# Investigating Ethical Issues in Engineering Design*

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**Keywords**: research agenda for engineering ethics, ethics in engineering design, intertwinement of ethical and technical issues in engineering, responsibility of engineers, responsibility and division of labour.

**ABSTRACT**: *This paper aims at contributing to a research agenda in engineering ethics by exploring the ethical aspects of engineering design processes. A number of ethically relevant topics with respect to design processes are identified. These topics could be a subject for further research in the field of engineering ethics. In addition, it is argued that the way design processes are now organised and should be organised from a normative point of view is an important topic for research.*

## 1. INTRODUCTION

The aim of this paper is to contribute to an agenda for research in the field of engineering ethics. Engineering ethics traditionally focuses on the ethical aspects involved in the actions and decisions of engineers.[1] In many (text) books on engineering ethics, attention is paid to codes of ethics for engineers and the responsibilities of engineers as *professionals*.[2,3,4,5,6,7] Such books deal with ethical issues like conflicts of interest, whistleblowing, competence, honesty, and dealing with safety. Usually such issues are discussed at the individual level. Recently, however, some authors have argued for broadening the scope of engineering ethics to include ethical aspects of the context in which engineers work or issues that are related to broader (social) aspects of technology like sustainability and social justice.[8, 9] Paying attention to such issues would require a broader focus than the individual engineer, including also

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other people involved in technical development and use like technicians, managers, (government) officials and users.

The approach in this paper is sympathetic to the plea for broadening the scope of engineering ethics but it tries to do so by focusing on one of the main engineering activities in which (individual) engineers are involved: engineering design. While some attention has been paid to ethics in design by a number of authors,[6,10,11,12,13] such efforts hardly add up to systematic consideration of the ethical aspects of engineering design. This paper tries to make a start with filling this gap by exploring ethical aspects of engineering design processes and possibilities for research in this area.

While engineers play an important part in design processes, they are in many cases not the only people involved. Design is often a collaborative effort, in which a number of engineers, technicians, researchers, managers and even sometimes users play a role. In this paper the focus is on the ethical aspects of design as a process, or an activity, not *only* on the ethical aspects that *engineers as professionals* might encounter in design processes. In fact, I do believe that such a broader focus is required to deal adequately with a number of ethical issues relating to how design processes should be organised and how decisions in design processes are to be made.

By focusing on design processes, I by no means want to claim that in this way all ethical issues in engineering can be dealt with. The focus on design stems from the conviction that there are important ethical issues in engineering design that have, until now, been relatively neglected in engineering ethics. Codes of ethics, for example, hardly offer a handle to deal with the issues in design processes that I will discuss in this paper. Moreover, I think that the design process is an important locus where ethical issues confronting (individual) engineers touch upon broader (social) ethical issues.

The paper starts by exploring in what ways choices made during engineering design processes are morally relevant. In doing so, I do not take a stance with respect to how these issues should be dealt with, i.e. what would be an ethically responsible way of dealing with these issues. However, I do maintain that these issues require ethical reflection. In addition, I will argue that dealing with these issues also requires (ethical) reflection on how design processes are and should be organised. I will illustrate the ethical aspects of design process by discussing the design of a new coolant for household refrigerators as an example. At the end of the paper, I will discuss the implications for a research agenda in the field of engineering ethics.

## 2. ETHICAL ASPECTS OF DESIGN PROCESSES

In this paper I will call aspects of the design process ethical (or moral) if they meet at least one of the following three criteria: 1) they bring about, or are connected to, possible negative or positive consequences for others than the designers, 2) they are related to moral norms of values that are either generally accepted or are central to groups involved in or affected by the design or 3) they are related to visions about how to live the ethically good life and virtues involved in that. In calling an aspect of the design process ethical, I thus take into account aspects of teleological and deontological approaches in philosophical ethics as well as from a virtue ethics approach. In this section, I try to develop a heuristic for recognising ethical aspects of engineering design processes. I do so by briefly discussing design methods and some insights from empirical studies of engineering design.

A number of authors have developed methods for the design process (see, e.g., Hubka;[14] for an overview see Cross[15] and Roozenburg & Cross.[16]) These methods usually divide the design process into a number of successive steps. While there are differences between different methods, most start with the analysis and formulation of the problem, including the formulation of certain goals and requirements to be met by a technology. Ethical considerations can play a role in the formulation of the goals a technology is to meet and in the formulation of other criteria and requirements, for example with respect to safety and sustainability (cf. the first and second criterion for ethical aspects mentioned above).

