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ACCEPTING AMBIGUITY OF ENGINEERING FUNCTIONAL DESCRIPTIONS

Pieter E. Vermaas
Delft University of Technology

ABSTRACT
In this paper I consider four approaches to the ambiguity of engineering functional descriptions, and explore the position to accept this ambiguity. The first and second approach aim at resolving the ambiguity by finding or imposing a single precise meaning for function. These approaches lead to consensus on the content of functional descriptions and to their unconditional interoperability. Yet, they counter current engineering practice to use different meanings of function side-by-side. The third and fourth approach stay close to that practice and accept the co-existing meanings of function; in the third a single overarching meaning is still posited, and in the fourth function is taken as a Wittgensteinian family resemblance concept. It is described how having the co-existing meanings allows engineers to use different design methods. It is argued that the meaning of function then depends on the task for with functional descriptions are used. And it is proposed that functional descriptions have the methodological role in common to relate goal descriptions of devices with structural descriptions in a general and interdisciplinary way.

Keywords: Functions in engineering, Ambiguity, Communication, Archiving, Design methods

1 INTRODUCTION
If the term function had had a single precise meaning in engineering, a number of problems would have disappeared. Functional descriptions of technical devices would then have been unambiguous descriptions. Engineers would have been able to exchange these descriptions in designing and to store them in archives without worrying about how others will understand them. Teaching students about functions would have been a straightforward affair. And formalisation of function would have been a well-defined task, bringing engineering closer to having structured databases of functional descriptions and to automated functional reasoning. Unfortunately, function lacks a single precise meaning. It is a term that has a number of co-existing meanings, which are used side-by-side in engineering. Functional descriptions are ambiguous, creating confusion in communication and archiving, and obstructing teaching and formalisation. This lack of precision seems, moreover, a phenomenon that is by and large accepted in engineering. Design methodologists are for more than a decade aware of the co-existing meanings of function [1,2,3,4,5,6,7,8,9] but usually avoid disputes or other efforts aimed at resolving it. Functional descriptions are effectively kept ambiguous in engineering; the maxim that consensus about key-terms is beneficial to science and technology, is ignored; it may even be argued that having flexibility in the meaning of function has its advantages to engineering [10].
In this paper I consider four approaches to the ambiguity of functional descriptions, and explore the position to accept this ambiguity. The first and second approach aim at resolving the ambiguity by, respectively, finding or imposing a single precise meaning for function. In these approaches the maxim is endorsed that consensus on key-terms is beneficial; confusion among engineers about how to describe devices functionally [11] is then avoided, and functional descriptions become unconditionally interoperable. Yet, the disadvantage is that these approaches counter current engineering practice. Engineers use the co-existing meanings of function side-by-side and do not bother about distinguishing differences. The co-existing meanings are relatively distinct and well-defined, so engineers could easily have separated these meanings and still use them side-by-side. Yet engineers do not do this; they speak about function *simpliciter*, and let evolve the meaning they attach to function with [8] or without [12] warning. The third and fourth approach stay close to this engineering practice and accept the co-existing meanings of functions; in the third a single overarching meaning is still posited, and in the fourth such a common meaning is not required by taking function as a family resemblance concept. In these latter approaches functional descriptions are accepted to be ambiguous,

raising questions about the advantages of having this ambiguity, about possible constraints on the meanings function can have, and about what defines descriptions as functional descriptions.

In section 2 to 5 the four approaches are discussed, and in sections 6 and 7 I consider the questions raised by the acceptance of the ambiguity of functional descriptions. In section 8 I argue for a task-dependency of the meaning of function, and section 9 gives conclusions.

2 CONVERGING TOWARDS A SINGLE MEANING

In science and technology consensus on key-terms yields clarity and interoperability of descriptions; function is a key-term in engineering, and consensus on it would allow engineers working in different disciplines or at different places around the globe to unconditionally share functional descriptions. Removing the current ambiguity in functional descriptions seems therefore evident.

A first approach on arriving at a single meaning consists of analysing the different engineering proposals to giving functional descriptions, and then extracting a single meaning from these proposals. Erden et al. [7], for instance, surveyed 18 of such proposals for "establishing a common frame and understanding of functional modeling". Functional modelling is taken by Erden et al. as a tool for producing overall system descriptions for designing in a common language that can overcome the barriers between engineering disciplines. Yet, the conclusion of this survey is that convergence among the 18 proposals is not yet available. The proposals are judged to be incompatible and historical and local roots are held responsible for this: the incompatibility is suggested to be "a result of the different disciplines in which the [functional modeling] engineers are educated as well as the different application domains the particular [proposals] are aimed at". This lack of convergence raises the question "if there is any [functional modeling] representation that is applicable to all domains or that can cover all possible modeling schemes." Yet, although Erden et al. see partial answers to this question, it is also suggested that research may still be "on the level of integrating/relating different modeling schemes by preserving their own existence, but not yet on a level to develop an encompassing [functional modeling] paradigm" (citations from [7], pp. 147 and 167).

