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Ibo van de Poel

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Abstract

Values have probably always played a role in engineering design. However, in current practices and design methods, the attention for values in engineering design tends to be implicit and unsystematic. Establishing Design for Values in engineering would require overcoming this situation. This contribution discusses which values play a role in engineering and engineering design, describes existing methods and experiences with Design for Values in engineering, and explores how values can be integrated into engineering design and existing design methods, in particular quality function deployment (QFD). It identifies four challenges for Design for Values in engineering: (1) discovery of the values to be included in engineering design; (2) translation of these values into engineering characteristics; (3) choice among design options that meet different values to different degrees; and (4) verification of whether a design indeed embodies the intended values.

Keywords

Engineering design • Values • Design methods • Design for Values • Design for X • QFD

Introduction

This chapter focuses on Design for Values in the traditional engineering disciplines, like civil engineering, mechanical engineering, chemical engineering, and electrical engineering. Values such as safety, human welfare, and sustainability obviously play an important role in design in these disciplines. However, there are few engineering design methods that explicitly pay attention to such values. This chapter will discuss the values that are relevant in engineering and how these values may be incorporated in the various phases of the engineering design process and possible methods for Design for Values in engineering.

Philosophers distinguish between what they call value monism and value pluralism. The first is the thesis that there is ultimately only one value in which all other values or value considerations can be expressed. Value pluralism, on the other hand, states that there exists a plurality of values which cannot, at least not in any straightforward way, be reduced to each other. The two viewpoints also surface in engineering. One might believe that ultimately all value considerations in engineering can be reduced to one value; possible candidates for such an overarching value in engineering are social utility, profit, customer satisfaction, or efficiency. The fact that there is such a range of candidates for the overarching value if one subscribes to value monism already seems to erode the credibility of the thesis that there is ultimately only one value as value monism posits. In this contribution, I will assume value pluralism, i.e., I will assume that a range of values is important in engineering, which cannot easily be reduced to each other.

Another distinction that philosophers often make is that between final (or intrinsic) values and instrumental values. The first are values that are strived for their own sake, while the latter are strived for the sake of other values. The suggestion that comes with this distinction is that final values are more important than instrumental values and there is indeed some truth to this suggestion.

Distinguishing between instrumental and final values does not yet tell us which values are instrumental and which are final. There may be considerable disagreement about this issue. Frankena (1973) lists 18 final values on the basis of a reading of the philosophical literature. This includes moral values like happiness, health, and morally good dispositions, but also nonmoral values like aesthetic experience and truth. In distinguishing between final and instrumental value, I will by and large follow Frankena's list. So I will assume that values like human well-being, justice, safety, health, and sustainability that play a role in engineering are final values, while values like economic profit, efficiency, reliability, and maintainability, which are obviously also important in engineering, are instrumental values.

I start this contribution with a brief description of engineering as a profession and the values that have been articulated as important in engineering generally and more specifically in engineering design. I will then look a bit deeper into the engineering design process, the different phases that might be distinguished in engineering design, and how value considerations may play a role in these. Next, I turn to design approaches to Design for Values in engineering. After discussing challenges and future work, I end with a brief conclusion.

Values in Engineering

While there has been quite some attention for the relation between values and technology, less attention has been paid to the role of values in engineering. I will understand engineering here as an activity that is aimed at understanding, creating, improving, and maintaining certain technologies (Van de Poel 2010). Values in engineering originate in part from the values that are to be realized by technology. Such values are, for example, incorporated in the engineering design process (Van de Poel 2009). Think of values like safety, sustainability, and human well-being. Values can, however, also emerge in engineering because it is a professional practice (Davis 1998; Pritchard 2009). Examples are values like integrity, honesty, loyalty, and independence. For determining the values of engineering, I start with discussing engineering as a profession and briefly consider the history of engineering as a profession. Then I discuss professional codes for engineers and the values they explicate. Finally I give an overview of some of the main instrumental and final values in engineering design.

Engineering as a Profession

Especially in the American literature on engineering ethics, engineering is often portrayed as a profession (Davis 1998; Harris et al. 2013). Michael Davis defines a profession as “a number of individuals in the same occupation voluntarily organized to earn a living by openly serving a certain moral ideal in a morally-permissible way beyond what law, market, and morality would otherwise require” (Davis 1998, p. 417). He believes that engineering, at least in most countries today, is a profession according to this definition because most engineering societies have committed themselves (voluntary) to hold paramount the safety, health, and welfare of the public. They have done so by formulating professional codes that I will discuss below. Before I do so, I briefly sketch the historical development of engineering as a profession for pointing out that the values held in engineering can differ among different engineering professions.

Historically, engineering was in many countries closely tied to the military and to a number of nonprofessional occupations like architect-inventors (such as Leonardo da Vinci), instrument-makers, land surveyors, millwrights, masons, and carpenters (Calhoun 1960, pp. 5–6). It was with the emergence of civil engineering that engineering emancipated itself from the military and these occupations and became a more independent professional activity. Civil engineering was established as a profession in the late eighteenth century in France (Abbott 1988, p. 92). In the USA, civil engineering became a profession in the second half of the nineteenth century (Calhoun 1960). The pattern of development was different from country to country: whereas in France and the Netherlands military engineers were the main predecessors, they were millwrights and instrument-makers in Great Britain (Calhoun 1960, p. 7; Lintsen 1985, pp. 16–22).

In the course of time, new engineering professions have emerged such as mining engineering, mechanical engineering, electrical engineering, and chemical engineering (Calvert 1967; Reynolds 1983). Sometimes the development of new engineering professions was due to the development of new technologies or to inventions, for example, in the case of nuclear engineering. In many cases, new professions had to emancipate themselves from already existing professions. Mining and mechanical engineering emancipated themselves from civil engineering in the late nineteenth century. Chemical engineering emancipated itself from mechanical engineering and chemistry.

What is interesting from the point of values in engineering is that the various engineering professions also seem to have somewhat different value sets. So physical safety and health are main values in, for example, chemical engineering, but they are, in general, less important in, for example, software engineering. Whereas in software engineering, privacy is a main value, it is less important, or sometimes even irrelevant, in chemical engineering. Despite the differences between engineering disciplines, there is also much communality to the values in engineering. In the remainder of this section, I will mainly focus on the values that are shared among most engineering professions. Nevertheless, it is important

to keep in mind that in addition to these more general values, there are also values that are more specific to particular engineering professions.

Professional Codes in Engineering

Professional codes formulated by engineering societies are often seen as a main expression of the values that are typical for engineering.¹ Such codes are often aspirational: they express the main values of engineering in rather general and abstract terms without the aim of giving detailed advice about how to behave in concrete situations or the aim of regulating professional behavior in detail.