A next step is the dividing up of the problem into smaller problems and the creation of alternative solutions to these problems. A third phase is the choice of one solution from the range of possible solutions considered by selecting the alternative that best meets the formulated requirements. This solution is the basis for detail design, ending with a design that can function as a blueprint for the production process.

If one focuses on formal design methods like the ones I mentioned above one may get the impression that ethical aspects are mainly relevant during the formulation of design requirements and criteria. This impression is, however, misleading. Design problems are often ill-structured problems.[6,15,17,18,19] Problems are ill-structured if they have at least one of the following two characteristics:[a] 1) it is not possible to make a complete or definite list of all possible alternatives (or, more precisely, the problem space cannot be fully specified); 2) it is not possible to formulate a criterion or a set of criteria with which all alternatives can be ordered on a scale from "good" or "satisfactory" to "bad" or "unsatisfactory". (This does not mean that two alternatives can never be ordered, but that at least some alternatives cannot be ordered.) More complex design problems often have both characteristics.

The ill-structured character of design problems implies that even if a temporal order existed in design processes from goals and requirements to design solutions meeting these requirements, logic does not dictate one particular design solution given particular goals and requirements. Usually different design solutions can be defended on rational grounds. In other words, choices are made in design processes that go beyond the originally formulated goals and requirements. Examples of such choices that are potentially ethically relevant are the choice for certain alternatives to be investigated during the design process and the choice for the design alternative that will be the basis for detail design.

While requirements and goals thus do not determine what artefacts are actually designed, they at least constrain the range of possible outcomes. In this respect, artefacts may be conceived of as imperfect embodiments of requirements.[19] One reason why artefacts are "imperfect" is that generally speaking not all requirements can be met

a. Different authors have formulated somewhat different characteristics for ill-structured problems, but these two characteristics seem me to be the main common denominators.

simultaneously.[20] Compromises or trade-offs between the requirements—or the (moral) norms and values on which these requirements are based—have to be accepted. The conflicts between the requirements can derive from various sources. Requirements may, for example, logically contradict each other. More often, however, requirements will conflict given certain technical possibilities. Such conflicts will often only become clear during the design process and attempts can be made to resolve them by developing new technical possibilities. Usually, however, at least some conflicts between the requirements will not be resolved during the design process, either for principled or pragmatic reasons. Thus trade-offs almost always have to be accepted. The question which trade-offs among ethically relevant requirements—and the (moral) norms and values that support them—are acceptable is an ethical one.

Another reason why existing design methods do not tell the whole story from an ethical point of view is that in many methods hardly any attention is paid to the unintended or unforeseen, but not necessarily unforeseeable, effects of technologies (unless the absence of such possible effects are formulated beforehand as explicit design requirements). From a moral point of view, however, such unintended or unforeseen effects are often highly relevant and may be a reason to reconsider a proposed technical solution.

So, artefacts are not only imperfect because they imply trade-offs between design criteria or requirements, but also because they have unintended properties. Such properties may manifest themselves as risks, hazards or other types of unintended effects. Such effects are ethically relevant according to my first (teleological) criterion for ethical aspects. Unintended properties may also manifest themselves, as what some authors have called, the script of an artefact:[21,22] the fact that artefacts allow, stimulate or demand certain forms of use or enable or constrain certain social developments (cf. also Winner[23]). Such scripts may also contain an implicit vision about the ethically good life or the ethically desirable society (cf. the third criterion above).

On the basis of the empirical and conceptual observations made above, at least five topics or moments in design processes that are potentially ethically relevant can be distinguished: 1) the formulation of goals, design criteria and requirements and their operationalization, 2) the choice of alternatives to be investigated during a design process and the selection among those alternatives at a later stage in the process, 3) the assessment of trade-offs between design criteria (given particular alternatives) and decisions about the acceptability of particular trade-offs, 4) assessment of risks and unintended or unforeseen effects and decisions about the acceptability or desirability of these and 5) the assessment of scripts and political and social visions that are (implicitly) inherent in a design and decisions about the desirability of these scripts.

The list is not meant as an exhaustive list of ethical issues in engineering design. Neither do I want to claim that in every design process ethical issues with respect to all of the mentioned issues play a role. Rather, the list is meant as a heuristic device for recognising ethical issues in engineering design. In the following section I will use this heuristic device for discussing a number of ethically relevant aspects in one particular case. As we will see this case also suggests further ethically relevant issues that I will discuss in section four.