This last remark identifies a weakness of the first approach to the ambiguity of functional descriptions. Extracting a single meaning of function from current proposals seems attractive since it may lead in a natural way to consensus among engineers: the single meaning then emerges from the current meanings engineers use, so acceptance of this single meaning by engineers may be expected. Yet, the approach can backfire by showing that convergence is impossible: analysis may actually confirm that functional descriptions are ambiguously in engineering. This last possibility is moreover rather realistic. Engineers do use different meanings of functions and there are even proposals in which it is explicitly defended that engineers use these meanings side by side. For instance, Chandrasekaran and Josephson ([3], p. 170, section 5.4) identify a "range of meanings for the term function in engineering science" formed by a *device-centric* meaning, an *environment-centric* meaning, and mixtures thereof. Chandrasekaran and Josephson then characterise designing as in part reasoning from functional descriptions using the environment-centric meaning, to descriptions using the device-centric meaning, which implies that these meanings co-exist in design (see also the discussion in section 4). A similar ambiguity is proposed by Deng ([4], pp. 344 and 352) who distinguishes two meanings captured with the terms *purpose function* and *action function*. In Deng's framework for design it can then occur that engineers map purpose functions to action functions. Chakrabarti [13] makes a distinction between functions viewed as *intended behaviour* and functions viewed more abstractly as *purpose*, and aims at supporting design reasoning that accommodates both. Finally, Srinivasan and Chakrabarti ([14], p. 418) give a model in which three different meanings of function can be used together. Given such multi-meaning proposals, it seems impossible that a single meaning of function can emerge from an analysis of current proposals; a single meaning is then rather to be imposed on engineering at the expense of in particular the multi-meaning proposals, which brings us to the second approach.

3. IMPOSING A SINGLE MEANING

The second approach to the ambiguity of functional descriptions is a revisionary approach in which one imposes on engineering on single meaning of function.

Any proposal in design methodology that contains a definition of function is in principle an instance of this revisionary approach. Yet, as noticed in the introduction, disputes aimed at showing superiority of one definition over others are rare in engineering. The revisionary approach can however be found in the discipline of formal ontology. Arp and Smith [15] have included a precise meaning of function in

the *Basic Formal Ontology*, and Burek et al. [16] do so for their *General Formal Ontology* (see [17] for a brief description of these two meanings).
Another effort to include functions in ontologies by Kitamura and Mizoguchi combines a moderate revisionary approach with a moderate acceptance of at least a number of the co-existing engineering meanings of function. Kitamura and Mizoguchi take a function as a "role played by a behaviour in a teleological context", where the concepts of role, behaviour and teleological context are defined in their *top-level ontology* and their *extended device ontology* [18,19] (see again [17] for a brief description). In less formal terms a function of a device is taken to be dependent on the way in which a device is embedded in a system related to the intentions of designers or users. The behaviour of the device is independent of the embedding of the device in such a context, but the role this behaviour plays – the function of the device – depends on that context. The illustration that Kitamura and Mizoguchi give is a heat exchanger that can be used as a heater or as a radiator depending on how the heat exchanger is embedded (e.g., [19]). This meaning of function is presented in [18,20] as one that stays close to engineering practice and that is suitable for making engineering functional descriptions precise, thus moderately pointing out advantages of the defined meaning over other proposals. Yet, taking the work by Kitamura and Mizoguchi as merely revisionary does not do justice to their attempts to accommodate other meanings of function in their ontological framework. They have developed a *reference ontology of functions* [21] in which a number of other meanings of function are classified, and that is meant for translating functional descriptions using those other meanings to functional descriptions based on their own. In [22] rules are given for translating functional descriptions generated by the proposal by Stone and Wood [23] into descriptions using Kitamura and Mizoguchi's "role played by a behaviour" meaning. This suggests that Kitamura and Mizoguchi accept at least some other meanings of function, turning their work into also an instance of the third approach as discussed in the next section.
This combination of arguing for one meaning of function and accepting other meanings as well, points at a weakness of the second revisionary approach. Imposing one meaning of function requires arguing for it and rejecting other meanings. Yet, such an argument may not be acceptable to engineers. Research on functional descriptions may still be "on the level of integrating/relating different modeling schemes by preserving their own existence". ([7], p. 167) Hence, the time seems not yet right to argue in favour of accepting one engineering meaning of function; tolerance towards the co-existing meanings rules, and may even be part and parcel of engineering.

