VIRTUAL FACTORY FOR CUSTOMIZED OPEN PRODUCTION

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TOBIAS REDLICH, JENS P. WULFSBERG, FRANZ-L. BRUHNS
Helmut-Schmidt-University / University of the Federal Armed Forces Hamburg, Laboratory of Production Engineering, Holstenhofweg 85, D-22043 Hamburg, Germany
tobias.redlich@hsu-hh.de, jens.wulfsberg@hsu-hh.de, mbrs@hsu-hh.de

ABSTRACT

This paper regards a holistic customer integration into value creating with a focus on the development of manufacturing equipment. Therefore the paradigm of Open Production will be introduced and the practicability of openness will be evidenced by practical examples.

INTRODUCTION

Today's markets are subject to strong fluctuations and saturation, so the push of supply is displaced by the pull of demand almost completely. That helps customers in a position to dictate the supply, so companies have to satisfy discontinuous demands dominated by the urge for individuality and self-realization needs. Many cost reduction strategies like mass production at this point are no longer contemporary. Much More is a comprehensive customer integration needed. It raises the question of whether the clear separation between producers and consumers, in our current view of the economy, remains valid, or if not a merger to "Prosumers" took place, as Toffler (1980) predicted. At least growing openness, resolving of rigid corporate boundaries is needed, in order to remain competitive.

Many points along the value creation process therefore provide the opportunity for integration of customers and users, participating in the value creation (Figure 1).

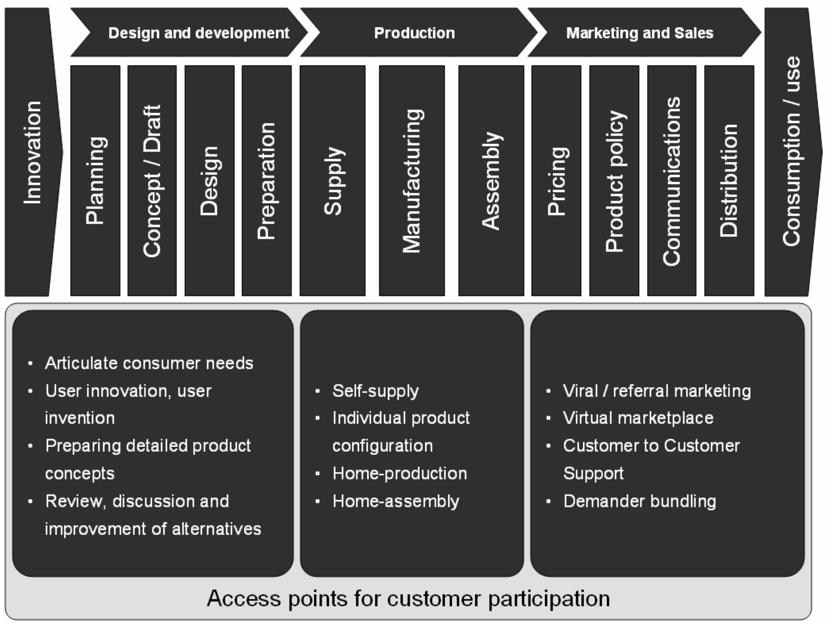

Figure 1: Potential access points for customer participation along the value creation process

In this context, two approaches are particularly promising. Firstly, open innovation, as a form of customer integration, and also as a form of outsourcing of development activity brings benefit to enterprises through its cost reduction potential (e.g. by the reduction of uncertainties in the product development process). Secondly, the mass customization approach, that offers various instruments for customers to take influence on the production process. So, a higher degree of individuality brings companies growth in sales through improved access to niche markets.
Both approaches, however, effect only selective customer integration in the value-added process. This paper, rather presents the concept of a "Virtual Factory for Customized Open Production" as a comprehensive approach for user integration along the entire value-added process.
Initially the known approaches Open Innovation and Mass Customization are depicted, which will then be merged with additional aspects to the whole Open Production concept. The practicality of open approaches in the value creation of physical goods will be evidenced through practical examples, and finally the concept of a "Virtual Factory for Customized Open Production" will be outlined.

OPEN INNOVATION AND MASS CUSTOMIZATION

Sticky information

Individual customer needs are the reason for the increasing heterogeneity of markets and market segments. In the conventional market research, however, the uniformity of a limited observation area is required or presumed. Thus, the effectiveness of the instruments of traditional market research, have to be mistrusted. The conventional approach to the acquisition and processing of information about customer needs has its base in the corporate domain, but is targeted at addressing the customer domain (Figure 2). This process makes market research time-consuming, expensive and often not feasible, which regularly occurring product flops show.