## 3. THE DESIGN OF COOLANTS AS AN EXAMPLE

To illustrate the ethical aspects of design processes I will now briefly discuss some aspects of the design process of an alternative coolant for household refrigerators. Until the 1990s, CFC 12 was the commonly used coolant for household refrigerators of the vapour compression type. It had come into common use in the 1930s when Thomas Midgley invented the CFCs. After 1970, however, CFCs came under increasing pressure due to their contribution to degradation of the ozone layer. In 1987, the Montreal Treaty called for a substantive reduction in the use of CFCs. International conferences following the Montreal Treaty recommended yet tougher measures and during the 1990s many Western countries decided to ban CFCs.

The reconstruction of the design and development process of alternative coolants that I present below is mainly based on articles from a number of journals like the *International Journal of Refrigeration* and the *ASHRAE Journal* (ASHRAE is the American Society of Heating, Refrigerating and Air-conditioning Engineers), proceedings of conferences on this subject and a number of interviews.[b] While these sources hardly can reveal how the design and development process took place in individual companies, they tell us something about efforts at a more collective level.[c] This collective level is important because it conditions the design efforts of individual engineers in particular companies. This is particularly the case because the assessment, development and testing of new chemicals that could function as alternative refrigerants require efforts that go well beyond the possibilities of one company, except perhaps for the large chemical producers of CFCs like Du Pont and ICI. Moreover, it was generally believed that there would be just *one* alternative to CFC 12, except perhaps for some niche markets. A main reason for this belief was that the market for refrigerants is relatively small.

The design of coolants is perhaps not an archetypal example of engineering design in the sense that it does not take place in an individual company. It is, however, a typical example of an engineering design problem. Solving it requires engineering knowledge; a range of solutions is possible which are nor given beforehand; there are several, possible conflicting, requirements; possible solutions have to be tested to assess whether they meet the posed requirements; and so on. Therefore, there are good reasons to believe that the type of ethical aspects that arise in the coolant story may arise in other engineering design problems as well. Nevertheless, the fact that the design process took place in an inter-organisational context may well have effected

b. For a more complete description of this case and references see my dissertation.[29] The description here highlights some aspects not dealt with in this earlier publication.

c. What I call the ‘collective’ level can be seen as the result of actions of individual actors. I call this level ‘collective’ because it is the effect of actions of various actors at various locations and because it, in turn, constitutes the context in which (these) actors have to act and that, in this way, conditions their further actions. In engineering, this collective level may have certain concreteness in collaborative (research) efforts, standardization activities, publications in commonly read journals and the like.

how these ethical problems were conceived and dealt with by the engineers and others involved.

In describing the design process of alternative coolants, I focus on the ethically relevant aspects. A first instance in which ethical aspects arose is the formulation of design requirements or criteria. Table 1 gives a list of commonly mentioned requirements for alternative coolants based on a number of articles from the *International Journal of Refrigeration* and the *ASHRAE Journal*.[24,25,26,27] Ethical aspects clearly play a role in the formulation of the requirements with respect to safety, health and the environment.

| | |
|---|---|
| **Chemical** | |
| | Stable and inert |
| **Thermal (thermodynamic and transport)** | |
| | Critical point and boiling point appropriate |
| | Good cycle efficiency |
| | Low vapor heat capacity |
| | Low viscosity |
| | High thermal conductivity |
| | Low freezing point |
| | Dry compression process |
| **Compatibility** | |
| | Compatibility with materials |
| | Miscibility with lubricants (solubility, lubricity) |
| | Compatibility with compressor |
| **Health & Safety** | |
| | No flammability |
| | Low or no toxicity |
| **Environment** | |
| | Low ODP (Ozone Depletion Potential) |
| | Low GWP (Global Warming Potential) |
| **Costs and Availability** | |
| | Low costs |
| | Available |