4 FINDING AN OVERARCHING MEANING

A third approach consists of finding an overarching meaning that accommodates the co-existing meanings of functions [17]. By giving their *reference ontology of functions*, as discussed in the previous section, Kitamura and Mizoguchi take the third approach partially. This ontology classifies some of the existing meanings, and by adding a "top" meaning to the ontology that has the classified meanings as instances, an overarching meaning of function is introduced.
Another example of the third approach is the analysis by Chandrasekaran and Josephson [3]. They identify two central meanings of function: the *environment-centric* meaning, according to which a function is the desired effect of a device on an environment outside the device; and the *device-centric* meaning, according to which a function is an intended or desired behaviour of the device itself. Chandrasekaran and Josephson then observe that in the first environment-centric meaning, a function still refers to the desired behaviour of a device, though entirely in terms of elements external to the device (including the *mode of deployment* of the device). That allows them to finally introduce a generalised meaning of function as behavioural constraints on a device, and to argue that the environment-centric and device-centric meanings are special cases of this generalised meaning.
In a later paper Chandrasekaran [5] takes a further step. He makes a distinction between two general research streams on functional descriptions, called *Functional Representation* and *Functional Modelling*, where each stream has its specific understanding and representation of function. For the Functional Representation stream this understanding is given by the generalised meaning proposed in Chandrasekaran and Josephson [3]. For the Functional Modelling stream Chandrasekaran refers to the work by Modarres and Cheon [24] and Stone and Wood [23], by which functions are described by verb and nouns and analysed in terms of basic, primitive functions. According to Chandrasekaran functional descriptions in the Functional Modelling stream are primarily modelling the behaviour of devices, thus ignoring that functions are only *desired* behaviour. Yet, by their analysis of behaviour in

terms of primitive functions, the Functional Modelling perspective provides content to the Functional Representation stream by giving information about how functions can be described as (desired) behaviour. Hence, the generalised meaning of Chandrasekaran and Josephson is eventually also overarching the meaning of function advanced in the Functional Modelling stream.

In [25] an overarching meaning is given that accommodates three archetypical engineering meanings: function as *intended behaviour* of devices, drawn from Stone and Wood [23]; function as *desired effects of behaviour* of devices, drawn from Lind [26]; and function as *purposes* for which a device is designed, drawn from Gero [27]. The overarching meaning that accommodates these archetypes is defined as a desired state of affairs in the world, or a desired sequence of such states of affairs, that is the result of states of affairs or sequences of states of affairs that involve the device.

This third approach of finding an overarching meaning of function may count as a disambiguation of the different co-existing meanings. These co-existing meanings are accepted, distinguished from one another, ordered and related, in part by the overarching meaning. Yet, this overarching meaning is not to be understood as the one and only *true* meaning of function; if it would, the third approach becomes equivalent to the first of arriving at a single meaning on the basis of current proposals. The third approach is a separate approach only if the overarching meaning is not meant to replace the existing meanings; it should be seen as defining yet another meaning of function in engineering, or as simply a conceptual tool for disambiguating the co-existing meanings. This understanding holds for the analysis in [25]; the overarching meaning defined in that analysis is merely meant for showing what the three archetypical meanings have in common. It may be debated whether this understanding holds also for the work by Chandrasekaran and Josephson. One may argue that the generalised meaning of function defined in [3] is not meant to replace the environment-centric and device-centric meanings of function; engineers are still taken to be using these last two meanings, and mixtures thereof. But one can argue that this tolerance is absent in [5], since Chandrasekaran seems to claim that the Functional Representation stream gives the correct meaning of function, and the Functional Modelling stream not.

5 FUNCTION AS A FAMILY RESEMBLANCE CONCEPT

In the final approach the co-existence of different meanings of function is also accepted, and the assumption is dropped that an overarching meaning exists. Function is in this approach taken as a *family resemblance concept*, as proposed by Carrara et al. [17] drawing on Wittgenstein [28].

