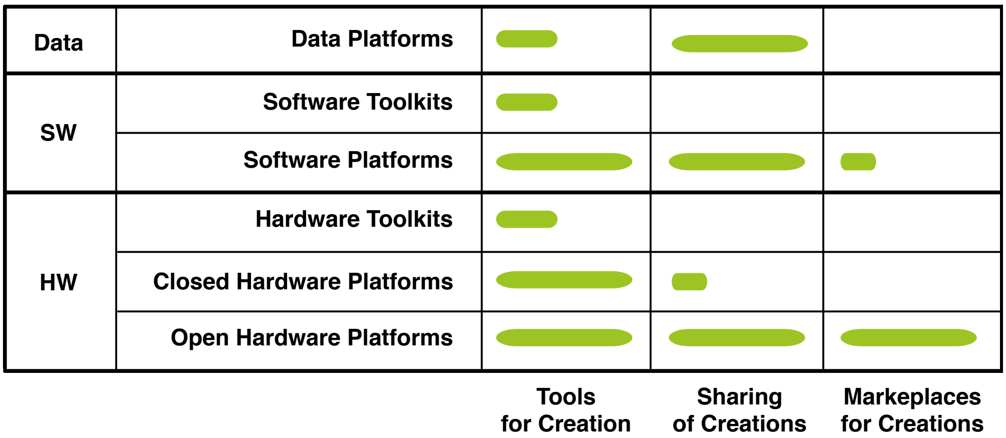

Figure 1. IoT Tool Hierarchy

platforms and *toolkits*: platforms are generic (horizontal) foundations for building (hardware or software) artifacts, while toolkits are focused on a particular domain or tailored for a particular purpose. Column 1 of Figure 1 (Tools for Creation) indicates the availability of tools in each platform and toolkit category. The number and quality of tools is not the same in all categories. Overall, however, each category has a more or less rich set of tools for creation. Column 2 (Sharing of Creations) indicates to what extent the artifacts that are created with these tools can be and are currently shared among users/innovators in an informal or social way. Column 3 (Marketplaces for Creations) indicates if marketplaces exist that can be used for exchanging and trading created artifacts and to what extent they are currently used. We define a marketplace as *a technical platform for efficient and effective distribution and discovery of artifacts*. In this sense, the iPhone app store is a marketplace, and so is Liquidware (www.liquidware.com), an online shop for open-source DIY hardware and gadgets. It is important to note that our notion of a marketplace, just like the iPhone App Store, does not require commercial transactions.

In the following we first examples from each category and discuss how they stack up with respect to the criteria for Columns 1 through 3. As our goal is to highlight the options that exist today we primarily focus on commercial or widely available offerings.

A. Hardware Platforms

Open Source Hardware Platforms. Open source hardware platforms have become a key enabler for creativity in the Internet of Things space. Open source hardware is hardware that is designed and offered in the same manner as free and open source software, i.e. the hardware design (schematics, bill of materials and PCB layout data) is openly available and development follows an open community model. A growing selection of open hardware platforms is available [37], with Berkeley motes [38] and Tinker's Arduino platform [39] the most prominent. The innovation activity around open hardware is strong. Tinker's Arduino platform, for example, has a very active community of developers who use openly available designs to manufacture Arduion-compliant components and use Arduino components to build more complex computer devices. Designs for Arduino creations are shared freely via online networks (Column 2). In addition, there is are physical online stores like Liquidware that sell Arduino boards and Arduino-based devices (Column 3). Interestlingly, Liquidware also offers an App Store for open source applications that run on open hardware platforms.

Closed Hardware Platforms. A decade of research on wireless sensor networks has led to a proliferation of sensing platforms that span a wide range of device capabilities, from resource-constraint device platforms like Particle [40] to powerful devices like SunSpots. These platforms are widely used to develop sensing solutions and to develop smart objects, i.e. physical objects augmented with sensing, processing and wireless networking capabilities [41]. In contrast to open hardware platforms these sensing platforms are mostly closed – their design is not openly shared and the hardware cannot be modified. The closed nature of the hardware has direct effect on the extent to which artifacts built with these devices are shared by developers. Compared to open hardware there is a less intense exchange of ideas and artifacts and there are no marketplaces for sharing artifacts built with closed platforms.