**Table 1:** *Design Requirements for Alternative Refrigerants*

Although the list of requirements might seem rather straightforward, it is not. First, at least some of the requirements in the list can be operationalised in different ways. Take, for example the Global Warming Potential (GWP) of a coolant. This can be measured using different so-called integration time horizons (ITHs), i.e. different time periods over which the contribution to global warming is integrated.[28] In this particular case, this makes little difference for the ordering of possible alternatives with respect to GWP; differences might, however, be more salient when one takes the Total Equivalent Warming Impact (TEWI) as the measure for the contribution to the greenhouse effect. TEWI combines the direct global warming effects of refrigerant emissions with the indirect global warming effects from energy consumption of the refrigerator (using certain assumptions with respect to how energy is generated).[28] Generally speaking, the TEWI of a household refrigerator is mainly determined by its energy consumption. However, on shorter time horizons, say 20 to 100 years, the direct effects of refrigerant emissions contribute relatively more to the TEWI of a household refrigerator than on longer time horizons. So, if coolant A has a lower GWP than coolant B but results in more energy consumption, the TEWI of a refrigerator using coolant A might be smaller than in the case of coolant B on a 20 years time horizon, while it is larger on a 500 years time horizon. So, the way design requirements are operationalised may make a difference for the choice between alternatives and ethical considerations can be involved. In this case, there is for example the ethical issue of responsibility to future generations, and its implications with regard to time horizons we have to consider for the future.

A second reason why the requirements in Table 1 are less straightforward than they might seem is that they do not reveal all considerations and therefore not all design requirements of the various actors involved.[19,29] Take for example the criterion of costs and availability. For refrigerator firms, who usually buy coolants from the chemical industry, it is important that refrigerants are not too expensive and easily available. For the chemical industry, on the other hand, it would be attractive if refrigerants are not too *in*expensive and that they, or their production process, can be patented, so that they can earn back development and testing efforts and make a good profit.

A related point is that the various people involved or possibly affected by the design of a new coolant did not completely agree on the relative importance of the various design requirements. In other words, there was no complete agreement about what trade-offs between the different requirements would be acceptable or desirable. One of the main trade-offs, which is also ethically relevant, is the trade-off between flammability of coolants and their environmental effects. This trade-off can be illustrated with the help of Figure 1. Figure 1 is drawn from a publication in the *ASHRAE Journal* of December 1987 by two engineers, McLinden and Didion, working at the National Bureau of Standards in the USA.[24] They argue that for a number of reasons that are mainly related to the chemical stability and thermal properties of possible coolants, the most likely alternative refrigerants are CFCs based on either methane or ethane. (CFCs are hydrocarbons in which one or more hydrogen atoms are replaced by chlorine or fluorine atoms). Figure 1 is a way to represent CFCs based on a particular hydrocarbon graphically. At the top, there is methane or ethane, or another hydrocarbon. If one moves one line to the bottom, one hydrogen atom is replaced by either a chlorine atom (if one goes to the left) or a fluorine atom (if one goes to the right). In this way, all CFCs based on a particular hydrocarbon can be represented.

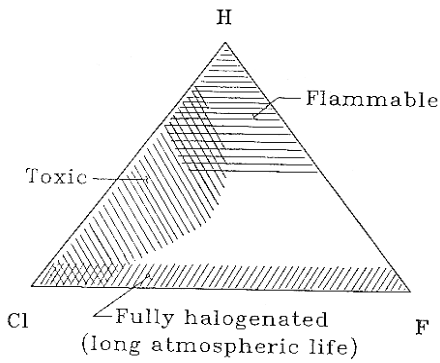


**Figure 1:** *A summary of the trade-offs among the properties of the CFC refrigerants*

The interesting point is that if one maps certain known properties of CFCs in Figure 1, certain patterns arise which make it possible 'to infer properties for compounds for which no data is available'.[24 (p. 38)] In Figure 1, this has been done for the properties flammability, toxicity and environmental effects. As measure for the (negative) environmental effects McLinden & Didion take the atmospheric lifetime of refrigerants because of the importance of this value for both the ODP and the GWP of a refrigerant. [24 (p. 40)] If one looks in more detail at both the known GWP and ODP of a number of CFCs, it seems that the ODP decreases as the number of chlorine atoms decreases while the GWP decreases as the number of fluorine atoms decreases.[d] So minimising both ODP and GWP of a refrigerant means maximising the number of hydrogen atoms, which increases flammability. This means that there is a fundamental trade-off between flammability and environmental effects expressed in terms of ODP and GWP.