Wittgenstein introduced the notion of a family resemblance concept to capture the relationship between a word and the phenomena to which the word refers. This relationship may be understood as one of commonality: all phenomena that are referred to by one word have something in common. In the first three approaches this understanding is adopted for function: by giving a single meaning or by giving an overarching meaning, one obtains that all properties, features or phenomena that can be called function, have one thing in common. Yet Wittgenstein argues by means of his example of ‘game’ that the relationship between phenomena that are referred to by one word need not always be one of commonality; this relationship may alternatively consist of “a complicated network of similarities, overlapping and criss-crossing” ([28], §66). And if this relationship for a word or concept is of such a more complicated nature, Wittgenstein calls the concept a family resemblance concept. Taking function as a family resemblance concept thus means accepting the different co-existing meanings of function *and* denying that there is a common element in these meanings. Functional descriptions then display also all kinds of similarities and overlaps – e.g., some of them share references to behaviours of devices [23,26], others share references to intentions of designers [26,27] – but there is no common core to these functional descriptions.

Wittgenstein supports his analysis that game is a family resemblance concept by its vagueness: game is a family resemblance concept because it may be impossible to draw a boundary around procedures such that all procedure taken as games, have something in common ([28], §68 and §71). Arguing that function is a family resemblance concept cannot proceed like this. Function does not seem to be a vague concept; it has well-defined co-existing meanings that still lack a common core.

The fourth approach of understanding function as a family resemblance concept is one that stays close to engineering practice. Its disadvantage is that function becomes a rather elusive concept: it has different meanings, and there is not a clear criterion that sets these meanings apart as meanings of function. Before considering in section 7 what such a criterion might be, I first turn to the advantages of having functional descriptions based on co-existing meanings.

6 THE ADVANTAGES OF AMBIGUITY

The aim of this paper is to explore the position of accepting the ambiguity of functional descriptions. So, can one defend adopting the third or fourth approach, and what are the consequences of doing so?

One argument for the position of accepting ambiguity is that it stays close to current engineering practice. Yet the flip-side of this is that a number of obvious improvements of these practices are rejected. The maxim that consensus on key-terms leads to clarity and interoperability of scientific and technical description still holds, and such consensus for function would enable the unconditional exchange of functional descriptions and make teaching and formalisation straightforward. These improvements are less easily realisable when ambiguity is accepted. What then keeps engineers to their practice of using function with different meanings? What advantages may outweigh the obvious advantages of disambiguation?

In [10] reasoning schemes in design methods are analysed for explaining that having different co-existing meanings of function is indeed advantageous to engineering. There are numerous design methods in design methodology and many of them propose that function is one of the key-terms in design reasoning. But methods differ in the precise structure of this reasoning and in the meaning attached to function. The explanation now consists of making plausible that both differences are related: in each design method a specific meaning is attached that is beneficial to the reasoning scheme proposed, which means that it is beneficial to engineers to have each specific meaning available.

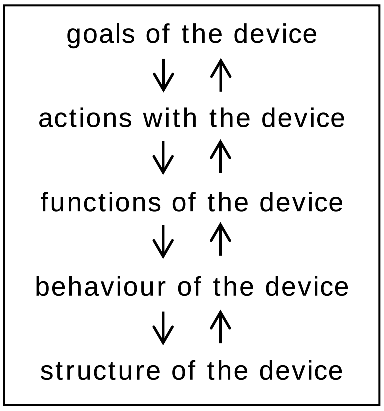

Figure 1. Reasoning from a device's goal to its structure [29,30]

For instance, Brown and Blessing [29] have given a detailed reasoning scheme for designing based on five key-terms: *goal*, *action*, *function*, *behaviour* and *structure*. With these five key-terms design reasoning displays a conceptual layering as given in Figure 1. One starts by considering a goal of prospective users. Then one determines a set of actions by which these users can realise the goal. Third, it is decided what functions the device to be designed has to have for letting these actions be successful. Fourth, the behaviour of the device is characterised such that it has the capacities corresponding to the required functions. And finally the structure of the device is fixed in a way that the device exhibits the behaviour. Design reasoning thus becomes an ordered sequence of steps through the five conceptual layers given in Figure 1, connecting first a goal description of the device with a description of the actions with the device, connecting second the action description with a functional description of the device, all the way down to a structural description (design reasoning is of course not linear but often iterates back upwards through the conceptual layers). In this account of design reasoning function is used in the meaning of a physicochemical capacity of the device that makes that the planned actions with the device are successful (I abstract here at points from [29], adopting terminology from a rational reconstruction of design as given in [30]).