B. Hardware Toolkits

One layer of abstraction above hardware platforms we find an increasing number of toolkits for developing tangible and physical objects quickly and without any knowledge of electronics. These include, for example, Phidgets [42,43], originally a toolkit for building physical interface widgets which has now morphed into a generic toolkit for USB sensing and control; the TinkerKit [44], a modular system of sensors and actuators based on Arduino hardware; and VoodooIO [45], a high-level toolkit of buttons, switches, knobs, sliders and lights to be connected to a substrate material. These toolkits differ in the level of hardware abstractions they provide, but they share the vision of making physical interaction and control as easily appropriable by users as graphical user interfaces. In effect, they blur the boundaries between interface developers, interaction designers and end-users. Similarly to closed hardware platforms, creations produced with these toolkits are rarely shared and there are no marketplaces for supporting the trading of artifacts.

C. *IoT Software Platforms*

Moving away from hardware, we find an increasing number of software platforms for tracking physical objects and processing sensor data. Fosstrak [46,47,48] is an open-source RFID platform that implements the specifications defined by the EPCglobal RFID community and allows developers to more quickly build, deploy and test large-scale RFID applications. Touchatag [49] is a commercial platform that focuses on contactless RFID cards and NFC mobile devices, and which provides a web-based API for creating web applications that link to real-world objects. Pachube [50], another commercial IoT software platform, is a data brokerage platform for managing data streams that enables everyone to store, share and discover real-time sensor on a global scale. Fosstrak is a traditional software platform: it is designed as a foundation for applications and solutions. In contrast, Pachube and Touchatag not only provide APIs, but also offer sharing features for developers to easily share data streams and widgets. Touchatag has online idea- and application-marketplaces and Pachube provides a web-based repository for Pachube application, widgets and data streams.

D. *Software Toolkits for End-Users*

Until now we have discussed tools and toolkits that require a rather high level of technical expertise. As identity and sensing technologies make their way into people's homes the question arises how people can be given greater control in their deployment and configuration. Studies have shown how end users continuously reconfigure their homes and technologies within it to meet their demands [51]. In response, high-level toolkits have been developed (e.g. [52,53,54,55]) that are aimed at non-technical users to support DIY development and deployment of smart home components by inhabitants. Although many of these tools succeed in their goal of radically reducing the required programming expertise, they have not seen widespread adoption and there is no evidence that artifacts created with them are shared.

E. *Data Platforms*

The Internet of Things is not just about connecting objects to the Internet, it is to a large extent about data and information about objects. In particular, object identify is the foundation and ultimate purpose of RFID technology. Until recently the "naming" of objects was strictly controlled by organizations like EPCglobal [56] that created and promotes a data standard for product identification. However, the wide availability of scanning technologies, coupled with Web2.0-style social collaboration has empowered people to invent their own naming schemes and to collectively compile open product databases. An example of a startup that follows this approach is Thinglink [57], which provides an open product database and a social sharing site that allows anyone to create web representations for everyday objects and to collaboratively annotate products. The unique thinglink id provides an open alternative to the commercial and closed EPC product code. In a similar direction go recent attempts at creating database for product reviews. Several web start-ups and open source projects like CompareEverywhere.com, Scanlife.com, Barcoo.com and codecheck.info provide product review sites that support automatic product identification via RFID or visual scanning. These sites allow anyone with a properly equipped mobile phone to read and write reviews for tagged products (see also [58,59]). Unlike Thinglink, these sites are limited to products with official product codes, but they allow collecting and sharing of metadata. Another important example of a data platform is Sourcemap [60], a crowd-sourcing platform for collaboratively compiling and sharing information about product supply chains to help users understand a product's environmental impact.

Data platforms are tools for creating digital representations of physical objects. These digital creations are as important as the physical objects themselves and a digital representation can be as innovative as any physical artifact. With the open data movement gaining ground an increasing number of open database are becoming available, not many however containing representations about physical objects. The existing platforms, like Sourcemap, are inherently social and facilitate sharing. However, there are no examples of what could be described as a marketplace for data, comparable to the market place for Arduino devices or even iPhone applications.

