SUSTAINABLE DEVELOPMENT AND PRODUCT DEVELOPMENT – FRIEND OR FOE?

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ABSTRACT

Sustainable development is the key issue for enabling the survival of human culture. Product development is sometimes seen as conflicting with the aims of sustainable development. This comes from a twofold impact: the production of new goods exploits scarce resources, and their use creates additional resource consumption and potential disparity. However, innovation and product development are important means to fulfil the needs of present and future generations and to achieve sustainable development. In this context, we must also consider the development of service products – classical services and product-related ones creating surplus value from physical products.

The contribution of product development to sustainability will depend on the way sustainability issues are integrated into the development process. An important focus is on the early phases of product development and especially on the process of requirements analysis since this integrates all sustainability role players as potential stakeholders.

Keywords: sustainable development, product development, sustainability, innovation

1. INTRODUCTION

From a "green" point of view, product development is often seen as an ambivalent if not negative contribution and as a process that is in conflict with the aims of sustainable development. This comes from two facts:

- The production of new goods exploits scarce resources and sometimes the production is not in accordance with ethical standards.
- The use of products creates additional resource consumption and potential disparity. Hence, the creation of new products is a potential threat for the desirable development path.

But when we look at the definition of "sustainable development", the needs of people are the central concern. Innovation and product development are important means to fulfil the needs of present and future generations and to achieve sustainable development.

In this paper, we will discuss the apparent contradiction between product development and sustainable development, and show some aspects in which product development can contribute to a more sustainable development.

The contribution of product development to sustainability will depend strongly on the way sustainability issues are integrated into the development process. An important focus is on the early phases of product development, especially on the process of requirements analysis, on modelling of requirements, and on the integration of the requirements of all sustainability stakeholders.

2. DEVELOPMENT

The common notion within the two objects of this paper is that of development. We will give an analysis and comparison of these concepts in the context of systems development.

2.1. Three basic concepts

Having a wide range of meanings, the core semantics of the word "development" is always connected with something that evolves. Development is a dynamic concept, and the object is evolving autonomously or being changed by an external influence.

In this paper, we consider the following examples for development processes:

- Systems development: The development of systems, persons, organisations or areas describes the dynamic evolution of these objects or persons either in an autonomous way or being guided by some developer. In the first case, the term corresponds with the notion of evolution of a system (according to some laws of dynamics) while in the second case, development is one aspect of influencing or even managing an object. The development of a system is always influenced by its environment in a system-theoretic sense (any real system is an open system). This influence does not depend on the intentions of the environmental system's components. For intelligent exterior components (individuals, organisations) we can differentiate between neutral behaviour and teleological influence. The latter takes into consideration the reactions of the system and the aims of the influencer. If several actors (persons, organisations) influence the system, we even have to consider game-theoretic aspects.

- Product and concept development: The development of a product starts from an idea or from the needs of potential users. It uses several more or less formal models, and it aims at a final product, service or concept. The difference lies in the fact that with this type of development the result is created as a new concept or as a new physical entity. When we talk about product development, we consider the product to be created by this process, but the description of the products evolves from an idea to a concise description. Hence, product development can be seen as a set of model transformations (Holzbaur 2007, Schmidt 2006).

- **Sustainable development:** Sustainability is a concept or vision describing an evolution of the world that allows forthcoming generations to fulfil their needs (WCED 1987). Sustainable development is an ongoing process of evolution of the earth including all natural or cultural subsystems. This process is influenced (in the positive and negative sense) by mankind. Several concepts such as stability, conservation, diversity and efficiency support sustainability, but it is important to keep in mind that these are not ends in themselves. For general concepts of sustainability see for example Rogers et al. (2007).

