An Engineer's Approach to the Philosophy of Engineering

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The paper presents the view of a practising engineer on how philosophy relates to engineering. It provides definitions of engineering, of technology, and of how they are related, and discusses how drawing the boundary between engineering and society has a significant effect on many of the philosophical issues currently under discussion within the context of Philosophy and Engineering. The paper then goes on to introduce a particular stage of the design process, the transition from functional requirements to physical realisation, and asserts that within this stage, *design in the functional domain*, lie a number of issues with significant philosophical aspects.

1 Introduction

The purpose of this paper is to present a practising engineer's view (and understanding) of what is included in "the philosophy of engineering" and what some of the outcomes of applying philosophy to engineering might be. Philosophy as a discipline in its own right is the domain of philosophers, but the "philosophy of something" must necessarily relate to and involve the practitioners of the "something"; just as the 'engineering of mining" involves the mining community and needs to relate to what the activity of mining encompasses, how it operates, and what its purpose is. The approach to the philosophy of engineering presented here arose as a result of taking a closer look a some of the processes and methodologies employed in engineering. In particular, in what is generally considered to be the core activity of engineering, which is design. When we observe the design activity in engineering, it appears to lie somewhere in the middle of the triangle formed by art, science, and craft, as illustrated in Fig. 1.

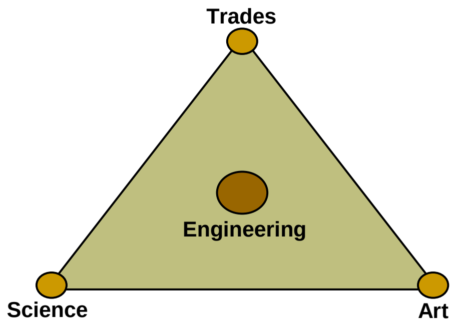

Figure 1 Engineering as a combination of science, art, and trades.

It draws on science for its knowledge about Nature and for its analytical procedures, it resembles art in its creative aspects, and has much in common with the crafts in its use of experience and heuristics. But in then trying to go beyond these externally observable characteristics and to understand design as a coherent activity based on a set of basic principles and with defined properties, one comes up against issues and questions that are also found in philosophy, if not in exactly this specific context.

A fist issue is that engineering needs to be placed within an ontological framework in order for it to become a subject of philosophical enquiry. That is, we need to have an agreed understanding of what engineering is about; the things we can talk about and address our philosophical enquiry to. There are a number of ontological frameworks, or upper ontologies, but most, such as e.g. the Sowa Diamond [1] or the Ontological Sextet [2], include an entity identified as a *process*, In the present context, we shall define a *class* of processes (they could perhaps be called professional processes) by the following definition of a class member [3]:

a. It is performed by people (the *practitioners*)
b. It has a *purpose* defined by a group of people (the *stakeholders*)
c. It is performed within a *timeframe*, starting with the definition of the purpose and ending when either the purpose is deemed to have been achieved or the attempt to achieve it is abandoned.
d. It has a *resource base*, from which the resources required to achieve the purpose is extracted.
e. It has a *knowledge base,* from which the knowledge of how to apply the resources is extracted.

Many instances of processes do not fall within this class, such as the change of seasons, erosion, and the processes taking place within stars, but equally it includes a wide range of processes outside of engineering, for example, in medicine, dentistry, and architecture.

Engineering forms a sub-class of this class, distinguished in part by the nature and content of the resource base and that of the knowledge base, in part by tradition (as is the delineation of any profession). The resource and knowledge bases of engineering constitute what I consider to be *technology*; this is in contrast to some authors, notably Li Bo-cong [4], who consider technology to be an activity. The engineering disciplines, such as civil, chemical, electrical, and mechanical engineering, are distinguished by a subdivision of the resource and knowledge bases, and the practitioners of the process are the *engineers*.

2 The Purpose of Engineering

A central issue in the philosophy of engineering is the purpose of engineering, and it is also a central part of most current definitions of what engineering is [4]. For example, the ABET definition contains the following description of the purpose: "…..to develop ways to utilize economically the materials and forces of nature for the benefit of mankind" [5]. However, instead of focusing on the class of processes called "engineering", another approach is to focus on the instances of this class, which we used in the above definition of the class, and which we shall call *projects*. In terms of projects, and with reference to the above definition, it is possible to distinguish two broad groups of engineering projects,

- projects that utilise the existing resource and knowledge bases to meet a *need* expressed by all or a part of society; and
- projects that increase the resource and knowledge bases.