F. *Analysis*

The tools and platforms introduced in this section to a varying degree enable users/developers to create, discuss and share new physical devices, software artifacts and object representations:

- Toolkit support is good across all levels of the IoT tool stack, with support for open hardware and software platforms especially strong.
- Support for diffusion of innovative ideas and artifacts is especially strong in the open hardware sector, due to the community spirit of the open hardware movement and the existence of (commercial) markets for devices.
- There is a good and growing support for building IoT software and applications in the form of IoT platforms, but support for sharing and disseminating software artifacts is still rudimentary. A look at the artifacts shared on Pachube and Touchatag reveals that adoption of the sharing aspect is still lagging and that complexity of shared items is low.
- Hardware and software toolkits (as opposed to platforms) aimed at non-technical users seem to have had no success so far. There is no evidence of use of these toolkits outside of research labs.
- Efficient marketplaces within the IoT space only exist for open hardware devices.

This last observation raises a central question: How can marketplaces play a role in IoT user innovation? In the next

Figure 2. Connected Marketplaces Supporting User Innovation in the IoT Space

section we will provide a preliminary answer by investigating how a set of *connected* marketplace can be realized to enable a community of users/developers to create, share and distribute innovative IoT artifacts and products. To ground our discussion in a concrete example we focus our attention on smart homes [61], an important realm for the Internet of Things, especially with respect to the recent upswing in smart energy solutions.

IV. CONNECTED IOT MARKETPLACES

In the previous sections we discussed how application marketplaces spur user innovation and diffusion in the mobile space. Such marketplaces provide an interesting starting point for an attempt to democratize innovation in the IoT space. However unlike the iPhone ecosystem, the Internet of Things cannot be confined to a single device platform and a unified distribution channel. Instead, the IoT ecosystem will necessarily consist of a heterogeneous collection of hardware, software and data components. This greatly complicates user innovation as it introduces dependencies and compatibility issues, which make it harder to share and reuse artifacts. Thus in order to foster user led innovation in the IoT space we argue for a *connected set of marketplaces*, each one addressing a particular innovation touchpoint. We define marketplaces as *connected if products of one marketplace can be used to enhance, control or interact with products of another marketplace*. A simple example of this concept is www.liquidware.com, the aforementioned online shop for open-source DIY hardware. Liquidware not only sells hardware but also offers an App Store for software that runs on this hardware. Following our definition, the Liquidware hardware store and the Liquidware App Store are connected. In order to be traded in connected marketplaces, products need to be compatible: in this example software in the one marketplace needs to be compatible to the hardware in the other. Another form of connection can be envisioned between a marketplace for sensor devices and a marketplace for sensor data produced by these devices. However, there is no example yet for such a link (even though simple forms of data marketplaces exist, for example as part of Pachube). Connection is a one-way relationship and connections between three or more marketplaces can be complex. For example, two sensor device marketplaces could be linked to the same data marketplace. Marketplaces may also be chained: a marketplace for electronics components may be connected with a marketplace for sensor devices built from these components, which in turn could be connected with a data marketplace.

Connected marketplaces create an open ecosystem that supports innovation and diffusion across multiple levels of complexity. An innovator can use lower-level marketplace to acquire devices and tools to build something more complex and use higher-level marketplace to share (or sell) his/her creations with others, who in turn can use them as a starting point their for their own innovations. This mechanism not only supports an innovation chain from low complexity to high complexity, it also allows for a distribution of ownership and control of marketplaces.

As example we apply the concept of connected marketplaces to the Internet of Things, or more precisely to smart buildings as a domain-specific subset of the Internet of Things. We propose five connected smart home marketplaces as shown in Figure 2: (1) Smart Object Marketplace, (2) Application Marketplace, (3) Configuration Marketplace, (4) Data Marketplace and (5) Data Manipulator Marketplace. In the following we describe each marketplace and discuss how these marketplaces will enable a rich spectrum of opportunities for innovation in the home.

Smart Object Marketplace: A future smart home can be assumed to contain a range of smart objects such as appliances that can be energy-managed (e.g. smart fridge), and smart furniture that can play a role in assistance of elderly. Smart objects are everyday physical objects augmented with computational intelligences aimed to provide value-added digital services beyond their well-established features. These objects must be able to interact with the infrastructure of the smart home and may thus all support the same basic smart home communication interface. In addition they will contain chunks of built-in intelligence that defines their behavior within the smart home. We envision that (some) users/inhabitants will want to build their own objects according to the smart home standards, and share or trade them with others. Thus, the Object Marketplace is akin to a DIY Ikea for self-made smart furniture or other augmented objects. Thus this first marketplace is primarily for hardware and design enthusiasts (and might itself be linked to a component marketplace like Liquidware).

