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ACCELERATING THE INNOVATION PROCESS WITH THE HELP OF OPEN SOURCE PROTOTYPING HARDWARE

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ABSTRACT: *Open source prototyping hardware appears to be easy to modify, extendable by function modules and its solutions are well-documented. Currently it is primarily used in domestic and scientific projects, but it seems to be perfect for the development of prototypes for companies, too. One resulting question, which is the focus of this research paper, is: to what extent can the use of open source prototyping hardware accelerates prototyping as one of the main parts of companies' innovation processes? In our upcoming research, various methods such as workshops for industrial prototyping, questionnaires and product-tests will be utilized.*
KEYWORDS: *innovation process, prototyping, open source hardware, electrical toolkits*

INTRODUCTION

Fast prototyping is very important for the innovation process to reduce development time and costs [1]. Rapid prototyping technologies help to produce components very fast but no electronic parts are realizable until yet. Today there are electrical open source toolkits on the rise that might be a complementary technology. This paper investigates the hypothesis that "open source electronic toolkits may accelerate the innovation process". At the beginning of this paper we will explain what an innovation process is. Then the process step "prototyping" and its link to electronic toolkits to realize physical computing prototypes will be specified, followed by an explanation of the term open source hardware, its advantages, challenges and current projects. Finally, one electronic open source toolkit will be described in detail. After covering the theoretical and conceptual background, the research questions and research setting will be stated. At the end of this paper the assumed results and the outlook will be discussed.

THEORETICAL AND CONCEPTUAL BACKGROUND – INNOVATION PROCESS

Historically the innovation process has changed its focus from technology push oriented over market pull oriented to a more interactive, "coupling" and integrated oriented innovation process whereas speed and efficiency become more and more important [1]. In this context, 5 basic phases - ideation, concept development, prototyping, market tests and market launch - have aroused [2,3].

Ideation, also known as "Fuzzy Front End" [4,5], means creating a pool of ideas for innovations. Idea corresponds with developable potential not with a matured concept. The pool of ideas contains only verbal descriptions of possible solutions about new or improved products / services. This innovation step is based on information about adopted open needs of potential customers. On this basis ideas are collected, systematized and evaluated in terms of cost-benefit ratio, idea compatibility with the product portfolio and strategy, legal restrictions and finally with the uniqueness compared to the competitors. Idea is primarily achieved by the research and development department but also supported by the marketing and sales department. [6,7]

The next step, named "concept development", takes place only in the research and development department. Concept development in this case means refinement and further development of the idea to a complete solution concept by means of research and development. In addition to the generation of a written concept, ideas need to be visualized by means of sketches, mock-ups, animations and simulations [8]. For the realization of the project along the innovation process should be defined a time schedule, an investment plan, an assessment of the technological feasibility and the market potential. According to Wheelwright and Clark [3], the concept as whole may then be evaluated by experts, the senior management and by market researchers. [6]

The objective of the process step "prototyping" is to transfer the concept into a fully functional test model of a planned product or component [6]. After that the developed prototype will be tested *under laboratory conditions in terms of performance and acceptance, which are also interpreted as specific scenarios [9]. The results will be compared with the hypotheses of the concept and until the perfect solution is found, iteration cycles are necessary to adjust the concept [10].*

The next step "market tests" is to evaluate the product under real circumstances. In order to do this, the prototype needs to be transferred from handicraft to a small batch production system for the first time. The product will then be tested as before on a test-market to assess it in terms of acceptance and performance. It helps to get a feedback from the market to make the last modifications and to configure the marketing mix for the market launch. [6]

The last step of the innovation process is the market launch. However, before releasing the product, the price, the distribution-channels as well as the brand- and communication-management need to be fixed and the sales staff needs to be trained. [6]

The following section describes the prototyping aspect in more detail.

