Abstract

Today, development of physical products does not only reflect the notion of tangible objects, but rather those of individualized products with associated services; which bring more value to final customers than the pure physical objects without any accessories and services. Thanks to new achievements in ICT, all product stakeholders (e.g., manufacturers, consumers, service providers) have got the possibility to more intensively interact with each other and thereupon profit from that. This novel approach has led the development features of products to a new era of cyber-physical systems, resulting in higher individualized and user-friendly product experiences, reflecting intelligent and connected products throughout their life-cycles. Accordingly, such products configure product-service systems with accompanying several merits, e.g., flexibility, adaptability, reactivity, expertise, and x-gradability. Prospective products due to their adaptable design, associated services and Avatars are able to cover a range of customizations upon the current and prospective needs of customers. Besides, manufacturers can profit from this approach for adopting new production strategies. This perspective is recommended and conceptually explored in this paper.

Keywords: Make-to-XGrade, Cyber-Physical System, Product Avatar, Personalized and Scalable Product Experience;

1. Introduction

The need for quickly adaptable, customizable and personalized products can today be identified across many different sectors with many different motivations. For example, over the past decades, the rapid development, ready availability and ease-of-use of consumer information and communication technology (ICT), products such as Smartphones have changed the way we communicate, socialize and go about our daily business, at home and at work. This ubiquity of ICT in our daily activities has changed the expectations of consumers with regards to product design, usage experience, and corresponding service offerings [1]. This is especially true regarding the personalization and customizability of products and services. For instance, the functionality of entertainment goods like televisions and games consoles, but increasingly also that of traditional products such as cars can be changed on the fly, simply e.g., by installing new apps or reconfiguring a motor chip. These expectations are beginning to extend to more and more product sectors. Future products’ design and manufacturing, including that of their service extensions, need to meet these expectations with new product development and life-cycle management concepts [2].

Sustainability is another example of a strong argument for the requirement of flexible and adaptable products. With today’s need for fuel and energy efficiency, a product’s performance and consequently the energy use should be tailored to fit the specific usage scenario in each individual case [3]. For example, a car will need a certain performance profile in town traffic, but a completely different one if used for a long, inter-city drive. Such a car can have a flexible
(scalable) functionality, recognized in the development phase, considering physical as well as service up-, down-, and side-gradability. A concept which supports the flexible reconfiguration of such a car (up-grading and down-grading performance based on needs) can go a long way to improving the overall energy efficiency of the vehicle. Indeed, this generic coverage of flexible functionality of such products outstandingly contributes to the sustainability factors that need to be explored more.

In a similar vein, manufacturers of products such as leisure boats can profit from a design and manufacturing concept, which takes into consideration future up-, down-, and side-grading services. In the current economic climate in Europe, these kinds of products are increasingly viewed as luxuries and consequently, sales exhibit a downward trend [4]. Boat builders are progressively looking toward providing services such as upgrades to offset the loss of their previous main revenue stream. A boat owner might sooner buy a new engine or new upholstery before he buys a completely new boat. Accordingly, the initial design of the boat must support this type of upgrades in physical (i.e., modules) as well as virtual functionalities (i.e., services), spanning the entire life-cycle of the boat. In doing so, a concept for design, manufacture, and usage of flexible and adaptive reconfiguration of products throughout their life-cycles can help manufacturers develop new services based around reconfiguring the already sold products, and tap into new revenue streams throughout those products’ life-cycles. This development concept of products conveys the notion of x-gradability alongside their life-cycles, which can reflect a new design and manufacturing concept, called make-to-xgrade (MTX) by the authors. Correspondingly, this concept can be introduced in accordance to some concurrent production strategies (e.g., Make-to-Order (MTO), Assemble-to-Order (ATO), etc. [5]), while considering contemporary technological developments and customer requirements.

In more specialized sectors, urgent operational requirements (UOR) can dictate the quick reconfiguration of existing products and equipment. This is especially the case, for example, in the field of emergency management, where environmental or situational conditions may demand a fast reaction towards the reconfiguration of equipment for fast and efficient operation. Here, the timely reaction to UORs which can be supported by the MTX concept can save lives and property. Moreover, a number of research issues need to be investigated to realize the MTX vision. They relate firstly to the functionality of products, only as complementary services to the application of them. The argument for accompanying products with services is increasingly being adopted by industry in response to the continuous increase of implicit customer requirements for better and more functionalities, besides the personalization of products throughout their life-cycles [14, 15, 16]. Since a major part of associated services are today either digitally delivered or provided, the modern notion of PSS can be facilitated by the Product Avatar, as a platform for offering services to many different stakeholders throughout the product life-cycle.