Historically, the development of professional codes for engineers began in England in 1771 with the code of the *Smeatonian Society*. More influential for the current professional codes for engineers was the formulation of a range of professional codes for different engineering professions like civil, mechanical, and electrical engineering in the first decade of the twentieth century in the USA. The early codes comprised rules for engineers that chiefly pertained to etiquette. The professional code regulated people's entry into the profession and the behavior of members toward each other and in relation to employers and clients. While the early codes did not address broader social issues raised by engineering, this changed after the Second World War. The duty of the engineer to serve the public interest was especially stressed in the new professional codes. Organizations like the National Society of Professional Engineers (NSPE), the American Society of Civil Engineers (ASCE), and the American Society of Mechanical Engineering (ASME) formulated professional codes stating that engineers "should hold paramount the safety, health and welfare of the public." Similar values are emphasized in the universal statement regarding the conduct of professional engineers that was issued by the European Federation of National Engineering Associations (FEANI).

Professional codes for engineers thus express the core values of the engineering profession. Most modern professional engineering codes relate to three domains: (1) conducting a profession with integrity and in a competent way, (2) obligations toward clients and employers, and (3) responsibility towards the public and society.

Integrity and Competent Professional Practice

All professional codes include the obligation to practice one's profession with integrity and honesty and in a competent way. The traditional core of all professional codes thus stresses such values as honesty, faithfulness, truthfulness, integrity, and competence.

¹This section draws on Van de Poel and Royackers (2011), Chap. 2.

Obligations Toward Clients and Employers

Obligations toward clients and employers are mentioned in most professional codes. In many cases, it is stipulated that engineers should serve the interests of their clients and employers and that they must keep secret the confidential information passed on by clients or employers. Values that are stressed in this respect include loyalty, confidence, trustworthiness, and fair play.

Social Responsibility and Obligations Toward the Public

Virtually all professional codes in one way or another emphasize the social responsibility of engineers. Values that are often mentioned include safety, health, the environment, sustainable development, and the welfare of the public.

Instrumental and Final Values in Engineering Design

I will now further explore and define some of the main values that play a role in engineering. In doing so my focus will be on values that engineers somehow try to incorporate in the technologies they research, develop, and design. The reason for this focus is that this contribution is about Design for Values in engineering, a focus that is narrower than just values in engineering. For this reason, I will not pay attention to such values as integrity, honesty, impartiality, expertise, loyalty, and rationality, which are all more related to engineering as a process (or an activity, if one wishes) rather than being values for which engineers design – develop and research – technologies. Below, I will follow the distinction between instrumental and final values that I introduced in the introduction.

Instrumental Values

We might distinguish the following instrumental values that are relevant to engineering design:

- *Effectiveness*, which may be defined as the degree to which an artifact fulfills its function.
- *Efficiency*, which could be defined as the ratio between the degree to which an artifact fulfills its function and the effort required to achieve that effect. Efficiency in the modern sense is usually construed as an output/input ratio (Alexander 2009).
- *Reliability*, which might be understood as “the ability of a product to perform its function adequately over a period of time without failing” (cf. Kuo et al. 2001, p. 252).
- *Robustness*, which may be defined as the “ability of a product to perform its function adequately in new or unforeseen circumstances” (cf. Vermaas et al. 2011, p. 113).
- *Maintainability*, which might be understood as “the probability that a failed system can be repaired in a specific interval of downtime against reasonable cost” (cf. Kuo et al. 2001, p. 251).

- *Compatibility*, which might be understood as the ability of a product to adequately perform its function in conjunction with other apparatus and infrastructure.
- *Quality*, which might be understood in a variety of ways. Sometimes it is used to refer to such values as reliability, robustness, and compatibility. It is also used in the sense of “robust in meeting the requirements (within certain acceptable limits) despite variations in the production process” (cf. Holt and Barnes 2010, p. 125). It might also be understood in terms of “meeting or even exceeding user requirements” or in terms of “user satisfaction.”

Final Values

In addition to these instrumental values, the following final values are relevant to engineering design and are often mentioned as paramount in engineering (in, e.g., professional codes):

- *Safety*, which is sometimes defined as the absence of risk and hazards. However, risk reduction is not always feasible or desirable. Safety is therefore maybe best understood in terms of “acceptable risk.” The ethical literature on risk has established that the moral acceptability of risks does not only depend on their magnitude but also on considerations like voluntariness, the balance and distribution of benefits and risks, and the availability of alternatives (Asveld and Roeser 2009; Hansson 2003, 2009; Shrader-Frechette 1991). So conceived, safety refers to the situation in which the risks have been reduced in as far that is reasonably feasible and desirable.
- *Health*, which is defined by the World Health Organization (WHO) as “state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” (World Health Organization 2006). In engineering, the focus is usually on avoiding negative influences on human health. It is not obvious that there is a requirement for engineering to contribute positively to human health, with the exception perhaps of some specific domains like health technologies.
- *Human well-being*. This value is being referred to under a number of headings like human welfare, happiness, quality of life, human flourishing, and good life. I will here use the term “human well-being” to refer to the value that is at stake in all these cases. Well-being does not just refer to feeling well here and now but it tells something about how someone’s life is going for that person.
- *Sustainability*. Although environmental values play a role in engineering for quite some time, in the last decade this has been increasingly understood in terms of the broader value of sustainability. The most influential definition of sustainable development has been provided by the Brundtland Commission: “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).

Other final values are relevant for engineering as well. Some of these final values are generally relevant for engineering. Examples are justice and democracy, and inclusiveness (Sclove 1995; Clarkson 2003; Erlandson 2008). In addition to such more general final values, one might distinguish final values that are more domain-specific. A typical example is aesthetics in architecture or privacy in ICT.

Incorporating Values in the Engineering Design Process

Engineering design is the process by which certain functions are translated into a blueprint for an artifact, a system, or a service that can fulfill these said functions. In traditional design methods, the engineering design process is usually depicted as a systematic process in which use is made of technical and scientific knowledge, but in which creativity and decision-making also play major roles. (For a discussion of some more recent design approaches and their relevance for Design for Values, see the chapters on “► Design Methods in Design for Values” and “► Participatory Design and Design for Values”).