PROTOTYPING

Prototyping gives a first impression of the product idea. With the testing of the prototype the constructing engineer evaluates his or her adopted hypothesis as already mentioned. During the iteration cycles the construct goes through several phases, from a low-fidelity mock up to a detailed high-fidelity solution. Prototypes can be classified in a proof-of-principle prototype, form-study prototype, visual prototype or a functional prototype according to their purpose. The first one is only for testing potential constructional variants, for instance in the field of mechanics, motion, as well as sensor and actuating systems. The second gives the research and development department a first impression concerning the appearance, basic size and feel of the potential product. This prototype is not suitable for long-term tests. Form study prototypes are either hand-made or chiefly made by rapid prototyping machines. Additive technologies (i.e. selective laser sintering, stereo lithography), subtractive technologies (i.e. computer numerical control machining, laser cutting) or formative technologies (i.e. electromagnetic forming, adaptive die casting) are used [11]. The visual prototype is made for market research or executive reviews because it represents the intended design aesthetics, such as appearance, color and surface using the real material. The functional prototype attempts to simulate the final design, aesthetics, materials and functionality of the intended design, but it may be reduced in size. [12]

Complementary to rapid prototyping are electrical toolkits to generate electrical prototypes very fast. Toolkits are electrical platforms with several modules for many applications. Currently, they are mainly used by artists and designers who are not limited to electronic technologies, to make art installations more interactive. This field is also known as physical computing, which means reading and computing data from the "physical word". For this purpose, data are collected via sensor systems, analyzed by microcontrollers and activate systems such as LEDs, speakers, displays, engines and communication interfaces. Toolkits belong to the field of proof-of-principle prototypes, or sometimes even in the field of functional prototypes. Sketching describes the activity of creating running hardware prototypes with toolkits.

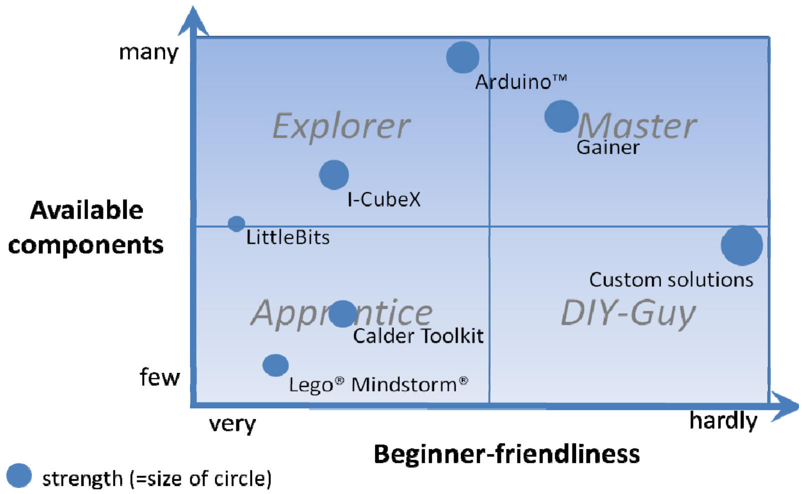

Figure 1 –Toolkit advisor framework [13]

Kowalski [13] made an advisor framework for toolkits (see figure 1). According to this framework, Lego® Mindstorm®, Calder Toolkit, and I-CubeX are closed source hardware. For some of them, APIs are available online free of charge. Lego® Mindstorm® is one of these, which excels with the capability of very easy and fast prototyping by means of stackable bricks and electronic hardware.

Furthermore, the programming of the microcontroller is visual via drag and drop. The second of these, Calder Toolkit, which is used for formable foam or modeling clay. The multimedia application authoring platform makes it easy to program. I-CubeX, which is primarily aimed at musicians, can be used to build musical instruments and multimedia applications. The electronic modules are also plug-and-playable. The programming is visual but no causal chain of different activities is realizable. LittleBits, Gainer and Arduino™ are open source hardware. LittleBits is an engineering puzzling platform with plug-and-playable autarkic modules which are connectable via magnetism. Therefore no programming is necessary but the consequence is that no complex projects are realizable. Gainer is a Japanese toolkit and the community around that speaks only Japanese. Therefore this toolkit is widespread only in Japan. The modules for the Gainer platform need to be assembled and soldered. The programming environment can be graphical or code-based. This is also true for Arduino™, which is a very popular microcontroller platform because it is easy to modify and extendable via shields. As mentioned before, LittleBits, Gainer and Arduino™ are open source hardware: in the next section the term open source hardware is defined in more detail. [13]