A new contribution to the explained features of modern products, with the associated services and capability of customization in their usage and extended usage phases, is the products with experiences. The personalization of products is more important than ever, thanks to the wider scope of products as well as richer awareness of end-users and commoditization of technologies. A new approach to customizing the standard functionalities of unique products with additional modules (physical or virtual) is required. Products marketed not as physical items, nor product service bundles, but as experiences reflect consumer trends based on changing lifestyle choices; which demand individually customized experiences and consequently requirements throughout the related product life-cycles [17]. The MTX concept caters to this new perception of products and can support the design, development, production, use and end-of-
life of future (MTX) products and the corresponding experiences.

Accordingly, customizability and scalability of services for products is the next improvement step towards product experiences encompassing physical products, services, and non-tangible experience components. This holds especially true when considering products with multiple end-users. For instance, medical devices may offer services to different end-users (i.e., either technicians or patients), like magnetic resonance imaging (MRI) with personalized patient experience, see e.g., http://www8.healthcare.philips.com/ae/. Therefore, such products have to have the capability to provide customized functional standards and services according to current need of the user. This issue is followed by the MTX concept in this paper.

However, in order to realize product experiences, whilst taking into consideration the x-gradability of the physical components as well as the associated services, some practical methodologies are needed. One of the well known and applicable strategies is the modular design of products as well as services in the form of extensible packages that offer scalability in the functions and experiences, e.g., see [15, 5]. In doing so, products are built and sold in the form of universal platforms (products with standard options) that regarding the customer need in terms of customized services and functionalities across the beginning of life (BOL), middle of life (MOL), and end of life (EOL) are x-gradable. Indeed, this concept reflects the idea of closed-loop product life-cycle (CPLM) [18], as an advantage of all stakeholders. CPLM is a direct consequence of a bilateral (forward and backward) product data management (PDM) throughout life-cycles, implicating data transmission and collection from the manufacturer side to customer side and vice a versa. This reflects the notion of cradle-to-cradle instead of cradle-to-grave [19], see Fig. 1.

Accordingly, the relation between customer and manufacturer undergoes a new era by means of digital connectivity through Product Avatar. On this basis, all stakeholders benefit from the inter-connectivity and exchange of information, e.g., see [21]. This leads to bilateral recommendations for x-grades (e.g., maintenance, motor upgrade, new required module, etc.) from manufacturer to customer and inversely. As soon as a realizable need or supplement is recognized by either / both party(ies) it can be ordered / offered without a fundamental change in the initial condition of the product.

However, the realization of Product Avatar, across life-cycle with the expected capabilities, requires integrated sensing and data collection functionalities. Thus, the other fundament of MTX is the contribution of cyber-physical systems (CPS) to it. The employment of sensors and computing elements embedded into physical elements to monitor and control the physical processes is the real contribution of CPS [22]. Or according to [23] CPS are those systems where the physical world is measured and controlled by means of state of the art in computation and control. Furthermore, the flexibility, adaptability and reactiveness of MTX products can be reflected in the listed fundamentals above.

3. Adequate product design and manufacturing approaches

The advantages of CPS together with Product Avatar are the constitutions of the MTX concept, resulting in embedded products (or modules), not only providing their connectivity, but also facilitating multilateral interactions and the notion of intelligent products for extended functionalities, e.g., usage instruction, upgrading user knowledge, offering preventive maintenance services to customers, and data collection for manufacturers. Passive and active sensor tags, e.g., radio frequency identification (RFID), as well as wireless sensor nodes are some technologies, profiting from internet of things (IoT), to be used by CPS in realizing MTX products. These have the missions of identification, data storage, sensing, data processing, and communication.