Design methods usually divide the design process in different stages between which iterations are possible (Pahl et al. 2007; Hubka 1982; Roozenburg and Cross 1991; Eekels and Roozenburg 1991; Ullman 1997; Cross 2008).² Although the exact stages are different from design method to design method, many of them contain a number of basic activities like analysis (of the design problem), synthesis (of possible design solutions), evaluation (of the possible solutions in the light of the problem), and choice (of one design solution). Additional steps that are often mentioned include simulation, embodiment design, and prototype testing. Simulation refers to making predictions about how possible design solutions (concept designs) will behave, a step that might involve calculation, modeling, testing, etc. Embodiment design is the phase that follows after one design solution has been chosen and has to be further detailed, finally resulting in design drawings and technical specification on basis of which the design can be built or produced. Prototype testing refers to the testing of prototypes of the system, possibly resulting in new insights and reiterations of the design process. Figure 1 depicts the basic stages of the design process.³

In all the mentioned phases of the design process, values play a role but the role they play is (quite) different in the various phases as I explicate below.

²Not all design methods conceptualize the design process as a linear process. Most methods contain possibilities for iteration. Moreover, especially design models from architecture stress that the design problem cannot be formulated completely independent from possible solutions (Roozenburg and Cross 1991, p. 188).

³The figure is largely based on Eekels and Roozenburg (1991).

Fig. 1 Phases of the design process

Analysis

During the analysis phase, the designer or the design team conceptualizes the design problem. This stage results in a certain formulation of the design problem and of certain design requirements that a good or acceptable solution has to meet. Findings in later stages can sometimes result in the revision of the problem formulation or the design requirements.

Values play a role in this stage in several ways. First, they will influence how the problem is conceived and framed. During the analysis stage, the designers also might make an inventory of relevant values based on, for example, the design brief, professional codes, and legislation or by inquiring the stakeholders. Values are in this stage also relevant as a source of design requirements (Van de Poel 2013).

Synthesis

In this phase the designer or design team thinks out potential solutions to a design problem. The focus is on an integral approach to the design problem. The designer does not try to realize each design requirement independently but works on a combination of design requirements and searches for a total concept that can bring about this combination. Creativity is important in this phase, especially for thinking out new solutions that might meet seemingly conflicting requirements or values. In this stage, the values that have been identified in the analysis stage and have been translated in that stage in design requirements are embodied in various conceptual design solutions.

Simulation

The concept designs are checked in the simulation stage to see whether they meet the design requirements. This takes place in a number of ways, e.g., through calculations, modeling, and computer simulations. Modeling plays an important part in this phase, and the models that one develops or uses should be appropriate to predict the effects of the conceptual design solutions on the various relevant value dimensions that have been identified in the analysis stage (see chapter on “► Modeling for Design for Values”). It might also be that in this phase,

unexpected consequences of the conceptual design may lead to the introduction of new values that should be considered in the design problem.

Evaluation

During the evaluation phase, the outcomes of the simulation of different design solutions are evaluated. They may be evaluated in terms of meeting the functional requirements or costs, but usually engineering values – instrumental as well as final – play a major part in this phase. Some of the values like efficiency may be readily measurable, but especially final moral values often will first need to be operationalized before their attainment can be measured and evaluated (see the chapter “► [Design for Values and the Definition, Specification, and Operationalization of Values](#)”).

Choice

In this stage, a choice is made which concept design is to be detailed further. This choice is based on the outcomes of the evaluation of the various concept designs. Values play a role as decision criteria in this phase. Often it will not be possible to choose a design that meets all design requirements and that meets all values to a maximum degree. So often a choice need to be made under conflicting values (see chapter on “► [Conflicting Values in Design for Values](#)”).

Embodiment

In the embodiment phase, one design is further detailed. In this phase, the relevant values are further translated and embodied in engineering characteristics of the design. In this phase, also choices are made with respect to, for example, the materials of which the design will be made and the production methods. This may introduce additional values, for example, related to the use of scarce materials or to labor circumstances of the producers of the product.

Prototype Testing

In this phase, a prototype of the design is tried out, which may lead to iterations in the design process. Prototype testing may be particularly relevant for verifying whether the designed system indeed embodies the intended values. But prototype testing may also point out unexpected consequences or value dimensions of the design. It may turn out that the design has unexpectedly certain health consequences, which means that an iteration of the design process is required taking the value of health into account.

Table 1 The roles of values in different stages of the design process

Stage	How values play a role	Activity
Analysis	In framing of design problem Discovery of relevant values Translation in design requirements	Discovery Translation
Synthesis	Embodiment of values in various concept designs	Translation
Simulation	As dimensions that should be included in modeling and simulation Potential discovery of new relevant values	Verification Discovery
Evaluation	As evaluation criteria Need for operationalization of values	Verification
Choice	As choice criteria Need for choice under conflicting values	Choice
Embodiment	Embodiment of values in detail design New value may be relevant for detailed choices	Translation Discovery
Prototype testing	Verification of values Potential discovery of new relevant values	Verification Discovery

I have summarized the different roles that values play in the different phases of the design process in Table 1. In the final column, I have related the various phases to the three steps or activities that are distinguished in a design method for Design for Values that has been proposed by Flanagan et al. (2008). Their method consists of three steps or activities:

- *Discovery*. This activity will result in a list of values that are relevant for the design project.
- *Translation*. Translation is “the activity of embodying or expressing . . . values in system design” (Flanagan et al. 2008 p. 338).
- *Verification*. This is assessing, e.g., through simulation, tests, or user questionnaires, whether the design indeed has implemented the values that were aimed at.

The table suggests that these steps or activities can indeed be associated with the various stages distinguished in traditional engineering design methods. It also suggests, however, certain additions to their method. First, it shows that particularly discovery is not an activity that is, or should be, restricted to the first design stage but is a continuously ongoing activity.

Second, the engineering design methods contain a step that is missing in the method of Flanagan et al: choice. It must be said, however, that there are also design methods in engineering that do not distinguish a separate choice stage. Also in practice, engineering designers are reported to often follow a single-concept strategy method (e.g., Stauffer et al. 1987; Ullman et al. 1987; Bucciarelli 1994; Henderson 1991; Visser 1990, 2009; Stauffer and Ullman 1988). Designers often quickly move to a possible solution, which may be based on their experience or

existing products. They will then try to further develop and improve that solution till it meets the design requirements. When it turns out to be impossible to meet the requirements, they may abandon their original solution concept and try a new one.

However, even if a single concept strategy is followed, the designer will go through different iterations of the steps discovery, translation, and verification that are distinguished by Flanagan et al. Moreover, they make at least implicit choices about whether the design developed is good enough, or to further develop it, or to consider another design option.

The upshot of the discussion then is that discovery, translation, verification, and choice are best seen as activities that are required for Design for Values even if they may not be strictly associated with certain stages of the design process.