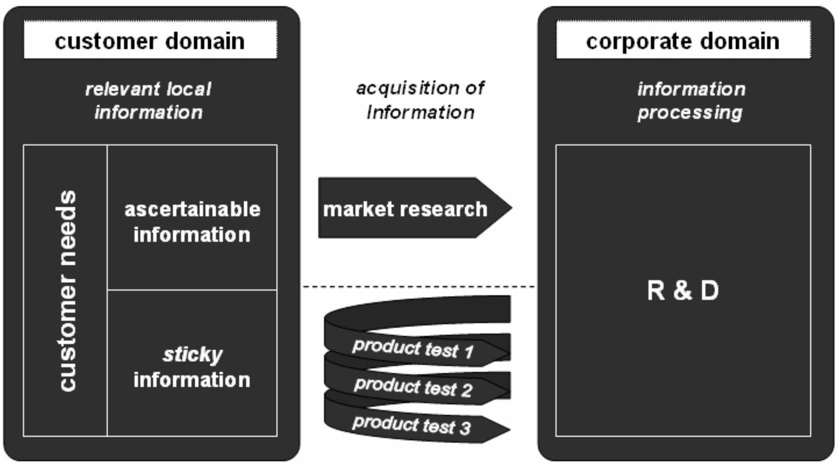

Figure 2: The problem of sticky information with conventional market research activities

Franke and von Hippel (2002) noted that so about 50% of all customer needs are typically not addressed. Added to that, customer needs change regularly during product use

(Rosenberg, 1982). Thus, is often an iterative approach needed to get these information, which is realized through product prototypes and their testing under high monetary and time expenditures.
Von Hippel (1994) states the “stickiness” of certain information as the reason for the difficulty of acquiring, transmitting and processing it. Sticky information is locally available, but hard globally ascertainable. Yet, without this information, the product development process provides high risks and flops are predictable.

User innovation

To meet customer needs in this increasingly discontinuous environment, efforts to customer integration and customized production in the form of Open Innovation and Mass Customization have to be made. With toolkits for user design and product configurations, customers can be involved into product development. Product configuration can be found mainly in companies in the consumer goods industry, which offer their products on the Internet.
Model examples of Mass Customization are internet shops for custom-made shirts (eg. www.tailorstore.de), which apart from individual measurements allow several million combinations regarding the design. The American company Thread Less (www.threadless.com) connects Mass Customization with Open Innovation, by asking its customers, to design T-shirts for themselves that can be evaluated by other customers. The most popular designs will than be awarded with cash prizes and offered on the internet shop.
Considering the stickiness of certain information the benefit of such instruments of customer involvement becomes clear. With a toolkit or configurator, the development process is shifted into the customer domain while the transfer of information into the corporate domain becomes unnecessary (Figure 3). In designing the desired product on their own, the entire information of customer needs is used to realize wish products. At the same time, the cost of customer acquisition and -retention will be reduced and the innovation process accelerated.

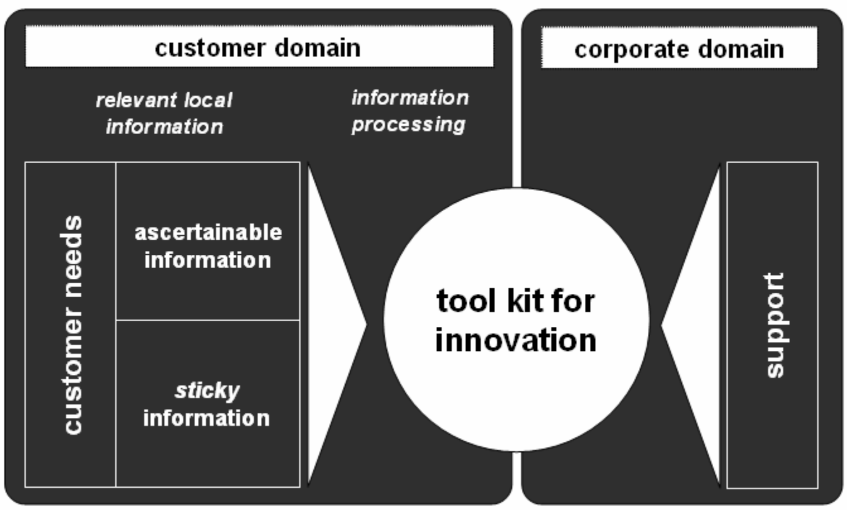

Figure 3: Information processing within the customer domain by using tool kits

Attaining the „long tail“

In addition to higher customer satisfaction, which results from Mass Customization by the fulfillment of individual desires, companies also benefit from the so-called long-tail effect (Anderson, 2004). This effect implies that an enterprise can be profitable by covering a large number of niche markets (although every niche for itself generates little revenue) instead of trying to cover a mass market. This strategy is promising for businesses that can manage to expand the circle of customers through a customized production without losing control over rising costs.