Other design methods are less meticulous and simplify design reasoning by "bypassing" some of the conceptual layers depicted in Figure 1. They do so in different ways. In, for instance, Lind's [26] method actions of users with devices are not considered, leading to a reasoning scheme that skips the action layer but still uses function in the capacity meaning. Other design methods propose more radical simplifications, and these have an effect on the meaning in which function is used. According to Stone and Wood [23] designing starts by deriving from customer needs a description of the overall product function of the device that is to be designed. This product function is captured by a verb-noun expression and represented as a black-boxed operation on flows of materials, energies and signals. The product function is then decomposed into a network of basic functions, and with this network design solutions are searched and composed. Designers reason by this method in one step from goals – the customer needs – to functions, and then in one step from functions to structure – the design solutions – bypassing the action and behaviour layers, as in Figure 2. Function is taken or represented by an operation on flows of materials, energies and signals, and it can be argued [10] that this amounts to giving function the meaning of intended behaviour, which is different to the capacity meaning of Brown and Blessing.

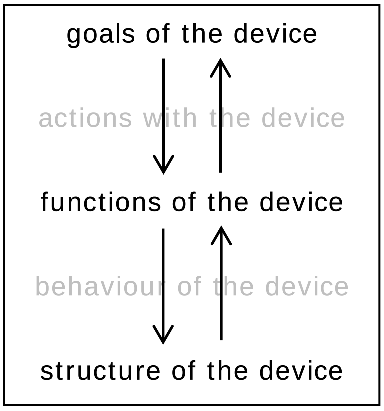

Figure 2. Bypassing actions and behaviour in design reasoning [23].

A third example is the method by Gero [28], in which the simplification of design reasoning consists of taking functions and goals of devices as coinciding; function is with this alternative simplification by definition used in the meaning of goal.

These examples show that the meaning by which function is used in a design method depends on how the reasoning by that method cuts through the five conceptual layers of Figure 1: if actions and behaviour are bypassed, function is used in its intended behaviour meaning; if only actions are bypassed, then one can stay with the capacity meaning; and if actions are bypassed and the key-terms of goal and function are taken as identical, one ends up with using function with a goal meaning. This point has been strengthened in [31] with an argument that the choices to attach different meanings to function in design methods are rational choices. So, the advantage for engineers to keep function ambiguous is that it allows them to use the different design methods for simplifying design reasoning.

7 THE METHODOLOGICAL ROLE OF FUNCTIONAL DESCRIPTIONS

The explanation given in the previous section may give a reason why engineers keep to their practice of using function with different meanings. Yet strictly speaking this explanation does not require that engineers take function as one concept *simpliciter*, instead of as a term that refers to three, or more, separate concepts. Engineers could accept the co-existing meanings and take them as defining separate concepts; the explanation then establishes that engineers benefit from having the concepts of "capacity-function", "intended-behaviour-function" and "goal-function" side by side. This alternative would amount to a straightforward disambiguation of function, undermining the position to accept ambiguity. So, why do engineers take function as a *single* ambiguous concept?

A possible answer to this last question can be found in the explanation given in the previous section. This answer also provides a way to further detail the position of accepting the ambiguity of functional descriptions. When discussion in section 5 the fourth family-resemblance approach it was noted that there is not a clear criterion that sets meanings apart as meanings of function, which would imply that the position may run the risk of allowing any description of a device to be a functional description.

In each of the design methods considered in the explanation given in the previous section, functional descriptions are used to reason from a goal to a structural description of the device to be designed. All these methods incorporate in this way the design-methodological guideline that design reasoning should not proceed directly from goals to known design solutions; rather engineers should use functional descriptions to abstract from those known solutions and to consider novel and more innovative solutions as available in their own disciplines as well as in other disciplines. More generally functional descriptions can, in designing and elsewhere, methodologically be taken as descriptions by which engineers can relate in a general way high-level goal descriptions of devices with low-level structural descriptions of the devices in a common language that can overcome the barriers between different engineering disciplines ([7], p. 147). In the design methods considered in the previous section all functional descriptions play this methodological role, and this can be taken as common to functional descriptions; descriptions are *functional* descriptions when they relate goal descriptions and structural descriptions of devices in a general and interdisciplinary way. Yet, this methodological role of functional descriptions is not singling out one specific meaning for function but underdetermines this meaning. The engineering practice to speak ambiguously about function *simpliciter* can now be understood as due to this underdeterminacy: in engineering there can be consensus on the methodological role of functional descriptions exactly because the different co-existing meanings are not distinguished. Functional descriptions can then be put on offer to engineering as a means to relate goal and structural descriptions of devices in a general and interdisciplinary way, and the guideline for designing can be formulated as that engineers should use functional descriptions for finding innovative solutions. If, in contrast, the co-existing meanings of function were to be distinguished by engineers, the methodological role would get fragmented and hard to promote in a straightforward slogan-style manner. The guideline for designing would then become rather opaque: engineers should abstract from known design solutions by using descriptions based on “capacity-function”, or descriptions based on “intended-behaviour-function”, et cetera.