Approaches to Design for Values in Engineering

The idea of incorporating values in design is not new. It might be argued that the practice of incorporating values in the design of technology is as old as technology itself or at least as old as engineering design as a specific activity in the development of technology. In recent decades, a number of authors have developed approaches for what might be called Design for Values.

I use the term Design for Values here for a number of approaches which come under different headings like Value-Sensitive Design (VSD), Values at Play, and Value-Conscious Design (Flanagan et al. 2008; Friedman 1996; Friedman and Kahn 2003; Friedman et al. 2006; Manders-Huits 2011, see also the chapter on “► Value Sensitive Design: Applications, Adaptations, and Critiques”; Cummings 2006; Albrechtslund 2007; Van den Hoven 2005). The general thrust of these approaches is the integration of values of ethical importance in a systematic way within engineering design. Design for Values has been particularly articulated in the domain of information systems and software (see chapter on “► Design for Values in ICT”). However, the idea is more generally applicable; it applies to all kinds of engineering design and in fact also to many kinds of nonengineering design like architectural design, policy design, or institutional design.

Design for Values is related to a number of other approaches in engineering and technological development. One family of approaches is Technology Assessment (TA) (Grunwald 2009). Traditional TA aims at predicting the social consequences of technological development. Although traditionally TA was not aimed at influencing design, most of the recent TA approaches try to incorporate social concerns and values at the design stage. This includes approaches such as Constructive Technology Assessment (CTA), Interactive Technology Assessment (ITA), and Real-Time Technology Assessment (Reuzel et al. 2001; Rip et al. 1995; Schot and Rip 1997; Grin and van der Graaf 1996; Guston and Sarewitz 2002; Grin and Hoppe 1995; see also the chapters on “► Technology Assessment and Design for Values” and “► Design for Values in Healthcare Technology”).

Although the general motivation of such approaches is the same as Design for Values, there is a difference in emphasis. TA approaches focus more on social concerns than on values. The approaches are moreover more procedural and sociological in nature, focus less on moral issues, and are less philosophically informed.

A second family of approaches is those that are critical of current technological development and that propose alternative approaches to technological development or engineering design. Some of these approaches are activist in nature. Such approaches can be found in the philosophy of technology (Winner 1986; Feenberg 1995; Sclove 1995) but also in the literature on design (Papanek 1984, 1995; Whiteley 1993). Sometimes authors merely criticize current technological development without offering an alternative or only stating alternatives in very general and abstract terms. Others have proposed more concrete alternative approaches under such names as socially responsible design, ethical design, design for the real world, design for society, and feminist design (Papanek 1984; Tatum 2004; Feng 2000; Whiteley 1993; Nieusma 2004). In many cases these alternative approaches either stay very general or they rather quickly move to practical guidelines, tools, and methods without considering the values at stake in any depth.

A third family of related approaches is based on ideas of concurrent engineering and “design for X” (DFX) that have been articulated in the engineering literature. Concurrent engineering is an approach to engineering in which downstream considerations, such as production, use, and maintenance, are integrated into upstream decisions in engineering design and development. In DFX approaches, X can stand for a certain value or for a life phase. DFX_{life phase} approaches include, for example, design for manufacture, design for assembly, design for disassembly, design for maintenance, design for recycling, and design for supply chain (Boothroyd et al. 2011; Holt and Barnes 2010; Bogue 2007, 2012; Kuo et al. 2001; Gaustad et al. 2010; Slater 2000; Manohar and Ishii 2009). DFX_{value} approaches for instrumental values include design for quality (like quality function deployment or QFD), design for reliability, and design for robustness (Raheja and Gullo 2012; King 1989; Hauser and Clausing 1988; Park and Antony 2008; Ireson et al. 1996; Cheng 2009; Akao 1990). Also DFX_{value} approaches for final values have been developed, sometimes within the engineering literature, sometimes in other areas. This includes affective design and emphatic design (Jordan 2003; Koskinen et al. 2003), inclusive and universal design (Keates and Clarkson 2003; Clarkson 2003; Imrie and Hall 2001; Erlandson 2008; Preiser and Ostroff 2001; see also the chapter on “► Design for the Value of Inclusiveness”), safety engineering and safe design (Hansson 2007; see also the chapter on “► Design for the Value of Safety”), ecological design and design for sustainability (Bhamra and Lofthouse 2007; Birkeland 2002; Van der Ryn and Cowan 2007; see also the chapter on “► Design for the Value of Sustainability”), and design for capabilities and design for human well-being (Van de Poel 2012; Desmet and Pohlmeier 2013; Oosterlaken 2009; see also the chapter on “► Design for the Value of Human Well-Being”).

Toward an Integrated Approach: Quality Function Deployment (QFD)

Of the various mentioned approaches, the VSD approach and DFX approaches are probably most directly relevant and applicable in engineering design. Most DFX approaches, however, focus on specific values. As Holt and Barnes (2010) argue in their overview article on DFX approaches, there is a need for an integrated DFX approach that combines different values, that is able to deal with trade-offs between values, and that offers decision support for such trade-offs decisions. The VSD approach, which was mainly developed in ICT, offers an integrated approach that could also be applied to engineering design. However, it does not explicitly address trade-offs and does not offer decision support for such decisions. It might therefore be interesting to look at an approach that can deal with trade-offs although it does not yet focus on a range of values: quality function deployment or QFD. The value that is central in QFD is user value or, more precisely, customer satisfaction.⁴ However, as I will show below, the QFD approach can be adapted to a more integrated approach that includes a range of values in engineering design.

The Traditional QFD Approach

Quality function deployment was originally developed in Japan in the late 1960s⁵. It is now widely used not only in Japan but also in Europe and the USA. The introduction of QFD, and other quality methods, in especially the USA was a response to the growing success of the Japanese industry during the 1970s. QFD was seen as an important tool to improve quality, to reduce development and other preproduction costs, to increase organization capabilities, and – all in all – to make the American industry more competitive. Apart from such business goals, QFD has been heralded as a means for the development of products that better fulfill users' needs.

A main goal of QFD is to translate customer demands into engineering characteristics. By systematically and quantitatively employing the relationship between customer demands and engineering characteristics, those engineering characteristics that are most promising for improving customer satisfaction can be selected. In this way, QFD leads to a more systematic attention for customer demands in the design and development process.

A central element in the QFD method is the so-called House of Quality (Fig. 2). This House of Quality relates customer demands to engineering characteristics. The idea is that in this way, the desires of customers can be translated into (numerical) target values for the engineering characteristics and into priorities for improving certain engineering characteristics.