Actually this effect can be observed in many areas of the digital media industry. A classic example therefore is the distribution of music files via platforms such as iTunes. Due to the low cost of disk space it is worthwhile for vendors to offer products (in this case files), which are sold very rarely.

While companies usually concentrate on covering an existing mass market with a very cost-effective mass production, the long tail is achieved through sales of a number of special (customized) products (Figure 4).

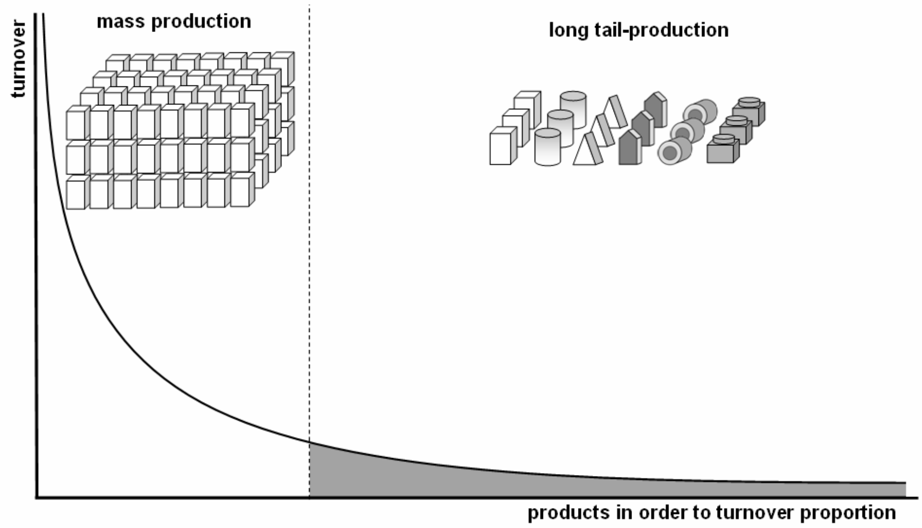

Figure 4**:** The long tail effect, distribution of sales of mass production (left) and long tail production (right)

ASPECTS OF AN OPEN PARADIGM

Collective Invention, Crowdsourcing and Co-Creation

Under the term Collective Invention Allen (1983) summarized trends in the creation of physical goods that can be compared with the concept of open source software. While Open Innovation and Mass Customization depict intensive customer integration in the innovation and development process, Collective Invention, as well as the terms Crowdsourcing and Co-Creation describe the cooperation of a lot of people to create goods, while there activity is not related to a regular employment.

Allen examined the innovation process in the British steel and iron industry and stated that competitors shared their innovations in this field with each other. Osterloh (2006) cites other examples. Among others the Homebrew Computer Club, in that (around 1980 founded club) people met, who were interested in the use of micro-processors. In a free newsletter, information was distributed and at meetings the members reported their latest innovations. As a member of this club Steve Wozniak, the later Apple co-founder, developed his first own computer. First as marketable products were created, and the club members faced each other as competitors, information which then became trade secret was not revealed anymore.

Motivation for Crowdsourcing

From the perspective of a whole community the sharing of knowledge is ideal, but single companies are better off, if they manage, to keep their knowledge secret. Although sharing of knowledge depicts a dilemma, however, at least in a pre-commercial stage knowledge-sharing indicates benefits.

In fact, in an early phase of development is great learning for all involved, so a knowledge-sharing brings synergy. Before the commercial stage of the product, losses may also not result (e.g. of market share) by the sharing of knowledge. But, there is the chance of an early influence and agreement on standards. Further crucial roles have selective incentives as reputation or profits of a value enhancement through knowledge sharing (Osterloh, 2006).

While the above example collapsed with the beginning of the commercial stage after the development of a "dominant design", in contrast the consistent model of open source software has to be considered. To transfer this model to other industry branches, however, the specific underlying motives have to be examined. As encouragement to participate in an open source project apply both intrinsic and extrinsic motivations:

- Profit through expanded functionality (extrinsic)
- Reputation (extrinsic)
- Commercial incentives (extrinsic)
- Pleasure (intrinsic) (Osterloh, 2006).

For the "homo economicus" within a community it would be rational, to act as a free rider, skimming but not contributing knowledge. Here is another dilemma that only then dissolves when the individual costs for a contribution are lower than the individual incentive for a contribution. Under certain conditions, the costs for individual contribution even can be low during the commercial stage.

First, distribution costs influence the individual costs. The more effective knowledge sharing gets, the lower the distribution costs are. So the dissemination of information and communications technology is therefore the best precondition. Secondly, the treatment of users as innovators provides an increased level of motivation. So this intrinsic motivation provides for a reduction of the perceived individual costs. A third option to shrink contribution costs is the modularization of the task. This allows multiple specialized users to work on the development in small steps independently (Osterloh, 2006).