8 A TASK-DEPENDENT MEANING

The position of accepting the ambiguity of functional descriptions may thus have advantages in engineering that outweigh the obvious advantages of disambiguation, and may demarcate functional descriptions from other descriptions by the criterion that they should relate goal descriptions and structural descriptions of devices in a general and interdisciplinary way.

Still, even if it is beneficial to engineering to gloss over the different co-existing meanings of function, one can argue that there are also benefits when engineers become more sensitive to these different meanings. One reason for this is that there are also constraints on the use of meanings for function. An obvious constraint is that when using a specific design method, one should adopt the meaning of function that comes with that method: in the Brown-Blessing method, one should use function in its capacity meaning; in the Stone-Wood method, function is to be used in its intended behaviour meaning; and so on. Hence, the term function gets its meaning depending on the design method used. Generalising this, function can be understood as a term with co-existing meanings, where the choice which specific meaning is to be adopted, depends on the task at hand. For the task of designing with method *x*, function is used with the meaning as defined by that method, and for the multi-meaning methods [3,4,13,14] function is used in more than one meaning. For tasks other than designing, function can be used in a meaning specific to that task. Archiving of functional descriptions and functional analyses in reverse engineering, for instance, may require also that function is used in meanings specific to those tasks.

Ferguson’s [32] analysis of engineering drawings may provide a useful parallel for this task-dependency of the meaning of function. Ferguson, when discussing sketching in designing, distinguishes three kinds of sketches which each serve different tasks for engineers: *thinking sketches* for focussing and guiding the nonverbal thinking of engineers, *prescriptive sketches* for directing the making of a finished drawing, and *talking sketches* for, e.g., explaining technical points in discussions among engineers ([32], pp. 96-97). Without going into detail, it can be envisaged that different constraints apply to such sketches depending on the thinking, prescribing or talking task at hand, which means that sketches are adjusted to the tasks for which they are used.

The understanding of function one arrives at by this parallel is as follows. Function is a term with a number of co-existing meanings and with the common role of relating goal descriptions of devices with structural descriptions of the devices in a general and interdisciplinary way. The specific meaning that function has in a particular functional description depends on the task at hand. This understanding is compatible with both the third and fourth approach to the ambiguity of functional descriptions. In both approaches one accepts the co-existing meanings of function, and in both approaches one can take the methodological role of relating goal descriptions and structural descriptions of devices in a general and interdisciplinary way, as the criterion that turns descriptions into functional descriptions.

9 CONCLUSION

In this paper I have considered four approaches to the ambiguity of engineering functional descriptions. The first and second approach aim at resolving the ambiguity by finding or imposing a single precise meaning for function. On the third and fourth approach the currently co-existing meanings of function are kept; in the third a single overarching meaning is still posited, and in the fourth function is taken as a Wittgensteinian family resemblance concept. I have explored the position to accept ambiguity, described how having the co-existing meanings allows engineers to use different design methods. On this position the meaning of function depends on the task for with functional descriptions are used, and functional descriptions have the methodological role in common to relate goal descriptions of devices with structural descriptions in a general and interdisciplinary way.

The upshot of the exploration is that it is tenable to accept the ambiguity of functional descriptions: this position stays close to current use of these descriptions in engineering, and this position has advantages relative to disambiguating functional descriptions. Whether this position should be endorsed is another matter. Replacing the spectrum of current co-existing meanings of functions with one single precise meaning seems evident. It has obvious practical advantages in exchanging functional descriptions, in teaching and in formalisation. From a philosophical-methodological point of view disambiguation is also the obvious advice, given the generality in science and technology of the maxim that consensus on key-terms leads to clarity and interoperability. Yet, the exploration in this paper shows that this obviousness alone will not do: the position to accept ambiguity in functions stays close to current engineering practice and has its own advantages. (And from a philosophically it is rather intriguing that this practice can exist and that engineers thus have reason to ignore a general maxim in science and technology.) Hence, those who reject the position have more work to do than merely pointing out the obvious advantages of disambiguation.

If, however, ambiguity of functional descriptions is accepted, other issues and a number of recommendations emerge.

First, for properly managing the ambiguity, it should become clear what meanings are possible in the first place. If functional descriptions are defined by the methodological role of relating goal and structural descriptions of devices in a general and interdisciplinary way, then the different possible meanings that function can have, can be explored and categorised. The current meanings used in engineering define such possible meanings, yet other meanings may be discovered as well. A categorisation of these meanings may capture the relations between these meanings, and ontological analyses, e.g., [21], seem suitable means for addressing this issue.