Application Marketplace: The second innovation touchpoint relates to the behavior of individual objects. Even though commercial objects or objects produced by DIY enthusiasts will come with initial built-in behavior we anticipate people's desire to modify the behavior of the objects they own. This creates the opportunity for an Application Marketplace for smart objects, which in spirit and function is akin to the iPhone marketplace. To support this notion, smart objects will have to be based on smart object platforms or runtime engines that support the execution of application-level software. An emerging example of such a platform is the Microsoft Surface platform, but we envision that a range of smart object platforms will exist within a smart home, for example for smart kitchen appliances or related to the electricity and water infrastructure.

The key here is that the Application Marketplace is linked to the Smart Object Marketplace described above, in that it contains applications to be run by smart objects.

Configuration Marketplace: A *configuration* is a software artifacts for coordinating smart objects in a home. Developing new configurations is similar in purpose and effect to DIY upgrades in the home or a home makeover, yet one that involves creating imaginative new forms of interactions among objects and devices in a home. A configuration is written against a well-defined configuration API that provides functions for discovery and control of objects in a home. A useful example is a configuration that energy manages a set of appliances and devices such as air conditioner, lamp, home A/V system, etc.

We argue that configurations are an important potential innovation touchpoint and might emerge in a DIY fashion in one home, yet be desired by others who want to reuse and adapt them for their own home. Thus we introduce a marketplace for configurations that is linked with the Object Marketplace and the Application Marketplace. g marketplaces in that its artifacts uses and operates artifacts of the other two marketplaces.

Data Marketplace: The Internet of Things is not only about ways to connect objects to the Internet, it is to a large extent about data and information about objects, often derived from sensors. Data streamed off devices in a home and collected by it will become an important commodity that users will want to share and even trade. For example, experiments with communal energy awareness have shown that users are interested and willing to share their energy consumption data [62,63]. The Data Marketplace is an instrument to enable users to share their personal data locally and globally. Such exposition of sensor data is might not be an innovative activity in itself, but can provide the foundation for some other innovation (see Manipulator Marketplace next). The Data Marketplace is linked to the preceding three markets in that it contains data emitted by objects, applications and configurations.

Manipulator Marketplace: The last marketplace that we introduce is a marketplace for data manipulators - a parameterized filter/aggregator that detects patterns across a set of data shared by the end-users (this ideas was inspired by phenomena discussed in [15]). Users can write their own manipulators, for example to understand their own energy consumption dynamics. Creative manipulators can provide innovative insights in the life of a smart home and their inhabitants. Shared with another home and applied to its local data, manipulators can help other users to gain the same insights about their life. This makes manipulators a valuable commodity. Manipulators may also operate on public data from more than one home so as to detect overall – communal – patterns or to identify similarities and differences between homes.

In sum, these five connected marketplaces provide inhabitants with rich opportunities for exchanging their local experimentations, from hardware to software and data. The connected nature of these marketplaces creates an *exponential innovation effect*: rather than five different innovation spaces a users has access to 2^5-1 innovation spaces, each one created by a combination of the five individual spaces.

V. DISCUSSION

Connected marketplaces are a means to foster user innovation in the IoT across hardware, software and data. In Section III we defined marketplaces as technical platforms for efficient and effective distribution and discovery of artifacts. This raises the question of the design and realization of such marketplaces, in terms of supporting infrastructure and technical prerequisites. In the following we discuss five key challenges for the realization of connected marketplaces, some focused on market design, others on technical aspects:

Challenge 1: Understanding and supporting user innovation touchpoints. In the definition of the above five marketplaces we have assumed that we understand where and how users want to innovate in their home. However, this is not really the case. We believe our assumptions are reasonable but we can't be certain that we have not ignored areas of potential user innovation. Thus the first key challenge is to properly identify user innovation touchpoints (in the home or any other domain). This requires research into home live practices and experimentation with – or better – by users. The result of such an investigation informs which marketplaces are suitable and which characteristics the respective artifacts should have.

Challenge 2: Understanding user incentives. Incentives are at the core of user innovation. On the one extreme, user/developers may simply value the process of innovating because of the enjoyment or learning that it brings them; on the other extreme, they may be able to monetize their innovation by selling products on an open marketplace. The sensor richness of the Internet of Things adds novel trading and monetization opportunities related to user-generated data. What are suitable monetization strategies for user-generated data? How can users resolve the conflict between maintaining privacy and realizing potential value of data? How can users trade or collect user-generated data without involving monetary transactions? These issues are particularly interesting for the proposed Data Marketplace.

