GENERAL INTRODUCTION

Anthonie Meijers, editor

"Now, if there are no artifacts, then there are no philosophical problems about artifacts."
[Van Inwagen, 1990, p. 128]

Not so very long ago most philosophers of science maintained that the subject-matter of this volume was uninteresting and most ontologists claimed it was non-existent. It was thought to be uninteresting because technology was taken to be an applied science in which the application itself presented no new philosophical challenges. It was believed to be non-existent, because technological artifacts and systems did not live up to the criteria for being part of the ultimate inventory of the world. A combination of these two views leads to the rather fatal conclusion that the philosophy of technology and engineering sciences is boring stuff about non-existing entities! This volume shows how completely wrong that conclusion is.

The fact that most philosophers of science have not regarded technology or engineering as a subject worthy of serious study clearly emerges from various well-known introductions, companions and anthologies. [Curd and Cover, 1998] and [Curd and Psillos, 2008], for example, do not have a single index entry for 'artifact', 'design', 'engineering' or 'technology' in 2000 pages of philosophy of science. There are some exceptions though, such as [Newton-Smith, 2000] which contains a small section on the philosophy of technology.[1]

In analytic ontology interest in technological artifacts has also been largely lacking.[2] If such artifacts are discussed at all it is often in the context of arguments intended to show that they do not really exist. The roots of this attitude lie in the positivist rejection of metaphysics.[3] What survived of metaphysics after positivism focused on the fundamental concepts of the natural sciences. Basic social sciences and humanities concepts were ignored, taken to refer to non-existing entities, or thought to be reducible to concepts in physics. Since technological artifacts are

[1]More evidence for the lack of interest shown by philosophers of science can be obtained from the *Philosopher's Index* (Philosopher's Information Center 2008), database 1940–2008. A search for the keyword 'science' produces 46,250 entries, a search for 'engineering' only 450 entries, and a search for 'technology' 1250 entries. The keywords 'artifact' and 'design' generated 300 and 1200 entries respectively. Entries with the subject label 'ethics' were excluded, because the focus of the search was on the philosophy of science.

[2]A combined search for 'artifact' and 'ontology' led to only 16 (!) entries in the Philosophers Index database 1940-2008.

[3]See Thomasson's chapter in this Volume, Part II.

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human-dependent objects, they do not fit the physicalist mould and are therefore an easy target for eliminativists.

There are many reasons why the above conclusion is wrong. The relation between science and technology is infinitely more complex than suggested by the simplistic idea that technology is just an applied science.[4] One only has to look at the pervasive role of technology in modern science to see this. Furthermore, the fact that most ontological accounts of artifacts, or medium sized objects in general, are eliminativist can be taken as an indication that there are serious problems with key concepts in metaphysics, such as the concepts of co-location and existence. So instead of simply biting the bullet about the non-existence of artifacts the conclusion might be that we should rethink basic ontological concepts.[5]

Technology forms a very rich philosophical terrain and the Handbook can be read as a map of the many fascinating issues that can be found here. A number of them have been investigated in depth in the philosophical literature, such as the relation between science and technology,[6] the theory of measurement,[7] or the role of professional standards in engineering practice.[8] Other issues have only been partially explored, such as the types of design problems that engineers solve;[9] the epistemic role of models in engineering,[10] or the notion of technological explanation as distinct from scientific explanation.[11] Many issues, however, have not been addressed at all and that is why there still is a lot of pioneering work to be done in the philosophy of technology and engineering sciences.

In what follows I will first define technology and the engineering sciences, which is the subject of this Handbook (Section 1). In Section 2, I will discuss various ways of studying the subject. This will include the approaches taken by historians of technology, by researchers working in the field of Science and Technology Studies (STS), and by philosophers of technology. I will then briefly review highlights in the history of the philosophy of technology and engineering sciences (Section 3). In Section 4, I discuss the architecture of the Handbook which consists of six parts, each covering major aspects of the field. Section 5, the final section, reflects on the nature of the essays in this volume. The philosophy of technology and engineering sciences is a relatively young discipline. In addition to well-established accounts there are explorative essays on a number of areas so far more or less uncharted by philosophers. The Handbook thus also aims to set a research agenda.

[4]See Radder's chapter Science, technology and the science-technology relationship in this Volume, Part I; and Houkes' chapter, The nature of technological knowledge, in this Volume Part II.

[5]See Thomasson's chapter Artifacts in metaphysics in this Volume Part II.

[6]See Radder's chapter, Science, technology and the science-technology relationship in this Volume Part I.

[7]See Suppes' chapter, Measurement theory and engineering in this Volume Part IV.

[8]See Pritchard's chapter, Professional standards in engineering practice, this Volume Part V.