To compare the three notions of development, we give the following table:

Table 1: A comparison of the concepts of development considered in this paper

	System development	Product development	Sustainable development
Relation of the concept of development to the concept of needs	Neutral or guided by the aims of the developer	Meet the needs of the customer (fulfil his requirements)	Allow present and future generations to meet their needs
Demand carrier	Developer/ customer	Customer/ market	Stakeholders/ mankind
Object	Any system	A concept for a new product	Earth

2.2. Sustainable development

The notion of sustainability goes back to the so-called Brundtland report of the World Commission on Environment and Development (WCED) named after the commission's chairwoman, Gro Harlem Brundtland. "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED 1987) The vision of sustainable development was stated in the 1992 Rio Declaration of the Agenda 21 (UN 1992). A Programme for Further Implementation of Agenda 21 was stated at the World Summit on Sustainable Development (WSSD) 2002 in Johannesburg (UN 2002).

Sustainable development is based on three pillars: ecology, economy and social issues. When we analyse the Brundtland Definition it is clear that sustainable development means that other people (intragenerational justice) and future generations (intergenerational justice) can fulfil their needs.

Sustainable development is the key issue for enabling the survival of human culture. The notion of development implies that this is a dynamic concept for changing the state of the world. Main issues are justice among and within generations, and the integration of economic, environmental, political and social aspects.

The notion of sustainability is closely coupled with the notion of people's needs. The present and forthcoming generations should be able to fulfil their respective needs. The question of needs, wishes and requirements and their respective fulfilment links psychology to technology.

Sustainability can be characterised by the notion of culture in its widest sense, which means the sum of all things and systems that are created by mankind. The economic and social systems are clearly man-made, but in ecology we also deal mainly with the man-made environment and cultural landscape such as forests or meadows.

2.3. Conflict

Product development is sometimes seen as conflicting with the aims of sustainable development. This comes from the fact that the development and production of new products exploits scarce resources, and that their use creates additional resource consumption and potential (social or economic) disparity and (ecological, social or political) risks.

An important success factor for products is the timing: when the product becomes available for the customer. "Time to market" is the time span from the customer's problem identification or from the technology making the solution possible to the point where the customer has access to the product. A short time to market promises high return on investment for the company. It also accelerates the innovation cycle and contributes to a higher throughput of industrial production. But this in fact is part of the problem: People accuse product development and marketing of increasing and accelerating the throughput of goods and the use of resources. Acceleration of the product life cycle is one of the causes of our unsustainable behaviour.

3. APPROACHES

3.1. Innovation and decoupling

Innovation and product development can be important factors in achieving sustainable development. Here, we must consider the development of service products – classical and product-related services creating surplus value from physical products. Education and communication are important factors as well. Innovation must be seen as contributing to sustainable development, and engineering must be imparted as being a part of the solution and not of the problem.

Product development can be a means to overcome these problems since it allows decoupling the creation of utility and wealth from negative impacts, especially the consumption of resources.

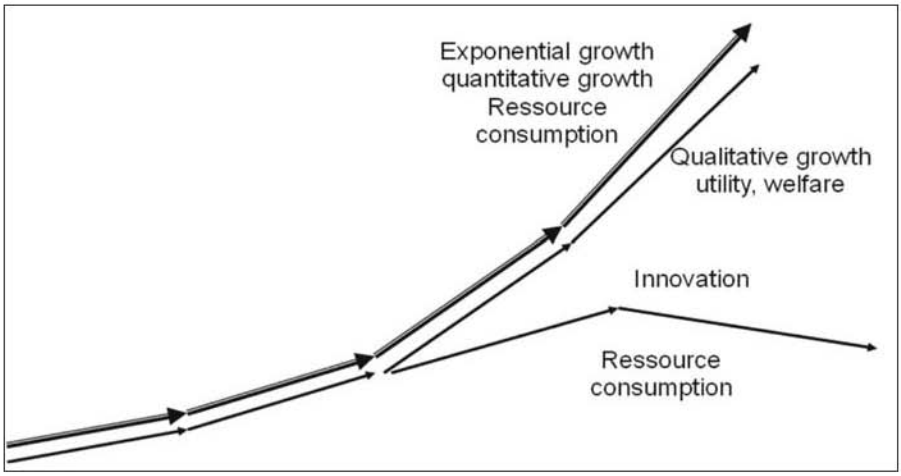

Figure 1: Decoupling welfare from resource consumption

This decoupling has been described as a "factor x" (factor 4, factor 10) by various authors (see section 3.3).