Or, in other words, projects in the first group *apply* technology in order to meet requirements imposed by entities or people who are generally not engineers, and it is these stakeholders that are the judges of project success; whereas projects in the second group *develop* technology using that part of the knowledge base that is provided by science, and their success is judged generally by other engineers. Let us agree to call these two groups of engineering projects *application projects* and *development projects*, respectively. There is not a sharp boundary between these two groups, and there will be many projects that contain sub-projects of both types.

The importance of this distinction becomes apparent when we consider some of the characteristics of the work undertaken by engineers in the two groups of projects:

(i) The projects in the two groups differ in what we might think of as the *distance* from the work of the engineer to its effect on society, and thereby in the level responsibility and accountability and, more generally, in the ethical issues involved. In the case of a development project, such as the development of a new type of semiconductor device or a new type of fastener, the engineer has no control over what the outcome of his work will eventually be used in; it could be a weapon of mass destruction or a life-saving piece of medical equipment. In the case of an application project, the engineer normally has a good idea of what the use of his work and its intended effect on society are.

(ii) While engineers in both types of projects will receive a reward in the form of personal satisfaction, the more tangible aspects of the reward structure are considerably different. In a technology development environment, the reward is mainly peer recognition based on published results and in an elevation to more senior status within the development organisation. In an application environment, the reward is more likely to be a gradual transition out of design (see below) and into project management, business development and corporate management roles, with commensurate privileges and remuneration increases.

(iii) The scope of the work that engineers undertake (or the roles that engineers play) within the two types of projects differs, in that in development projects the work is mainly comprised of such “core” engineering activities as studies, experiments, design, and fabrication, whereas in application projects engineers are additionally involved in project management, procurement, construction, commissioning, community consultation, and interfaces to various stakeholders, such as the debt providers.

However, despite these differences, which we shall exploit presently by focusing on development projects, projects within both groups do have a purpose which is external to the engineer; without such a purpose it would not be engineering, but rather art (as self-fulfilment) or simply playing or dreaming. Different projects have different purposes, but if we reduce the level of detail in the description of the projects, they will start to form groups with the same purpose, in the sense that both a motorway project and a rail project can be thought of as having the purpose of providing public transportation. And as we continue to decrease the level of detail in the description, we are led to ask; Is there a purpose that is common to all projects?

I believe the answer is yes, and to justify this, we need to look more closely at the process of engineering and its core: design. That design is the core of engineering has been recognised by a number of authors, as cited in [5]. But first, a basic question to philosophers: Why are “the engineering criteria of effectiveness and efficiency” thought to be an impediment to making engineering a subject of philosophical enquiry, and “engineering pragmatism may become for philosophy conceptual shallowness” [6]? May I paraphrase one of your elders [7]:

> Every art and every inquiry, and similarly every action and pursuit, is thought to aim at some good. Will not the knowledge of it, then, have a great influence on our actions? Shall we not, like archers who have a mark to aim at, be more likely to hit upon what is right? If so, we must try, in outline at least, to determine what it is.

So, the fact that the good of engineering is usefulness is not an impediment to studying what it is and what its characteristics are; on the contrary, the philosophical outcome of being “more likely to hit upon what is right” is in itself very useful.

3 Design and The Process of Engineering

The *process of engineering* is the process involved in executing an application project. Central to understanding this process is the realisation that its function is to meet a *need* expressed by society or a group within society as a part of a set of *stakeholder requirements* on a project. The engineer attempts to meet that need by creating an object that meets the relevant part of the stakeholder requirements and, when put into operation, provides a *service* that meets the need. The judgement of the stakeholders as to the extent to which the service meets the need is the measure of the project's success. This process is illustrated in the diagram in Fig. 2.

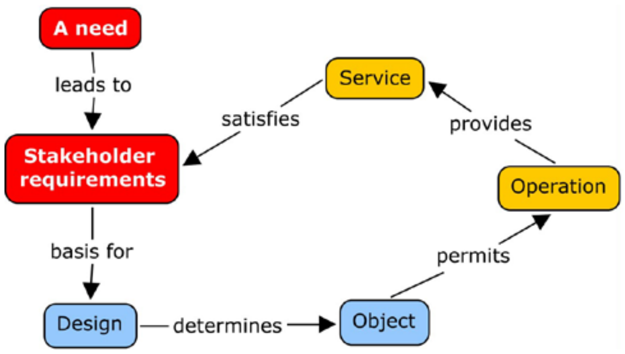

Figure 2 The main concepts involved in the process of engineering.