[9]See Dorst and Van Overveld, Typologies of design practices, this volume Part III.

[10]See Part IV, this Volume.

[11]See Pitt's chapter, Technological explanation in this Volume Part IV.

1 TECHNOLOGY AND THE ENGINEERING SCIENCES

The difficulty of delimiting the subject of this volume does not arise from the lack of definitions of technology or engineering as there are dozens of such definitions.[12] The problem is rather how to come up with a sensible definition given this multitude. The aim of providing such a definition here would be to mark out the kinds of phenomena this Handbook covers. The purpose would not be to specify the essence of the subject (if any), to describe the linguistic origin of these words or to prescribe what the terms *should* mean.

The English word 'technology' comes from the Greek τέχνη, which is usually translated as art, craft or skill.[13] For modern language users this needs further clarification, because the Greek notion of τέχνη was intimately connected to the notion of knowledge.[14] For the Greeks there was therefore no need to combine the word τέχνη with the word *logos* (as in technology), because τέχνη already involved *logos*. In Plato's early writings there are two types of τέχνη: one requiring a lot of physical work (resulting in paintings or sculptures) and one requiring only minimal physical work (arithmetic, logic, astronomy). In later works the notion of τέχνη became associated with the knowledge and activities aimed at *making* or *producing*.

The English word 'engineering' originates from the Latin *ingenera*, meaning to implant, generate or produce.[15] In the late Middle Ages it was linked to the making and operating of military hardware. The term 'civil engineering' was introduced in the 17th century to distinguish non-military applications, such as roads and bridges. Engineering was defined at the beginning of the 19th century as 'the art of directing the great sources of power in nature for the use and convenience of man'.[16] In later definitions 'art' was substituted by 'science and mathematics': engineering is "the application of science and mathematics by which properties of matter and the sources of energy are made useful to people".[17]

These definitions show that technology and engineering cannot be identified exclusively in terms of a body of systematic knowledge. After all they do not aim at knowledge for its own sake, but rather at the development and use of knowledge for practical purposes. Technology or engineering is primarily a *practice* which is knowledge-based. In this practice scientific knowledge, but also experience-based know-how, codes and standards, customer requirements, organizational, legal and economic constraints, physical circumstances, scarcity of resources, uncertainty and ignorance play an important role. The title of the Handbook seeks to empha-

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[12] See Mitcham and Schatzberg's chapter, Defining technology and engineering science in this Volume Part I.

[13] See for an extended discussion [Mitcham, 1994, 114–134].

[14] This excluded those skills that the Greeks took to be solely based on experience, such as cooking or swimming.

[15] *Ibid.*, 144–149.

[16] This is the classic definition of engineering as a civilian enterprise formulated by Thomas Tredgold for the Royal Charter of the British Institution of Civil Engineers (1828). See also Mitcham and Schatzberg's chapter in this Volume Part I.

[17] Webster's Third New International Directory (2002).

size both aspects. It refers to the practice of technology and engineering, but also to the engineering sciences as a body of systematic knowledge. Thus defined the philosophy of technology and engineering sciences has a broader scope than most philosophies of the so-called special sciences. It is therefore better to see it as part of the philosophy of technology than as part of the philosophy of science, though these are partly overlapping domains.

Carl Mitcham made a useful distinction between four modes of technology:[18]

- technology as a set of artifacts or systems of artifacts;
- technology as a form of knowledge (for the design, production, maintenance and use of technological artifacts and systems);
- technology as a range of activities (designing, producing, maintaining and using artifacts); and
- technology as an expression of the will of its makers, designers and producers (volition).

This distinction shows in another way that the cognitive dimension of technology is important, but does not suffice to define technology.[19]

It is on the basis of Mitcham's distinction that the subject-matter of this Handbook can be delimited. It first of all deals with technological artifacts and systems, the objects that technology and the engineering sciences produce. In the second place it covers technology as a body of systematic knowledge. This includes the methodology and epistemology of the engineering sciences as well as the relationship of technology to the natural and social sciences. The Handbook finally addresses technology as a range of activities. The main focus is on the activity of design but the Handbook also looks at other key engineering activities.

An important qualification needs to be made at this point. Though Mitcham's first three modes of technology clearly fall within the scope of the Handbook, the focus is on *science-based engineering*. The authors of this Volume are mainly interested in the knowledge and activities of modern engineers and in the objects they produce. Users of technological artifacts are only considered insofar as they are relevant to science-based engineering (for example, artifacts are usually designed by engineers with users in mind and they come with a manual). The Handbook only marginally touches on the roles of craftsmen, managers and other professionals involved in the technological domain. This reflects an important decision in the design of the Handbook. The rationale behind this decision is twofold. Firstly, the editors wanted to focus on those aspects that are currently underexposed and ill-understood within the realm of the philosophy of technology. The Handbook thus clearly fills a gap in the field. Secondly, since this is a Handbook in a series

[18]See [Mitcham, 1994].