3.2. Impact drivers

It is important to reduce the negative impact on the natural environment in both the developed and developing countries. Two important areas of influence are the consumption of energy and resources and the production of waste, pollutants and greenhouse gases. These impacts come mainly from the consumption of goods which is a means to fulfil people's needs.

The reduction of these impacts is usually connected with the concepts of efficiency and sufficiency. For a detailed analysis, we split up the chain of inference from people's needs to non-sustainability (here to resource consumption) in a more detailed way than is usually presented in literature:

The detailed formula reads

$I/P = I/R \times R/G \times G/U \times U/N \times N/P$

The variables have the following meaning:

- I is the (negative) impact on sustainability, e.g. by resource consumption
- R is the amount of resources needed to run or produce a certain good (product)
- G is the amount of goods (products)
- U is the level of wishes for some utility (service, benefit)

- N is the level of needs or demands
- P is the number of persons

Although it is not easy to qualify or measure the quantities I, U and N, we believe that their meaning is intuitively clear.

We give an example from driving cars:

- I is the consumption of mineral oil or gas, resp. the production of Co2
- R is the amount of fuel needed to run a car
- G is the number of miles and the (shared) use of a car
- U is the number of miles and the number of cars a person needs
- N is the level of mobility a person needs (for business, personal and family purposes)
- P is the number of persons

The quotients can now be analysed separately:

- Consistency means to reduce the negative impact I on the environment by using methods or materials that are "environmentally friendly" which means that their relative impact I/R on the environment is less than that of classical methods or material.

- Efficiency is related to the resource consumption per good R/G. Increasing efficiency or resource productivity means to reduce the resource consumption or other effects of the goods or products. This can be mainly done by technical means.

- Intelligent solutions on the part of the provider of goods (e.g. providing service instead of a physical product, making reusable or multi-purpose products, increasing the lifetime of goods), may help to improve the service units per good, hence it decreases G/U.

- Changing behavioural patterns of the user (e.g. sharing a product or maintenance) may help to improve the amount or level of needs that can be satisfied by a certain utility; hence it decreases U/N. This is also a question of education since "Values mediate how needs are transformed into wants" (Raskin 2002).

- Sufficiency means to reduce the need of people N/P. This can be based on educational measures but is also related to the tradition and morals of specific cultures. The fact that needs are not fixed is depicted for example by Maslow's hierarchy of needs.

In our example, we can link the optimisation of the quotients to various methods.

- Consistency: CSS, bio fuel, photovoltaic, bio and recycled materials, safe cars
- Efficiency: motor efficiency, e-mobility, optimized production, platform concepts
- Solutions: car sharing, bus/train/taxi
- Behavioural patterns: car sharing
- Sufficiency: reducing the mobility required for work

3.3. Factor X

There are several concepts for decoupling the negative impacts on environment (more generally: any factor conflicting with sustainability, more specifically: resource consumption) from the well-being of people (more generally: on sustainable development, more specifically: on the utility of certain products).

A factor of 4 was brought into discussion by Weizsäcker in the early 1990s (Weizsäcker 1995) while the concept of a factor of 10 was brought into discussion by Schmidt-Bleek (1993 and 1998) together with the concepts of the "ecological knapsack" which pictures the ecological fingerprint of a product and the MIPS (mass impact per service unit) which leads the discussion from products to services (utility).

In the chain indicated above, every element can be changed and contributes to the change. Easy calculation shows that the impact of a change in any of the factors is the same. This means that a 10% decrease in any factor will imply a 10% decrease in the product. By multiplication we find that e.g. a 10% decrease of all five factors will just lead to a 41% decrease in the product. To achieve a 90% decrease of the negative impacts per person, we only need a 37% decrease in all five parameters.