According to McLinden and Didion the blank area in the triangle (Figure 1) contains refrigerants that are acceptable in terms of toxicity, flammability and environmental effects. They also say that 'initial research efforts should be directed towards CFC compounds from that region or mixtures where the major component is from this region'. [24 (p. 42)] It should be noted that by drawing the blank region in Figure 1, they make an implicit value judgement about what trade-offs, especially between flammability and environmental effects, are acceptable.[e] Here, ethical aspects play a

d. This assessment is based on the available IPCC data for the ODP and GWP values for CFCs. The pattern does not quite hold, however, for isomeric forms (Isomeric forms contain the same number and kind of atoms but in a different configuration. They are designated by a,b or c, as in the case of HFC 134a).

e. Although McLinden and Didion say the figure is about tradeoffs between the properties of CFC refrigerants, the figure might also be read in the sense that the blank area denotes the area in which requirements of flammability, toxicity and environmental effects are sufficiently met according to McLinden and Didion. At some point in their article, they indeed suggest this interpretation.[24 (p. 42)] In that case, the figure would contain an implicit value judgement about what threshold values for the different design criteria should be met minimally.

role. As we will see below, the implicit choice made by McLinden and Didion would be criticised by others.

In practice, the development and testing efforts of many chemical companies, refrigerator firms and government financed research institutes focused on a substance that is indeed in the blank region in Figure 1: HFC 134a.[29] This coolant was, however, not only preferred for the 'technical' reasons mentioned by McLinden and Didion. Commercial considerations and the fact that the chemical industry took the lead in developing an alternative to CFC 12 were important as well. For chemical firms like Du Pont, it would not have been attractive if CFCs were substituted by chemicals that are easily manufactured and, therefore, inexpensive. HFC 134a was attractive from this point of view because it is rather expensive and—parts of—its production process could be patented.

The fact that the chemical industry took the lead in developing alternative refrigerants meant that already much R&D effort had gone into HFC 134a when other actors like refrigerator firms, producers of compressors for refrigerators and governments became interested in alternative coolants. As an effect, HFC 134a had a competitive advantage in this respect compared to other possible coolants.[29] In the event, refrigerator firms, compressor manufacturers and the government jumped on the HFC 134a bandwagon. Nevertheless, some independent researchers and environmental groups criticised the choice of HFC 134a. In particular, these people criticised two ethically relevant choices in the design and development process of alternative coolants. First, they criticised the contribution of HFC 134a to the greenhouse effect and the trade-off that had been made, in their eyes, between flammability and environmental effects. They argued that flammable coolants might be acceptable not only because they (usually) contribute less to greenhouse warming but also because flammable coolants did not necessarily make refrigerators 'unsafe'. Second, they criticised the focus on HFC 134a. They urged for more research on other alternatives. Environmental groups, in particular, argued that such alternatives as HFC 152a and hydrocarbons, which are flammable but have a lower GWP than HFC 134a, might be better alternatives to CFC 12. Table 2 lists the ODP and GWP values of these alternatives.

| **Substance** | **ODP (relative to CFC 11)** | **GWP (100 years ITH) (relative to $CO_2$)** |
|---|---|---|
| **CFC 12** | 1 | 8500 |
| **HFC 134a** | 0 | 1300 |
| **HFC 152a** | 0 | 140 |
| **Propane (HC 290a)** | 0 | 3 |
| **Isobutane (HC 600a)** | 0 | 3 |

**Table 2** *ODP and GWP for a number of potential refrigerants*

In parts of Europe, the tide has turned against HFC 134a since Greenpeace in the early 1990s found a refrigerator firm from former East Germany, Foron, willing to develop a refrigerator with hydrocarbons as coolant. When Greenpeace and Foron in August 1992 succeeded in collecting more than 50,000 orders for Foron's so-called *Greenfreeze,* within months the main German refrigerator firms switched to the hydrocarbon isobutane as coolant. In December 1992, *Greenfreeze* acquired safety approval from the German certification authorities. Although there has been some discussion about the energy consumption of refrigerators with hydrocarbon as coolants, current studies seem to suggest that refrigerators with isobutane as a coolant are at least as energy efficient as those using HFC 134a (cf.[28]; some researchers claim that the use of isobutane substantially reduces energy consumption[30]).

## 4. FURTHER ANALYSIS OF ETHICAL ISSUES IN DESIGN

The preceding section illustrates a number of ethical aspects of design processes. In particular, it illustrates ethical issues in relation to the formulation and operationalisation of design requirements, the selection of alternatives and the assessment of trade-offs between requirements. All these ethical aspects were mentioned in the second section of this paper. In addition, the case study suggests two other issues, i.e. 1) the intertwinement between ethical and technical issues and 2) the organisation of, and decision-making during, the design process. I will elaborate both issues below.