[19]Houkes argues in detail in Part II of this Volume that it is very difficult to distinguish between science and technology solely in terms of this cognitive dimension.

on the philosophy of science, it also seemed appropriate to focus on *science-based* engineering.

Several definitions of technology and engineering given in the Handbook refer to one of these three modes or to a combination of modes. For example, Hans Radder describes technology as “a (type of) artifactual, functional system with a certain degree of stability and reproducibility” (this Volume Part V). Paul Nightingale, on the other hand, defines engineering as “the art of organizing and negotiating the design, production, operation and decommissioning of artifacts, devices, systems and processes that fulfil useful functions by transforming the world to solve recognized problems” (this Volume Part II). The first definition primarily perceives technology as a system of artifacts whilst the second sees technology as a range of activities.

Mitcham’s fourth mode of technology, technology as volition, largely extends beyond the scope of this Handbook. It concerns the social, cultural, political and anthropological aspects of technology. The philosophy of technology has a rich tradition of analysing these aspects as testified by authors such as Mumford, Ortega Y Gasset, Heidegger and Ellul. In addition, there has always been a strong emphasis on the ethics of technology, both from the point of view of the user and the professional engineer That the subject-matter of the Handbook is limited to the first three modes of technology reflects once again the desire of the editors to concentrate on those aspects that are currently underexposed. The four modes of technology, however, should not be taken as independent of each other. That is why there is also some discussion of the ethical, social and anthropological aspects of technology in Part V.[20]

2 VARIOUS APPROACHES

The subject-matter of the Handbook can be studied in many ways. Historians, STS researchers, engineers themselves and philosophers of technology have all contributed to a better understanding of the theory and practice of engineering. They do this from different theoretical and methodological perspectives. Some studies are of an empirical and descriptive nature, others are conceptual and/or normative; yet other studies seek to explain while others aim to evaluate; some studies focus on specific theories and methods of engineering while yet others concentrate on the social and economic forces interacting with technology and the engineering sciences. Obviously, one need not be committed to just one of these approaches.

Historians have long been interested in technology as an object of empirical study. Apart from comprehensive overviews of the history of technology [Singer *et al.*, 1954; McNeil, 1996], there are numerous historical case studies of engineers and engineering. For example, there are the biographies of individual engineers, such as Isambard Brunel [Rolt, 1959; Buchanan, 2002], Thomas Edison [Israel,

[20]These aspects of technology are prominent in, for example, [Scharff and Dusek, 2003].

2000] or Vannevar Bush [Zachary, 1997]. Likewise there are the studies of the development of certain artifacts, such as the steam engine [Hills, 1993], the airplane [Constant, 1980; Abzug and Larrabee, 2005] or the atomic bomb [Rhodes, 1995]. There are also inquiries into the nature of technological knowledge that are based on historical cases [Vincenti, 1990]. Increasingly, however, the focus of historical studies has shifted from technology as a subject in its own right to the role of technology in the development of modern societies. Examples are the role of steel in the making of modern America [Misa, 1998], or the role of computers in the transition to an information society [Friedman, 2005]). Landmark studies in this respect are two book series on the role of technology in the formation of Dutch society in the 19th and 20th centuries, edited by Lintsen and Schot [Lintsen, 1995; Schot, 1998].

Researchers engaged in the field of Science and Technology Studies (STS) have always been averse to traditional disciplinary boundaries. They are interested in using social science methods (for example ethnographical methods) to study science and technology. They try to explain their object of study primarily in terms of *social action*. Science and technology are seen as historically situated social practices that produce knowledge, meaning and impact. Instead of looking at the relation between a theory and the available empirical evidence, STS researchers focus rather on the negotiation processes between actors in the scientific field when explaining the acceptance of a given theory. The primary explanatory objective of STS is to produce "a precise, empirical, multilevel account of the production [of knowledge], influence, and change".[21] One example is the study by Geels en Schot of the various ways in which sociotechnical regimes change.[22] The concept of a sociotechnical regime includes here not only the shared cognitive routines in an engineering community but also the social context of policy makers, users and special interest groups. There are two main theoretical positions in STS: the social construction of technology[23] and actor-network theory.[24] They share a strong empirical orientation in their study of science and technology, whereas their differences concern, among other things, the question of whether *all* scientific phenomena can ultimately be explained in terms of social action.[25]

It is fair to say that STS has mainly been a explanatory enterprise. Though the editors of the recent *Handbook of Science and Technology Studies* believe that the explanatory goal of STS must be "wedded to an agenda of social change, grounded in the bedrock of ethical principles and explicit values (equality, democracy, equity,

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[21]See [Hackett *et al.*, 2008, Introduction, p. 4]. Given the large numbers of STS researchers it is probably a simplification to subsume all of them under one explanatory goal.