The colouring of the entities in Fig. 2 is intended to indicate that, while the process is called "the process of engineering", the degree to which engineers are involved in the entities varies greatly from project to project. Only the two objects coloured blue, design and object, can be unequivocally ascribed to engineering, and I shall return to this issue below.

Providing the service will have a *value* to that subset of the stakeholders that expressed the need (often called the "users") and thereby generate a *revenue*. This value may not necessarily be measured directly in monetary terms; it may be through such outcomes as education, public health, social stability, military capability, etc. But, as the creation of the object that is to provide the service (often called the "system" or the "plant") will incur a *cost*, again not always directly in monetary terms (e.g. as voluntary labour, degradation of the environment, depletion of non-renewable resources, etc.), and, as Fig. 2 indicates, this comes before the object can start to provide a service, it is in the form of an *investment*. The decision to make this investment will be based on some form of comparison between the cost and the revenue provided by the users' valuation of the service; that is, on some expected *return on investment*. Viewed under this perspective, every engineering project is the pursuit of an investment opportunity.

Now, if the same revenue can be generated with a lesser investment, or a greater revenue with the same investment, or a combination of both, there would be every reason to chose this course of action, and so, with this very generalised interpretation of cost and revenue, we can now formulate the purpose of engineering common to every application project as *maximising the return on investment*.

The significance of the existence of a common purpose arises from an approach to engineering called systems engineering [8]; it is a methodology for handling the increasing complexity in engineering projects [9]. The central feature of this methodology is to view the large number of requirements placed on such a complex project as a set of interacting elements, where the interactions transform the set of elements into a system. And the process for developing the set of elements is a *top-down* process; starting with the most general (least detailed) description of the project as a single element and developing it in a step-wise fashion into larger and larger sets of elements, until the individual elements are at a level of complexity that is convenient for us to handle. Having identified the common purpose of every project as maximising the return on investment, the top-down process always starts from the common element that defines the return of investment. This introduces a structure into the space of functional elements, and opens the way for developing reusable elements and thereby greatly improving the efficiency of modelling and design in the functional domain [10].

Returning to the diagram in Fig.2, we see that it is important to be clear about exactly what is included in “engineering” when we consider the philosophy of engineering. In what might be considered the “narrowest” interpretation, design starts with a set of stakeholder requirements, and the professional obligation of the engineer is to design and build a system that, when put into operation, will produce a service that satisfies these requirements at the least possible cost, while observing all legal requirements, whether these are referred to in the stakeholder requirements or not. This applies irrespectively of what the requirements are, and the engineers should not let their personal views and beliefs regarding the purpose of the project influence the quality of their work. This is the same as in the medical profession, where the doctor should provide the same care to a sinner as to a saint, and to a friend as well as to a foe. In this interpretation, there needs to be a clear distinction between the engineer as a professional and the engineer as a member of society, and between engineering and the application of the results of engineering.

In a “wider” interpretation of “engineering”, but still within the context of the process depicted in Fig. 1, we recognise that engineers may take on a number of different roles within projects besides design and build, including management, operations, and sales. If these roles are included in “engineering”, then the interface between engineering and society becomes considerably wider and more direct, and the obligations of engineers now include ones related to the purpose and conduct of the project.

In the “widest” interpretation, “engineering” could be interpreted as encompassing activities performed by engineers beyond projects, and the obligations could include the duty to inform the public debate and influence the political process in all matters where engineering knowledge and experience are relevant. It is evident that, as the interpretation is widened, the extent of philosophical aspects not only increases, but shifts from mainly epistemological aspects of the design process to ethical aspects of the interaction with society. The scope of “engineering” is the subject of much debate, both within professional organisations and, in particular, in the development of engineering curriculae. What is important in the context of Philosophy and Engineering is to state clearly which view of engineering is being subjected to philosophical enquiry; to a newcomer to the field there appears to be considerable confusion in this regard.

4 Philosophy and Functional Design

Squarely within the “narrowest” interpretation of engineering is my long-standing interest in the front end of design, or *design in the functional domain* [11]. As projects increase in size and complexity, one can observe that when the outcome is less than satisfactory, the reason is more often than not in the formulation of the requirements rather than in any inadequacy of the engineering process itself. Somewhat simplified and idealised, the situation is that, as already mentioned, the stakeholders require a service, and they do not care how this service is provided. The power station or mobile telephone are examples of the engineers’ solution to providing a service. But instead of defining the service in solution-independent terms, it is easier and more convenient to define it in terms of an existing solution; that is, in terms of an existing physical object or process, and it does often not take much analysis to see that what should be the definition of a service or function is formulated with a particular solution framework in mind. We ask for a corkscrew when what we require is the function of removing the cork from a bottle, and at the other end of the complexity scale the ultimate functional requirement is that for a good existence, an existence that fulfils our needs as humans (e.g. as identified and structured by Maslow), but our requirements are almost always formulated in terms of the solutions we already have. This is perhaps best illustrated in the use of military force and the tactics used to employ that force; the idiocy of marching forward in closed formation once firearms had been invented and of rushing infantry *en masse* against well-entrenched machinegun positions are two examples, and one does not have to look far to see other examples today of solution frameworks being extended well beyond their use-by date.