Second, for managing the effectiveness of communication, functional descriptions should be accompanied with specifications of the meaning used. With such a specification functional descriptions become clear and well-defined within designing, communication and archiving. Moreover, given that functional descriptions using different meanings will co-exist as well, translation algorithms of functional descriptions using different meanings should be developed. Ontologies may again be suitable means, as is shown in [22,33,34], in which different meanings of function are formalised, and then related to one another via the formalisations.

Finally, when the co-existing meanings of function are accepted, the constraints on the use of specific meanings should be analysed and made explicit. If the task-dependency as described in section 8 holds, the constraints that specific tasks impose on the meaning attached to function should be charted. For the task of designing with a particular design methods, the constraint is simply that function should be used in the meaning that is laid down by the method. When functional descriptions are archived to form databases to be used in design methods, it is clear that function is to be used in the meaning laid down by that design method. Both the methods by Gero [27] and by Stone and Wood [23] invoke databases in which past knowledge about design solutions are stored, and it would be counterproductive if these databases are to be filled with functional descriptions using a different meaning for function than the meaning employed in the design method at hand. Similarly, if reverse engineering is meant to provide functional descriptions that can be of direct use in designing, the meaning of function used should be the same as the meaning used in the designing. Yet, if archiving or reverse engineering is done for more general reasons than designing, it may be argued that both activities should be conducted using one fixed, well-defined and detailed meaning of function. If archiving is done for storing functional descriptions for future use or for historical or academic reasons, it seems detrimental to use the different co-existing meanings side-by-side. For this the maxim that consensus on concepts is beneficial applies unconditionally. When, say, technical devices have life-cycles longer than 20 years, the engineers involved in maintenance or disassembly are typically others in person and in training than the engineers that designed and produced the devices. In that case it becomes beneficial if not highly relevant – think of devices containing nuclear technology – that functional descriptions are understandable independently of traditions confined to individual firms or individual periods.

An advanced understanding of the ambiguity of functional descriptions helps improve communication, formalisation and possibly also the teaching of functional descriptions. This improvement may be incremental relative to the advantages disambiguation brings. Yet, it is uncertain whether disambiguation can make it to engineering; in current engineering functional ambiguity rules.

REFERENCES

[1] Chakrabarti A. and Blessing L. Special issue: representing functionality in design. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 1996, 10, 251-253.

[2] Chittaro L. and Kumar A.N. Reasoning about function and its applications to engineering. *Artificial Intelligence in Engineering*, 1998, 12, 331-336.

[3] Chandrasekaran B. and Josephson J.R. Function in device representation. *Engineering with Computers*, 2000, 16, 162-177.

[4] Deng Y.M. Function and behavior representation in conceptual mechanical design. *Artificial Intelligence for Engineering Design, Analysis, and Manufacturing*, 2002, 16, 343-362.

[5] Chandrasekaran B. Representing function: relating functional representation and functional modeling research streams. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 2005, 19, 65-74.

[6] Far B.H. and Elamy A.H. Functional reasoning theories: problems and perspectives. *Artificial Intelligence for Engineering Design, Analysis, and Manufacturing*, 2005, 19, 75-88.

[7] Erden M.S., Komoto H., Van Beek T.J., D'Amelio V., Echavarria E. and Tomiyama T. A review of function modeling: approaches and applications. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 2008, 22, 147-169.

[8] Goel A.K., Rugaber S. and Vattam S. Structure, behavior, and function of complex systems: the structure, behavior, and function modeling language. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 2009, 23, 23-35.

[9] Van Eck D. On relating functional modeling approaches: abstracting functional models from behavioral models. In *eProc International Conference on Engineering Design, ICED 09*, Stanford, August 2009, pp. 2.89-2.100 (Design Society).

[10] Vermaas P.E. The flexible meaning of function in engineering. In *eProc International Conference on Engineering Design, ICED 09*, Stanford, August 2009, pp. 2.113-2.124 (Design Society).

[11] Alink T., Eckert C., Ruckpaul A. and Albers A. Different notions of function: results from an experiment on the analysis of an existing product, manuscript.

[12] Vermaas P.E. and Dorst K. On the conceptual framework of John Gero's FBS-model and the prescriptive aims of design methodology. *Design Studies*, 2007, 28, 133-157.

[13] Chakrabarti A. Supporting two views of function in mechanical design. In *Proc Workshop on Functional Modelling and Teleological Reasoning, Fifteenth AAAI National Conference on Artificial Intelligence*, Wisconsin, 1998.