3.4. Sustainability and innovation

Sustainability seems to be a static concept in contrast to the dynamic concept of innovation. But sustainability is a highly dynamic concept since our current system is far from being sustainable. Hence, efforts must be made and innovations are necessary, to transform the present state of the world to a status of sustainable development.

Even if and when sustainable development is reached, it will be a stable but not a static state. Sustainable development means that ongoing innovations have to take place to ensure the ability of future generations to meet their own needs. Innovation, research, design and development are the basis for a

sustainable development replacing qualitative growth by quantitative growth.

4. THE SOLUTION

4.1. Education for sustainable development

One of the most promising and viable ways to sustainable development is education. Education not only makes people more sensitive towards their environment, it also gives them the ethical basis and the sets of values to lower their demand and consumption and to decrease their direct impact. Education on all levels helps people to find better solutions to fulfil the needs of their own generation without using up the resources needed by forthcoming generations. It also helps them to contribute to stable and sustainable economic, social and ecological systems.

We mentioned before that acceleration of the product life cycle contributes to an unsustainable lifestyle. But the main reason for that lies in the consumer's behaviour: new products must be bought and environmentally friendly products lead to a rebound effect (Plepy 2001). Hence, education and the concentration on values instead of consumption is an important contribution to sustainable development.

4.2. Product quality and development

There is a relation between quality and sustainability on the organisational and on the product level.

On an organisational level, quality and sustainable development can de subsumed by the notion of excellence or governance. Excellence is the aim to perform well in any aspect. That means that a company will not only make money but will also fulfil the customer's and society's needs.

Excellence means among other things that the company will not allow the waste of resources of any kind – neither natural nor financial nor human resources. And that it will not allow the results of its activities to endanger nature, culture, economy or people. Quality management, corporate social responsibility, environmental management and sustainability management are outcomes and demonstrations of this way of thinking, leading to an integrated management system that embraces all of these components and more into ethical management.
Other aspects of sustainability can be seen as components of product quality and some of them are also perceived as quality factors at least by some groups of customers:

- Avoidance of ecological damage e.g. by use of energy and material resources

- Environmentally friendly production and use of products
- Socially acceptable and responsible production (e.g. no child labour) and use
- The cost-benefit ratio as an indicator (in most cases) of an efficient use of resources
- Economic aspects such as regional production and local supply
- Longevity as an important component of quality

The contribution of product development to sustainability will depend on the way sustainability issues are integrated into the development process. "The ideal model of sustainability is much more comprehensive. From now on the horizon of values for technological developments must be expanded to questions of environmental quality (compatibility with the environment) and quality of life (compatibility with society and individuals). This is a high ranking, interdisciplinary question." (Jischa 1998)

An important focus is on the early phases of product development and the requirements analysis integrating all sustainability role players as potential stakeholders.

4.3. Sustainable consumption and production

As one example for the activities towards sustainability in products, we mention the Marrakech Process of the UNEP (United Nations Environment Programme) and UN DESA (Department of Economic and Social Affairs) on sustainable consumption and production. It has the goals

- to assist countries in their efforts to green their economies,
- to help corporations develop greener business models, and
- to encourage consumers to adopt more sustainable lifestyles. (UNEP 2007)

The task of the National Cleaner Production Centers (NCPCs) is to support developing countries in their efforts to:

- spread the message about sustainable consumption and production;
- train local experts and build local capacity for sustainable production;
- provide technical assistance to individual enterprises;
- support development of project proposals related to cleaner development;
- disseminate technical information; and
- provide policy support to governments. (UNEP 2007)