Moreover, not only the final customers can profit from this digital connectivity to other stakeholders like manufacturers, but also the manufacturers can simplify their processes by postponing the complex and costly process of product individualization to the vicinity of the customer, while increasing the personalization potentials of products. For instance, this importance can be fulfilled by means of modules, in both physical and service forms, which are x-graded to an original product throughout its life-cycle to reflect personalized experiences. The producers can collect the real requirements of customers in terms of functionalities of their existing as well as expected products and try to x-grade them locally, either with new modules. This leads to higher sale as well as lower of cost and complexity in the development and production phases, see Fig. 2.

Indeed, the vision of personalized products with sustainability factor necessitates a more specialized and intelligent design and manufacturing procedures, so that the end-user is more intensively engaged within the whole development processes. The modularity, as a known enabling feature in product design, has been considered for a while in the design of particular products if applicable [24]. For instance, product design may fully follow the modular
principle of LEGO in their design, while postponing the assembly and even the final functionalities of the product to the end-user location [5]. Alternatively, it may just postpone the final assembly of the product to the vicinity of the customer, yet with predefined functionalities of the product, e.g., the IKEA concept [25]. Nonetheless, the complexity of design, production, and maintenance of the modules – as independent entities as well as building blocks of a final product – has been a challenging issue for manufacturers. This modularity feature has to be freshly motivated, to some extent, with new application fields in terms of simplicity, traceability, adjustability, and up-, down-, and side-gradeability for products, production, and services. This cannot be achieved without connected products with feedback provision and expertise.

Fig. 2. MTX among other production strategies.

Therefore, thanks to the MTX advantages, manufacturers can undertake this concept as a new production strategy to produce the solicited modules based on Avatar information, see Fig. 3. This can resemble the simple ATO, or even Make-to-Stock strategy, since the requests are already observed across interactions and demand (for physical / service modules) is there. Moreover, the research gap between the existing models and MTX locates on the initiation of product design, development, and production with the purpose of x-gradeability for intelligent products, so that they can keep personalization and alternative experiences for end-users throughout their life-cycles by means of Avatar, CPS, modularity, and associated service contributions.

4. Exemplary product Avatar and MTX

The personalization and reconfiguration of products is not a new idea, but there is still a wide gap between the requirements described above and manufacturers’ offers [24]. To close that gap, products designed to fulfill these requirements should not only encompass modular, flexible, and reconfigurable physical core products along with respective service extensions. But it should also consist of digital representations; which are capable of acting as an interface to both the consumer and manufacturer for managing the configuration of the product throughout its life-cycle. The digital representation, or Product Avatar, can fulfill a number of roles. For one, it can be used for monitoring the current usage conditions on the basis of sensors and other usage data acquisition technologies embedded into the core physical product and its components. For another, it can act as an interface for both the consumer and the manufacturer or service provider to monitor, select, define, and order different product configurations. In other words, interaction of product stakeholders can so be intensified, so that the consumer can even affect the development and production phases and, in a similar manner, the manufacturer the usage, extended usage, and end-of-life phases of products.

Accordingly, Product Avatar can also be used as a digital representation of a product, not yet physically manufactured: Thanks to the direct integration of end-users into the product development and configuration, they have the possibility to request new types of up-, down-, and side-grades for their products or services, in accordance with their real needs. An end-user may have a specific requirement / desire concerning the product’s functionality or the associated services that can be announced to the designer or manufacturer in the form of a new module, which previously did not exist. This suggestion may later draw the attention of the other users of similar products as well as the interest of the manufacturers for getting produced and provided to the end-users. For instance, the developed framework of BOMA (the boat Avatar) employs social networks for proliferating the public information sharing and intensifying the interactions, see Fig. 4.

In this framework, CPS of boats interacts with Avatar to provide the required information about, e.g., components situation and tracking, energy consumption and sustainability issues, temperature and humidity, winter storage conditions, maintenance status, electronic pads upgrades, etc. Later, this information is analyzed and communicated to the stakeholders for various purposes, among such the possible x-grades suggestions coming from Avatar itself or the stakeholders. For example, the boats are stored in winter time, thus, it is time for Avatar to expertize the condition and ask the consumer for temporarily down-grading the associated service modules (e.g., online monitoring of sailing weather forecasts, sailing insurance, monthly check-up, etc.) for the next 3-4 months. Besides, Avatar can inform him about new upgrades (physical
and virtual) for the next sailing season. On the other hand, the manufacturer receives the technical information from Avatar, in order to consider them into its design criteria, production plan, and maintenance services. Accordingly, this performance leads to a favorable assistance for manufacturers to not only profit from complete standard boats, but also from the suggested/demanded modules directly by consumers or from the expertise of Avatar.