Co-Creation

The cooperative provision and use of experience, intelligence and abilities of a large number of people, with the aim of value creation is called Co-Creation. This special form of value creation can already be observed sporadically. World-wide, there are a large number of individuals, building spacecraft in their shed (e.g. as part of the X-Prize competition), or developing Farnsworth's fusion reactors in their basement (Bowyer, 2007b).

These are examples for very specific applications, what explains their limited occurrence. More likely is an application of this idea to the less expensive development and production of consumer and industrial goods. Basically it is the idea that an additional benefit to the community results from the widest possible participation of a number of their members. The demand for the skills and competencies to the articulation and implementation of their own individual needs increases with the progression of the development process. Consequently, there are a greater number of those participating in generating product ideas and in planning than there are of those involved in detailed designing and contributing to the engineering (Figure 5). (Füller, 2006)

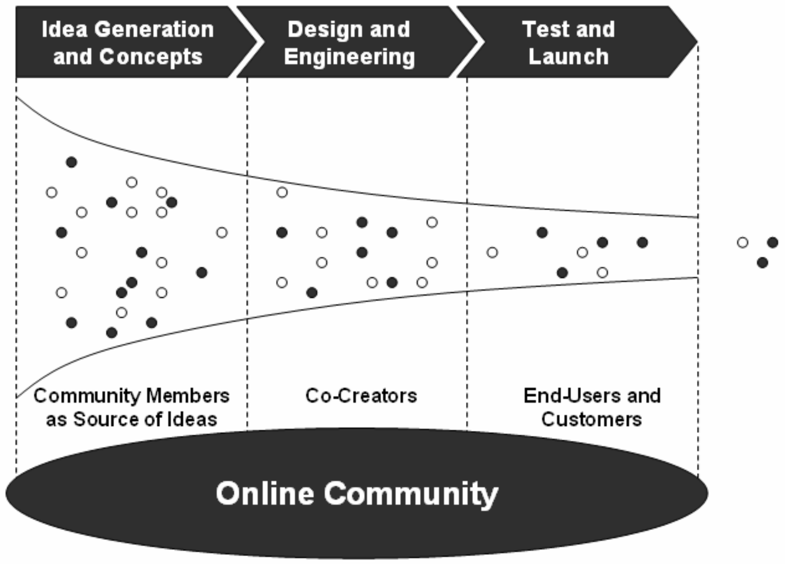

Figure 5: Co-Creation (Füller, 2006)

OPEN PRODUCTION - AN OPEN PARADIGM FOR PHYSICAL GOODS

The authors of this paper are of the view that an open approach is not only appropriate for the production of informational goods, such as software (Linux, Mozilla), editorial content (Wikipedia), or the initiation of development (Open Innovation). Rather, it is acknowledged the need for a holistic open approach. Below, “Open Production” is therefore introduced as a novel concept, which encompasses the entire value creation process of physical goods (development, manufacturing, sales, support, etc.).

The “open” term in this context has the same meaning as in open source software. Hence, openness means not the freedom in the sense of “free beer” but primarily in terms of “freedom of speech” (Stallmann, 1999). So the view that everything "open" is against maintaining intellectual property or trade secrets is wrong. With such concepts it is intended to allow the realization of integrated systems of "proprietary" and "open" designs.

Open Design

Without any protection the openness of Co-Creation and similar approaches would be endangered by patents or utility models. For that reason the rules of Open Design (OD) represent a sufficient precaution (Vallance et. al., 2001). The Open Design rules describe

how collaborative developments can be protected of losing their openness as base for further development by a certain type of license. As a result OD leads to freedoms, which can be formulated in line with the freedoms of open source software (Figure 6). The conditions for such licenses were elaborated by the Open Design Foundation (ODF) (Vallance et. al., 2001 and ODF, 2007). For the design of OD-licenses only a few principles must considered.
The most important point is linking the development of Open Design Systems (ODS) to a regular and freely available documentation. That forms the crucial basis for all further development steps. Secondly, a clear labeling of the ODS is required, if redistributed (whether free or for a fee) in combination with a proprietary system. And thirdly, modifications of any kind are allowed of the ODS. But if there is a further distribution of the modified system, it is compulsory to document the modification, and to release the extended documentation for free.