**The Interwinement of Ethical and Technical Issues**

If one looks into how ethical issues are dealt with in the case study I presented, it is striking that this regularly happens implicitly. In the operationalisation of design criteria or in discussions about trade-offs, ethical or normative questions are hardly *explicitly* dealt with. Choices with respect to ethically relevant aspects often seem to be either made implicitly or considered purely technical, or both, by the engineers involved.

Insofar as ethical or normative issues are recognised, engineers often do not seem to consider it their task to reflect on them. In the case of coolants, requirements with respect to safety, health and the environment mainly came from governments, certification authorities and standards. McLinden and Didion, for example, derive the requirement that refrigerants should be nonflammable and of low toxicity from the ASHRAE Safety Code for Mechanical Refrigeration.[24 (p. 33-34)] Engineers hardly seem to consider it their task to think further about such requirements or about trade-offs among them in a normative way; that is the task of politicians, regulators, managers and so on. They, in other words, seem to propose a division of labour in which normative issues are a matter to be decided by non-engineers like managers, politicians and (potential) users of a technology and in which the task of engineers is technical or instrumental[10] (see also Florman [31,32]). In this division of labour, as illustrated in Figure 2, politicians, managers, principals and customers formulate the goals, requirements and criteria a technology has to meet.[33] The task of engineers is to find the best possible technical solution given these goals and requirements. This task is seen as morally neutral. Moral questions may again arise in the user phase when technologies are being used for certain purposes and produce certain (social) effects.

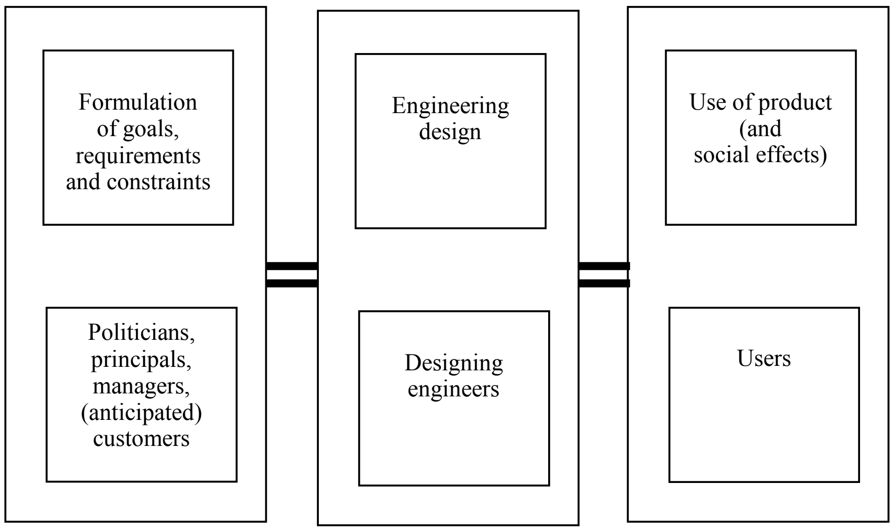


**Figure 2:**
*Division of labour with respect to engineering design proposed by some authors*

Two things should be noted about such a proposed division of labour. One is that in actual fact, engineers are involved in a range of issues with ethical or normative dimensions like the thinking out of (user) requirements, technical norm setting, and the evaluation of acceptable risk. Engineers are usually 'heterogeneous engineers' who deal with more than technical issues alone.[34] The other point is that it is difficult to see how the ethical aspects of the issues mentioned could be separated completely from their technical aspects. Of course, one can separate the (normative) discussion about what requirements to pose for a certain design from the actual operationalisation and application of those requirements. The operationalisation and application of requirements is, however, often not a straightforward process and can thus involve ethical choices. In the meantime, the operationalisation and application of requirements usually requires engineering expertise. Something similar applies for trade-offs as illustrated in the case study of coolants. Some engineering knowledge or expertise is required to understand the trade-offs between different requirements, while ethical aspects are involved in choices about the acceptability of trade-offs. The inevitable conclusion seem to be that it is—at least in actual practice—not possible to separate technical and ethical issues completely and that a division of labour based on such a complete separation will not be attainable.