OPEN SOURCE HARDWARE

"Open source hardware is hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design. The hardware's source, the design from which it is made, is available in the preferred format for making modifications to it. Ideally, open source hardware uses readily-available components and materials, standard processes, open infrastructure, unrestricted content, and open-source design tools to maximize the ability of individuals to make and use hardware. Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs." [14]

As of 19th February 2011 this definition was accepted by 114 open source hardware activists. There are advantages when information and knowledge are no economic goods [15]. In research and development projects a lack of transparency in terms of information and knowledge is often seen as problematic [15,16]. With open source this problem may be avoided. Open source in the hardware sector is nothing new: in the 1970s computer engineers around the Homebrew Computing Club engineered in an open way, first computers and trade circuit designs amongst members [17]. The tenor was "give help to others".

Inspired by the success of the open source software movement, today this approach comes back to the engineering field. As no costs for design are incurred for the manufacturers, the price of open source hardware seems to be very low. In open source hardware developments you can benefit from a big source of good ideas, a high participation of the community and a high level of transparency in the development process, a high development speed, often a high modularity in their solutions, extra development potential for free and a high level of continuous improvement. Closed source hardware is governed by the vendor. Product changes or upgrades are common. The end consumer needs to get familiar with the new product and adjusts its surrounding structures. If the customer uses the vendor's product as a component or platform to develop new products, the customer has to update his product because the older version will be no more available sooner or later. Furthermore, the customer is not allowed to manufacture it by himself without owning the appropriate patent. Open source developments are differing in the sense that every direction of development remains available and the customer is allowed to manufacture the product by himself.

As already mentioned, open source hardware mainly takes the form of platforms that are easy to be modified and to be learned, with the aim of developing various individual solutions. This is why open source hardware is seen as a chance for the developing countries to improve knowledge within technologies [18]. The developing countries will be sustainably enabled to develop and produce products according to their ideas, in order to finally start a new business. Applications could be either a web radio [19] or a 3D-printer [20]. To create and produce these, it is not necessary to cover the whole supply chain such as engineering, programming, purchasing, work scheduling, manufacturing, assembly, *logistics, quality management and service. The developers can also focus on some particular processes. At the beginning they will just engineer and program. This creative process is the core of open source hardware development. But further on, they could also cover more processes of the supply chain such as manufacturing and assembly.*

Making your design public could give you a very big benefit, as already mentioned. However, publishing could also be a mistake if you want to sell your designs. Beside that open source hardware faces different challenges. As physical material is required, the barrier to entry is higher in comparison to software. Moreover, the upgrade process is much more complicated. Sometimes the hardware components need to be replaced. To create hardware, high expertise in each specific subject is necessary and the hardware manufacturer should not be completely excluded from the development process. If the product is not intended for self-assembly, the manufacturer is the one who does this. Therefore the production technology of the manufacturer needs to fit to the product design. In contrast to proprietary hardware development, no clear time schedule can be fixed. That means the open source community, which operates mainly without monetary incentives, cannot be assigned a specific order and a delivery date. But nevertheless various open source hardware projects have occurred (see table 1). [17]. In the following section, one open source hardware product will be explained in detail.

Table 1 – Various Open Source Hardware projects

Author	Cases	Typ	Explanation	Findings
Raasch et al. 2009 [27]	OSCar OSGV RepRap Neuros OSD Openmoko	Car Car 3D-printer Entertainment System Mobile phone	Car with sustainable mobility concept Sport utility vehicle (SUV) 3D printer for home use Home theater system Mobile phone	OSS development principles are also adaptable for the development of physical products
Gibb 2009 [28]	Bug Labs™	Microcontroller platform	Modular system for building devices	Credo “flexibility, modularity and the power to choose”, program in their language you want
Hill and Culler 2002 [29]	MICA	Microcontroller platform	Wireless Platform for deeply embedded networks	2 distinct classes of network-applications: long lifetime; highly dynamic sense-and-control network
Thompson 2008 [30]	Arduino™	Microcontroller platform	Prototyping Microcontroller Platform	Suitable for hobbyists to build their own gadgets with sensors and actors