[22]See [Geels and Schot, 2007].

[23]See for example [Bijker, T. P. Hughes and Pinch, 1987] and [MacKenzie, 1993].

[24]See for example [Latour, 1987; 2005].

[25]In his later work Latour opposed Bloor's so-called 'strong programme' in the sociology of scientific knowledge, according to which success and failure in science should be examined and explained symmetrically. Latour saw this as a form of sociological reductionism. See [Latour, 1992].

freedom, and others)", this is largely taken to be an emerging challenge rather than a reflection of current practice.[26]

Numerous engineers have also contributed to a better understanding of the knowledge, activities and objects of the engineering sciences and technological practices. Examples include David Billington's work on the role of aesthetic values in structural engineering,[27] Larry Bucciarelli's, Clive Dym's, John Gero's and Henry Petroski's respective work on engineering design,[28] Billy Koen's work on heuristics and the engineering method,[29] and Andries van Renssen's work on an applied ontology for the process industry.[30] Engineers-historians have also carried out important studies. Walter Vincenti's and Edwin Layton's work on the nature and taxonomy of technological knowledge are exemplary.[31] These studies are primarily descriptive and aim at clarifying and giving a systematic account of the practice and science of engineering.

The distinctive character of the approach taken in this Handbook cannot be defined in terms of a *unique* method. There is no such method and in this respect the philosophy of technology and the engineering sciences will always be eclectic. Descriptive studies, historical and social explanations, conceptual analyses and normative evaluations can all be found in this Handbook. There are, for example, historical chapters on the emergence of the engineering sciences (Part I), on the way that conceptions of design have evolved over the course of time (Part III), on the notion of a model (Part IV) and on the concept of efficiency (Part V).

What sets the Handbook apart from historical, STS, and engineering approaches, though, is its strong emphasis on conceptual, methodological and normative issues (or combinations of them). For example, in Part I Mitcham and Schatzberg reflect on the very idea of defining technology and the engineering sciences, and on the types of definitions that can be given in relation to explanatory purposes and contexts. Houkes critically examines, in Part II, the epistemological claim put forward by Layton, Staudenmaier, Vincenti and others that technological knowledge forms a category of its own. He concludes that such a strong claim cannot be upheld on the basis of the arguments given but that there is still room for a weaker form of emancipation from scientific knowledge. In Part III Kroes, Franssen and Bucciarelli evaluate to what extent engineering design, which is a creative and social process of decision making, can be called a rational process. In addressing this issue they distinguish between various notions of rationality, such as means-ends rationality, procedural rationality and substantive rationality. Several chapters in Part IV explore the notion of a model, the varieties of models, and the methodological and epistemic roles of models in the engineering sciences. Radder investigates,

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[26] [Hackett *et al.*, 2008, Introduction, p. 5]. Philosophers of technology inspired by Latour's actor-network theory, such as Achterhuis and Verbeek, have focused on these moral aspects from the very beginning. See, for example, [Achterhuis, 1995] and [Verbeek, 2000/2005].

[27] See [Billington, 1985].

[28] See [Bucciarelli, 1996; Gero, Tham and Lee, 1992] and [Dym, 1994].

[29] See [Koen, 2003].

[30] See [van Renssen, 2005].

[31] See [Vincenti, 1990] and [Layton, 1974].

in Part V, the normativity of technology and argues that it is not only normative in a contingent sense but also inherently. He thus makes a conceptual claim.

Though the emphasis is on conceptual, methodological and normative issues, the editors of the Handbook believe that the philosophy of technology and engineering sciences should be empirically informed. Many chapters therefore refer to specific technologies, engineering theories and engineering practices as cases from which something can be learned. For example, Nersessian and Patton partly base their account of model-based reasoning (in Part IV) on cases drawn from biomedical engineering. Borgo and Vieu, when developing an applied ontology for artifacts in Part II, analyse ways in which these artifacts are represented in information systems. Boon and Knuuttila and Zwart discuss in Part IV the work of Carnot and Froude in order to gain a better grasp of the epistemological roles of models in engineering. The final part of the Handbook, which is devoted to philosophical issues in specific technologies, reflects the empirically informed approach taken here as a whole.