⁴Customer satisfaction may, depending on one's theory of human well-being, be seen as a value that contributes to the value of human well-being (see chapter on "► [Design for the Value of Human Well-Being](#)").

⁵This section draws on Van de Poel (2007).

[illegible]

Filling in the House of Quality starts with listing the customer demands in the rows in the central part of the house. Subsequently, the degree of importance of the customer demands is filled in. The score of the own existing product and that of competitors with respects to the customer demands are then listed, usually on an integer scale from 1 to 5. On the basis of this competitive benchmarking and strategic considerations, the company plan for each customer demand is chosen, again on an integer scale from 1 to 5. The rate of improvement is calculated by dividing the company plan by the current company score.⁶ Next, sales points are set for customer demands that are expected to influence sales more than average. Sales points usually take the values 1.5, 1.2, or 1. The absolute weight of the customer demands is calculated by multiplying the degree of importance with the rate of improvement and the sales point (Akao 1990; King 1989).

⁶It might be argued, however, that since both the company plan and the current company score are measured on an ordinal scale (expressed in the integers 1,2,3,4,5), this division is not allowed because ordinal scales do not allow for this arithmetical operation.

Δ (weak correlation), which are presumed to correspond with numerical values like, for example, 9, 3, and 1. On the basis of the weighted customer demand and the relationship matrix, the relative importance of the engineering characteristics is calculated. The numerical values of the engineering characteristics for the current product and those of competitors are listed, and targets for the engineering characteristics may be set. As a final step, the trade-offs between the engineering characteristics are listed in the roof of the House of Quality. Usually five types of relations between engineering characteristics are used: strong positive, weak positive, no relation, weak negative, and strong negative.

The House of Quality thus gives insight in the relative importance of the engineering characteristics based on the customer demands. This relative importance may be used to set priorities in further design and development efforts or to select among different conceptual designs. By making a number of further charts, the relative importance of customer demands or engineering characteristics can also be translated into relative weights for certain functions, mechanisms, parts, process steps, and failure mechanisms and in setting priorities for these and for cost reduction (Akao 1990; King 1989).

Also (numerical) target values for the engineering characteristics can be determined. Apart from the relative weights of the engineering characteristics, estimates about what is technically feasible against what costs and efforts, and strategic considerations at the company level do play a role in setting targets. In the initial method, setting targets was left to the discretion of the engineers on the basis of the filled in House of Quality.

QFD as an Integral Approach to Design for Values

The focus in QFD is on customer demands and ultimately on the value of customer satisfaction. Nevertheless, it is possible to include a range of other values into QFD. Indeed, QFD theorists and practitioners have already tried to incorporate additional kinds of considerations in QFD. In the original QFD method proposed by Akao, for example, the relative importance of the customer demands is not just based on what customers want, but also on the basis of considerations of the producers, like what is the company good at compared to competitors and which customer demands will probably raise sales (Akao 1990). With respect to regulatory requirements, some authors have suggested that these could be treated as customer demands in QFD (Govers 1996).

In line with, and expanding these suggestions, I think there are three main possibilities for incorporating additional values, in addition to customer satisfaction, in QFD:

- The values could be treated as or translated into demands that are treated in the QFD similarly to the customer demands. An advantage of this method is that the relevant values are met as good as possible and desirable in the light of the other relevant demands and the technical possibilities. A potential disadvantage of this approach is that it does not define a minimum level for the values below which products are not acceptable.

- The values could be treated as or translated into minimal requirements to be met by each alternative. The advantage of doing this is that one is sure that the relevant values are respected by any alternative. A possible disadvantage is that only the minimal is met while it may be desirable to do more than the minimal.
- Values could also be used to “correct” the relative importance of the (customer) demands. This is the approach chosen with respect to considerations on behalf of the producer in the original QFD approach. An advantage of this approach is that values are treated as overall considerations rather than as demands besides the other demands (as in the other options). This may be more appropriate, at least for some value considerations like the concern for safety. A disadvantage might be that this way of “correcting” the outcomes of the QFD matrix might be rather arbitrary because we lack an adequate way, let alone methodology, to carry out such corrections.

It seems thus possible to employ QFD as an integral approach to Design for Values. Main advantages of the QFD approach are (1) that it supports the *translation* of values into engineering characteristics and (2) that it helps to trace possible *trade-offs* (in the roof of the House of Quality). Does the approach also offer decision support for making choices in design? It certainly aims to do so. In fact, a range more or less sophisticated quantitative approaches to QFD have been developed that offer decision support. Most of these approaches do so by aiming at a maximization of customer satisfaction. As I have pointed out elsewhere (Van de Poel 2007), such QFD approaches are beset with methodological problems which make it questionable whether they can indeed maximize customer satisfaction.⁷ When QFD is extended to include other values in addition to user values, these methodological problems will likely increase (see also the chapter on “► [Conflicting Values in Design for Values](#)”). It is therefore doubtful whether QFD can offer decision support for trade-offs between values in Design for Values.

Challenges and Future Work

In section “[Incorporating Values in the Engineering Design Process](#),” I distinguished four activities in engineering design that are crucial for Design for Values: (1) discovery of values, (2) translation of values into design requirements and engineering characteristics, (3) choice: design support for trade-offs between values, and (4) verification of values. In the ideal case, approaches or methods for Design for Values should support all these activities. As we have seen QFD can offer support for activity 2 (translation) and some support for 3 (choice). VSD offers support for activity 1 (discovery) and some support for activity 2 (translation)

⁷However, a more qualitative approach to QFD might be possible that at least is likely to increase customer satisfaction compared with the current situation.

and activity 4 (verification) but hardly for activity 3 (choice). Although various DFX offer support for these four activities for specific values, they usually do not in an integral way that does justice to a range of values.

As far as I know, there is currently no method or approach that supports all four mentioned activities and does so in an integral way. One challenge for the future then is to develop such a method or approach. This might not require a completely new method or approach, as it can also build on, extend, or combine existing methods or approaches. In addition to this more general challenge, there are a number of more specific challenges related to these four activities. It could be argued that these more specific challenges should first be tackled before it is useful to develop a more general Design for Values approach.

Discovery

Both in engineering design (see, e.g., Pahl et al. 2007) and in VSD (see chapter on “► Value Sensitive Design: Applications, Adaptations, and Critiques”), methods have been developed that are useful for the discovery and the elicitation of values. Especially in VSD, more general social scientific methods are used for this purpose like interviews, surveys, scenarios, participant observation, and ethnographic research. However, the activity of value discovery in design requires more than just identifying potentially important values. Designers also need to answer the *normative* question what values are worth pursuing in design. This normative question in turns raises a number of more foundational and metaphysical philosophical questions about values. Is value subjective or objective? Should we distinguish between final and instrumental values? Are there universal values or are value relative to culture and place? Manders-Huits (2011) argues that VSD lacks a normative criterion to decide what values should be included in the design and that it should therefore be supplemented by a normative moral theory of values.