If engineers are involved in ethically relevant choices but often do not recognise them as such, does this mean that such choices are made arbitrarily? Not entirely; engineers seem to follow certain general norms and rules in their practice. Grunwald in this issue[35] even claims that in many actual cases a pragmatically complete, locally consistent, unambiguous, commonly accepted and factually observed normative framework exists on which engineers can fall back to decide about normative issues *without the need for further reflection*.[f]

Did such a framework exist in the case of the design of coolants? Yes and no. Yes, because some norms were commonly shared among the engineers involved. One such norm was that coolants should not be flammable. Another more implicit norm was that an alternative coolant should as much resemble CFC 12 as possible, except for its environmental effects. So, certain shared norms and rules with respect to refrigerator and coolant design existed, and in terms of these rules the choice of HFC 134a is quite understandable.[g] These norms and rules were, however, not all shared by all people possibly affected by choices made in coolant (and refrigerator) design, especially not by environmental groups, some researchers and parts of the public. In this sense, the normative framework of the engineers involved was not commonly accepted. This seems to be a more common problem as is, for example, illustrated in discussions about nuclear technology or biotechnology. Also, no societal consensus exists about issues regarding what are acceptable technical risks or even about how risks should be assessed.[36,37]

Even if a normative framework could be created that is not only commonly accepted but also locally consistent, unambiguous and factually observed, it is hard to see how it could be (pragmatically) complete in the sense that the norms, principles and customs included in the normative framework are sufficient to decide about all morally relevant choices engineers face in design processes, especially in the case of new technologies. The arguments above seem to imply that the search for such a normative framework that covers *all* of the choices made by engineers is in vain. This does not mean that a commonly accepted framework is not desirable or that engineers should continually reflect ethically about the choices they make. It does, however, imply that choices that require ethical reflection are to some extent inherent to engineering design.

**Organisation of the Design Process**

The arguments above lead to the conclusion that it is not possible to separate technical and ethical aspects of engineering design completely. In other words, a division of labour with respect to engineering design in which non-engineers decide about ethical (political, social) aspects and the engineers “only” have to carry out a morally neutral task is not feasible. This does, however, not mean that dealing with the issues I mentioned requires just ethically responsible engineers and nothing more. In fact, engineers are not the only ones involved in design processes and related decisions. Moreover, the way design processes are organised may sometimes set serious limits to

f. See Grunwald’s contribution in this issue for a definition of the various terms.[35]

g. Some authors have called such shared rules with respect to the design and development of a technology the 'technological regime' of that technology. See, for example Rip and Kemp[50] or Van de Poel.[29]

the extent to which engineers, and others involved, can responsibly deal with the issues mentioned.

While the organisation of the design process does not determine how engineers deal with ethical issues, it at least creates a number of opportunities and constraints for dealing with such issues. In engineering ethics, it has repeatedly been argued that the fact that many engineers work as employees in hierarchical organisations sets serious limits to the degree to which they can exercise ethical judgement independently from their employer. This is the case because—also according to the law—it is the employer who is to decide whether the engineer did his work well.[4,38,39] This can seriously limit the degree to which engineers can live up to ethical considerations or codes of conduct for engineers formulated by professional organisations.

Hierarchical relations and the law are, however, often not the only relevant factors when it comes to the organisation of the design process. Informal rules and institutions are important as well. This includes the way design teams are organised and managed, the communication and possible competition between design teams, the inclusion of particular actors in and exclusion of other actors from the design process, and the way choices and decisions made earlier structure current ones.[12,40,41,42] As may be clear from this list, I use the term 'organisation of the design process' in a broad sense, also including a range of issues in the cultural and institutional context of engineering design processes that are not necessarily deliberately organised. More empirical and theoretical knowledge, and therefore more research, is required to distinguish the various relevant issues here. On the basis of what we already know, however, I think that two normative issues are particularly important with respect to the organisation of engineering design processes. I briefly discuss them below.

The first issue is how the decision-making about the ethical (political, social) aspects of design should be organised. I have argued that engineers, whether they want it or not, play a role in such decision-making but that argument does not imply that decisions should be solely made by engineers. In fact, this seems to me to be undesirable. Not only are many non-engineers with their own interests and values involved in the design and development of new technology, such technologies may also affect the lives of many more people (with different interests and values). Several authors have, on the basis of ethical considerations, argued that those people that are (potentially) affected by new technologies should be informed and be involved in decision-making about, or consent to, the design and use of these technologies.[5,39,43] Involvement of citizens or (social) actors, which are now usually not or only marginally involved, in (decision-making about) technical design and development has also been advocated for democratic reasons[44] and because it enhances the chance that attention is paid to all kinds of social considerations and (unintended) effects of technology in the design of new technologies.[45,46]

While it may be desirable to include different kinds of non-engineers in decision-making about design choices, it is at the moment hardly clear how precisely this can and should be organised. A particular problem is that many choices in design processes are now made implicitly and are not considered ethically relevant. Another problem is that choices in design usually require not only ethical (social, political) considerations but also engineering expertise. Non-engineers will often lack such expertise. For pragmatic reasons, it may therefore turn out to be desirable to leave a number of design decisions to the judgement of engineers, and others directly involved in design processes (in contrast to those possibly affected but not directly involved). Engineers would then be responsible for these decisions to people possibly affected but who are or cannot be involved in design decisions.