EXAMPLE FOR AN ELECTRICAL OPEN SOURCE PROTOTYPING TOOLKIT – HARDWARE

Arduino™ [19] is a micro-controller based platform aiming to be an easy-to-learn and easy-to-use development environment for manifold projects in the field of physical computing. The basic structure of the Arduino™ development environment consists of hardware (I/O-microcontrollerboard) and software (programming environment). Both are available as open source. On the hardware side, Arduino™ initially consists of a board with an Atmel-Microcontroller and analog as well as digital inputs and outputs. The board is available in several versions and can be reconstructed by using free available circuit board layouts. Besides the implemented USB serial converter Arduino is also extendable on a modular basis without soldering by means of stackable shields. A variety of expansions are available as shields, breakout-boards or individual components, which are controlled by inputs and outputs of the board. These include various sensors (temperature, ultrasound, infrared, GPS, etc.), actuators (motors, LEDs, displays and interfaces such as LAN, WLAN, Bluetooth, ZigBee, GSM, etc.) and power sources (accumulators, solar, etc.). [22]

An ever-growing community has been formed around Arduino™, so that a multiplicity of sketches, tutorials, examples and descriptions of prototypes are available online. Among others Arduino™ is used for the realization of toys (OS Game Boy), musical instruments (laser harp), cameras (module for high-

speed photography), tracking systems (autopilot for model aircraft) and monitoring systems (for plants, tanks, rooms and buildings). [23-26]

EXAMPLE FOR AN ELECTRICAL OPEN SOURCE PROTOTYPING TOOLKIT – SOFTWARE

The programming on Arduino™ tends to be easy to learn and to use. Moreover it should also be easily understood by non-professional developers and engineers. There are various tools available (partially as open source) for programming, designing and simulation prototypes of circuits and whole products.

Programming Arduino™ includes a cross-platform integrated development environment (IDE) based on the programming environments Processing [31] and Wiring [32]. With the IDE programs, known as sketches, will be written in standard C/C++, debugged, compiled by the avr-gcc and uploaded to the board. The serial monitor enables you to communicate with Arduino™ over the USB port in both directions, for example sending and receiving data such as commands or sensor values. In addition to numerous examples and libraries, the programming environment also includes a boot loader for the use of different boards. Basically the Arduino™ IDE and an Arduino™-compatible board are the only two things needed to start developing.

Modkit™ [33] is a web-based graphical programming environment for Arduino™. It is inspired by the Scratch programming environment [33]. Modkit™ makes it possible to create tangible interfaces by using graphical blocks and editable text code. The blocks will be plugged together by drag and drop to create a complete program without using typical code syntax. The sketches can also be saved and loaded online on the Modkit™ website. Modkit™ is adapted for beginners and new developers who do not have any programming experience. [35]

VirtualBreadboard [36] is a graphical development environment for microcontrollers and circuits. An extremely interesting feature is the possibility to simulate various circuits with prepackaged electrical components such as microcontrollers, LCDs or motors. VirtualBreadboard allows computer-aided testing without using real hardware, so it is ideally suited to running prototypes in a virtual environment.

Fritzing [37] is an open source initiative which is intended to support the developing of prototypes with interactive electronics especially for designers, artists, researchers and hobbyists. There is a growing community around the researchers in the Interaction Design Lab at the University of Applied Sciences, Potsdam (Germany). Fritzing is a very useful tool for rapid prototyping. Basically it is an electronic design automation (EDA) tool with supportive visual components to develop a virtual prototype. It comes with a library of different electronic parts and provides different views (breadboard, schematic, printed circuit board) for the user. It can be used to design diverse circuits. The projects will be visualized, illustrated and well documented. Furthermore, printed circuit boards for manufacturing can be derived directly from the software Fritzing. This is very important in order to realize the prototypes without special knowledge of professional circuit designing and manufacturing. [38]

Besides EDA, normal CAD-tools can be used to design circuits and especially prototypes of whole products. For example, different 3D models of Arduino™ boards are available free of charge by using Sketchup™ [39] and the accompanying 3D Warehouse. With Sketchup™, prototypes can be designed in completely 3D and can also be published by printing or uploading them to the online library "3D Warehouse".