Translation

The translation of values into the materiality of the object designed might be broken down into at least two steps: (1) the specification of general values in terms of design requirements and (2) the translation of such requirements into engineering characteristics. For the first step use may be made of methods and approaches developed in requirements engineering (e.g., Hull et al. 2005; Young 2003; Grady 1993) or in decision theory (e.g., Keeney 1992). Building on these, Van de Poel (2013) proposes an approach for translating values into design requirements. Also the chapter “► Design for Values and the Definition, Specification, and Operationalization of Values” is relevant.

The second translation, from requirements to engineering characteristics, is made, for example, in QFD as we have seen, although QFD does not offer specific

guidelines or suggestions on how to make this translation. At the background here is the question how QFD is able to translate descriptions in the functional or value domain in to descriptions in the structural or physical domain; some of these issues are discussed in De Vries (2009). The more fundamental philosophical issue here is the idea that designed technical artifacts have a dual nature, they are both intentional social objects and have a technical structure that can be understood in terms of natural science, and the question is how we translate requirements in the intentional or value domain into characteristics in the technical, natural domain (e.g., Kroes 2010).

Choice

There is a plethora of methods for making choices in engineering design (e.g., Pahl et al. 2007; Cross 2008; Pugh 1991; Dym et al. 2014; Akao 1990) and also more generally in the area of decision theory (e.g., Keeney and Raiffa 1993) for dealing with cases of conflicting criteria or values in design. As has been shown by Franssen (2005), many of these methods run into Arrow's Theorem, a well-known impossibility theory from decision theory (or they do not actually offer decision support but only reconstruct decisions).

When the choice to be made in engineering design is not just understood as a multi-criteria choice problem, but also as a problem in terms of multiple values, this raises additional philosophical issues related to what philosophers have called value incommensurability (Raz 1986; Chang 1997). Two or more values are incommensurable if they cannot be measured on the same scale. Incommensurability may arise from the fact that it is impossible or at least inappropriate to cancel out losses in one value domain by benefits in another value domain. Value incommensurability raises fundamental philosophical questions about choices under value conflict in design and the rationality of such choices. Some of the relevant issues are discussed in Van de Poel (2009) and in the chapter “► [Conflicting Values in Design for Values](#).”

Verification

Verification in Design for Values is, as far as I am able to tell, still largely an unresolved issue on which hardly work has been done. There are standard (social science) methods for evaluating whether a design *in use* meets or respects certain values according to the *current users*. It would, however, be most helpful to have methods to evaluate or validate proposed designs with respect to their incorporated values already in the design phase before they are actually used. Methods may be available for specific value, like safety, but no general approaches seem to have been established.

The underlying philosophical issue is whether values can be embedded in designed technical artifacts, and if so what it exactly means to say that a design embeds or embodies certain values, an issue that obviously needs to be clarified (or at least assumed) if verification methods for Design for Values are to be developed.

The issues of the value-ladenness of technology and how it is exactly to be understood is hotly debated; different positions are discussed in Kroes and Verbeek (2014).

Conclusions

Values have probably always played a role in engineering design. However, most current engineering design practices and methods are characterized by an implicit and unsystematic attention for values in the design process. In as far as values have received explicit and systematic attention, the focus has often been on more instrumental values such as effectiveness, efficiency, reliability, and customer satisfaction, but there are also some design methods or approaches that explicitly address final values in engineering design. What is still missing yet is an integral approach to Design for Values that offers support to four key activities in Design Values, i.e., (1) discovery of values, (2) translation of these values into engineering characteristics, (3) choice about conflicting values and trade-offs, and (4) verification of values in the designed product.

It remains to be seen whether Design for Values in engineering requires the development of completely new methods. It might be possible and more effective to build on existing methods and approaches such as QFD. More important than developing new design methods as such is the addressing of the four challenges for Design for Values in engineering that I have identified. These are the challenges: (1) How to decide what values should be incorporated from a normative point of view in a design? (2) How to make the translation from the intentional, functional domain to the structural, natural domain for values? (3) How to deal with conflicting values in design? (4) How to verify or validate whether a design indeed embodies or represents the values for which it has been designed?

Cross-References

- ▶ [Conflicting Values in Design for Values](#)
- ▶ [Design for the Value of Human Well-Being](#)
- ▶ [Design for the Value of Inclusiveness](#)
- ▶ [Design for the Value of Safety](#)
- ▶ [Design for the Value of Sustainability](#)
- ▶ [Design for Values and the Definition, Specification, and Operationalization of Values](#)
- ▶ [Design for Values in Healthcare Technology](#)
- ▶ [Design for Values in ICT](#)
- ▶ [Design Methods in Design for Values](#)
- ▶ [Modeling for Design for Values](#)
- ▶ [Participatory Design and Design for Values](#)
- ▶ [Technology Assessment and Design for Values](#)
- ▶ [Value Sensitive Design: Applications, Adaptations, and Critiques](#)