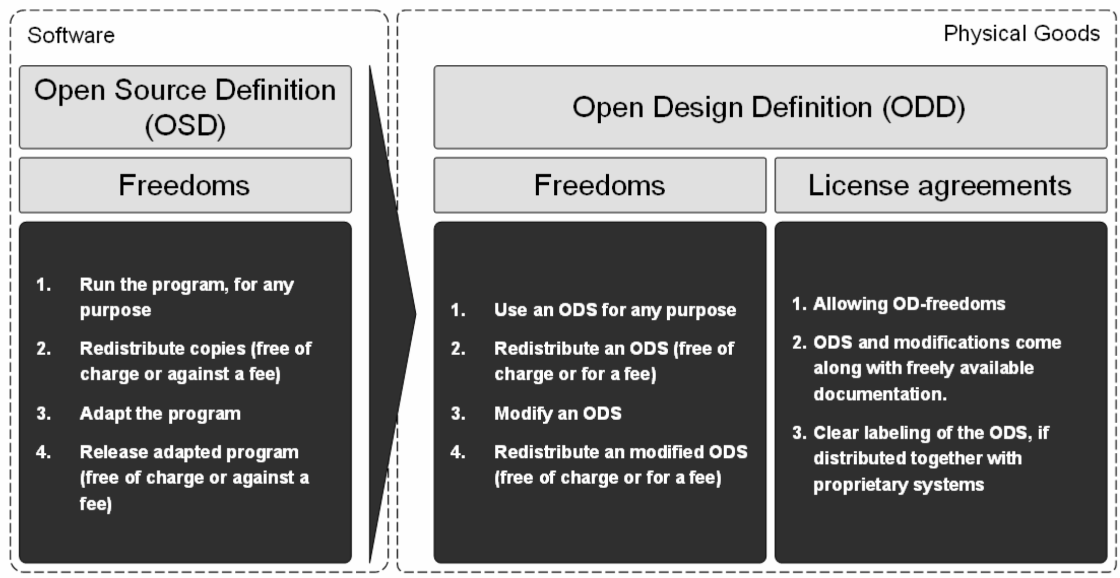

Figure 6: Freedoms of Open Design and key license agreements (Vallance et. al., 2001 and ODF, 2007)

Thus, Open Production is more than the production for the “public domain”. As for the open source software, every user is free to make money from redistributed modifications. There is, however, the obligation to share the documentation for a modified design, if any product with the modified design is redistributed for a fee or even free of charge. This allows that previous contributors also to participate in the progressing development.

Is there a future for Openness?

The sustainability of an open paradigm is easy to reason because in its fundamental nature and in its targets, it is similar to the science method (Vallance et. al., 2001). And there is a consensus, that science is the key driver of (technological) advances.
Science is the acquisition of new knowledge through research and its dissemination through teaching. This research is the methodical search for new discoveries, their

systematic documentation and publication in the form of scientific work. In doing so other scientists should be able to understanding the research results and working with them. So the exchange of information allows reproducing and varying experimental results, and adding to previous scientific findings through own efforts.
Akin to the scientific method, an open paradigm allows the rapid development and continuous improvement through exchange.

EXAMPLES FOR OPEN PRODUCTION

While in industry only few activities with holistic open source approaches can be found, however, the number of professionally managed projects of university or private origin is increasing. In the following, three current projects are presented, that base on the open paradigm and for which the development and production of physical goods is central. Additionally, with Square Foot Manufacturing a new type of machine concept is introduced, that could become another suitable example for the Open Production of manufacturing equipment.

OScar

The project OScar (Open Source Car, http://www.theoscarproject.org) is supposed to be the first one to develop an automobile completely on the Internet (Honsig, 2006). The basic pillars of this project are a communications and a development platform, implemented with open source software. After a preliminary specification as basis for discussion and drawing a series of design studies, the online community was to begin its work.
The goal is designing a modular vehicle with a full and freely available documentation (geometric data, information on parts and materials) one can take to the nearby contract manufacturer, who than completes the desired OScar.
The core team consisting of the heads of module teams meets basic decisions, while the independent working module teams design the vehicle modules. Challenges such as the question of product liability or variations and quality management still have to be overcome prior to the production.

RepRap

Within the RepRap project (http://reprap.org/) at the University of Bath a rapid prototyping machine has been designed, which can produce the majority of its components itself. The project can be found as the resumption of the already 1950 by von Neumann developed idea of the "universal constructor". This is a system of computers and production machinery, which together have the ability to create a copy of its own.
Rapid prototyping technology encompasses methods for the rapid production of parts direct from CAD data. The work piece is build layer by layer out of amorphous material with the use of physical and chemical effects.
For realization of such a machine individual participants in the RepRap project designed and constructed a heated print head with a nozzle and a controlled material feed. In addition, a kinematics for the relative movement of the nozzle and software to control all processes on a desktop PC were developed.
The framework of the machine consists of a steel rod scaffold whose connection elements were produced by the machine itself. Thus, the required elements of the RepRap are

whether produced itself easily or they are easy to procure. It is assumed that the costs of parts for this machine are no more than 400 euros (Bowyer, 2007a).
The current use of thermoplastic as raw material for the RP technology within this project limits the range of possible products of such a machine, while commercial RP machines already fabricate work pieces of metal or ceramic materials. But there are attempts to combine insulating and conductive plastics, thus to produce electronic components.