Challenge 3: Understanding the characteristics of open innovation platforms. Platforms are at the heart of marketplaces. The challenge is to understand what makes a compelling platform from an innovation and engineering point of view. Which abstractions should these platforms expose to allow non-technical user to experiment? Which abstractions should they offer to facilitate creation, distribution and adoption? Discover and matching functionalities, as those provided by the App Store, are as important as device APIs. A related question refers to the nature of the platform interface. For example, the iPhone uses an API-centric approach to define the iPhone platform. Other platforms uses protocols or RESTless service interfaces.

Challenge 4: Identifying IoT business models. IoT marketplaces create opportunities for novel business models (even though monetary aspects are not the core of user innovation). Would a future smart appliance that provides information about its use back to the manufacturer be sold like appliances today, would it be rented on per-usage basis [64] or would it be provided for free in return for access to user-generated data? The challenge is to identify new business models related to smart physical objects and to develop technical means for supporting them within a marketplace. As of now, for example, we do not know how to price personal data that a user wants to disclose, share or trade for services.

Challenge 5: Identifying and mapping potential open IoT ecosystems. Smart-homes are one IoT example of where market driven approach could be beneficial. The challenge is to identify other domains, in which similar connected marketplaces may emerge, to map them out in terms of innovation touchpoints, user incentives and technical characteristics.

Addressing these five challenges requires interdisciplinary, collaborative research in computer science, software engineering, software business management, and economics. Most of the raised questions are not new, but they will gain renewed importance and require new answers in a world of physical/digital products and sensor-rich environments.

VI. CONCLUSION

Concerns about the direction of the development of the Internet of Things are rising. In order to supplement the influence of industrial IoT players we need to look for ways to foster user innovation in a similar way to what the iPhone ecosystem has achieved for mobile computing. As IoT end users are empowered to create and share their own innovations they will become producers in a newly emerging ecosystem in which users/developers and companies can fruitfully cooperative. We see market-based innovation and user-led innovation as necessary complements for the way forward in developing the Internet of Things. In this paper we surveyed current IoT tools ranging from hardware over software to data. We uncovered a rich set of tools for creation of hardware, software and data but identified poor support for distribution and sharing of such artifacts. We uncovered that marketplaces are emerging, albeit slowly and unconnected. To remedy this situation we proposed a set of connected marketplaces that provides user/developers with rich opportunities for creating and sharing innovative artifacts, and enables effective user innovation in the Internet of Things.

REFERENCES

[1] The Extraordinaries. http://app.beextra.org

[2] The WildLab. http://www.thewildlab.com

[3] Noah. http://www.networkedorganisms.com

[4] SparkVue. http://www.pasco.com/featured-products/sparkvue-for-iphone/index.cfm

[5] 360News. http://www.360ne.ws

[6] Sundmaeker, H., Guillemin, P., Friess, P., Woelfflé, S. (2010). Vision and Challenges for Realising the Internet of Things. Cluster of European Research Projects on the Internet of Things (CERP- IoT). March 2010.

[7] van Kranenburg, R (2007). The Internet of Things: A critique of ambient technology and the all-seeing network of RFID, Network Notebooks 02, Institute of Network Cultures, Amsterdam, 2007.

[8] van Kranenburg, R. (2010): A Poor or a Rich Internet of Things; our choice now. In Harald Sundmaeker, Patrick Guillemin, Peter Friess, Sylvie Woelfflé Vision and Challenges for Realising the Internet of Things. Cluster of European Research Projects on the Internet of Things (CERP- IoT). March 2010.

[9] Flowers, S., Mateos-Garcia, J., Sapsed, J., Nightingale, P., Grantham, A. and Voss, G. (2008) The New Inventors: How users are changing the rules of innovation. Project Report. NESTA, London, UK.

[10] von Hippel, E., & Katz, R. (2002). Shifting Innovation to Users via Toolkits. Management Science, 48(7), 821-833.

[11] Michahelles, F (2009). How the Internet of Things will gain momentum: Empower the users, Invited Paper, International Conference of Impact on Ubiquitous RFID/USN Systems to Industry, Sunchon, Oct 6, 2009.