3 A BRIEF HISTORY OF THE FIELD

The history of the philosophy of technology and engineering sciences as defined above is not very long. One could alternatively say that it does not yet have a history, only a prehistory. During the last century individual researchers worked on topics such as the nature of technological knowledge, the analysis of design problems, the difference between natural and artificial objects, and the difference between science and technology. Their number has been very small, especially when compared to the number of researchers working on science and technology studies, on the social and ethical problems of technology or on the history of technology. Only after the turn of the century did a community of researchers of a certain size emerge which had a joint interest in the philosophy of technology and engineering sciences.[32]

From the very beginning to the second half of the 20th century the philosophy of technology (in a broad sense) paid little attention to the topics of this Handbook. Philosophers such as Ernst Kapp, Lewis Mumford, José Ortega Y Gasset, Martin Heidegger, Jacques Ellul, and Hans Jonas were primarily interested in anthropological, ethical and metaphysical studies of technology. There were exceptions though. The work of Jacques Lafitte, Gilbert Simondon, Tadeusz Kotarbinsky, Alard DuBois-Reymond, and Hendrik van Riessen, to name but a few, contained analyses of the concepts of machine and system, taxonomies of machines and their parts and discussions of the process of invention and technological evolution.[33]

The eighties witnessed a small wave of publications in the field, largely based on studies carried out in the previous decade. Books were published by Rogers on

[32]The American-European *Society for Philosophy and Technology* (SPT) has a much broader orientation than the philosophy of technology and engineering sciences and has historically been dominated by social and ethical questions concerning technology.

[33]See [Mitcham, 1994].

the nature of engineering [Rogers, 1983], by Laudan on the nature of technological knowledge [Laudan, 1984], by Bunge on the philosophy of science and technology [Bunge, 1985] and by Staudenmaier on key issues concerning our understanding of technology [Staudenmaier, 1985].[34] One landmark study was Walter Vincenti's book *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* [Vincenti, 1990]. The productivity of the nineties did not match that of the eighties though there were a number of articles on the subject in the journal *Techné* and in the book series *Research in Philosophy and Technology*), edited by Carl Mitcham. Mitcham's own book *Thinking Through Technology; The Path Between Engineering and Philosophy*, which was published in 1994, gave a predominantly historical overview of the philosophy of technology. The book was (and still is) influential because it contains an analytic framework for studying technology philosophically (see Section 1). It also made an impassioned appeal to philosophers to engage more intensively in the dialogue with engineers and to take technology much more seriously.[35] In so doing, Mitcham paved the way for more research on the subject of this Handbook. On a whole, however, the nineties can be characterized as a period of stagnation. No major studies were published and no major initiatives were taken. The subject was also virtually absent in mainstream philosophy journals.

Gradually things started to change. At the turn of the century a lot of new activities were launched in the Netherlands. The research programme *The Dual Nature of Technical Artifacts* in Delft turned out to be a kernel for much more research in the philosophy of technology and engineering sciences, not only in Delft but also elsewhere. The *Dual Nature* programme focused on the general concept of a technical artifact, as an entity that can be described in functional-intentional and in physical terms. The results of the programme were published in a special issue of a mainstream philosophy of science journal: *Studies in History and Philosophy of Science* [Kroes and Meijers, 2006], which was a remarkable deviation from standard publication practices in both the philosophy of technology and the philosophy of science. In parallel developments several philosophies of specific technologies emerged. The electronic journal *Hyle* started publishing articles on the philosophy of chemistry from 1995 onwards, including articles on chemical technology.[36] The philosophy of information technology became a major topic of specialized research in its own right,[37] while the philosophy of biotechnology gained prominence.[38] Other important developments included the emergence of a philosophy of scientific

[34]In his book, Staudenmaier analyzed 25 years of publications in the historical journal *Technology and Culture*.

[35]See [Mitcham, 1994, p. 268].

[36]See http://www.hyle.org.

[37]See, for example, [Floridi, 2003] and Brey and Søraker's chapter in this Volume Part VI. A separate volume in the Handbook series *Philosophy of Science* is also devoted to the philosophy of information.

[38]See Van de Belt's chapter in this Volume, Part VI.

instrumentation,[39] and of a philosophy of risk. The philosophy group at KTH Stockholm played a leading role in the development of the latter.[40]

In the last decade the community of researchers working on the philosophy of technology and engineering sciences has also become better organized. They have created and organized a portfolio of substantive research programmes, publication projects, regular conferences and workshops. Professional societies such as the SPT showed increased interest by arranging sessions at its biennial conferences on issues such as engineering design, nanotechnology and artifact ontology. Furthermore, the Society's journal *Techné* started publishing more and more articles on the subject. There were new initiatives as well. Specialized workshops on the philosophy of engineering were organized in Delft (2007) and in London (2008). Finally, in another initiative, the Division of *Logic, Methodology and Philosophy of Science* of the *International Union of History and Philosophy of Science* has decided to give the philosophy of technology and engineering sciences much more prominence in its future activities.