References

- Abbott A (1988) *The system of professions. An essay on the division of expert labor*. University of Chicago Press, Chicago
- Akao Y (ed) (1990) *Quality function deployment. Integrating customer requirements into product design*. Productivity Press, Cambridge, MA
- Albrechtslund A (2007) Ethics and technology design. *Ethics Inf Technol* 9:63–72
- Alexander JK (2009) The concept of efficiency: an historical analysis. In: Meijers A (ed) *Handbook of the philosophy of science, vol 9, Philosophy of technology and engineering sciences*. Elsevier, Oxford, pp 1007–1030
- Asveld L, Roeser S (eds) (2009) *The ethics of technological risk*. Earthscan, London
- Bhamra T, Lofthouse V (2007) *Design for sustainability: a practical approach*. Gower, Aldershot
- Birkeland J (2002) *Design for sustainability. A source book for ecological integrated solutions*. Earthscan, London
- Bogue R (2007) Design for disassembly: a critical twenty-first century discipline. *Assembly Autom* 27(4):285–289. doi:10.1108/01445150710827069
- Bogue R (2012) Design for manufacture and assembly: background, capabilities and applications. *Assembly Autom* 32(2):112–118. doi:10.1108/01445151211212262
- Boothroyd G, Dewhurst P, Knight WA (2011) *Product design for manufacture and assembly*, 3rd edn, Manufacturing engineering and materials processing. CRC Press, Boca Raton
- Bucciarelli LL (1994) *Designing engineers*. MIT Press, Cambridge, MA
- Calhoun DH (1960) *The American civil engineer. Origins and conflict*. MIT Press, Cambridge, MA
- Calvert MA (1967) *The mechanical engineer in America. 1830–1910*. John Hopkins University Press, Baltimore
- Chang R (ed) (1997) *Incommensurability, incomparability, and practical reasoning*. Harvard University Press, Cambridge, MA
- Cheng T (2009) Design for reliability and robustness. *IEEE Des Test Comput* 26(6):2–3
- Clarkson J (2003) *Inclusive design: design for the whole population*. Springer, London/New York
- Cross N (2008) *Engineering design methods. Strategies for product design*, 4th edn. Wiley, Chichester
- Cummings ML (2006) Integrating ethics in design through the value-sensitive design approach. *Sci Eng Ethics* 12:701–715
- Davis M (1998) *Thinking like an engineer. Studies in the ethics of a profession*. Oxford University Press, New York/Oxford
- De Vries MJ (2009) Translating customer requirements into technical specifications. In: Meijers A (ed) *Handbook of the philosophy of science, vol 9, Philosophy of technology and engineering sciences*. Elsevier, Oxford, pp 489–512
- Desmet PMA, Pohlmeier AE (2013) Positive design: an introduction to design for subjective well-being. *Int J Des* 7(3):5–19
- Dym CL, Little P, Orwin EJ (2014) *Engineering design: a project-based introduction*, 4th edn. Wiley, New York
- Eekels J, Roozenburg NFM (1991) A methodological comparison of the structures of scientific research and engineering design. Their similarities and differences. *Des Stud* 12(4):197–203
- Erlandson RF (2008) *Universal and accessible design for products, services, and processes*. CRC Press, Boca Raton
- Feenberg A (1995) *Alternative modernity: the technical turn in philosophy and social theory*. University of California Press, Berkeley
- Feng P (2000) Rethinking technology, revitalizing ethics: overcoming barriers to ethical design. *Sci Eng Ethics* 6(2):207–220
- Flanagan M, Howe DC, Nissenbaum H (2008) Embodying values in technology. Theory and practise. In: Van den Hoven J, Weckert J (eds) *Information technology and moral philosophy*. Cambridge University Press, Cambridge, pp 322–353

- Frankena WK (1973) *Ethics*, 2nd edn. Prentice Hall, Englewood Cliffs
- Franssen M (2005) Arrow's theorem, multi-criteria decision problems and multi-attribute preferences in engineering design. *Res Eng Des* 16:42–56
- Friedman B (1996) Value-sensitive design. *Interactions* 3(6):17–23
- Friedman B, Kahn PHJ (2003) Human values, ethics and design. In: Jacko J, Sears A (eds) *Handbook of human-computer interaction*. Lawrence Erlbaum Associates, Mahwah, pp 1177–1201
- Friedman B, Kahn PHJ, Borning A (2006) Value sensitive design and information systems. In: Zhang P, Galletta D (eds) *Human-computer interaction in management information systems: foundations*, vol 5, *Advances in management information systems*. M.E Sharpe, Armonk, pp 348–372
- Gaustad G, Olivetti E, Kirchain R (2010) Design for recycling. *J Ind Ecol* 14(2):286–308. doi:10.1111/j.1530-9290.2010.00229.x
- Govers CPM (1996) What and how about quality function deployment (QFD). *International Journal of Production Economics* 46–47:575–585
- Grady JO (1993) *Systems requirements analysis*. McGraw-Hill, New York
- Grin J, Hoppe R (1995) Toward a comparative framework for learning from experiences with interactive technology assessment. *Org Environ* 9(1):99–120. doi:10.1177/108602669500900105
- Grin J, van der Graaf H (1996) Technology assessment as learning. *Sci Technol Hum Values* 21(1):72–99
- Grunwald A (2009) Technology assessment: concepts and methods. In: Meijers A (ed) *Handbook of the philosophy of science*, vol 9, *Philosophy of technology and engineering sciences*. Elsevier, Oxford, pp 1103–1146
- Guston DH, Sarewitz D (2002) Real-time technology assessment. *Technol Soc* 24(1-2):93–109. doi:10.1016/s0160-791x(01)00047-1
- Hansson SO (2003) Ethical criteria of risk acceptance. *Erkenntnis* 59:291–309
- Hansson SO (2007) Safe design. *Techné* 10(1):43–49
- Hansson SO (2009) Risk and safety in technology. In: Meijers A (ed) *Handbook of the philosophy of science*, vol 9, *Philosophy of technology and engineering sciences*. Elsevier, Oxford, pp 1069–1102
- Harris CE, Pritchard MS, Rabins MJ (2013) *Engineering ethics: concepts and cases*, 5th edn. Wadsworth – Cengage, Boston
- Hauser JR, Clausing D (1988) The house of quality. *Harv Bus Rev* 66(3):63–73
- Henderson K (1991) Flexible sketches and inflexible data bases: visual communication, conscription devices, and boundary objects in design engineering. *Sci Technol Hum Values* 16(4):448–473
- Holt R, Barnes C (2010) Towards an integrated approach to “Design for X”: an agenda for decision-based DFX research. *Res Eng Des* 21(2):123–136
- Hubka V (1982) *Principles of engineering design*. Butterworth Scientific, London
- Hull E, Jackson K, Dick J (2005) *Requirements engineering*, 2nd edn. Springer, London
- Imrie R, Hall P (2001) *Inclusive design : designing and developing accessible environments*. Spon Press, London; New York
- Ireson WG, Coombs CF, Moss RY (1996) *Handbook of reliability engineering and management*, 2nd edn. McGraw Hill, New York
- Jordan PW (2003) *Designing pleasurable products: an introduction to the new human factors*. Taylor & Francis, London
- Keates S, Clarkson J (2003) *Countering design exclusion: an introduction to inclusive design*. Springer, London
- Keeney RL (1992) *Value-focused thinking: a path to creative decisionmaking*. Harvard University Press, Cambridge, MA
- Keeney RL, Raiffa H (1993) *Decisions with multiple objectives: preferences and value tradeoffs*. Cambridge University Press, Cambridge, UK/New York