Focusing on engineering, the first step in designing an object that, when put into operation, will meet stakeholder requirements for a service i.e. the functional requirements within a set of stakeholder requirements, is to ask what the *functionality* of that object would have to be, i.e. what an object must *do* in order to meet the requirements. This is quite independent of what the object must *be*; in fact, there does not need to be any mention or involvement of a physical object at all. The functionality can be formulated completely independently of any particular object that will provide it, in a process of *abstraction* the service is represented by a point in the space of all possible functionalities – the *functional domain*. However, there will often be more than one way of providing a particular service, each one involving different functions and interactions between them, so that the service is represented by a set of points in the functional domain, and the choice of the most appropriate one is the purpose of an activity that might be called *architecting in the functional domain*.

Here it is relevant to note that the concept of function, as opposed to form or structure, has been the subject of a series of papers in the area of Philosophy and Engineering. In particular, by the Techné group and the research program "The Dual Nature of Technical Artefacts" [12], and also in the last fPET conference and in a recent paper, both by Vermaas [13]. However, that program views function as one part of the description of an existing artefact, whereas the functional domain is not associated with individual artefacts at all. Functionality is prior to the existence of any artefact that provides the functionality (to a greater or lesser extent).

There will in general be a number of physical objects that can provide a required functionality, and so the second step in the design process, which is the *transition* from the functional domain into the physical domain, also involves a *choice*, as illustrated in Fig. 3. This figure also indicates what often happens: taking a short-cut by going directly from the stakeholder requirements (i.e. the requirements on the service) to a physical artefact; usually based on previous experience.

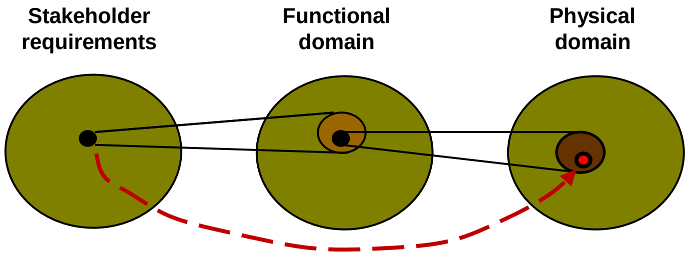

Figure 3 The two-step design process, converting stakeholder requirements into a physical artefact that will meet those requirements.

It is in this second step that the cause of much of what is considered to be the current inadequacies of engineering can be found because, as the functionality becomes more complex, not only is it increasingly difficult to ensure that one has identified all possible or relevant physical realisations, but how does one determine the decision criterion? What is the *best* choice?

One approach to handling that transition step in the design process is to apply the system concept; a mode of description that describes a complex entity as a set of less complex, but interacting entities. Instead of formulating the functionality in terms of a particular, previously employed physical architecture and thereby attempting to make the transition from a complex set of stakeholder requirements directly into the physical domain (as illustrated in Fig.3), we could first describe the functional stakeholder requirements as a set of smaller and simpler, but interacting, functional elements, and then make the transition into the physical domain for each element, while preserving the interactions. These *functional elements* define actions in the physical domain, such as e.g. “producing electric power”, but without any reference to any physical entity carrying out the action. Developing and manipulating such functional elements is what I have called “design in the functional domain”.

The functional domain raises a number of issues, many of which have a philosophical aspect:

a. What sort of entity is a functional element? It is not a “thing”.
b. What entities can be properties of a functional element? Obviously, “weight” cannot be one of them, but can we talk of the “size” or “complexity” of a functional element? Is the “size” one dimensional, or can we identify more than one dimension?
c. What is meant by the interaction of functional elements?
d. Are there any relations among functional elements? What is the topology, if any, of the functional domain? For example, can we talk of the “distance” between two elements? Is the functional domain a metric space?

These are just a few examples; I am certain philosophers can identify a number of other issues relating to the functional domain and its properties, and perhaps this paper can ignite some interest in this direction.

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