Despite all these positive developments there is also good reason to be modest about what has been accomplished. In his book *The Nature of Engineering: A Philosophy of Technology* (1983) Gordon Rogers tried to give a systematic account of the notion of technological explanation, as distinct from scientific explanation and historical explanation. He distinguished between two types of technological explanation. First-order explanations are teleological in nature and are intended to answer questions of the type 'What is this flywheel for?' (To reduce the fluctuations in torque which arise from the intermittent nature of the processes in a reciprocating engine), or 'Why is the spark initiated before the end of the compression stroke?' (To compensate for the delay in the ignition process).[41] More mature technological explanations are of a causal nature and try to answer such questions as 'Why did this bridge collapse?', or 'What causes the ignition delay in an engine?', or 'How can one account for the heat transfer in fluid metals in a fast breeder reactor?'. According to Rogers these technological explanations are causal explanations but they differ from each other in that they occupy a different place in a spectrum of causal explanation ranging from scientific explanations to historical explanations.[42] Obviously, much more can and should be said about this. Technological explanation is an important issue in the philosophy of engineering. However, it is fair to say that little if any work has been done on the subject in the last twenty-five years.[43]

Notwithstanding this sobering fact, the *Handbook Philosophy of Technology and Engineering Sciences* clearly marks a milestone in the history of the field. It brings together for the first time more than fifty scholars who have written extensively

[39] See [Radder, 2003] and [Baird, 2004].

[40] See http://www.infra.kth.se/phil/riskpage/index/htm and [Hansson, 2003]. The philosophy of risk focusses on the epistemological as well as the ethical aspects of risks.

[41] [Rogers, 1983, p. 42].

[42] *Ibid.*, p. 43.

[43] An exception is Jeroen de Ridder's PhD thesis on the design and explanation of artifacts [de Ridder, 2007] and Joseph Pitt's chapter "Technical Explanation", this Volume Part IV.

on such diverse topics as the function theories of artifacts, means-end reasoning, the role of scale models in engineering, notions of computation and efficiency, and philosophical theories of architecture.

4 ARCHITECTURE OF THE HANDBOOK

The Handbook consists of six parts, each of which covers a cluster of related issues. These parts correspond to major aspects of the philosophy of technology and engineering sciences. Together they do not exhaust the field though. There is very little on production and maintenance, for example, while the existing parts could easily be expanded (see also the next section).

Part I of the Handbook focuses on the demarcation of the object of study: technology and the engineering sciences. Various *types* of definitions of technology and engineering are discussed as are the aims that these definitions serve. The relationships between technology and the natural sciences and between technology and the social sciences are subsequently analyzed, to situate technology in the disciplinary landscape. Finally, the historical emergence of the engineering sciences together with their diversity and coherence are examined. These issues are central to the field. Part I also contributes to the other parts of the Handbook because it defines their object of analysis.

Part II addresses the ontology and epistemology of technological artifacts. It discusses these artifacts in the context of analytic metaphysics and applied ontology. The latter is crucial to the representation of artifacts in information systems. There is also an in-depth discussion of a key property of artifacts: their function. Existing theories of function are evaluated in terms of their ability to account for the functions of technological artifacts. In addition, functional part-whole relationships and their use in engineering are explored. Part II furthermore analyses the notion of technological knowledge. This is a wide concept consisting of many elements. Taxonomies of these elements are presented and the claim that technological knowledge is different from scientific knowledge is carefully evaluated. In addition the role of tacit knowledge in engineering design is discussed. Finally, there is an analysis of means-end reasoning which is central to technological rationality.

Part III focuses on a defining activity of engineering: the design of technological artifacts and systems. It includes a historical account of design concepts, a typology of design practices and a discussion of how customer requirements are translated into technical specifications. An analysis is made of the design process in terms of the so-called function-structure relation. A design starts with the specification of an artifact's desired function. In the process of designing this is transformed into a description of the artifact's structural properties and a manual for its use. Another topic that is studied is the computational representation of functions in engineering design. Increasingly, engineering design is a computer-supported activity and the ability to represent functions in information systems is crucial then. There is also an in-depth analysis of the rationality of design. Design includes rational problem solving activities but also social and creative processes. Finally, the complexities of the design of socio-technical systems or mixed systems of artifacts and humans, are discussed.

Part IV is about methodological issues. Since models are so central to engineering, for example computer models or scale models, most of this part is devoted to the analysis of models and modelling. Firstly, there is an extensive historical account of the notion of a model. This is followed by a semantic analysis of functional modelling and mathematical models. Several case-studies are presented to show how in engineering models are actually used as epistemic and methodological tools. Case studies also form the basis for an account of model-based reasoning. Since scales and dimensions play an important role in modelling, there is also an in-depth discussion of dimensional analysis and measurement theory. Finally, there is an analysis of the notion of explanation, traditionally a key concept in methodology, but in engineering its meaning and use is distinct from that in the natural sciences.