[12] Kawsar F. (2009). A Document-Based Framework for User Centric Smart Object Systems, PhD dissertation, Dept. Computer Science, Waseda Univ., Feb. 2009.

[13] www.dyse.org

[14] Trappeniers, L., Roelands, M., Godon, M., Criel, J., Dobbelaere, P. (2009). Towards Abundant DiY Service Creativity. Successfully

Leveraging the Internet-of-Things in the City and at Home, ICIN 2009, Bordeaux, September 2009

[15] Roelands, M., Godon, M. Feki, M.A., Trappeniersesearch, L. (2010). Orientation towards Do-it-Yourself Internet-of-Things Mass Creativity. Workshop on Pervasive Workshop :What can the Internet of Things do for the citizen?. Pervasive Computing Conference 2010.

[16] Rogers, E.M. (1995). Diffusion of innovations (4th edition). The Free Press. New York.

[17] Barrett, R., Maglio, P. P. (1998). Informative things: how to attach information to the real world. In UIST '98: Proceedings of the 11th annual ACM symposium on User interface software and technology, pages 81–88, New York, NY, USA, 1998. ACM Press.

[18] Sarma, S., Brock, D.L., Ashton, K (2000). The Networked Physical World. TR MIT-AUTOID-WH-001, MIT Auto-ID Center, 2000.

[19] Ferguson, G.T (2002). Have your objects call my objects. In: Harvard Business Review. Harvard Business School Publishing Corporation 80 (6), pp. 138–144, 2002.

[20] Schoenberger, C., Upbin, B (2002). The Internet of Things. In: Forbes Magazine. 169 (6), pp. 155-160, 2002.

[21] Neil Gershenfeld, Raffi Krikorian and Danny Cohen (2004). The Internet of Things . In Scientific American, (291) 4: 76--81, Scientific American, New York, NY, USA, Year 2004.

[22] Fleisch, E., Mattern, F. (Eds) (2005) Das Internet der Dinge. Springer-Verlag, 2005.

[23] International Telecommunication Union (2005). The Internet of Things. Internet Report 2005. Available at http://www.itu.int/osg/spu/publications/internetofthings.

[24] Santucci, G. (2010). The Internet of Things: Between the Revolution of the Internet and the Metamorphosis of Objects. In Harald Sundmaeker, Patrick Guillemin, Peter Friess, Sylvie Woelfflé Vision and Challenges for Realising the Internet of Things.. Cluster of European Research Projects on the Internet of Things (CERP- IoT). March 2010.

[25] Williams, B. (2008). What is the Real Business Case for the Internet of Things?, Synthesis Journal, iTSC, 2008

[26] Allmendinger, G. and Lombreglia, R. (2005). Four Strategies for the Age of Smart Services. Harvard Business Review, vol. 83, no. 10 October 2005, pp. 131-145.

[27] Trifa, V. and Guinard, D (2010). Towards the Web of Things, Whitepaper 1.0. Available online at http://www.scribd.com/doc/16292620/Web-of-Things-whitepaper-v1

[28] Stirbu, V. (2008). Towards a RESTful Plug and Play Experience in the Web of Things. In Semantic Computing, 2008 IEEE International Conference on, 512-517, 2008.

[29] Wilde, E. (2007). Putting Things to REST, UCB iSchool Report 2007-015, School of Information, UC Berkeley, 2007.

[30] ThingM www.thingm.com

[31] Tinker www.tinker.it

[32] Berg London www.berglondon.com

[33] Arduino. http://www.arduino.cc

[34] Open Source Sensing Initiative (2010). Home page http://opensourcesensing.org. [Accessed 2 April 2010].

[35] von Hippel, E. (2002). Open Source Projects as Horizontal Innovation Networks - By and For Users (June 2002). MIT Sloan Working Paper No. 4366-02. Available at SSRN: http://ssrn.com/abstract=328900

[36] von Hippel, E. (2005). Democratizing Innovation. MIT Press.

[37] www.allaboutopenhardware.com

[38] www.tinyos.net/scoop/special/hardware/

[39] www.tinker.it

[40] particle.teco.edu/

[41] Kortuem, G., Kawsar, F., Sundramoorthy, V., Fitton, D. (2010). Smart Objects as Building Blocks for the Internet of Things, IEEE Internet Computing, pp. 44-51, January/February, 2010.