[14] Srinivasan V. and Chakrabarti A. Sapphire: an approach to analysis and synthesis. In *eProc International Conference on Engineering Design, ICED 09*, Stanford, August 2009, pp.2.417-2.428 (Design Society).

[15] Arp R. and Smith B. Function, role, and disposition in basic formal ontology. *Nature Precedings*, 2008, 1941.1. http://precedings.nature.com/documents/1941/version/1/html.

[16] Burek P., Herre H. and Loebe F. Ontological analysis of functional decomposition. In *Proc Conference on New Trends in Software Methodologies, Tools, and Techniques*, 2009, pp.428-439 (IOS Press, Amsterdam).

[17] Carrara M., Garbacz P. and Vermaas, P.E. If engineering function is a family resemblance concept: assessing three formalization strategies. *Applied Ontology*, forthcoming.

[18] Kitamura Y. and Mizoguchi R. Ontology-based systematization of functional knowledge. *Journal of Engineering Design*, 2004, 15, 327-351.

[19] Kitamura Y., Koji Y. and Mizoguchi R. An ontological model of device function: industrial

deployment and lessons learned. *Applied Ontology*, 2005, 1, 237-262.
[20] Kitamura Y. and Mizoguchi R. Characteri23g functions based on ontological models from an engineering point of view. In *Proc Formal Ontology in Information Systems, FOIS*, 2010, pp.301-314 (IOS Press, Amsterdam).
[21] Kitamura Y., Takafuji S. and Mizoguchi R. Towards a reference ontology for functional knowledge interoperability. In *Proc IDETC/CIE Conference*, Las Vegas NV, September 2007, DETC2007-35373 (ASME).
[22] Okubo M., Koji Y., Sasajima M., Kitamura Y. and Mizoguchi R. Towards interoperability between functional taxonomies using an ontology-based mapping. In *Proc International Conference on Engineering Design, ICED 07*, Paris, August 2007, pp.154.1-154.12 (Ecole Centrale Paris).
[23] Stone R.B. and Wood K.L. Development of a functional basis for design. *Journal of Mechanical Design*, 2000, 122, 359-370.
[24] Modarres M. and Cheon S.W. Function-centered modeling of engineering systems using the goal tree–success tree technique and functional primitives. *Reliability Engineering and System Safety*, 1999, 64, 181-200.
[25] Vermaas P.E. Technical functions: towards accepting different engineering meanings with one overall account. In *Proc Tools and Methods of Competitive Engineering, TMCE 2010*, Vol. 1, Ancona, April 2010, pp. 183-194 (Delft University of Technology).
[26] Lind M. Modeling goals and functions of complex plants. *Applied Artificial Intelligence*, 1994, 8, 259-283.
[27] Gero J.S. Design prototypes: a knowledge representation schema for design. *AI Maga23e*, 1990, 11(4), 26-36.
[28] Wittgenstein L. *Philosophical Investigations*, 1953 (Blackwell, Oxford).
[29] Brown D.C. and Blessing L. (2005). The relationship between function and affordance. In *Proc IDETC/CIE Conference*, Long Beach CA, September 2005, DECT2005-85017 (ASME).
[30] Houkes W. and Vermaas P.E. *Technical Functions: On the Use and Design of Artefacts*, 2010 (Springer, Dordrecht).
[31] Van Eck D. Incommensurability and rationality in engineering design: the case of functional decomposition. *Techné*, forthcoming.
[32] Ferguson E.S. *Engineering and the Mind's Eye*, 1992 (MIT Press, Cambridge MA).
[33] Borgo S., Carrara M., Garbacz P. and Vermaas P.E. Formalizations of functions within the DOLCE ontology. In *Proc Tools and Methods of Competitive Engineering, TMCE 2010*, Vol. 1, Ancona, April 2010, pp.113-126 (Delft University of Technology).
[34] Borgo S., Carrara M., Garbacz P. and Vermaas P.E. A formal ontological perspective on behaviors and functions of technical artifacts. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 2009, 23, 3-21.

Contact: Pieter E. Vermaas
Delft University of Technology
Department of Philosophy
Jaffalaan 5, 2628 BX Delft
The Netherlands
Tel: Int +31 15 2783323
Email: p.e.vermaas@tudelft.nl
URL: http://www.tbm.tudelft.nl/p.e.vermaas

Pieter Vermaas is senior researcher in the Department of Philosophy at Delft University of Technology. Since 2000 his research focused on design methodologies and on the concepts of function and of artifact as used in engineering and philosophy of technology. Research for this paper was supported by the Netherlands Organization for Scientific Research (NWO).