SYNTHESIS AND RESEARCH QUESTION

Rothwell [1] underlines that fast prototyping is very important for the innovation process to reduce development time and costs. Furthermore, scholars determined a lack of transparency within the innovation process in terms of information and knowledge [15,16]. Therefore, the primary aim of this research is to find a way to accelerate the development of new products and to increase the transparency in the innovation process. Electrical open source toolkits seem to be suitable for this purpose. Currently they are mainly used in the domestic and scientific sector; the industrial sector is excluded.

This research is also part of bigger interdisciplinary project - IREKO - which is founded by the European Social Fund and the Free State of Saxony / Germany. It runs inter alia by the Department of Factory Planning and Factory Management of the Chemnitz University of Technology. This project aims to achieve sustainable realization of innovations in the regional working context as well as to increase *the qualification of the researchers in the field of new innovations for the Saxon labor market. Therefore, the second aim of our research is to trigger an innovation transfer of electrical open source toolkits from the domestic and scientific sector to the engineering sector which would deliver practical benefits as part of the IREKO project. The main research question we would like to answer is: "To what extent can the use of open source hardware - such as electrical open source toolkits - accelerate the innovation process of companies?"*

RESEARCH SETTING

To answer the above mentioned research question, workshops, questionnaires and product tests will be utilized.

Workshops should help to reduce the training effort and to overcome the obstacle of learning something complex on your own. The workshop is primarily addressed to interested companies. It is divided into two parts. The morning session will cover the theoretical background, an explanation of the electrical open source toolkit Arduino and a first task to create virtual Arduino projects to get a feeling for electronics and microcontrollers. In the theoretical part, the relevance of easy and fast prototyping within the innovation process will be explained. Then electrical open source toolkits and possible applications will be sketched, for instance to extend the monitoring of production lines and products, so that the manufacturer can immediately react and maintain before trouble arises. Afterwards, the advantages of open source hardware will be stated. Obviously it is has a lot of benefits when information and knowledge are no economic goods. Still in the morning session the facilitator informs about the electrical open source toolkit Arduino, its functionality, shields, modules, programming language (code-based and graphical), open source philosophy and its large community with a wide range of well-documented solutions. The workshop will then concentrate on practical aspects. The participants will be assigned the task of developing an information source for a production line using a virtual Arduino environment under the guidance of the facilitator. After this, they can develop solutions on their own. In the afternoon session, participants will have the opportunity to create small projects on their own, and for this purpose the rest of the workshop will be held in the Experimental and Digital Factory [40,41] of the Department of Factory Planning and Factory Management at Chemnitz University of Technology. Problems and ideas for solutions will be sought and project teams will be formed. Every project team will receive an Arduino building kit with limited modules and shields. The facilitator gives guidance in order to avoid a trial-and-error development on the part of the participants. At the end of the workshop they present their results.

After the workshop, participants are requested to complete a questionnaire relating to solution finding with the help of solutions documented by the Arduino open source hardware community, the plug-and-play capability and to the generating of software code for microcontrollers.

To evaluate the industrial compatibility of the open source toolkit Arduino, the prototypes - developed during the workshop - need to undergo a long-term test in the Experimental and Digital Factory.

CONCLUSIONS AND OUTLOOK

We assume that the investigated open source toolkit is suited to industrial applications and will enhance the innovation process within the scope of physical computing. Enterprises, also of smaller size, will now realize that open source hardware has significant potential. Furthermore we assume that the enterprises which took part in the workshop will at least reflect on electrical open source toolkits when they are facing similar problems within the field of process and product monitoring. If enterprises see a big potential for improvement in their developed toolkit project, we presume they consider making the project public in the hope of receiving suggestions for improvement.

Current open source hardware projects can only be found in the domestic and scientific sector. When will be enterprises using open source hardware? And which products will be the next ones that go open source? Today the biggest open source hardware communities have been founded around microcontrollers. Hence they are universally useable as is the operating system Linux. It is assumed that open source products will initially consist of cheap electronic components, although someday, we assume, industrial machinery for factories will be open source. "What effects will this have on factories, for instance in terms of adaptability?", could be a research question for future investigations. Beside that the social aspects of open source hardware developments in industry surroundings with questions such as "How does an individual as well as an enterprise behaves in an open source hardware *community?" and "How is the world of working changing, when the creative work is free of charge?" needs to be addressed in future researches.*

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