Fab@home

Like the RepRap project under the Fab@home project, a machine was developed, which, equipped with RP technology, allows each user, to "print" desired products from a file on his desktop PC. The projects' homepage (fabathome.org) is organized as a wiki so each registered user can participate in the development.
Inspired users can expect a guide to the construction of such a desktop factory, including parts lists and technical drawings, manuals etc. Links to vendors allow both, purchasing parts of the machine as a package or already assembled machines. The homepage also provides product suggestions and ideas for improvements to the hardware and software. The costs for all parts of the machine should not exceed about 2300 US dollars, according to the information on the site.

Square Foot Manufacturing

The Laboratory of Production Engineering developed a factory and manufacturing concept for the fabricating of micro-parts, named Square Foot Manufacturing (SFM) due to the size of its footprint (Figure 7).

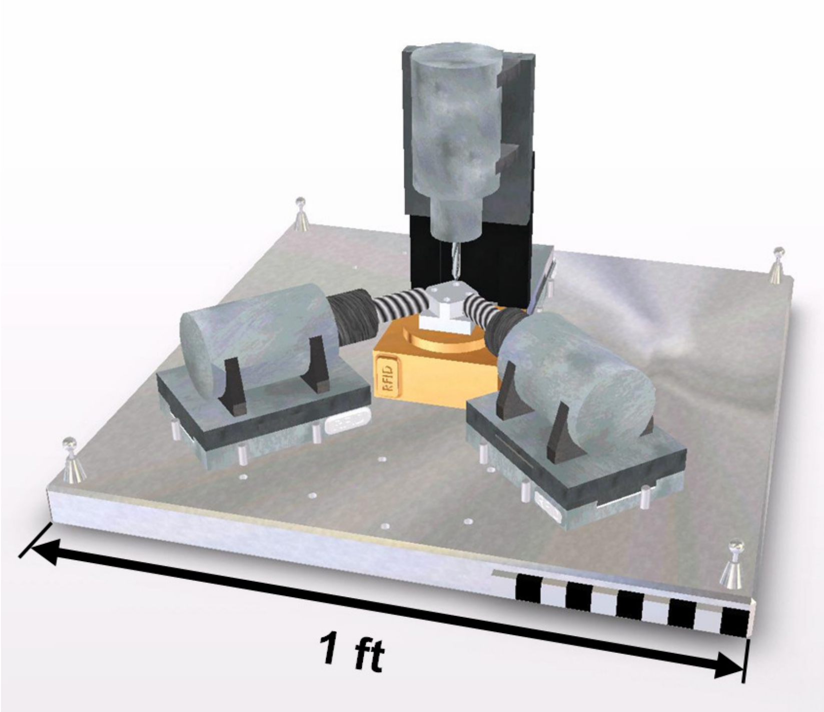

Figure 7: Square Foot Manufacturing

SFM is a low-cost machine concept, matching changeability requirements especially because of its scalability, so it suits for the small-lot and made-to-order production. This benefit to the end user is the basic prerequisite for this machine concept being further developed and distributed under aspects of Open Production of manufacturing equipment.

Open Production capability of changeable machine concepts

Usually machine tools are expensive and come along with enormous measures. Therefore, only companies with mass production aims can afford the necessary investments. However, the trend toward individualized production with much smaller lot sizes recovers large potential for scalable and versatile machine concepts as described with SFM or the Rapid Prototyping projects.

Despite this potential, however, further development is slow, because the industry is not particularly ambitious to make this technology available for cheap. So machine systems remain large, very expensive and complex. So the current market for versatile and scalable systems is as small as it is. It is a vicious circle, because niche applications imply a small demand for such systems and so they stay expensive and complex, why they keep worthwhile only for niche applications in turn.

Square Foot Manufacturing was developed as a cheap machine concept for the end user to break this vicious circle. In order to maximize the potential benefits for users, they will be fully integrated in further value creation processes. In addition, the machine systems should be designed as changeable as possible, to meet individual needs. Because depending on how useful the machines become for users, the greater the feedback of the market will be. If successful, this approach will lead to a rapid expansion of the technology.

As a framework for the comprehensive customer integration qualifies the Open Production concept. It is based on openness and collaboration between companies and customers to achieve the above aims.

VIRTUAL FACTORY FOR CUSTOMIZED OPEN PRODUCTION

The previous sections have shown the existing opportunities for the customer and user integration along the value creation process. Examples reaffirmed the practicality of open approaches. Therefore, the implementation of Open Production in a Virtual Factory (VF) for manufacturing equipment (e.g. SFM) will be described in the following.