4.4. Needs and requirements analysis

Within the product design and development process, the first step is the most important: to analyse the needs and requirements of the potential customer. The overall process from needs to their fulfilment is a central issue of quality management and (software) engineering. The quality norms ISO 9001 ff. (DIN 2000) describe how customers' satisfaction can be achieved and how these processes have to be documented. The main process chart of ISO 9001 depicts the transformation of customers' requirements into customers' satisfaction using the four process components management responsibility (including commitment and strategy), resource management, product realisation (from the planning of product realisation to production and service) and the implementation of a CIP (continuous improvement cycle) via measurement, analysis and improvement. The V-models of software engineering (Böhm 1981) and of the German Federal Office of Defence Technology and Procurement (BWB) (IABG 2008) give a detailed description of how to implement products in order to guarantee a successful implementation. The V-model of Böhm relates the phases of design and development to the phases of testing and deployment. To every design and development stage (descending branch of the V), there is a corresponding testing, verification and validation stage (ascending branch of the V). The top level of the V is given by the real-world models (requirements and use).The BWB "Vorgehensmodell" (process model) for the development of hard- and software is based on that visualisation and gives detailed guidelines for phases and activities. A case study on the application of the V-model to the development of mechatronic systems is given in Hehenberger (2010).

The following picture shows the chain from the user's needs and requirements to the user's satisfaction. It is drawn on the basis of the V-models as well as the basic principles of ISO 9001.

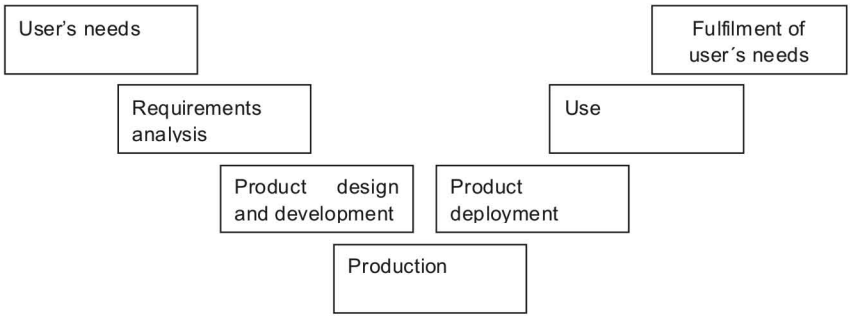

Figure 2: From needs to customer satisfaction

4.5. Customers and stakeholders

While quality only addresses the customer of a product, the issue of sustainable development addresses a much wider target group. Everyone who is influenced by the production, use or disposal of a product is a stakeholder of that product and of its development. Of course, (future) customers are one of the most important groups of stakeholders.

Stakeholders are, most of the time, tacit, even unaware of the development. Only if and when the impact on a group is too high, will the group organise itself and take action in order to influence the production or use of the product. Stakeholder management needs to take care of them, for example by informing them in time or by addressing their needs in the early phases. The first – and most important – step is to identify potential stakeholders of a development and to identify their needs and wants. This can help to avoid problems in later stages.

4.6. Modelling and the early phases

When we search for the most important setscrews for reducing the negative impacts from products in relation to their benefit, we must take into consideration the "law" of error impacts. Experience from software and hardware development tells us that the relative costs to fix an error will multiply by some number (usually between 2 or 10) for each phase between causation and detection of the error. Here we have more than a factor of 10, since an error in the requirements analysis will multiply its cost through the deployment, production and production phase for a factor of 100 or 1000. The impact in the phase of product use may be an additional factor of 10.

Concise modelling of requirements, stakeholder involvement and product environment in early phases of the product development plays an important role in the fitness for use of a future product. The huge variety of models (cf. e.g. Holzbaur, 2010b) should be used to make sure that the model matches the requirements of the development process. This includes the modelling of environmental impacts and interfaces (Wainwright 2004).

The most important effect is the fitness for use: a product that does not fulfil the customer's needs is of no use at all and will achieve a benefit/cost-relation of 0 which results in an infinite cost/benefit relation. Rapid prototyping plays an important role in this requirements analysis. For physical goods and for software, a prototype can increase the reliability of a requirements analysis tremendously and decrease the chance of a failure in development, production and use.