[42] www.phidgets.com

[43] Greenberg, S. and Fitchett, C. (2001). Phidgets. Video Proceedings of the ACM UIST 2001 14th Annual ACM Symposium on User Interface Software and Technology. November 11-14, Orlando, Florida.

[44] www.tinkerkit.it

[45] Villar, Nicolas and Gilleade, Kiel and Ramduny-Ellis, Devina and Gellersen, Hans (2007) The VoodooIO Gaming Kit: a real-time adaptable gaming controller. Computers in Entertainment (CIE), 5 (3).

[46] www.fosstrak.org

[47] Floerkemeier, C., Roduner, C., Lampe, M. (2007). RFID Application Development with the Accada Middleware Platform. IEEE Systems Journal, Special Issue on RFID Technology, Vol. 1, No. 2, pp. 82-94, December 2007

[48] Floerkemeier, C., Lampe, M. Roduner, C. (2007). Facilitating RFID Development with the Accada Prototyping Platform. Proceedings of PerWare Workshop 2007 at IEEE International Conference on Pervasive Computing and Communications. New York, USA, March 2007.

[49] www.touchatag.com

[50] www.pachube.com

[51] Rodden, T., Benford, S. (2003). The evolution of buildings and implications for the design of ubiquitous domestic environments. Proceedings of the conference on Human factors in computing systems '03, 9 – 16, 2003.

[52] Kawsar, F., Nakajima, T., Fujinami, K. (2008). Deploy spontaneously: supporting end-users in building and enhancing a smart-home. In Proceedings of the 10th international Conference on Ubiquitous Computing (Seoul, Korea, September 21.

[53] Dey, A., Sohn, T., Streng, S., Kodama, J. (2006). iCAP: Interactive Prototyping of Context-Aware Applications. Pervasive 2006: 254-271

[54] Dey, A. Hamid, R., Beckmann, C., Li, I., Hsu, D. (2004). A Cappella: Programming by demonstration of context-aware applications. In ACM CHI 2004, 2004.

[55] Humble, J., Crabtree, A., Hemmings, T., Åkesson, K. Rodden, T., Hansson, P. (2003). Playing with your bits': user composition of ubiquitous domestic environments. In Ubicomp 2003.

[56] www.epcglobalinc.org

[57] www.thinglink.com

[58] F. von Reischach,; Dubach, E.; Michahelles, F.; Schmidt, A. (2010): An Evaluation of Product Review Modalities for Mobile Phones, In Proceedings of the 12th ACM SIGCHI SIGMOBILE International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'10), Portugal, September 2010.

[59] F. von Reischach, F. Michahelles, A. Schmidt (2009). The Design Space of Ubiquitous Product Recommendation Systems, In Proceedings of the 8th ACM SIGMOBILE Conference on Mobile and Ubiquitous Multimedia (MUM'09), United Kingdom, November 2009.

[60] www.sourcemap.com.

[61] Chan, M., Estève, D., Escriba, C., and Campo, E. (2008). A review of smart homes-Present state and future challenges. Comput. Methods Prog. Biomed. 91, 1 (Jul. 2008), pp. 55-81.

[62] Foster, D., Blythe, M., Lawson, S., Doughty, Mark (2009). Social networking sites as platforms to persuade behaviour change in domestic energy consumption. In: AISB 2009, Edinburgh, UK, 2009.

[63] Foster, D., Blythe, M., Cairns, P., and Lawson, S (2010). Competitive carbon counting: can social networking sites make saving energy more enjoyable?. In Proceedings of the 28th of the international Conference Extended Abstracts on Human Factors in Computing Systems (Atlanta, Georgia, USA, April 10 - 15, 2010). CHI EA '10. ACM, New York, NY, 4039-4044.

[64] Fitton, D., Sundramoorthy, V., Kortuem, G., Brown, J., Efstratiou, Ch., Finney, J. and Davies, N. (2008). Exploring the Design of Pay-Per-Use Objects in the Construction Domain. In Third European Conference on Smart Sensing and Context (EuroSSC 2008), Zurich, Switzerland, October 29-31, 2008, 192-205.

[65] Admob.com (2010). January 2010 Mobile Metrics Report, (Available online at http://metrics.admob.com/2010/02/january-2010-mobile-metrics-report/)