Open Production of Square Foot Manufacturing-Systems

The intention of this VF is an efficient development, production and distribution of customized goods (in this case Square Foot Factories). SFM provides a proper concept for the implementation of a “Virtual Factory for Customized Open Production” for several reasons. Because of the miscellaneous applications that are likely with SFM, a distributed development is more beneficial than the development by a professional but smaller development team. In addition, SFM is still in an early stage of development, therefore developers are not facing each other as competitors. Much more arise synergy effects from the cooperative provision of knowledge and the possibility for an early agreement on standards. Furthermore, SFM due to its low cost and modular design has a special suitability for such a development concept. Compared to conventional complex and expensive machine tools, with Square Foot Manufacturing a customized production may be achieved so additional markets and even the long tail of manufacturing equipment production comes into reach.

Virtual Factory

A Virtual Factory (VF) is typically a connection of independent companies to a temporary production network, with the goal of solving a narrowly defined problem efficiently. This original understanding has to be extended by two essential points. Firstly, as a network partner in our case, all customers will be added. Secondly, the closely-defined mission here is no less than the entire value creation process for SFM systems from product development to user support.

The information and communications technology offers the appropriate tools for Open Production. All interactions so can be collectively managed through a broker. This broker is the hub for knowledge and products. It will be realized by three Internet platforms (Figure 8).

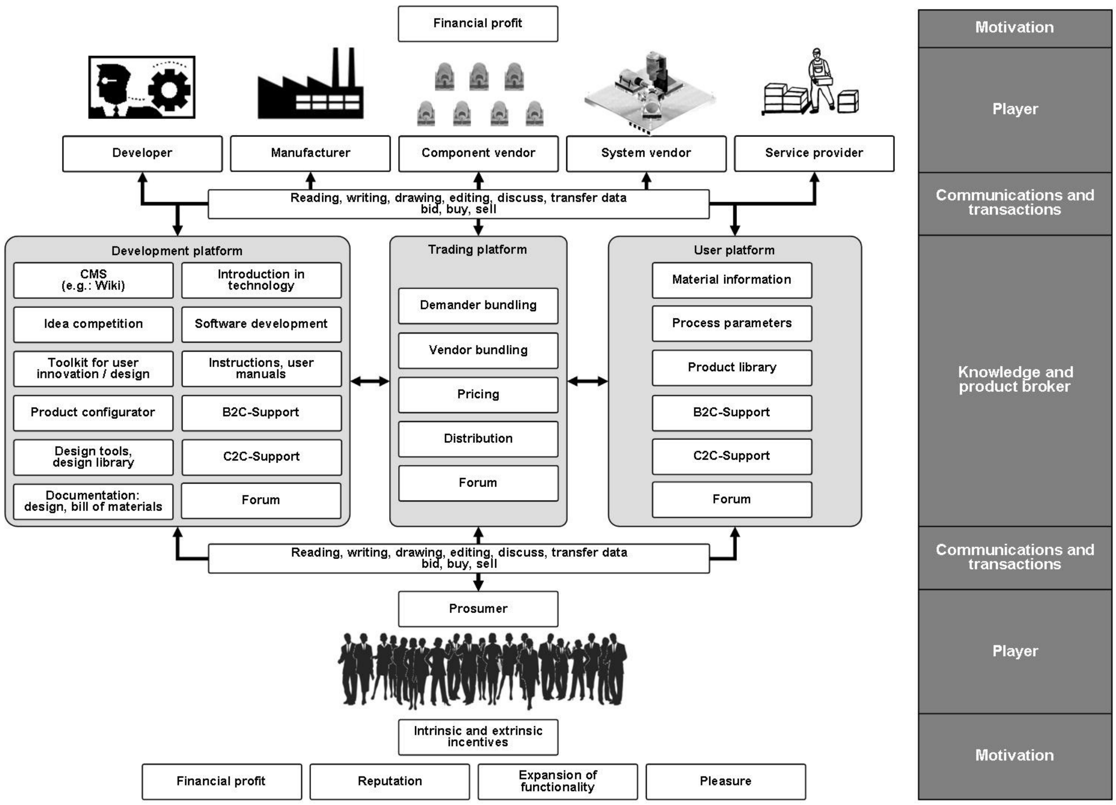

Figure 8: Virtual Factory for Customized Open Production

The Virtual Factory can be depicted as the interaction network of a variety of players that are linked by both communications as well as transaction channels. For all interactions the broker platforms are used. The players on the one side are the users, customers and consumers. Because of their participation in the value creation they become more or less producers and therefore are referred to as “Prosumers”. Their ambition for various possible interactions is not only extrinsic (reputation, profit, etc.) but also intrinsic (e.g.