Fig. 4. The schema of the boat Avatar framework [4].

Therefore, the design, manufacture, and service concepts of MTX are fully compatible with the notion of physical as well as service modules. This concept can reflect e.g., the ATO production strategy as well as the Design-for-X (DFX) strategy, employing modularity, intelligence, and embedded ICT services.

Table 1. MTX services for stakeholders based on cloud platforms.

| Cloud Platforms  | Consumer   | Embedded Products | Service Provider | Manufacturer | Virtual Supply Network | Recycling |
|------------------|------------|-------------------|------------------|--------------|------------------------|----------|
|                  | Avatar-as-a-Service | Experience-as-a-Service | Software-as-a-Service | Platform-as-a-Service | Infrastructure-as-a-Service | Platform-as-a-Service |
| Public Cloud     | Avatar-as-a-Service | Experience-as-a-Service | Software-as-a-Service | Platform-as-a-Service | Infrastructure-as-a-Service | Platform-as-a-Service |
| Private Cloud    | Avatar-as-a-Service | Experience-as-a-Service | Software-as-a-Service | Platform-as-a-Service | Infrastructure-as-a-Service | Platform-as-a-Service |
| Hybrid Cloud     | Avatar-as-a-Service | Experience-as-a-Service | Software-as-a-Service | Platform-as-a-Service | Infrastructure-as-a-Service | Platform-as-a-Service |

5. Methods of digital representation of and integration with MTX products

Furthermore, the virtual world for supporting the stakeholders’ integration, realization of product Avatar, and provision of a forum for interactions can be facilitated by the state-of-the-art cloud environment on a virtual basis; which can support IoT, CPS, and virtual computing as well as communication services in a scalable context for manufacturing and service purposes. The alternative service platforms as well as different service models of cloud [26] make this state-of-the-art ICT quite suitable for realizing the MTX concept. Several service models can be imagined for MTX in addition to the conventional services as Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS), and Infrastructure-as-a-Service (IaaS). Those services include: CPS-as-a-service (which covers SaaS and PaaS), Avatar-as-a-service (covers SaaS, PaaS, IaaS), experience-as-a-service (covers SaaS), manufacturing-as-a-service (MaaS), and recycling-as-a-service (covers MaaS, SaaS). For more information about the contribution of cloud to MTX stakeholders see Table 1.

Accordingly, an Avatar-based network for MTX consists of component information about a product itself, x-gradable modules, production operations, de-manufacturing, recycling, etc. Thus, products with Avatar are equipped with sensors and communication means for collecting data, communication between modules, and even advising the end-users in alternative applications (i.e., upgrading the user’s know-how). It is tried to profit from the provided virtual intelligence of products and utilize a collective wisdom of Avatars to make the products as interactive as possible with all stakeholders. This concept of MTX also contributes to standardization efforts within the Quantum Lifecycle Management (QLM) [27].

6. Business model and corresponding service

In the business model of MTX some supporting necessities have to be taken into account. One of the major supports for the MTX concept is the realization of virtual enterprise (VE) and virtual supply network [28]. The MTX interested enterprises must facilitate the possibility of direct communication with other product stakeholders and with Product Avatars, so that any x-grade can be accomplished within an acceptable timeframe. The advantages of MTX for such virtual enterprises include flexibility in design, supply, manufacturing, and service offering.