- King B (1989) Better designs in half the time. Implementing quality function deployment in America, 3rd edn. Goal/QPC, Methuen, MA
- Koskinen I, Battarbee K, Mattelmäki T (eds) (2003) Emphatic design. User experience in product design. IT Press, Helsinki
- Kroes P (2010) Engineering and the dual nature of technical artefacts. *Camb J Econ* 34(1):51–62. doi:10.1093/cje/bep019
- Kroes P, Verbeek P-P (eds) (2014) The moral status of technical artefacts. Springer, Dordrecht
- Kuo T-C, Huang SH, Zhang H-C (2001) Design for manufacture and design for 'X': concepts, applications, and perspectives. *Comput Ind Eng* 41(3):241–260. doi:10.1016/s0360-8352(01)00045-6
- Lintsen H (1985) Ingenieur van Beroep. Historie, Praktijk, Macht en Opvattingen van Ingenieurs in Nederland. Ingenieurspers, Den Haag
- Manders-Huits N (2011) What values in design? The challenge of incorporating moral values into design. *Sci Eng Ethics* 17(2):271–287. doi:10.1007/s11948-010-9198-2
- Manohar K, Ishii K (2009) Design for supply chain: evaluation of supply chain metrics. In: IMECE2008: proceedings of the ASME international mechanical engineering congress and exposition, Boston, Massachusetts, USA, vol 4, pp 203–211
- Nieusma D (2004) Alternative design scholarship: working toward appropriate design. *Des Issues* 20(3):13–24
- Oosterlaken I (2009) Design for development: a capability approach. *Des Issues* 25(4):91–102
- Pahl G, Beitz W, Feldhusen J, Grote K-H (2007) Engineering design: a systematic approach (trans: KWaLBTa), 3rd edn. Springer, London
- Papanek VJ (1984) Design for the real world: human ecology and social change, 2nd edn. Van Nostrand Reinhold, New York
- Papanek VJ (1995) The green imperative: natural design for the real world. Thames and Hudson, New York
- Park SH, Antony J (2008) Robust design for quality engineering and Six Sigma. World Scientific, Singapore/Hackensack
- Preiser WFE, Ostroff E (2001) Universal design handbook. McGraw-Hill, New York
- Pritchard MS (2009) Professional standards in engineering practice. In: Meijers A (ed) Handbook of the philosophy of science, vol 9, Philosophy of technology and engineering sciences. Elsevier, Oxford, pp 953–971
- Pugh S (1991) Total design: integrated methods for successful product engineering. Addison-Wesley, Wokingham/Reading
- Raheja D, Gullo LJ (2012) Design for reliability, Wiley series in quality & reliability engineering. Wiley/IEEE Press, Hoboken
- Raz J (1986) The morality of freedom. Oxford University Press, Oxford
- Reuzel RPB, van der Wilt GJ, ten Have HAML, de Vries Robb PF (2001) Interactive technology assessment and wide reflective equilibrium. *J Med Philos Forum Bioeth Philos Med* 26(3):245–261
- Reynolds TS (1983) 75 years of progress. A history of the American Institute of Chemical Engineers, 1908–1983. The Institute, New York
- Rip A, Misa T, Schot J (eds) (1995) Managing technology in society. The approach of constructive technology assessment. Pinter, London/New York
- Roozenburg N, Cross N (1991) Models of the design process—integrating across the disciplines. In: International Conference on Engineering Design (ICED-91), Zurich, pp 186–193.
- Schot J, Rip A (1997) The past and future of constructive technology assessment. *Technol Forecast Soc Change* 54(2/3):251–268
- Sclove RE (1995) Democracy and technology. The Guilford Press, New York
- Shrader-Frechette KS (1991) Risk and rationality. Philosophical foundations for populist reform. University of California Press, Berkeley
- Slater JA (2000) Design for maintenance. In: Quality Reliability and Maintenance (Qrm 2000), pp 253–256

- Stauffer LA, Ullman DG (1988) A comparison of the results of empirical studies into the mechanical design process. *Des Stud* 9(2):107–114
- Stauffer LA, Ullman DG, Dietterich TG (1987) Protocol analysis of mechanical engineering design. In: Eder WE (ed) *Proceedings of the 1987 international conference on engineering design*, ICED 87, Boston
- Tatum JS (2004) The challenge of responsible design. *Des Issues* 20(3):66–80. doi:10.1162/0747936041423307
- Ullman DG (1997) *The mechanical design process*. McGraw-Hill, New York
- Ullman DG, Stauffer LA, Dietterich TG (1987) Toward Expert CAD. *Comput Mech Eng* November/December 1987:56–70
- Van de Poel I (2007) Methodological problems in QFD and directions for future development. *Res Eng Des* 18(1):21–36
- Van de Poel I (2009) Values in engineering design. In: Meijers A (ed) *Handbook of the philosophy of science, vol 9, Philosophy of technology and engineering sciences*. Elsevier, Oxford, pp 973–1006
- Van de Poel I (2010) Philosophy and engineering: setting the stage. In: Van de Poel I, Goldberg DE (eds) *Philosophy and engineering. An emerging agenda*. Springer, Dordrecht, pp 1–11
- Van de Poel I (2012) Can we design for well-being? In: Brey P, Briggie A, Spence E (eds) *The good life in a technological age*. Routledge, New York, pp 295–306
- Van de Poel I (2013) Translating values into design requirements. In: Mitchfelder D, McCarty N, Goldberg DE (eds) *Philosophy and engineering: reflections on practice, principles and process*. Springer, Dordrecht, pp 253–266
- Van de Poel I, Royakkers L (2011) *Ethics, technology and engineering*. Wiley-Blackwell, Oxford
- Van den Hoven J (2005) Design for values and values for design. *Inf Age* 7(2):4–7
- Van der Ryn S, Cowan S (2007) *Ecological design, 10th anniversary edn*. Island Press, Washington, DC
- Vermaas P, Kroes P, van de Poel I, Franssen M, Houkes W (2011) *A Philosophy of technology: from technical artefacts to sociotechnical systems, vol 6. Synthesis lectures on engineers, technology and society, vol 1*. doi:10.2200/S00321ED1V01Y201012ETS014
- Visser W (1990) More or less following a plan during design: opportunistic deviations in specification. *Int J Man-Machine Stud* 33:247–278
- Visser W (2009) Design: one, but in different forms. *Des Stud* 30:187–223
- WCED (1987) *Our common future*. Report of the World Commission on Environment and Development. Oxford University Press, Oxford
- Whiteley N (1993) *Design for society*. Reaktion Books, London
- Winner L (1986) *The whale and the reactor; a search for the limits in an age of high technology*. The University of Chicago Press, Chicago/London
- World Health Organization (2006) *Constitution of the World Health Organization – basic documents, supplement, Forty-fifth edn*
- Young RR (2003) *The requirements engineering handbook*, Artech House technology management and professional development library. Artech House, Boston