pleasure). On the other side of the network developers, manufacturers, suppliers and other service providers can be found, whose actions are motivated solely extrinsic.
The interaction network consists of different modules, while each individual module is suitable, to increase the potential involvement of all players in the value creation process.
The basis of the development platform is a content management system (CMS), with which the necessary information is collected, managed and will be provided. For such a "knowledge database" (such as Wikipedia) moderated or unmoderated systems can be used. The CMS allows the provision of the necessary know-how for product development. One can on this basis provide an “Introduction to technology”. Furthermore, the progress of the development process is documented here. Detailed design instructions, drawings, manuals and parts lists may be stored and handled in appropriate file formats. For the entire development process, the principles of the open design have to be applied to ensure the openness for the entire value creation.
Additionally, there is the possibility to discuss within a number of forums to several topics so that besides B2C also C2C support can be given. Companies have the possibility to initiate idea competitions and to reward innovative contributions.
After the product development is completed, product configurators are used to customize the machines and on the trading platform orders can be made while there are various ways of pricing. For example, customers with the same or similar needs can be bundled or pooled to lower costs for both, customers and providers. Prices can be found through supply, demand or double auctions etc. Both, system and component suppliers can also offer fixed prices.
On the user platform instruments should be set up to permit the initiation of further developments on the development platform. Product examples, process parameters for certain operations and material information will be exchanged in a forum.
The “knowledge and product broker” in the network is the mediating body and overtakes control functions. This includes responsibility for the observance of the rules of the Open Design during the development process. The broker is also responsible for the design and management of the CMS, so that the greatest possible participation can be achieved. For this, the broker has to be independent of all players.

CONCLUSION

With the implementation of a “Virtual Factory for Customized Open Production” for the development of manufacturing equipment like SFM, every user of such a system obtains the ability to participate at the value creation within the range of his capability. Even selfish motivated players result benefit for the community with their individual participation. In Contrast to popular models the customer integration remains not limited to the innovation process. Rather the customer influence on the entire value creation process effects benefit through using customer related information directly within the product development process.
The realization of the outlined concept is part of further research, which aims on the rapid development of a technology with Open Production. It represents a contribution to changeable production systems as a dynamic response to the changing economic environment.

REFERENCES

Allen, R. C. (1983). Collective Invention. Journal of Economic Behaviour and Oranisation 4 (1), 1-24.

Anderson, C. (2004). "The long tail". Wired Magazine, Issue 12.10 – October 2004. http://www.wired.com/wired/archive/12.10/tail.html

Bartl, M. (2006). Virtuelle Kundenintegration in die Neuproduktentwicklung. Deutscher Universitäts-Verlag. Wiesbaden, 2006.

Bowyer, A. (2007a). The Self-replicating Rapid Prototyper ─ Manufacturing for the Masses. Proc. 8th National Conference on Rapid Design, Prototyping & Manufacturing, Centre for Rapid Design and Manufacture, High Wycombe, June 2007.

Bowyer, A. (2007b). Why Accountants are Dull and Guitarists are Glamorous - The End of Intellectual Property. Time Compression Technology Magazine 15 (3), 33.

Ceruzzi P.E. (2000). A History of Modern Computing, The MIT Press 2000.

Franke, N. and von Hippel, E. (2002). Satisfying Heterogeneous User Needs via Innovation Toolkits: The Case of Apache Security Software. Working Paper 4341-02, MIT Sloan School of Management.

Füller, J.; Bartl, M.; Ernst, H.; Mühlbacher, H. (2006). Community based innovation: How to integrate members of virtual communities into new product development. Springer Science+Business Media, LLC 2006 Electron Commerce Res (2006) 6, 57-73.

Honsig, M. (2006). Das offenste aller Autos. Technology Review, Heise Zeitschriftenverlag GmbH & Co. KG 01/2006, 46-53.

Jeppesen, L.B. (2005). User Toolkits for Innovation: Consumers Support Each other. The Journal of Product Innovation Management 22, 347-362.

ODF. (2007). Open Design Foundation. "Open Design Definition". http://www.opendesign.org/odd.html

Osterloh, M. et. Al. (2006). Collective Invention als neues Innovationsmodell? in Drossou, O. Die Wunderbare Welt der Wissensvermehrung. 65-76**.**

Rosenberg, N. (1982). Inside the Black Box: Technology and Economics. Cambridge University Press. New York, 1982.

Stallman, R. (1999). "The GNU Operating System and the Free Software Movement". In Open Sources: Voices from the Open Source Revolution. O'Reilly & Associates 1999 p. 3.

Toffler, A. (1980). Die dritte Welle – Zukunfts Chance. Bertelsmann. München, 1980.

Vallance, R.; Kiani, S.; Nayfeh, S. (2001). Open Design of Manufacturing Equipment, CIRP 1st international conference on agile, reconfigurable manufacturing, Ann Arbor. Michigan, 2001.

von Hippel, E. (1994). Sticky Information and the Locus of Problem Solving: Implications for Innovation. Management Science 40 (4), 429-439.

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