5. PRODUCT IMPACTS AND SOLUTIONS

We have already integrated aspects of different product types; hence, the

following section simply gives some additional remarks.

5.1. Physical products and infrastructure

When the product is a physical one there is always some production involved, and the result is a tangible item. This implies that the physical realisation must be prepared after or in parallel with the development (tooling, production preparation). The impacts lie in the production and use of the product. For products using natural resources (e.g. wood) there is the so-called "slaughter-house paradox" (Suda 1998) which says that the natural resource and the product are both "very strongly perceived and positively evaluated" while the process chain from resource to product is evaluated in a very negative way by the public.

For the use and the fulfilment of needs, infrastructure can be even more important than product properties. This is obvious for mobility (roads and traffic control) or telecommunication (networks), but also for all products that need energy, maintenance or distribution. Logistics provides the right product in the right quality and quantity at the right place for the right time and is essential for a product's use. Logistics also uses up time, space, infrastructure and resources and contributes essentially to the environmental, economic and social impact of a product. The impact of the infrastructure may be more important than that of the product, especially to those people that are not users of the product (e.g. cars, cell phones, and mail). This implies that the indirect impact of the product is high and creates many stakeholders.

5.2. Software

The product "software" consists of code and related documentation. Software can be multiplied and installed many times. Nevertheless, the resource consumption by the use of software is tremendous. On the client side, new hardware has to be installed and the use of computers contributes essentially to a household's or company's power consumption. The use of the Internet means that huge amounts of energy are needed to run the servers worldwide. A study (AMD 2007) estimates that "in 2005, total data center electricity consumption in the U.S., including servers, cooling and auxiliary equipment, was approximately 45 billion kWh". This is a continuous power consumption of 5 GW for the US in 2005. On the other hand, the Internet saves on a lot of travelling and shipping of paper, and new algorithms (e.g. MP3 compression) provide more use for less resource consumption. Nevertheless, there is the "rebound effect" which means that the saving of resources may more than compensate for the other savings by increasing the use of these devices or creating the need for more and even additional devices (Plepys 2001).

5.3. Services

When we develop a service concept, we must consider that the important

actions are done by individuals and received by individuals. Services may require other products and may be developed in combination with other products. Most times, hardware and software are useless if they are not supported by corresponding service products.

5.4. Events and tourism

Events are a special kind of service, delivered to a group of persons and supported by an event location. One of the main issues is to address people emotionally. The development of an event goes from the vision, goal and purpose to the planning of contents, location, catering and logistics (Holzbaur 2010). Conflicts with sustainability come mainly from resource consumption, logistics, transport and waste. On the other hand, events can be an important tool for education for sustainable development.

Tourism is another special kind of service that is related to a special area, where you can't bring the service to the customer. The basic resources – landscape, culture and environment – are susceptible to negative influences by visitors, tourism and supporting infrastructure. This means that tourism may destroy its own basis. Here, sustainability is important, and we must integrate the three components of sustainability:

- Ecological conservation and development of the land, its resources and ecosystems
- Preservation and development of the region's social system and its cultural heritage
- Economic development of the region without the creation of risks or inequity.

This requires a diligent analysis of the ecological, economic and social systems and of all stakeholders of the area. An ISO Norm (ISO 20121) on managing the sustainability of events will soon be available.

6. SUMMARY

We pointed out the main reasons for a – perceived – conflict between product development and sustainable development with the main argument being an acceleration of resource consumption.

From an analysis of the impact factors of the fulfilment of human needs to sustainability and the mechanisms of multiplication of the consequences of errors from analysis of product to use, we concluded that the main impact factor lies in product development and especially in the analysis of requirements and stakeholders.

The contribution of product development to sustainability will depend on the way sustainability issues are integrated into the development process. An important focus is on the early phases, with the requirements analysis integrating all sustainability role players as potential stakeholders.

Keeping this in mind and implementing sustainability as a quality factor, product development can play an important role in fostering sustainable development and engineering can become – and also should be perceived as – part of the solution and not part of the problem.

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