In order to picture MTX in its generic framework several interacting aspects of the major players as product, manufacture, service and, user have to be considered, see Fig. 5. Moreover, except the contributions of ICT, other design and manufacturing capabilities like design-for-x (DFX), flexible manufacturing (FM), modularity, and postponement are needed as well. In doing so, interactive design tools are required to directly employ the collected information from
7. Summary and future work

In this paper, a new concept for future products as well as a new strategy for production is introduced, called MTX. The paper depicts some characteristics and necessities for products, end-users, and manufacturers, interacting within a virtual network with the purpose of flexibility and scalability in functionalities. The advantages of MTX leads to higher revenue for manufacturers, more sustainable products thanks to the x-gradability concept of them, and additional satisfaction for users by delighting them with more intensive engagement in product (modules) design, functionalities, services, and individual experiences. All in all, the state of the art in ICT plus the new approaches to the small series production of personalized products instead of the traditional mass production support the introduction MTX. The development of virtual social networks, besides IoT, CPS, and cloud services are in line with the requirements of MTX product and production concept. Wireless sensor networks besides other ICT means like tablet and smartphone with free access to internet and cloud services provide a competent platform for integrating and connecting not only every product stakeholders together, but also the products to this collaborative network. The example of BOMA and boat Avatar for motor boats in the text represents the initial prototype for realizing this concept later in a comprehensive manner.

Moreover, in this framework, provision of various relevant services for the end-users and to an MTX product is crucial. Tele-maintenance, application instruction for end-users, x-grades of modules, and recycling information can be some of the associated service offerings. These all require to be realized by means of ICT in its software and hardware formats, employing, e.g., cloud computing, CPS, and virtual enterprise (VE), e.g., see Fig. 6.

Fig. 6. The supporting factors of MTX.
product-service systems. In Technology Management in the IT-Driven Services (PICMET), 2013 Proceedings of PICMET'13, IEEE, 2013. p. 9-25.

[16] Tseng M M, Jiao R J, Wang C. Design for mass personalization. CIRP Ann Manuf Technol, 2010; 59/1. p. 175-178.

[17] Knox S, Payne A, Ryals L, Maklan S, and Peppard J. Customer relationship management. Routledge, 2012.

[18] Hong-Bae J, Kiritsis D, Xirouchakis P. Research Issues on Closed-loop PLM. COMPUT IND; 2007; 58/8-9. p.855-868.

[19] Pokharel S, Mutha A. Perspectives in reverse logistics: A review. RESOUR CONSERV RECY; 2009; 53/4. p. 175-182.

[20] Hribernik K A, von Stietencron M, Hans C, Thoben K D. Intelligent products to support closed-loop reverse logistics. In Globalized Solutions for Sustainability in Manufacturing. Springer Berlin Heidelberg, 2011. p. 486-491.

[21] Wuest T, Hribernik K, Thoben K D. Digital Representations of Intelligent Products: Product Avatar 2.0. In Smart Product Engineering, Springer Berlin Heidelberg, 2013. 675-684.

[22] Niemueller T, Ewert D, Reuter S, Karras U, Ferrein A, Jeschke S, Lakemeyer G. Towards Benchmarking Cyber-Physical Systems in Factory Automation Scenarios. In KI 2013: LECT NOTES ARTIF INT, Springer Berlin Heidelberg, 2013. p. 296-299.

[23] Kirisci P T, Thoben K D, Klein P, Hilbig M, Modzelewski M, Lawo M, Klen E. Supporting Inclusive Design of Mobile Devices with a Context Model. Advances and Applications in Mobile Computing. InTech. 2012.

[24] Peng D X, Liu G J, Heim G R. Impacts of information technology on mass customization capability of manufacturing plants. INT J OPER PROD MAN; 2011; 31/10. p. 1022-1047.

[25] Mochon D, Norton M I, Ariely D. Bolstering and restoring feelings of competence via the IKEA effect. INT J RES MARK; 2012; 29/4. p. 363-369.

[26] Tao F, Zhang L, Venkatesh V C, Luo Y, Cheng Y. Cloud manufacturing: a computing and service-oriented manufacturing model. Proceedings of the Institution of Mechanical Engineers, P I MECH ENG H-J ENG; 2011; 225/10. p. 1969-1976.

[27] Parrotta S, Cassina J, Terzi S, Taisch M, Potter D, Främling K. Proposal of an Interoperability Standard Supporting PLM and Knowledge Sharing. In Advances in Production Management Systems. Sustainable Production and Service Supply Chains, Springer Berlin Heidelberg, 2013. p. 286-293.

[28] Camarinha-Matos L M, Afsarmanesh H, Galeano N, Molina A. Collaborative networked organizations—Concepts and practice in manufacturing enterprises. Computers & Industrial Engineering, 2009; 57/1. p. 46-60.