Part V investigates the norms and values that are at work in engineering. As discussed in Section 1, technology and engineering aim at the design and production of technological artifacts and systems that are *useful or valuable* to human beings. They have inherent normativity. This normativity and the normative statements that can be made about artifacts are analysed in great detail in this part. There are also accounts of the various ways in which non-epistemic values and norms play a role in engineering design and engineering practice. In particular the role of aesthetic values is discussed in relation to the design of such diverse artifacts as urban areas, software, and molecules. In addition to this the values of efficiency and safety in engineering are analyzed. Finally, the central concepts and methods of technology assessment are discussed as is the interaction between technology and ethics.

Part VI is of a different nature in that it takes specific engineering disciplines as its object of analysis. It thus gives a different cross-section of the landscape of the philosophy of technology and engineering sciences. Some of the analyses presented are strictly specific to certain disciplines, such as the notion of a gene in biotechnology or the notion of computation in information technology. Other analyses are more general. The part also contains discussion about how developments in one discipline can influence developments in another. For example, developments in medical technology have influenced the notion of disease in medicine. The focus is both on more classical engineering disciplines such as architecture, agricultural technology and medical technology, and on more recent disciplines such as biotechnology and information technology.

5 THE HANDBOOK AS A RESEARCH AGENDA

The overview of the various parts of the Handbook clearly shows that it does not cover the field of philosophy of technology and engineering sciences in full. As already mentioned, the Handbook can also be read as a research agenda. This will be discussed below using a distinction made at the beginning of the chapter between topics that have been studied in depth, topics that have been partially explored and topics that have not been addressed at all.

Topics that fall into the first category are the following: the definition of technology and engineering, the relation between science and technology, the history of design, the translation of customer requirements into technical specifications, the notion of a model, measurement theory, the normative status of artifacts, professional standards in engineering, notions of risk and safety, technology assessment, the philosophy of biotechnology and the philosophy of information technology.

There are many more topics that fit into the second category in the Handbook. I have already mentioned the ontology of artifacts which is a topic in need of further elaboration. Similarly, the theories of function in the philosophy of biology appear to be inadequate when it comes to accounting for technological artifacts, while the theories of function that have been specifically developed for these artifacts are still in their early stages.[44] Technological knowledge is also an underdeveloped topic. The notion is intrinsically linked to human goals and actions. Many of its elements require further systematic philosophical analysis. For example, the role of practical usefulness (rather than truth-likeness) when validating theories and models in the engineering sciences, or the role of technological rules in engineering practices.[45]

Other topics that fall into the second category and are included in the Handbook are these: the role of social science in engineering, functional decomposition and mereology in engineering, typologies of design practices, the design of socio-technical systems, the epistemic roles of models in engineering sciences, similarity and dimensional analysis, technological explanation, the concept of efficiency, the philosophy of architecture and the philosophy of medical technology.

A number of topics that belong to the first two categories are unfortunately lacking in the Handbook or only briefly addressed. They are:

- the role of technology in experimental sciences (Part I);[46]
- the dual nature of technical artifacts as functional-intentional and as physical objects;[47] the distinction between technical artifacts and natural objects; a structural mereology of artifacts as opposed to a functional mereology; knowledge management in large engineering projects and organizations (Part II);
- the evaluation of design methodologies;[48] optimization methods in engineering design (Part III);
- the relevance of systems theory to engineering; the engineer's toolbox (finite elements methods, unified modelling language, simulation techniques);

[44]See Preston's chapter, Philosophical theories of artifact function in this Volume Part II.
[45]See Houkes' chapter, The nature of technological knowledge in this Volume Part II.
[46]See [Radder, 2003].
[47]See [Kroes and Meijers, 2006].
[48]See journals such as *Design Studies* and *Research in Design*.

the principles of performance measurement; error theory; the foundations of control theory; the role of heuristics and rules of thumb; the role of technical codes and standards; the visual aspects of engineering; the role of idealization in technology; an account of how computers have changed engineering methodologically (Part IV);

- the role of aesthetic values in the design of medium-sized objects (Part V).
- the philosophy of chemical engineering (Part VI).[49]

The number of topics falling into the third category is also substantial. They have been on the editors' lists of issues to explore for a long time. Occasionally we found researchers who were prepared to do serious work in those areas so that their finding could be turned into chapters in the Handbook. But the remaining list of items is still very long. It includes:

- an analysis of basic artifact types (Part II);
- an account of the trade-offs in design (Part III);
- an analysis of the notion of technological rule, as opposed to the notion of scientific law; an investigation into the role and justification of engineering theories; an account of the operational principles of artifacts (Part IV);
- epistemic norms in engineering (Part V);
- the foundations of nanotechnology, and of classical engineering disciplines such as mechanical engineering and structural mechanics (Part VI). Military technology is also a *terra incognita* in terms of philosophical analyses, but it cannot be strictly called a discipline. It is rather a collection of technologies used in a certain field of application. The role of military technology is of fundamental importance to the understanding of the development of other technological disciplines.