Here we touch on the second normative issue with respect to the organisation of design processes: the division of labour and responsibilities. In the ideal case, one would wish an allocation of responsibilities which stimulates all people involved to behave in an ethically responsible way (whatever that exactly means), and which makes it possible to hold people accountable or even legally liable for their deeds and for properties or effects of technologies that are considered undesirable. Given the complexity and heterogeneity of, and the large number of people usually involved in design processes, it is often very hard to hold some individual responsible once something has gone wrong. This general problem is known as the 'problem of many hands'.[47,48] The challenge is to design divisions of labour and responsibilities that further individual ethical behaviour, stimulates ethical deliberation, reflection and decision-making, minimises the occurrence of undesirable effects,[h] and stimulates the occurrence of desirable effects.

## 5. QUESTIONS FOR RESEARCH

In this paper I have explored both by an empirical example and at a more general level, what the ethical aspects of engineering design processes are. While the example I gave related to a rather large-scale design process and not within one company, it would seem plausible that many of the ethical issues mentioned also play a role in smaller scale day-to-day design activities. In such cases, ethical considerations, trade-offs, risks and the like are also often involved. It might be that in such cases there is more moral agreement about how such issues should be dealt with. This is, however, something we hardly know at the moment because hardly any research has been done on how engineers, and others, deal with ethical issues in engineering design. In engineering ethics, little attention has been paid until now to design processes as I mentioned in the introduction. From Science and Technology Studies (STS) and other research on engineering design,[i] a lot can be learned about what engineers do in designing and about how design processes are organised. Such research has, however, hardly focused on ethical aspects and should, therefore, be supplemented. The heuristic I have

h. There are several reasons why undesirable effects may occur. Undesirable effects may be nobody's (role) responsibility, they may be unforeseen and unforeseeable, or they may be emergent—not intended by any of the actors involved but still the effect of the sum of their actions. A certain division of labor can sometimes also help to prevent unforeseen or emergent undesirable effects because making some actors responsible (accountable) for undesirable effects may motivate them to anticipate undesirable effects or to avoid or correct emergent effects.

i. See, for example, the journals *Design Studies* and *Research in Engineering Design*.

developed in this article to recognise ethical aspects in engineering design may be a first step to do so.

Focusing on design processes would, I think, not only give rise to new empirical questions in engineering ethics but also to new normative ones. While codes of ethics for engineers have something to say on which requirements, like safety, should from an ethical point of view play a role in the design process, they hardly address such issues as how such general requirements should be operationalised or what trade-offs between requirements are acceptable.

There are, I think, three categories of general questions that should be addressed in further research on the ethical aspects of design processes. The first category relates to questions on how engineers now, both as individuals and collectively, in for example design teams, deal with ethical issues and how they could and should deal with such issues. Such research could, for example, reveal whether engineers recognise aspects that can be called ethical on the basis of the criteria that I mentioned above (or on the basis of another set of criteria), and explicitly deal with them and why and when they do so or not. The second category of research questions is related to the organisation of the design process. Research could reveal how the organisation of the design process creates possibilities and constraints for responsible behaviour by engineers and how the organisation of the design process influences actual design outcomes. Research could also help us to become more precise about the various aspects of the 'organisation of the design process'. It might further reveal how design processes could be organised differently and reflect on what divisions of labour between engineers and non-engineers are desirable. A third category of research would be related to more or less formal methods and methodologies that are used by designers in engineering design. In engineering such methods have been developed to structure the design process, to make decisions between alternatives (cost benefit analysis and multi criteria analysis) and to operationalise requirements and reveal tensions between them (quality function deployment).[49] It would be interesting to assess such methods critically from an ethical point of view and to see if they, possibly in an adapted form, offer possibilities to make explicit and to improve ethically relevant decisions during design processes. If this would be successful, it would also offer a good opportunity for integrating ethical considerations into design courses.

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