In addition to these topics there is also an entire aspect not yet covered by the Handbook. That has to do with all the issues related to the production, operation and maintenance of technological artifacts and systems as a part of science-based engineering.[50] Scientific theories of production and organization such as Taylor's, theories of multi-agent systems, the role of ISO standards, decision and planning theories and the social context of engineering are among the topics still to be explored in this domain.

Thus defined, the research agenda requires substantial effort on the part of philosophers. It calls for a widening of the community of researchers involved. There are indications that this may occur in the near future. Increasingly, philosophers of technology are publishing in mainstream philosophical journals, thus

[49]See the journal *Hyle*.
[50]Some of these topics are briefly mentioned by Sørensen in Part I and by Radder in Part V.

reaching a larger audience when discussing topics studied in this Handbook.[51] At the same time, philosophers specialized in action theory, ontology, the philosophy of mind and the philosophy of science are turning increasingly to the philosophical problems of artifacts. This has recently resulted in books such as Baker's *The Metaphysics of Everyday Life* (2007), Thomasson's *Ordinary Objects* (2007) and Margolis and Laurence's *Creations of the Mind: Theories of Artifacts and their Representation* (2007).[52]

To conclude, the Handbook gives the reader an overview of the current state of affairs in the philosophy of technology and the engineering sciences. This field can best be characterized as a field in transition. There are very interesting developments going on and many new topics are being explored. Since this situation will probably continue for some time to come, given the extensive research agenda sketched above, the editors hope that the Handbook will also be made available online in the not too distant future. Ideally it should become a living document that can be improved and extended whenever new or better studies become available. It should give philosophers and engineers easy access to the best and most up-to-date knowledge on the subject. Viewed from this angle the *Philosophy of Technology and Engineering Sciences* Handbook is merely a step, albeit a step in the right direction.[53]

6 THE COMPILATION OF THE HANDBOOK AND ACKNOWLEDGEMENTS

"Thalassa! Thalassa!"
(The sea! The sea!)
Xenophon, *Anabasis*.

This Handbook has been a very ambitious project, both in its intellectual and its organizational scope. From the start it was clear that in addition to having chapters on well-researched topics the Handbook would contain explorative chapters on new aspects of the field. The aim was not only to survey the philosophy of technology and engineering sciences in its present state but also to contribute substantially to its development.

On the basis of extensive literature searches the first Handbook outlines were produced in the spring of 2004. More than 10 areas were defined, each containing between 5 to 10 topics that were considered to be important. In total 65 topics were chosen that could possibly be turned into chapters. A number of these topics were suggested by the philosophers who later became the associate editors of the

[51] See, for instance: [Lelas, 1993; Houkes and Vermaas, 2004; Boon, 2006; Hansson, 2007; Kroes and Meijers, 2006; Zwart and Franssen, 2007; Hughes, Kroes and Zwart, 2007; Vaesen and van Amerongen, 2008], and [Radder, 2008].

[52] See also [Dipert, 1993; Perlman, 2004; Baker, 2004; 2007; Thomasson, 2007] and [Margolis and Laurence, 2007].

[53] The author would like to thank Sven Ove Hansson, Wybo Houkes, Peter Kroes and Hans Radder for their valuable comments on an earlier version of this Introduction.

Handbook. What then followed was a time-consuming effort to find authors who were sufficiently qualified to write on these topics. In some cases that was easy because there were well-known experts in the fields in question. In other cases it turned out to be extremely difficult or sometimes even impossible. The list of authors and topics became relatively stable after two years, though changes were made even in the final phase. Over the five years of the making of the Handbook the number of topics gradually decreased from 65 to 41 and came to involve 51 authors.

In January 2007 a workshop was organized at Eindhoven University of Technology to discuss the first versions of the chapters. In parallel sessions in-depth discussions were held between authors writing on similar topics. The aim was to give feedback and improve the chapters but also to create a certain synergy and demarcate the topics. After the workshop a long process followed. The practical limitations of a number of authors and the fact that many chapters addressed new topics requiring a great deal of new research all caused the completion of the Handbook to be delayed. This did not come as a surprise to the editors, given the ambitious nature of the project. We had to walk the tightrope between including chapters on new topics in the Handbook and meeting a certain deadline. In the last phase several chapters had to be omitted so that the final deadline could be honoured.

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